SAM3U Series

Atmel | SMART ARM-based Flash MCU

DATASHEET

Description

The Atmel® | SMART SAM3U series is a member of a family of Flash microcontrollers based on the high performance 32-bit ARM® Cortex®-M3 RISC processor. It operates at a maximum speed of 96 MHz and features up to 256 Kbytes of Flash and up to 52 Kbytes of SRAM. The peripheral set includes a High Speed USB Device Port with embedded transceiver, a High Speed MCI for SDIO/SD/MMC, an External Bus Interface with NAND Flash controller, up to 4 USARTs, up to 2 TWIs, up to 5 SPIs, as well as 4 PWM timers, one 3-channel 16-bit general-purpose timer, a low-power RTC, a 12-bit ADC and a 10-bit ADC.

The SAM3U devices have three software-selectable low-power modes: Sleep, Wait, and Backup. In Sleep mode, the processor is stopped while all other functions can be kept running. In Wait mode, all clocks and functions are stopped but some peripherals can be configured to wake up the system based on predefined conditions. In Backup mode, only the RTC, RTT, and wake-up logic are running.

The Real-time Event Managment allows peripherals to receive, react to and send events in Active and Sleep modes without processor intervention.

The SAM3U architecture is specifically designed to sustain high speed data transfers. It includes a multi-layer bus matrix as well as multiple SRAM banks, PDC and DMA channels that enable it to run tasks in parallel and maximize data throughput.

It can operate from 1.62V to 3.6V and comes in 100-pin and 144-pin LQFP and BGA packages.

The SAM3U device is particularly well suited for USB applications: data loggers, PC peripherals and any high speed bridge (USB to SDIO, USB to SPI, USB to External Bus Interface).

1. Features

- Core
  - ARM Cortex-M3 revision 2.0 running at up to 96 MHz
  - Memory Protection Unit (MPU)
  - Thumb®-2 instruction set
- Memories
  - 64 to 256 Kbytes embedded Flash, 128-bit wide access, memory accelerator, dual bank
  - 16 to 48 Kbytes embedded SRAM with dual banks
  - 16 Kbytes ROM with embedded bootloader routines (UART, USB) and IAP routines
  - Static Memory Controller (SMC): SRAM, NOR, NAND support. NAND Flash controller with 4 Kbytes RAM buffer and ECC
- System
  - Embedded voltage regulator for single supply operation
  - POR, BOD and Watchdog for safe reset
  - Quartz or resonator oscillators: 3 to 20 MHz main and optional low power 32.768 kHz for RTC or device clock
  - High precision 8/12 MHz factory trimmed internal RC oscillator with 4 MHz Default Frequency for fast device startup
  - Slow Clock Internal RC oscillator as permanent clock for device clock in low power mode
  - One PLL for device clock and one dedicated PLL for USB 2.0 High Speed Device
  - Up to 17 Peripheral DMA Controller (PDC) channels and 4-channel central DMA
- Low Power Modes
  - Sleep, Wait, and Backup modes, down to 1.65 µA in Backup mode with RTC, RTT, and GPBR
- Peripherals
  - USB 2.0 Device: 480 Mbps, 4-Kbyte FIFO, up to 7 bidirectional Endpoints, dedicated DMA
  - Up to 4 USARTs (ISO7816, IrDA®, Flow Control, SPI, Manchester support) and one UART
  - Up to 2 TWI (I2C compatible)
  - 1 Serial Perpheral Interface (SPI)
  - 1 Synchronous Serial Controller (SSC) (I2S)
  - 1 High Speed Multimedia Card Interface (HSMCI) (SDIO/SD/MMC)
  - 3-channel 16-bit Timer/Counter (TC) for capture, compare and PWM
  - 4-channel 16-bit PWM (PWMC)
  - 32-bit Real-time Timer (RTT) and Real-time Clock (RTC) with calendar and alarm features
  - 8-channel 12-bit 1 msps ADC with differential input mode and programmable gain stage
  - 8-channel 10-bit ADC
- I/O
  - Up to 96 I/O lines with external interrupt capability (edge or level sensitivity), debouncing, glitch filtering and on-die Series Resistor Termination
  - Three 32-bit Parallel Input/Outputs (PIO)
- Packages
  - 100-lead LQFP – 14 × 14 mm, pitch 0.5 mm
  - 100-ball TFBGA – 9 × 9 mm, pitch 0.8 mm
  - 144-lead LQFP – 20 × 20 mm, pitch 0.5 mm
  - 144-ball LFBGA – 10 × 10 mm, pitch 0.8 mm

1.1 Configuration Summary

The SAM3U series devices differ in memory sizes, package and features list. Table 1-1 summarizes the configurations of the six devices.

Table 1-1. Configuration Summary

Feature	ATSAM3U4E	ATSAM3U2E	ATSAM3U1E	ATSAM3U4C	ATSAM3U2C	ATSAM3U1C
Flash	2 x 128 Kbytes Dual plane	128 Kbytes Single plane	64 Kbytes Single plane	2 x 128 Kbytes Dual plane	128 Kbytes Single plane	64 Kbytes Single plane
SRAM	52 Kbytes	36 Kbytes	20 Kbytes	52 Kbytes	36 Kbytes	20 Kbytes
Package	LQFP144 BGA144	LQFP144 BGA144	LQFP144 BGA144	LQFP100 BGA100	LQFP100 BGA100	LQFP100 BGA100
External Bus Interface	8 or 16 bits, 4 chip selects, 24-bit address	8 or 16 bits, 4 chip selects, 24-bit address	8 or 16 bits, 4 chip selects, 24-bit address	8 bits, 2 chip selects, 8-bit address	8 bits, 2 chip selects, 8-bit address	8 bits, 2 chip selects, 8-bit address
Number of PIOs	96	96	96	57	57	57
SPI	5	5	5	4	4	4
TWI	2	2	2	1	1	1
USART	4	4	4	3	3	3
ADC 12-bit	8 channels	8 channels	8 channels	4 channels	4 channels	4 channels
ADC 10-bit	8 channels	8 channels	8 channels	4 channels	4 channels	4 channels
FWUP, SHDN pins	Yes	Yes	Yes	FWUP	FWUP	FWUP
HSMCI Data Size	8 bits	8 bits	8 bits	4 bits	4 bits	4 bits

Note: 1. The SRAM size takes into account the 4 Kbyte RAM buffer of the NAND Flash Controller (NFC) which can be used by the core if not used by the NFC.

2. Block Diagram

Figure 2-1. 144-pin SAM3U4/2/1E Block Diagram

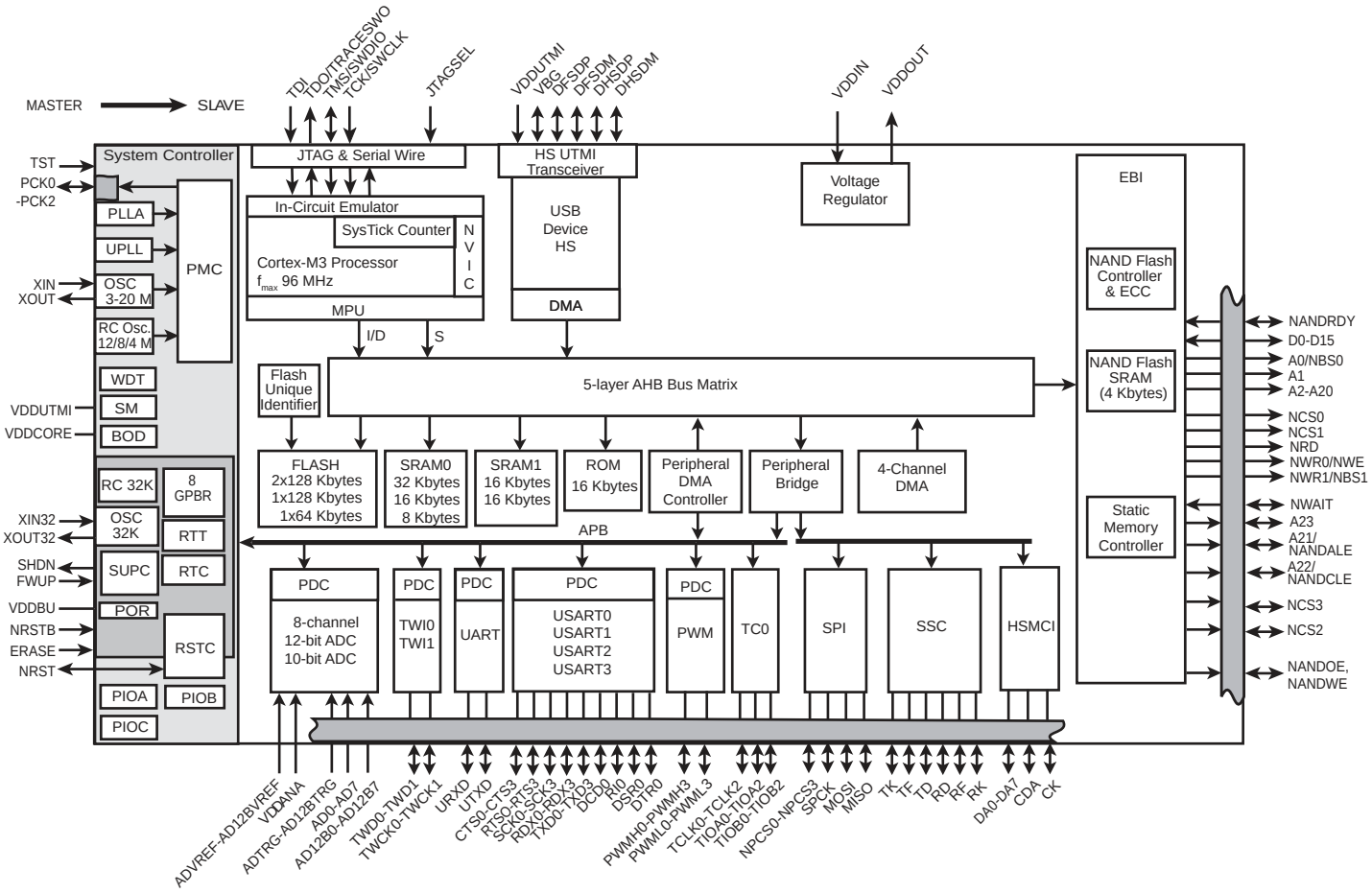
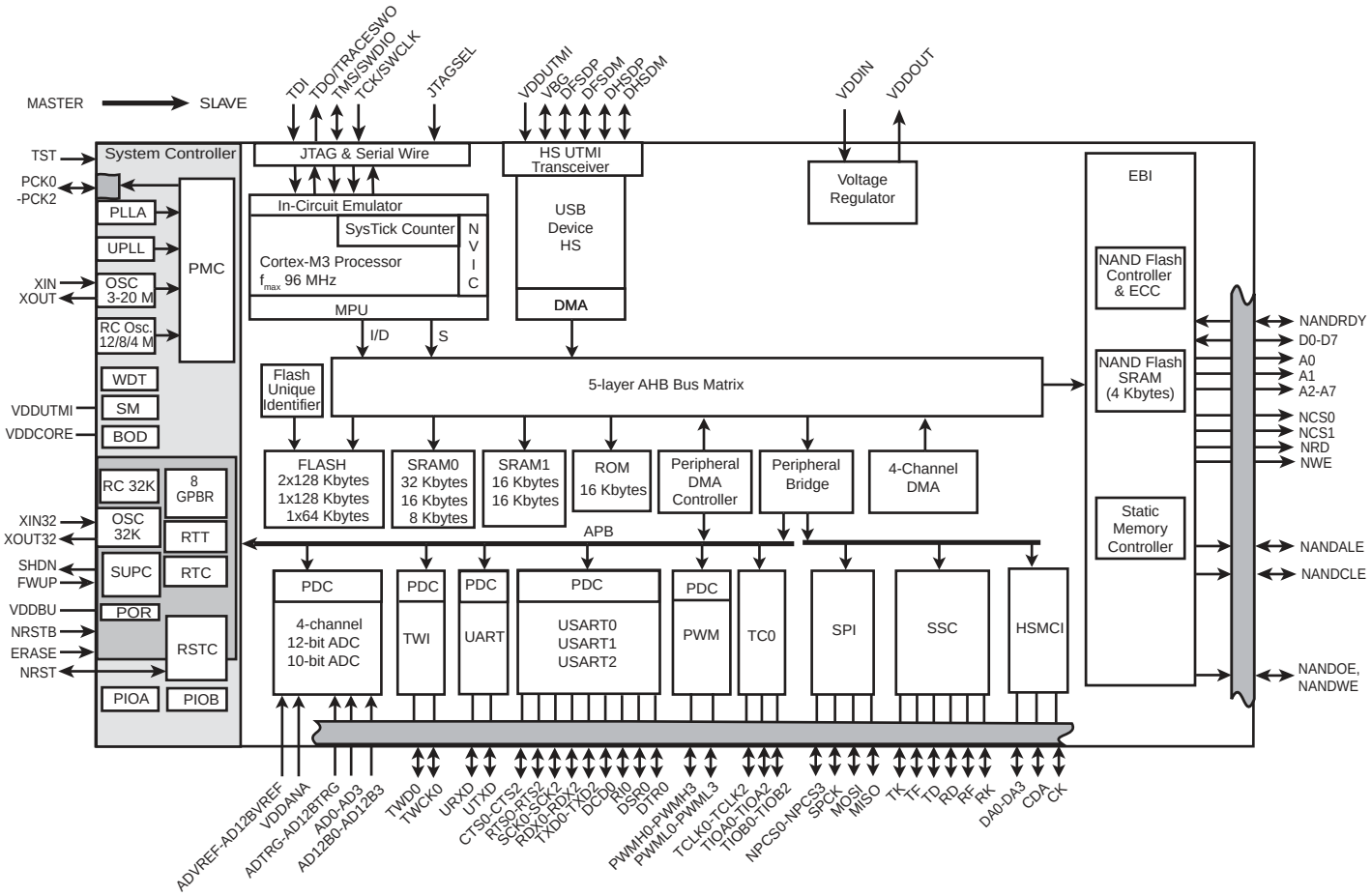


Figure 2-2. 100-pin SAM3U4/2/1C Block Diagram



3. Signal Description

Table 3-1 gives details on the signal names classified by peripheral.

Table 3-1. Signal Description List

Signal Name	Function	Type	Active Level	Voltage Reference	Comments
Power Supplies					
VDDIO	Peripherals I/O Lines Power Supply	Power			1.62V to 3.6V
VDDIN	Voltage Regulator Input	Power			1.8V to 3.6V
VDDOUT	Voltage Regulator Output	Power			1.8V
VDDUTMI	USB UTMI+ Interface Power Supply	Power			3.0V to 3.6V
GNDUTMII	USB UTMI+ Interface Ground	Ground			
VDDBU	Backup I/O Lines Power Supply	Power			1.62V to 3.6V
GNDBU	Backup Ground	Ground			
VDDPLL	PLL A, UPLL and Osc 3–20 MHz Power Supply	Power			1.62 V to 1.95V
GNDPLL	PLL A, UPLL and Osc 3–20 MHz Ground	Ground			
VDDANA	ADC Analog Power Supply	Power			2.0V to 3.6V
GNDANA	ADC Analog Ground	Ground			
VDDCORE	Core, Memories and Peripherals Chip Power Supply	Power			1.62V to 1.95V
GND	Ground	Ground			
Clocks, Oscillators and PLLs					
XIN	Main Oscillator Input	Input		VDDPLL	
XOUT	Main Oscillator Output	Output			
XIN32	Slow Clock Oscillator Input	Input		VDDBU	
XOUT32	Slow Clock Oscillator Output	Output			
VBG	Bias Voltage Reference	Analog			
PCK0–PCK2	Programmable Clock Output	Output		VDDIO	
Shutdown, Wakeup Logic					
SHDN	Shut-Down Control	Output		VDDBU	Push/pull 0: The device is in backup mode 1: The device is running (not in backup mode)
FWUP	Force Wake-Up Input	Input	Low		Needs external pull-up
Serial Wire/JTAG Debug Port (SWJ-DP)					
TCK/SWCLK	Test Clock/Serial Wire Clock	Input		VDDIO	No pull-up resistor
TDI	Test Data In	Input			No pull-up resistor
TDO/TRACESWO	Test Data Out/Trace Asynchronous Data Out	Output[4]			
TMS/SWDIO	Test Mode Select/Serial Wire Input/Output	Input			No pull-up resistor
JTAGSEL	JTAG Selection	Input	High	VDDBU	Internal permanent pull-down

Table 3-1. Signal Description List (Continued)

Signal Name	Function	Type	Active Level	Voltage Reference	Comments
Flash Memory					
ERASE	Flash and NVM Configuration Bits Erase Command	Input	High	VDDBU	Internal permanent 15K pulldown
Reset/Test					
NRST	Microcontroller Reset	I/O	Low	VDDIO	Internal permanent pullup
NRSTB	Asynchronous Microcontroller Reset	Input	Low	VDDBU	Internal permanent pullup
TST	Test Select	Input			Internal permanent pulldown
Universal Asynchronous Receiver Transceiver - UART					
URXD	UART Receive Data	Input			
UTXD	UART Transmit Data	Output			
PIO Controller - PIOA - PIOB - PIOC					
PA0–PA31	Parallel IO Controller A	I/O		VDDIO	Schmitt Trigger (1) Reset State: - PIO Input - Internal pullup enabled
PB0–PB31	Parallel IO Controller B	I/O			Schmitt Trigger (2) Reset State: - PIO Input - Internal pullup enabled
PC0–PC31	Parallel IO Controller C	I/O			Schmitt Trigger(3) Reset State: - PIO Input - Internal pullup enabled
External Bus Interface					
D0–D15	Data Bus	I/O			
A0–A23	Address Bus	Output			
NWAIT	External Wait Signal	Input	Low		
Static Memory Controller - SMC					
NCS0–NCS3	Chip Select Lines	Output	Low		
NWR0–NWR1	Write Signal	Output	Low		
NRD	Read Signal	Output	Low		
NWE	Write Enable	Output	Low		
NBS0–NBS1	Byte Mask Signal	Output	Low		

Table 3-1. Signal Description List (Continued)

Signal Name	Function	Type	Active Level	Voltage Reference	Comments
NAND Flash Controller - NFC					
NANDOE	NAND Flash Output Enable	Output	Low		
NANDWE	NAND Flash Write Enable	Output	Low		
NANDRDY	NAND Ready	Input			
High Speed Multimedia Card Interface - HSMCI					
CK	Multimedia Card Clock	I/O			
CDA	Multimedia Card Slot A Command	I/O			
DA0–DA7	Multimedia Card Slot A Data	I/O			
Universal Synchronous Asynchronous Receiver Transmitter - USARTx					
SCKx	USARTx Serial Clock	I/O			
TXDx	USARTx Transmit Data	I/O			
RXDx	USARTx Receive Data	Input			
RTSx	USARTx Request To Send	Output			
CTSx	USARTx Clear To Send	Input			
DTR0	USART0 Data Terminal Ready	I/O			
DSR0	USART0 Data Set Ready	Input			
DCD0	USART0 Data Carrier Detect	Input			
RI0	USART0 Ring Indicator	Input			
Synchronous Serial Controller - SSC					
TD	SSC Transmit Data	Output			
RD	SSC Receive Data	Input			
TK	SSC Transmit Clock	I/O			
RK	SSC Receive Clock	I/O			
TF	SSC Transmit Frame Sync	I/O			
RF	SSC Receive Frame Sync	I/O			
Timer/Counter - TC					
TCLKx	TC Channel x External Clock Input	Input			
TIOAx	TC Channel x I/O Line A	I/O			
TIOBx	TC Channel x I/O Line B	I/O			
Pulse Width Modulation Controller - PWMC					
PWMHx	PWM Waveform Output High for channel x	Output			
PWMLx	PWM Waveform Output Low for channel x	Output			Only output in complementary mode when dead time insertion is enabled
PWMFI0–2	PWM Fault Input	Input			

Table 3-1. Signal Description List (Continued)

Signal Name	Function	Type	Active Level	Voltage Reference	Comments
Serial Peripheral Interface - SPI					
MISO	Master In Slave Out	I/O			
MOSI	Master Out Slave In	I/O			
SPCK	SPI Serial Clock	I/O			
NPCS0	SPI Peripheral Chip Select 0	I/O	Low		
NPCS1–NPCS3	SPI Peripheral Chip Select	Output	Low		
Two-Wire Interface - TWI					
TWDx	TWIx Two-wire Serial Data	I/O			
TWCKx	TWIx Two-wire Serial Clock	I/O			
12-bit Analog-to-Digital Converter - ADC12B					
AD12Bx	Analog Inputs	Analog			
AD12BTRG	ADC Trigger	Input			
AD12BVREF	ADC Reference	Analog			
10-bit Analog-to-Digital Converter - ADC					
ADx	Analog Inputs	Analog			
ADTRG	ADC Trigger	Input			
ADVREF	ADC Reference	Analog			
Fast Flash Programming Interface - FFPI					
PGMEN0–PGMEN2	Programming Enabling	Input		VDDIO	
PGMM0–PGMM3	Programming Mode	Input			
PGMD0–PGMD15	Programming Data	I/O			
PGMRDY	Programming Ready	Output	High		
PGMNVALID	Data Direction	Output	Low		
PGMNOE	Programming Read	Input	Low		
PGMCK	Programming Clock	Input			
PGMNCMD	Programming Command	Input	Low		
USB High Speed Device - UDPHS					
DFSDM	USB Device Full Speed Data -	Analog		VDDUTMI	
DFSDP	USB Device Full Speed Data +	Analog			
DHSDM	USB Device High Speed Data -	Analog			
DHSDP	USB Device High Speed Data +	Analog			

Notes:
1. PIOA: Schmitt Trigger on all except PA14 on 100 and 144-pin packages.
2. PIOB: Schmitt Trigger on all except PB9 to PB16, PB25 to PB31 on 100 and 144-pin packages.
3. PIOC: Schmitt Trigger on all except PC20 to PC27 on 144-pin package.
4. TDO pin is set in input mode when the Cortex-M3 Core is not in debug mode. Thus an external pull-up (100 kΩ) must be added to avoid current consumption due to floating input.

3.1 Design Considerations

To facilitate schematic capture when using a SAM3U design, refer to the application note *SAM3U Microcontroller Series Schematic Check List* (Atmel literature No. 11006). This application note and additonal documenation are available on www.atmel.com.

4. Package and Pinout

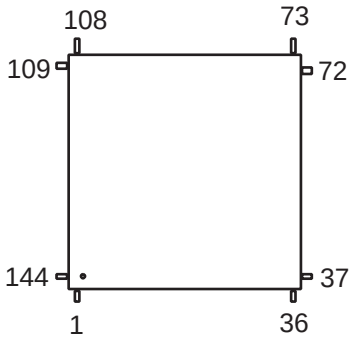
SAM3U4E / SAM3U2E / SAM3U1E devices are available in 144-lead LQFP and 144-ball LFBGA packages.

SAM3U4C / SAM3U2C / SAM3U1C devices are available in 100-lead LQFP and 100-ball TFBGA packages.

4.1 Package and Pinout (SAM3U4E / SAM3U2E / SAM3U1E Devices)

4.1.1 144-lead LQFP Package Outline

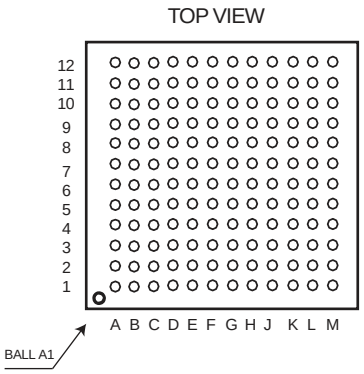
Figure 4-1. Orientation of the 144-lead LQFP Package



See Section 43.3 “144-lead LQFP Package” for mechanical drawings and specifications.

4.1.2 144-ball LFBGA Package Outline

Figure 4-2. Orientation of the 144-ball LFBGA Package



See Section 43.4 “144-ball LFBGA Package” for mechanical drawings and specifications.

4.1.3 144-lead LQFP Pinout

Table 4-1. 144-lead LQFP Pinout (SAM3U4E / SAM3U2E / SAM3U1E Devices)

1	TDI	37	DHSDP	73	VDDANA	109	PA0/PGMNCMD
2	VDDOUT	38	DHSDM	74	ADVREF	110	PC0
3	VDDIN	39	VBG	75	GNDANA	111	PA1/PGMRDY
4	TDO/TRACESWO	40	VDDUTMI	76	AD12BVREF	112	PC1
5	PB31	41	DFSDM	77	PA22/PGMD14	113	PA2/PGMNOE
6	PB30	42	DFSDP	78	PA30	114	PC2
7	TMS/SWDIO	43	GNDUTMI	79	PB3	115	PA3/PGMNVALID
8	PB29	44	VDDCORE	80	PB4	116	PC3
9	TCK/SWCLK	45	PA28	81	PC15	117	PA4/PGMM0
10	PB28	46	PA29	82	PC16	118	PC4
11	NRST	47	PC22	83	PC17	119	PA5/PGMM1
12	PB27	48	PA31	84	PC18	120	PC5
13	PB26	49	PC23	85	VDDIO	121	PA6/PGMM2
14	PB25	50	VDDCORE	86	VDDCORE	122	PC6
15	PB24	51	VDDIO	87	PA13/PGMD5	123	PA7/PGMM3
16	VDDCORE	52	GND	88	PA14/PGMD6	124	PC7
17	VDDIO	53	PB0	89	PC10	125	VDDCORE
18	GND	54	PC24	90	GND	126	GND
19	PB23	55	PB1	91	PA15/PGMD7	127	VDDIO
20	PB22	56	PC25	92	PC11	128	PA8/PGMD0
21	PB21	57	PB2	93	PA16/PGMD8	129	PC8
22	PC21	58	PC26	94	PC12	130	PA9/PGMD1
23	PB20	59	PB11	95	PA17/PGMD9	131	PC9
24	PB19	60	GND	96	PB16	132	PA10/PGMD2
25	PB18	61	PB12	97	PB15	133	PA11/PGMD3
26	PB17	62	PB13	98	PC13	134	PA12/PGMD4
27	VDDCORE	63	PC27	99	PA18/PGMD10	135	FWUP
28	PC14	64	PA27	100	PA19/PGMD11	136	SHDN
29	PB14	65	PB5	101	PA20/PGMD12	137	ERASE
30	PB10	66	PB6	102	PA21/PGMD13	138	TST
31	PB9	67	PB7	103	PA23/PGMD15	139	VDDBU
32	PC19	68	PB8	104	VDDIO	140	GNDBU
33	GNDPLL	69	PC28	105	PA24	141	NRSTB
34	VDDPLL	70	PC29	106	PA25	142	JTAGSEL
35	XOUT	71	PC30	107	PA26	143	XOUT32
36	XIN	72	PC31	108	PC20	144	XIN32

4.1.4 144-ball LFBGA Pinout

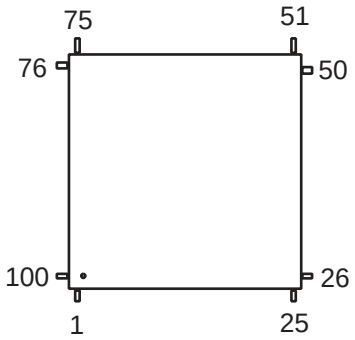
Table 4-2. 144-ball LFBGA Pinout (SAM3U4E / SAM3U2E / SAM3U1E Devices)

A1	VBG	D1	DFSDM	G1	PB0	K1	PB7
A2	VDDUTMI	D2	DHSDM	G2	PC26	K2	PC31
A3	PB9	D3	GNDPLL	G3	PB2	K3	PC29
A4	PB10	D4	PC14	G4	PC25	K4	PB3
A5	PB19	D5	PB21	G5	PB1	K5	PB4
A6	PC21	D6	PB23	G6	GND	K6	PA14/PGMD6
A7	PB26	D7	PB24	G7	GND	K7	PA16/PGMD8
A8	TCK/SWCLK	D8	PB28	G8	VDDCORE	K8	PA18/PGMD10
A9	PB30	D9	TDI	G9	PC4	K9	PC20
A10	TDO/TRACESWO	D10	VDDBU	G10	PA6/PGMM2	K10	PA1/PGMRDY
A11	XIN32	D11	PA10/PGMD2	G11	PA7/PGMM3	K11	PC1
A12	XOUT32	D12	PA11/PGMD3	G12	PC6	K12	PC2
B1	VDDCORE	E1	PC22	H1	PC24	L1	PC30
B2	GNDUTMI	E2	PA28	H2	PC27	L2	ADVREF
B3	XOUT	E3	PC19	H3	PA27	L3	AD12BVREF
B4	PB14	E4	VDDCORE	H4	PB12	L4	PA22/PGMD14
B5	PB17	E5	GND	H5	PB11	L5	PC17
B6	PB22	E6	VDDIO	H6	GND	L6	PC10
B7	PB25	E7	GNDBU	H7	VDDCORE	L7	PC12
B8	PB29	E8	NRST	H8	PB16	L8	PA19/PGMD11
B9	VDDIN	E9	PB31	H9	PB15	L9	PA23/PGMD15
B10	JTAGSEL	E10	PA12/PGMD4	H10	PC3	L10	PA0/PGMNCMD
B11	ERASE	E11	PA8/PGMD0	H11	PA5/PGMM1	L11	PA26
B12	SHDN	E12	PC8	H12	PC5	L12	PC0
C1	DFSDP	F1	PA31	J1	PB5	M1	VDDANA
C2	DHSDP	F2	PA29	J2	PB6	M2	GNDANA
C3	XIN	F3	PC23	J3	PC28	M3	PA30
C4	VDDPLL	F4	VDDCORE	J4	PB8	M4	PC15
C5	PB18	F5	VDDIO	J5	PB13	M5	PC16
C6	PB20	F6	GND	J6	VDDIO	M6	PC18
C7	PB27	F7	GND	J7	PA13/PGMD5	M7	PA15/PGMD7
C8	TMS/SWDIO	F8	VDDIO	J8	PA17/PGMD9	M8	PC11
C9	VDDOUT	F9	PC9	J9	PC13	M9	PA20/PGMD12
C10	NRSTB	F10	PA9/PGMD1	J10	PA2/PGMNOE	M10	PA21/PGMD13
C11	TST	F11	VDDCORE	J11	PA3/PGMNVALID	M11	PA24
C12	FWUP	F12	PC7	J12	PA4/PGMM0	M12	PA25

4.2 Package and Pinout (SAM3U4C / SAM3U2C / SAM3U1C Devices)

4.2.1 100-lead LQFP Package Outline

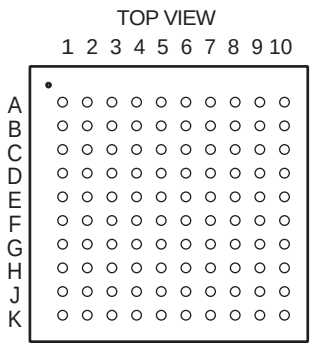
Figure 4-3. Orientation of the 100-lead LQFP Package



See Section 43.1 “100-lead LQFP Package” for mechanical drawings and specifications.

4.2.2 100-ball TFBGA Package Outline

Figure 4-4. Orientation of the 100-ball TFBGA Package



See Section 43.2 “100-ball TFBGA Package” for mechanical drawings and specifications.

4.2.3 100-lead LQFP Pinout

Table 4-3. 100-lead LQFP Pinout (SAM3U4C / SAM3U2C / SAM3U1C Devices)

1	VDDANA	26	PA0/PGMNCMD	51	TDI	76	DHSDP
2	ADVREF	27	PA1/PGMRDY	52	VDDOUT	77	DHSDM
3	GNDANA	28	PA2/PGMNOE	53	VDDIN	78	VBG
4	AD12BVREF	29	PA3/PGMNVALID	54	TDO/TRACESWO	79	VDDUTMI
5	PA22/PGMD14	30	PA4/PGMM0	55	TMS/SWDIO	80	DFSDM
6	PA30	31	PA5/PGMM1	56	TCK/SWCLK	81	DFSDP
7	PB3	32	PA6/PGMM2	57	NRST	82	GNDUTMI
8	PB4	33	PA7/PGMM3	58	PB24	83	VDDCORE
9	VDDCORE	34	VDDCORE	59	VDDCORE	84	PA28
10	PA13/PGMD5	35	GND	60	VDDIO	85	PA29
11	PA14/PGMD6	36	VDDIO	61	GND	86	PA31
12	PA15/PGMD7	37	PA8/PGMD0	62	PB23	87	VDDCORE
13	PA16/PGMD8	38	PA9/PGMD1	63	PB22	88	VDDIO
14	PA17/PGMD9	39	PA10/PGMD2	64	PB21	89	GND
15	PB16	40	PA11/PGMD3	65	PB20	90	PB0
16	PB15	41	PA12/PGMD4	66	PB19	91	PB1
17	PA18/PGMD10	42	FWUP	67	PB18	92	PB2
18	PA19/PGMD11	43	ERASE	68	PB17	93	PB11
19	PA20/PGMD12	44	TST	69	PB14	94	PB12
20	PA21/PGMD13	45	VDDBU	70	PB10	95	PB13
21	PA23/PGMD15	46	GNDBU	71	PB9	96	PA27
22	VDDIO	47	NRSTB	72	GNDPLL	97	PB5
23	PA24	48	JTAGSEL	73	VDDPLL	98	PB6
24	PA25	49	XOUT32	74	XOUT	99	PB7
25	PA26	50	XIN32	75	XIN	100	PB8

4.2.4 100-ball TFBGA Pinout

Table 4-4. 100-ball TFBGA Pinout (SAM3U4C / SAM3U2C / SAM3U1C Devices)

A1	VBG	C6	PB22	F1	PB1	H6	PA15/PGMD7
A2	XIN	C7	TMS/SWDIO	F2	PB12	H7	PA18/PGMD10
A3	XOUT	C8	NRSTB	F3	VDDIO	H8	PA24
A4	PB17	C9	JTAGSEL	F4	PA31	H9	PA1/PGMRDY
A5	PB21	C10	VDDBU	F5	VDDIO	H10	PA2/PGMNOE
A6	PB23	D1	DFSDM	F6	GND	J1	PB6
A7	TCK/SWCLK	D2	DHSDM	F7	PB16	J2	PB8
A8	VDDIN	D3	VDDPLL	F8	PA6/PGMM2	J3	ADVREF
A9	VDDOUT	D4	VDDCORE	F9	VDDCORE	J4	PA30
A10	XIN32	D5	PB20	F10	PA7/PGMM3	J5	PB3
B1	VDDCORE	D6	ERASE	G1	PB11	J6	PA16/PGMD8
B2	GNDUTMI	D7	TST	G2	PB2	J7	PA19/PGMD11
B3	VDDUTMI	D8	FWUP	G3	PB0	J8	PA21/PGMD13
B4	PB10	D9	PA11/PGMD3	G4	PB13	J9	PA26
B5	PB18	D10	PA12/PGMD4	G5	VDDCORE	J10	PA0/PGMNCMD
B6	PB24	E1	PA29	G6	GND	K1	PB7
B7	NRST	E2	GND	G7	PB15	K2	VDDANA
B8	TDO/TRACESWO	E3	PA28	G8	PA3/PGMNVALID	K3	GNDANA
B9	TDI	E4	PB9	G9	PA5/PGMM1	K4	AD12BVREF
B10	XOUT32	E5	GNDBU	G10	PA4/PGMM0	K5	PB4
C1	DFSDP	E6	VDDIO	H1	VDDCORE	K6	PA14/PGMD6
C2	DHSDP	E7	VDDCORE	H2	PB5	K7	PA17/PGMD9
C3	GNDPLL	E8	PA10/PGMD2	H3	PA27	K8	PA20/PGMD12
C4	PB14	E9	PA9/PGMD1	H4	PA22/PGMD14	K9	PA23/PGMD15
C5	PB19	E10	PA8/PGMD0	H5	PA13/PGMD5	K10	PA25

5. Power Considerations

5.1 Power Supplies

The SAM3U product power supply pins are the following:

- VDDCORE pins: Power the core, the embedded memories and the peripherals; voltage range 1.62–1.95 V
- VDDIO pins: Power the peripherals I/O lines; voltage range 1.62–3.6 V
- VDDIN pin: Powers the voltage regulator
- VDDOUT pin: Output of the voltage regulator
- VDDBU pin: Powers the Slow Clock oscillator and a part of the System Controller; voltage range 1.62– 3.6V. VDDBU must be supplied before or at the same time as VDDIO and VDDCORE.
- VDDPLL pin: Powers the PLL A, UPLL and 3–20 MHz Oscillator; voltage range 1.62–1.95 V
- VDDUTMI pin: Powers the UTMI+ interface; voltage range 3.0–3.6 V, 3.3V nominal
- VDDANA pin: Powers the ADC cells; voltage range 2.0–3.6 V

Ground pins GND are common to VDDCORE and VDDIO pins power supplies.

Separated ground pins are provided for VDDBU, VDDPLL, VDDUTMI and VDDANA. These ground pins are respectively GNDBU, GNDPLL, GNDUTMI and GNDANA.

5.2 Power-up Considerations

5.2.1 VDDIO Versus VDDCORE

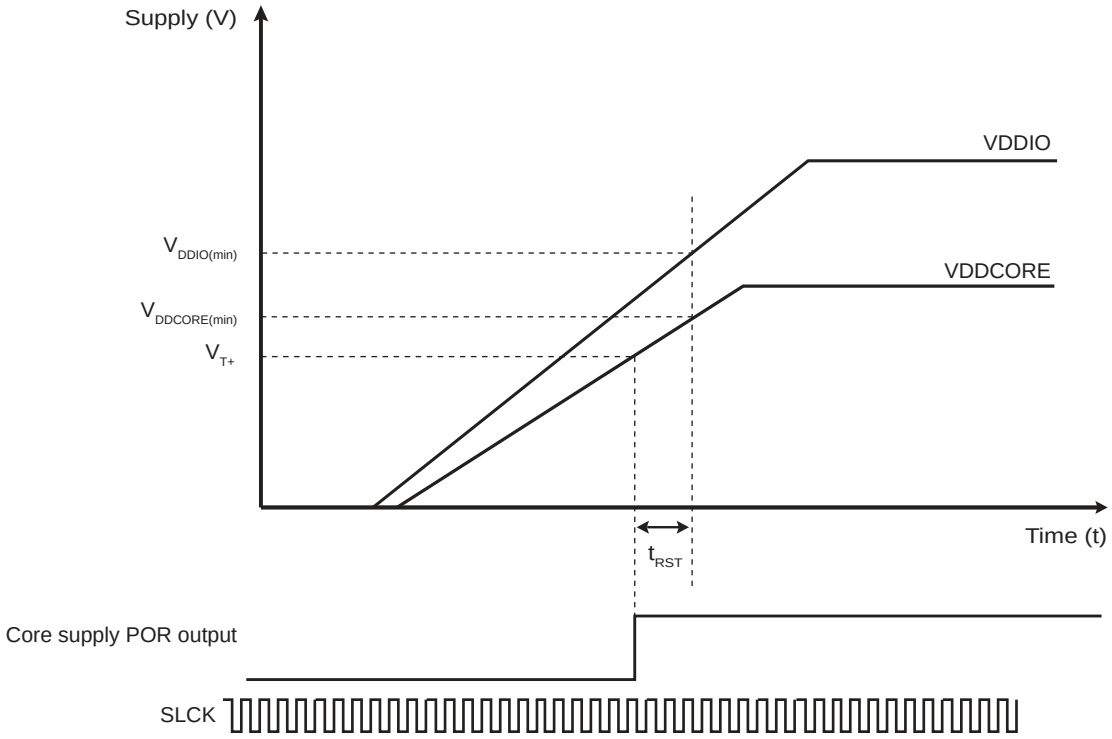
V_{DDIO} must always be higher or equal to V_{DDCORE}.

V_{DDIO} must reach its minimum operating voltage (1.60 V) before V_{DDCORE} has reached $V_{DDCORE(min)}$. The minimum slope for V_{DDCORE} is defined by ($V_{DDCORE(min)}$ - V_{T+}) / t_{RST}.

If V_{DDCORE} rises at the same time as V_{DDIO}, the V_{DDIO} rising slope must be higher than or equal to 5V/ms.

If VDDCORE is powered by the internal regulator, all power-up considerations are met.

Figure 5-1. VDDCORE and VDDIO Constraints at Startup



5.2.2 VDDIO Versus VDDIN

At power-up, V_{DDIO} needs to reach 0.6 V before V_{DDIN} reaches 1.0 V.

VDDIO voltage needs to be equal to or below (VDDIN voltage + 0.5 V).

5.3 Voltage Regulator

The SAM3U embeds a voltage regulator that is managed by the Supply Controller.

This internal regulator is intended to supply the internal core of SAM3U but can be used to supply other parts in the application. It features two different operating modes:

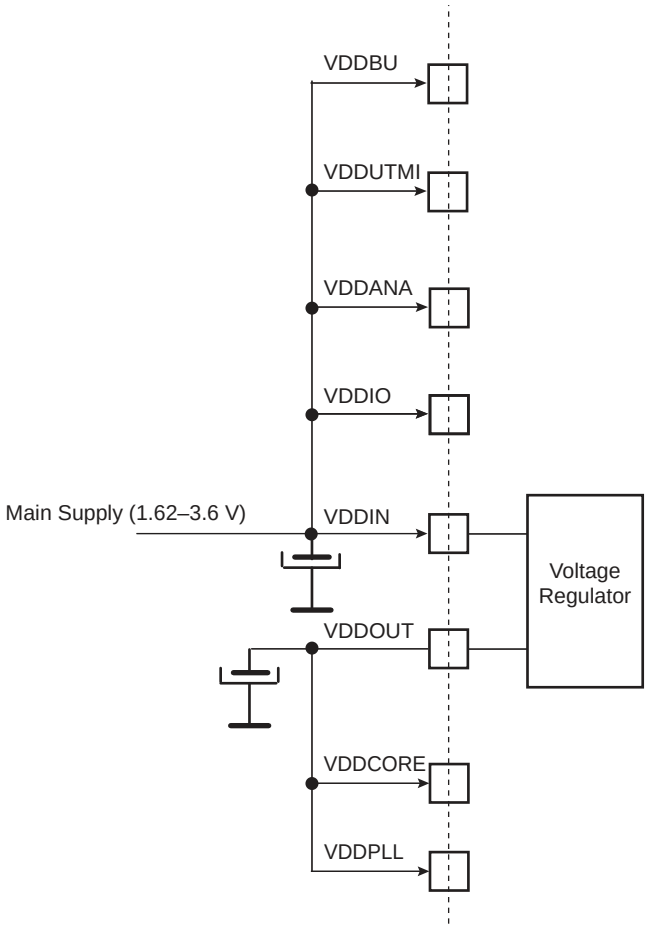
- In Normal mode, the voltage regulator consumes less than 700 µA static current and draws 150 mA of output current. Internal adaptive biasing adjusts the regulator quiescent current depending on the required load current. In Wait mode or when the output current is low, quiescent current is only 7 µA.
- In Shutdown mode, the voltage regulator consumes less than 1 µA while its output is driven internally to GND. The default output voltage is 1.80 V and the startup time to reach Normal mode is inferior to 400 µs.

For adequate input and output power supply decoupling/bypassing, refer to Table 42-3, “1.8V Voltage Regulator Characteristics,” on page 1089.

5.4 Typical Powering Schematics

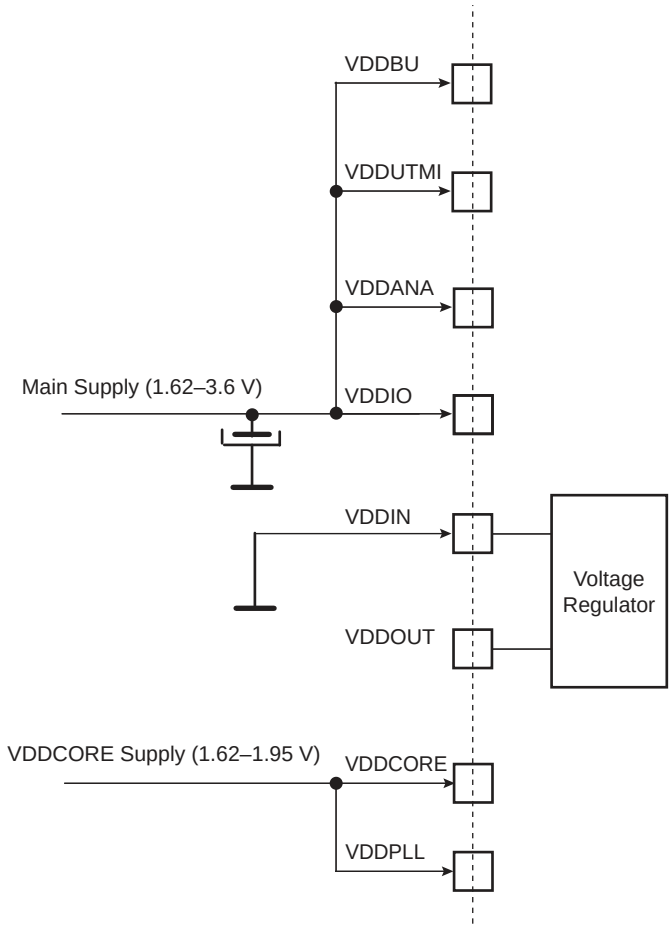
The SAM3U supports a 1.62–3.6 V single supply mode. The internal regulator input connected to the source and its output feed VDDCORE. Figure 5-2, Figure 5-3, and Figure 5-4 show the power schematics.

Figure 5-2. Single Supply



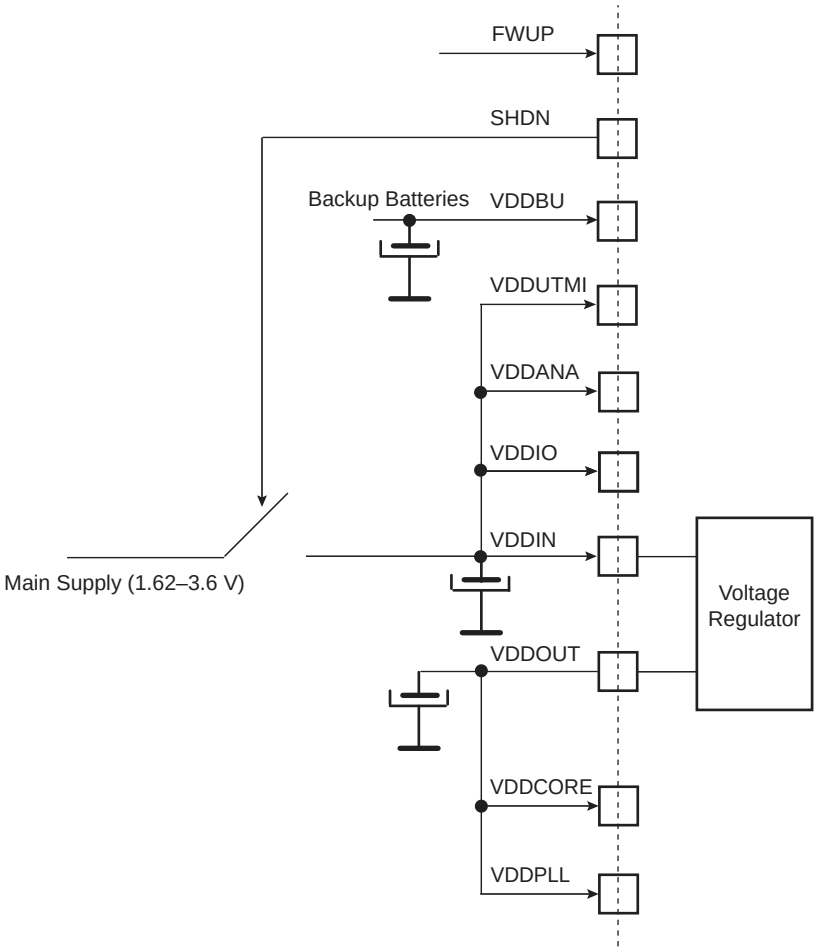
Note: Restrictions:
With Main Supply < 2.0 V, USB and ADC are not usable.
With Main Supply ≥ 2.4V and < 3V, USB is not usable.
With Main Supply ≥ 3V, all peripherals are usable.

Figure 5-3. Core Externally Supplied



Note: Restrictions:
With Main Supply < 2.0 V, USB and ADC are not usable.
With Main Supply ≥ 2.4V and < 3V, USB is not usable.
With Main Supply ≥ 3V, all peripherals are usable.

Figure 5-4. Backup Batteries Used



Note: Restrictions
With Main Supply < 2.0 V, USB and ADC are not usable.
With Main Supply ≥ 2.4V and < 3V, USB is not usable.
With Main Supply ≥ 3V, all peripherals are usable.

5.5 Active Mode

Active mode is the normal running mode with the core clock running from the fast RC oscillator, the main crystal oscillator or the PLLA. The power management controller can be used to adapt the frequency and to disable the peripheral clocks.

5.6 Low-power Modes

The SAM3U has the following low-power modes: Backup, Wait, and Sleep.

5.6.1 Backup Mode

The purpose of backup mode is to achieve the lowest power consumption possible in a system which is performing periodic wake-ups to perform tasks but not requiring fast startup time (< 0.5 ms).

The Supply Controller, zero-power power-on reset, RTT, RTC, backup registers and 32 kHz oscillator (RC or crystal oscillator selected by software in the Supply Controller) are running. The regulator and the core supply are off.

Backup mode is based on the Cortex-M3 deep-sleep mode with the voltage regulator disabled.

The SAM3U Series can be woken up from this mode through the Force Wake-Up (FWUP) pin, and Wake-Up input pins WKUP0–15, Supply Monitor, RTT or RTC wake-up event. Current consumption is 2.5 µA typical on VDDBU.

Backup mode can be entered by using the WFE instruction.

The procedure to enter Backup mode using the WFE instruction is the following:

1. Write a 1 to the SLEEPDEEP bit in the Cortex-M3 processor System Control Register (SCR) (refer to Section 12.20.7 ”System Control Register”).
2. Execute the WFE instruction of the processor.

Exit from Backup mode happens if one of the following enable wake-up events occurs:

- Low level, configurable debouncing on FWUP pin
- Level transition, configurable debouncing on pins WKUPEN0–15
- SM alarm
- RTC alarm
- RTT alarm

5.6.2 Wait Mode

The purpose of the Wait mode is to achieve very low power consumption while maintaining the whole device in a powered state for a startup time of less than 10 µs.

In this mode, the clocks of the core, peripherals and memories are stopped. However, the core, peripherals and memories power supplies are still powered. From this mode, a fast start up is available.

This mode is entered via Wait for Event (WFE) instructions with LPM = 1 (Low Power Mode bit in PMC_FSMR). The Cortex-M3 is able to handle external events or internal events in order to wake up the core (WFE). This is done by configuring the external lines WKUP0–15 as fast startup wake-up pins (refer to Section 5.8 “Fast Startup”). RTC or RTT Alarm and USB wake-up events can be used to wake up the CPU (exit from WFE).

Current Consumption in Wait mode is typically 15 µA on VDDIN if the internal voltage regulator is used or 8 µA on VDDCORE if an external regulator is used.

The procedure to enter Wait mode is the following:

1. Select the 4/8/12 MHz fast RC oscillator as Main Clock
2. Set the LPM bit in PMC_FSMR
3. Execute the WFE instruction of the processor

Note: Internal Main clock resynchronization cycles are necessary between the writing of MOSCRCEN bit and the effective entry in Wait mode. Depending on the user application, waiting for MOSCRCEN bit to be cleared is recommended to ensure that the core will not execute undesired instructions.

5.6.3 Sleep Mode

The purpose of sleep mode is to optimize power consumption of the device versus response time. In this mode, only the core clock is stopped. The peripheral clocks can be enabled. This mode is entered via Wait for Interrupt (WFI) or WFE instructions with LPM = 0 in PMC_FSMR.

The processor can be woken up from an interrupt if WFI instruction of the Cortex-M3 is used, or from an event if the WFE instruction is used to enter this mode.

5.6.4 Low-power Mode Summary Table

The modes detailed above are the main low-power modes. Each part can be set to on or off separately and wake up sources can be individually configured. Table 5-1 shows a summary of the configurations of the low-power modes.

Table 5-1. Low Power Mode Configuration Summary

Mode	SUPC, 32 kHz Osc., RTC, RTT, GPBR, POR (VDDBU Region)	Regulator	Core Memory Peripherals	Mode Entry	Potential Wake-up Sources	Core at Wake-up	PIO State While in Low Power Mode	PIO State at Wake-up	Consumption (2) (3)	Wake-up Time(1)
Backup Mode	ON	OFF SHDN = 0	OFF (Not powered)	WFE + SLEEPDEEP = 1	FWUP pin Pins WKUP0–15 SM alarm RTC alarm RTT alarm	Reset	Previous state saved	PIOA & PIOB & PIOC Inputs with pull-ups	2.5 µA typ(4)	< 0.5 ms
Wait Mode	ON	ON SHDN = 1	Powered (Not clocked)	WFE + SLEEPDEEP = 0 + LPM = 1	Any event from: - Fast startup through pins WKUP0–15 - RTC alarm - RTT alarm - USB wake-up	Clocked back	Previous state saved	Unchanged	13 µA/20 µA(5)	< 10 µs
Sleep Mode	ON	ON SHDN = 1	Powered(7) (Not clocked)	WFE or WFI + SLEEPDEEP = 0 + LPM = 0	Entry mode = WFI interrupt only; Entry mode = WFE any enabled interrupt and/or Any event from: - Fast startup through pins WKUP0–15 - RTC alarm - RTT alarm - USB wake-up	Clocked back	Previous state saved	Unchanged	(6)	(6)

Notes:
1. When considering wake-up time, the time required to start the PLL is not taken into account. Once started, the device works with the 4/8/12 MHz Fast RC oscillator. The user has to add the PLL startup time if it is needed in the system. The wake-up time is defined as the time taken for wake-up until the first instruction is fetched.
2. The external loads on PIOs are not taken into account in the calculation.
3. BOD current consumption is not included.
4. Current consumption on VDDBU.
5. 13 µA total current consumption - **without** using internal voltage regulator.
   20 µA total current consumption - **using** internal voltage regulator.
6. Depends on MCK frequency.
7. In this mode the core is supplied and not clocked but some peripherals can be clocked.

5.7 Wake-up Sources

The wake-up events allow the device to exit Backup mode. When a wake-up event is detected, the Supply Controller performs a sequence which automatically reenables the core power supply. See Figure 18-7 “Wake Up Sources” on page 273.

5.8 Fast Startup

The SAM3U device allows the processor to restart in a few microseconds while the processor is in Wait mode. A fast startup can occur upon detection of a low level on one of the 19 wake-up inputs (WKUP0 to 15 + RTC + RTT + USB).

The fast restart circuitry (shown in Figure 27-3 “Fast Startup Circuitry” on page 454) is fully asynchronous and provides a fast startup signal to the Power Management Controller. As soon as the fast startup signal is asserted, the PMC automatically restarts the embedded 4/8/12 MHz fast RC oscillator, switches the master clock on this 4 MHz clock by default and reenables the processor clock.

6. Input/Output Lines

The SAM3U has different kinds of input/output (I/O) lines, such as general purpose I/Os (GPIO) and system I/Os. GPIOs can have alternate functions thanks to multiplexing capabilities of the PIO controllers. The same GPIO line can be used whether it is in IO mode or used by the multiplexed peripheral. System I/Os are pins such as test pin, oscillators, erase pin, analog inputs or debug pins.

With a few exceptions, the I/Os have input Schmitt triggers. Refer to the footnotes associated with “PIO Controller - PIOA - PIOB - PIOC” on page 7 within Table 3-1, “Signal Description List”.

6.1 General Purpose I/O Lines (GPIO)

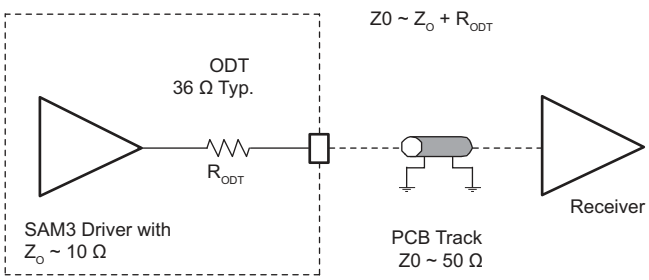
GPIO Lines are managed by PIO controllers. All I/Os have several input or output modes such as, pull-up, input Schmitt triggers, multi-drive (open-drain), glitch filters, debouncing or input change interrupt. Programming of these modes is performed independently for each I/O line through the PIO controller user interface. For more details, refer to Section 29. ”Parallel Input/Output Controller (PIO)”.

The input output buffers of the PIO lines are supplied through VDDIO power supply rail.

The SAM3U embeds high-speed pads able to handle up to 65 MHz for HSMCI and SPI clock lines and 35 MHz on other lines. See Section 42.9 ”AC Characteristics” for more details. Typical pull-up value is 100 kΩ for all I/Os.

Each I/O line also embeds an ODT (On-Die Termination) (see Figure 6-1). ODT consists of an internal series resistor termination scheme for impedance matching between the driver output (SAM3) and the PCB track impedance preventing signal reflection. The series resistor helps to reduce I/Os switching current (di/dt) thereby reducing in turn, EMI. It also decreases overshoot and undershoot (ringing) due to inductance of interconnect between devices or between boards. In conclusion, ODT helps reducing signal integrity issues.

Figure 6-1. On-Die Termination Schematic



6.2 System I/O Lines

System I/O lines are pins used by oscillators, test mode, reset, flash erase and JTAG to name but a few.

6.3 Serial Wire JTAG Debug Port (SWJ-DP)

The SWJ-DP pins are TCK/SWCLK, TMS/SWDIO, TDO/TRACESWO, TDI and commonly provided on a standard 20-pin JTAG connector defined by ARM. For more details about voltage reference and reset state, refer to Table 3-1, “Signal Description List”.

The JTAGSEL pin is used to select the JTAG boundary scan when asserted at a high level. It integrates a permanent pull-down resistor of about 15 kΩ to GNDBU, so that it can be left unconnected for normal operations.

By default, the JTAG Debug Port is active. If the debugger host wants to switch to the Serial Wire Debug Port, it must provide a dedicated JTAG sequence on TMS/SWDIO and TCK/SWCLK which disables the JTAG-DP and enables the SW-DP. When the Serial Wire Debug Port is active, TDO/TRACESWO can be used for trace.

The asynchronous TRACE output (TRACESWO) is multiplexed with TDO. So the asynchronous trace can only be used with SW-DP, not JTAG-DP.

All the JTAG signals are supplied with VDDIO except JTAGSEL, supplied by VDDBU.

6.4 Test Pin

The TST pin is used for JTAG Boundary Scan Manufacturing Test or fast flash programming mode of the SAM3U series. The TST pin integrates a permanent pull-down resistor of about 15 kΩ to GND, so that it can be left unconnected for normal operations. To enter fast programming mode, see Section 21. ”Fast Flash Programming Interface (FFPI)”. For more on the manufacturing and test mode, refer to Section 13. ”Debug and Test Features”.

6.5 NRST Pin

The NRST pin is bidirectional. It is handled by the on-chip reset controller and can be driven low to provide a reset signal to the external components or asserted low externally to reset the microcontroller. It will reset the Core and the peripherals, except the Backup region (RTC, RTT and Supply Controller). There is no constraint on the length of the reset pulse and the reset controller can guarantee a minimum pulse length.

The NRST pin integrates a permanent pull-up resistor to VDDIO of about 100 kΩ.

6.6 NRSTB Pin

The NRSTB pin is input only and enables asynchronous reset of the SAM3U when asserted low. The NRSTB pin integrates a permanent pull-up resistor of about 15 kΩ. This allows connection of a simple push button on the NRSTB pin as a system-user reset. In all modes, this pin will reset the chip including the Backup region (RTC, RTT and Supply Controller). It reacts as the Power-on reset. It can be used as an external system reset source. In harsh environments, it is recommended to add an external capacitor (10 nF) between NRSTB and VDDBU. (For filtering values refer to Section 42.9.2 ”I/O Characteristics”.)

It embeds an anti-glitch filter.

6.7 ERASE Pin

The ERASE pin is used to reinitialize the Flash content and some of its NVM bits. The ERASE pin and the ROM code ensure an in-situ reprogrammability of the Flash content without the use of a debug tool. When the security bit is activated, the ERASE pin provides the capability to reprogram the Flash content. It integrates a permanent pull-down resistor of about 15 kΩ to GND, so that it can be left unconnected for normal operations.

This pin is debounced by SCLK to improve the glitch tolerance. When the ERASE pin is tied high during less than 100 ms, it is not taken into account. The pin must be tied high during more than 220 ms to perform the reinitialization of the Flash.

Even in all low power modes, asserting the pin will automatically start up the chip and erase the Flash.

7. Architecture

7.1 APB/AHB Bridges

The SAM3U product embeds two separated APB/AHB bridges:

- Low speed bridge
- High speed bridge

This architecture enables to make concurrent accesses on both bridges.

All the peripherals are on the low-speed bridge except SPI, SSC and HSMCI.

The UART, 10-bit ADC (ADC), 12-bit ADC (ADC12B), TWI0–1, USART0–3, and PWM have dedicated channels for the Peripheral DMA Controller (PDC) channels. These peripherals can not use the DMA Controller.

The high speed bridge regroups the SSC, SPI and HSMCI. These three peripherals do not have PDC channels but can use the DMA with the internal FIFO for channel buffering.

Note that the peripherals of the two bridges are clocked by the same source: MCK.

7.2 Matrix Masters

The Bus Matrix of the SAM3U device manages five masters, which means that each master can perform an access concurrently with others to an available slave.

Each master has its own decoder and specifically defined bus. In order to simplify the addressing, all the masters have the same decoding.

Table 7-1. List of Bus Matrix Masters

Master 0	Cortex-M3 Instruction/Data Bus
Master 1	Cortex-M3 System Bus
Master 2	Peripheral DMA Controller (PDC)
Master 3	USB Device High Speed DMA
Master 4	DMA Controller

7.3 Matrix Slaves

The Bus Matrix of the SAM3U manages 10 slaves. Each slave has its own arbiter, allowing a different arbitration per slave.

Table 7-2. List of Bus Matrix Slaves

Slave 0	Internal SRAM0
Slave 1	Internal SRAM1
Slave 2	Internal ROM
Slave 3	Internal Flash 0
Slave 4	Internal Flash 1
Slave 5	USB Device High Speed Dual Port RAM (DPR)
Slave 6	NAND Flash Controller RAM
Slave 7	External Bus Interface
Slave 8	Low Speed Peripheral Bridge
Slave 9	High Speed Peripheral Bridge

7.4 Master to Slave Access

All the Masters can normally access all the Slaves. However, some paths do not make sense, for example allowing access from the USB Device High speed DMA to the Internal Peripherals. Thus, these paths are forbidden or simply not wired, and shown as "–" in Table 7-3 below.

Table 7-3. SAM3U Master to Slave Access

Slaves	Masters	0	1	2	3	4
		Cortex-M3 Instruction/Data Bus	Cortex-M3 System Bus	Peripheral DMA Controller (PDC)	USB Device High Speed DMA	DMA Controller
0	Internal SRAM0	–	X	X	X	X
1	Internal SRAM1	–	X	X	X	X
2	Internal ROM	X	–	X	X	X
3	Internal Flash 0	X	–	–	–	–
4	Internal Flash 1	X	–	–	–	–
5	USB Device High Speed Dual Port RAM (DPR)	–	X	–	–	–
6	NAND Flash Controller RAM	–	X	X	X	X
7	External Bus Interface	–	X	X	X	X
8	Low Speed Peripheral Bridge	–	X	X	–	–
9	High Speed Peripheral Bridge	–	X	X	–	–

7.5 DMA Controller

- Acting as one Matrix Master
- Embeds 4 channels:
  - 3 channels with 8 bytes/FIFO for Channel Buffering
  - 1 channel with 32 bytes/FIFO for Channel Buffering
- Linked List support with Status Write Back operation at End of Transfer
- Word, HalfWord, Byte transfer support
- Handles high speed transfer of SPI, SSC and HSMCI (peripheral to memory, memory to peripheral)
- Memory to memory transfer
- Can be triggered by PWM and T/C which enables to generate waveforms though the External Bus Interface

The DMA controller can handle the transfer between peripherals and memory and so receives the triggers from the peripherals listed below. The hardware interface numbers are also given in Table 7-4.

Table 7-4. DMA Controller

Instance Name	Channel T/R	DMA Channel HW Interface Number
HSMCI	Transmit/Receive	0
SPI	Transmit	1
SPI	Receive	2
SSC	Transmit	3
SSC	Receive	4
PWM Event Line 0	Trigger	5
PWM Event Line 1	Trigger	6
TIO Output of TImer Counter Channel 0	Trigger	7

7.6 Peripheral DMA Controller

- Handles data transfer between peripherals and memories
- Nineteen channels
  - Two for each USART
  - Two for the UART
  - Two for each Two Wire Interface
  - One for the PWM
  - One for each Analog-to-Digital Converter
- Low bus arbitration overhead
  - One Master Clock cycle needed for a transfer from memory to peripheral
  - Two Master Clock cycles needed for a transfer from peripheral to memory
- Next Pointer management for reducing interrupt latency requirement

The PDC handles transfer requests from the channel according to the priorities (low to high priorities) defined in Table 7-5.

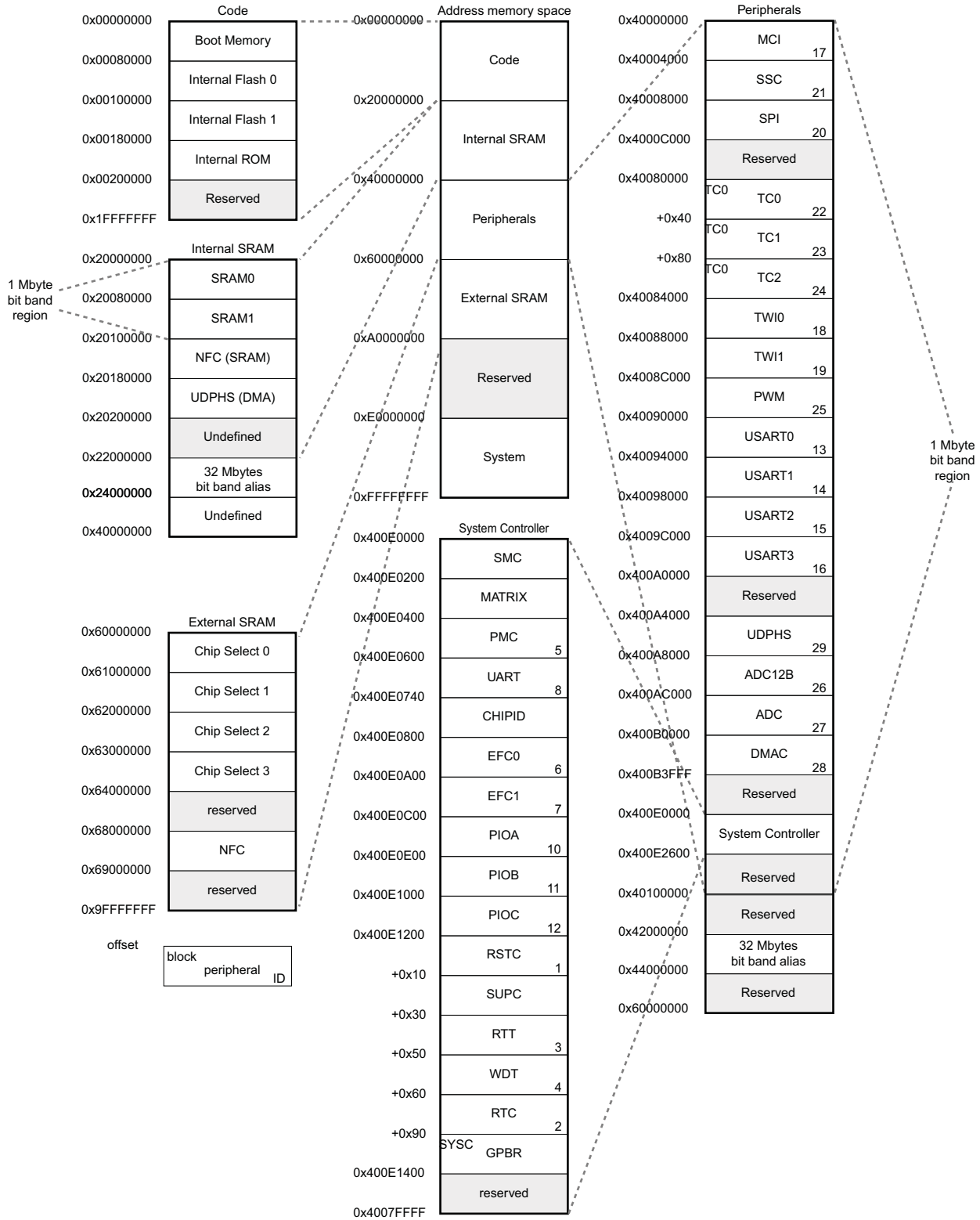
Table 7-5. Peripheral DMA Controller

Instance Name	Channel Transmit/Receive
TWI1	Transmit
TWI0	Transmit
PWM	Transmit
UART	Transmit
USART3	Transmit
USART2	Transmit
USART1	Transmit
USART0	Transmit
TWI0	Receive
TWI1	Receive
UART	Receive
USART3	Receive
USART2	Receive
USART1	Receive
USART0	Receive
ADC	Receive
ADC12B	Receive

8. Memories

8.1 Memory Mapping

Figure 8-1. SAM3U Memory Mapping



The memories are described in Section 8.2 ”Embedded Memories” and Section 8.3 ”External Memories”.

8.2 Embedded Memories

8.2.1 Internal SRAM

Table 8-1 shows the embedded high-speed SRAM for the various devices.

Table 8-1. Embedded High-speed SRAM per Device

Device	Pin Count	SRAM0 (KB)	SRAM1 (KB)	NFC SRAM (KB)	Total SRAM (KB)
SAM3U4	144/100	32	16	4	52
SAM3U2	144/100	16	16	4	36
SAM3U1	144/100	8	8	4	20

SRAM0 is accessible over System Cortex-M3 bus at address 0x2000 0000 and SRAM1 at address 0x2008 0000. The user can see the SRAM as contiguous at 0x20078000–0x20083FFF (SAM3U4), 0x2007C000–0x20083FFFF (SAM3U2) or 0x2007E000–0x20081FFFF (SAM3U1).

SRAM0 and SRAM1 are in the bit band region. The bit band alias region is from 0x2200 0000 and 0x23FF FFFF.

The NAND Flash Controller (NFC) embeds 4224 bytes of internal SRAM. If the NFC is not used, these 4224 bytes can be used as general-purpose SRAM. It can be seen at address 0x2010 0000.

8.2.2 Internal ROM

The SAM3U product embeds an Internal ROM, which contains the SAM-BA® Boot and FFPI program.

At any time, the ROM is mapped at address 0x0018 0000.

8.2.3 Embedded Flash

8.2.3.1 Flash Overview

Table 8-2 shows the Flash organization for the various devices.

Table 8-2. Embedded Flash Memory Organization per Device

Device	Flash Size	Number of Banks	Pages per Bank	Page Size	Plane
SAM3U4	256 Kbytes	2	512	256 bytes	Dual
SAM3U2	128 Kbytes	1	512	256 bytes	Single
SAM3U1	64 Kbytes	1	256	256 bytes	Single

The Flash contains a 128-byte write buffer, accessible through a 32-bit interface.

8.2.3.2 Flash Power Supply

The Flash is supplied by VDDCORE.

8.2.3.3 Enhanced Embedded Flash Controller

The Enhanced Embedded Flash Controller (EEFC) manages accesses performed by the masters of the system. It enables reading the Flash and writing the write buffer. It also contains a User Interface, mapped within the Memory Controller on the APB.

The Enhanced Embedded Flash Controller ensures the interface of the Flash block with the 32-bit internal bus. Its 128-bit wide memory interface increases performance.

The user can choose between high performance or lower current consumption by selecting either 128-bit or 64-bit access. It also manages the programming, erasing, locking and unlocking sequences of the Flash using a full set of commands.

One of the commands returns the embedded Flash descriptor definition that informs the system about the Flash organization, thus making the software generic.

The SAM3U4 (256 Kbytes internal Flash version) embeds two EEFC (EEFC0 for Flash0 and EEFC1 for Flash1) whereas the SAM3U2/1 embeds one EEFC.

8.2.3.4 Lock Regions

Several lock bits are used to protect write and erase operations on lock regions. A lock region is composed of several consecutive pages, and each lock region has its associated lock bit.

Table 8-3. Number of Lock Bits

Product	Number of Embedded EEFCs	Number of Lock Bits Managed per EEFC	Number of Protected Flash Regions(1)	Number of Lock Regions	Number of Pages per Lock Region	Page Size	Lock Region Size
SAM3U4	2	16	32	32	32	256 bytes	8 Kbytes
SAM3U2	1	16	32	16	32	256 bytes	8 Kbytes
SAM3U1	1	8	8	8	32	256 bytes	8 Kbytes

Note: 1. Protected against inadvertent Flash erasing or programming commands.

If a locked-region's erase or program command occurs, the command is aborted and the EEFC triggers an interrupt.

The lock bits are software programmable through the EEFC User Interface. The command "Set Lock Bit" enables the protection. The command "Clear Lock Bit" unlocks the lock region.

Asserting the ERASE pin clears the lock bits, thus unlocking the entire Flash.

8.2.3.5 Security Bit Feature

The SAM3U features a security bit, based on a specific General Purpose NVM bit (GPNVM bit 0). When the security is enabled, any access to the Flash, SRAM, Core Registers and Internal Peripherals either through the ICE interface or through the Fast Flash Programming Interface, is forbidden. This ensures the confidentiality of the code programmed in the Flash.

This security bit can only be enabled, through the command "Set General Purpose NVM Bit 0" of the EEFC User Interface. Disabling the security bit can only be achieved by asserting the ERASE pin at 1, and after a full Flash erase is performed. When the security bit is deactivated, all accesses to the Flash, SRAM, Core Registers and Internal Peripherals either through the ICE interface or through the Fast Flash Programming Interface are permitted.

It is important to note that the assertion of the ERASE pin should always be longer than 200 ms.

As the ERASE pin integrates a permanent pull-down, it can be left unconnected during normal operation. However, it is safer to connect it directly to GND for the final application.

8.2.3.6 Calibration Bits

NVM bits are used to calibrate the brownout detector and the voltage regulator. These bits are factory configured and cannot be changed by the user. The ERASE pin has no effect on the calibration bits.

8.2.3.7 Unique Identifier

Each device integrates its own 128-bit unique identifier. These bits are factory configured and cannot be changed by the user. The ERASE pin has no effect on the unique identifier.

8.2.3.8 Fast Flash Programming Interface (FFPI)

The FFPI allows programming the device through either a serial JTAG interface or through a multiplexed fully-handshaked parallel port. It allows gang programming with market-standard industrial programmers.

The FFPI supports read, page program, page erase, full erase, lock, unlock and protect commands.

The FFPI is enabled and the Fast Programming Mode is entered when TST, NRSTB and FWUP pins are tied high during power up sequence and if all supplies are provided externally (do not use internal regulator for VDDCORE). Please note that since the FFPI is a part of the SAM-BA Boot Application, the device must boot from the ROM.

8.2.3.9 SAM-BA Boot

The SAM-BA Boot is a default Boot Program which provides an easy way to program in-situ the on-chip Flash memory.

The SAM-BA Boot Assistant supports serial communication via the UART and USB.

The SAM-BA Boot provides an interface with SAM-BA Graphic User Interface (GUI).

The SAM-BA Boot is in ROM and is mapped in Flash at address 0x0 when GPNVM bit 1 is set to 0.

8.2.3.10 GPNVM Bits

The SAM3U2/1 features two GPNVM bits whereas SAM3U4 features three GPNVM bits. These bits can be cleared or set respectively through the commands “Clear GPNVM Bit” and “Set GPNVM Bit” of the EEFC User Interface.

The SAM3U4 is equipped with two EEFC, EEFC0 and EEFC1. EEFC1 does not feature the GPNVM bits. The GPNVM embedded on EEFC0 applies to the two blocks in the SAM3U4. The GPNVM2 is used only to swap the Flash 0 and Flash 1:

- If GPNVM2 = ENABLE, the Flash 1 is mapped at address 0x0008_0000 (Flash 1 and Flash 0 are continuous).
- If GPNVM2 = DISABLE, the Flash 0 is mapped at address 0x0008_0000 (Flash 0 and Flash 1 are continuous).

Table 8-4. General-purpose Non-volatile Memory Bits

GPNVMBit[#]	Function
0	Security bit
1	Boot mode selection (boot always at 0x00) on ROM or Flash
2	Flash selection (Flash 0 or Flash 1) Only on SAM3U4 (256 Kbytes internal Flash version)

8.2.4 Boot Strategies

The system always boots at address 0x0. To ensure a maximum boot possibilities the memory layout can be changed via GPNVM.

A general purpose NVM (GPNVM1) bit is used to boot either on the ROM (default) or from the Flash.

Setting the GPNVM Bit 1 selects the boot from the Flash, clearing it selects the boot from the ROM. Asserting ERASE clears the GPNVM Bit 1 and thus selects the boot from the ROM by default.

GPNVM2 enables to select if Flash 0 or Flash 1 is used for the boot. Setting the GPNVM2 bit selects the boot from Flash 1, clearing it selects the boot from Flash 0.

8.3 External Memories

The SAM3U offers an interface to a wide range of external memories and to any parallel peripheral.

8.3.1 Static Memory Controller

- 8 or 16-bit Data Bus
- Up to 24-bit Address Bus (up to 16 Mbytes linear per chip select)
- Up to 4 chip selects, Configurable Assignment
- Multiple Access Modes supported
  - Byte Write or Byte Select Lines
- Multiple device adaptability
  - Control signals programmable setup, pulse and hold time for each Memory Bank
- Multiple Wait State Management
  - Programmable Wait State Generation
  - External Wait Request
  - Programmable Data Float Time
- Slow Clock mode supported

8.3.2 NAND Flash Controller

- Handles automatic Read/Write transfer through 4224 bytes SRAM buffer
- DMA support
- Supports SLC NAND Flash technology
- Programmable timing on a per chip select basis
- Programmable Flash Data width 8-bit or 16-bit

8.3.3 NAND Flash Error Corrected Code Controller

- Integrated in the NAND Flash Controller
- Single bit error correction and 2-bit Random detection
- Automatic Hamming Code Calculation while writing
  - ECC value available in a register
- Automatic Hamming Code Calculation while reading
  - Error Report, including error flag, correctable error flag and word address being detected erroneous
  - Supports 8 or 16-bit NAND Flash devices with 512, 1024, 2048, or 4096-byte pages

9. Real-time Event Management

The events generated by peripherals are designed to be directly routed to peripherals managing/using these events without processor intervention. Peripherals receiving events contain logic by which to determine and perform the action required.

9.1 Embedded Characteristics

- Timers, IO peripherals generate event triggers which are directly routed to event managers such as ADC, for example, to start measurement/conversion without processor intervention.
- UART, USART, SPI, TWI, ADC (10-bit ADC and 12-bit ADC), PIO also generate event triggers directly connected to Peripheral DMA Controller (PDC) for data transfer without processor intervention.

9.2 Real-time Event Mapping

Table 9-1. Real-time Event Mapping List

Function	Application	Description	Event Source	Event Destination
Measurement trigger	General-purpose	Trigger source selection in 10-bit ADC (1)	PIO (ADTRG)	ADC
			TC: TIOA0	
			TC: TIOA1	
			TC: TIOA2	
		Trigger source selection in 12-bit ADC (2)	PIO (AD12BTRG)	ADC12B
			TC: TIOA0	
			TC: TIOA1	
			TC: TIOA2	
	Motor control	ADC-PWM synchronization (3)(4) Trigger source selection in ADC (1)	PWM Event Line 0	ADC
			PWM Event Line 1	
		ADC12B-PWM synchronization (3)(4) Trigger source selection in ADC12B (2)	PWM Event Line 0	ADC12B
			PWM Event Line 1	
Direct Memory Access	General-purpose	Peripheral trigger event generation to transfer data to/from system memory (5)	USART/UART, PWM, TWI, ADC, ADC12B	PDC

Notes:
1. Refer to Section 41.5.5 "Conversion Triggers" and Section 41.6.2 "ADC Mode Register" (ADC_MR).
2. Refer to Section 40.5.8 "Conversion Triggers" and Section 40.6.2 "ADC12B Mode Register" (ADC12B_MR).
3. Refer to Section 37.7.31 "PWM Comparison x Value Register" (PWM_CMPVx).
4. Refer to Section 37.6.3 "PWM Comparison Units" and Section 37.6.4 "PWM Event Lines".
5. Refer to Section 25. "Peripheral DMA Controller (PDC)".

10. System Controller

The System Controller is a set of peripherals, which allow handling of key elements of the system, such as but not limited to power, resets, clocks, time, interrupts, and watchdog. (Refer to Figure 18-1 “Supply Controller Block Diagram” on page 265.)

The System Controller User Interface also embeds the registers used to configure the Matrix.

10.1 System Controller and Peripheral Mapping

Please refer to Figure 8-1 “SAM3U Memory Mapping” on page 32.

All the peripherals are in the bit band region and are mapped in the bit band alias region.

10.2 Power-on-Reset, Brownout and Supply Monitor

The SAM3U embeds three features to monitor, warn and/or reset the chip:

- Power-on-Reset on VDDBU
- Brownout Detector on VDDCORE
- Supply Monitor on VDDUTMI

10.2.1 Power-on-Reset on VDDBU

The Power-on-Reset monitors VDDBU. It is always activated and monitors voltage at start up but also during power down. If VDDBU goes below the threshold voltage, the entire chip is reset. For more information, refer to Section 42. ”Electrical Characteristics”.

10.2.2 Brownout Detector on VDDCORE

The Brownout Detector monitors VDDCORE. It is active by default. It can be deactivated by software through the Supply Controller (SUPC_MR). It is especially recommended to disable it during low-power modes such as wait or sleep modes.

If VDDCORE goes below the threshold voltage, the reset of the core is asserted. For more information, refer to Section 18. ”Supply Controller (SUPC)” and Section 42. ”Electrical Characteristics”.

10.2.3 Supply Monitor on VDDUTMI

The Supply Monitor monitors VDDUTMI. It is not active by default. It can be activated by software and is fully programmable with 16 steps for the threshold (between 1.9V to 3.4V). It is controlled by the Supply Controller. A sample mode is possible. It allows to divide the supply monitor power consumption by a factor of up to 2048. For more information, refer to Section 18. ”Supply Controller (SUPC)” and Section 42. ”Electrical Characteristics”.

11. Peripherals

11.1 Peripheral Identifiers

Table 11-1 defines the Peripheral Identifiers of the SAM3U. A peripheral identifier is required for the control of the peripheral interrupt with the Nested Vectored Interrupt Controller and for the control of the peripheral clock with the Power Management Controller.

Note that some peripherals are always clocked. Please refer to the table below.

Table 11-1. Peripheral Identifiers

Instance ID	Instance Name	NVIC Interrupt	PMC Clock Control	Instance Description
0	SUPC	X		Supply Controller
1	RSTC	X		Reset Controller
2	RTC	X		Real-time Clock
3	RTT	X		Real-time Timer
4	WDT	X		Watchdog Timer
5	PMC	X		Power Management Controller
6	EEFC0	X		Enhanced Embedded Flash Controller 0
7	EEFC1	X		Enhanced Embedded Flash Controller 1
8	UART	X	X	Universal Asynchronous Receiver Transmitter
9	SMC	X	X	Static Memory Controller
10	PIOA	X	X	Parallel I/O Controller A
11	PIOB	X	X	Parallel I/O Controller B
12	PIOC	X	X	Parallel I/O Controller C
13	USART0	X	X	Universal Synchronous Asynchronous Receiver Transmitter 0
14	USART1	X	X	Universal Synchronous Asynchronous Receiver Transmitter 1
15	USART2	X	X	Universal Synchronous Asynchronous Receiver Transmitter 2
16	USART3	X	X	Universal Synchronous Asynchronous Receiver Transmitter 3
17	HSMCI	X	X	High Speed Multimedia Card Interface
18	TWI0	X	X	Two-Wire Interface 0
19	TWI1	X	X	Two-Wire Interface 1
20	SPI	X	X	Serial Peripheral Interface
21	SSC	X	X	Synchronous Serial Controller
22	TC0	X	X	Timer Counter 0
23	TC1	X	X	Timer Counter 1
24	TC2	X	X	Timer Counter 2
25	PWM	X	X	Pulse Width Modulation Controller
26	ADC12B	X	X	12-bit Analog-to-Digital Converter
27	ADC	X	X	10-bit Analog-to-Digital Converter
28	DMAC	X	X	DMA Controller
29	UDPHS	X	X	USB High Speed Device Port

11.2 Peripheral Signal Multiplexing on I/O Lines

The SAM3U features three PIO controllers (PIOA, PIOB, and PIOC) that multiplex the I/O lines of the peripheral set.

Each PIO controller controls up to 32 lines. Each line can be assigned to one of two peripheral functions, A or B. The multiplexing tables in the following pages define how the I/O lines of peripherals A and B are multiplexed on the PIO controllers.

Note that some output-only peripheral functions might be duplicated within the tables.

11.2.1 PIO Controller A Multiplexing

Table 11-2. Multiplexing on PIO Controller A (PIOA)

I/O Line	Peripheral A	Peripheral B	Extra Function	Comments
PA0	TIOB0	NPCS1	WKUP0[1][2][3]	
PA1	TIOA0	NPCS2	WKUP1[1][2][3]	
PA2	TCLK0	ADTRG	WKUP2[1][2][3]	
PA3	MCCK	PCK1		
PA4	MCCDA	PWMH0		
PA5	MCDA0	PWMH1		
PA6	MCDA1	PWMH2		
PA7	MCDA2	PWML0		
PA8	MCDA3	PWML1		
PA9	TWD0	PWML2	WKUP3[1][2][3]	
PA10	TWCK0	PWML3	WKUP4[1][2][3]	
PA11	URXD	PWMFI0		
PA12	UTXD	PWMFI1		
PA13	MISO			
PA14	MOSI			
PA15	SPCK	PWMH2		
PA16	NPCS0	NCS1	WKUP5[1][2][3]	
PA17	SCK0	AD12BTRG	WKUP6[1][2][3]	
PA18	TXD0	PWMFI2	WKUP7[1][2][3]	
PA19	RXD0	NPCS3	WKUP8[1][2][3]	
PA20	TXD1	PWMH3	WKUP9[1][2][3]	
PA21	RXD1	PCK0	WKUP10[1][2][3]	
PA22	TXD2	RTS1	AD12B0[5]	
PA23	RXD2	CTS1		
PA24	TWD1[4]	SCK1	WKUP11[1][2][3]	
PA25	TWCK1[4]	SCK2	WKUP12[1][2][3]	
PA26	TD	TCLK2		
PA27	RD	PCK0		
PA28	TK	PWMH0		
PA29	RK	PWMH1		
PA30	TF	TIOA2	AD12B1[5]	
PA31	RF	TIOB2		

Notes:
1. Wake-Up source in Backup mode (managed by the SUPC)
2. Fast startup source in Wait mode (managed by the PMC)
3. WKUPx can be used if PIO controller defines the I/O line as "input".
4. Only on 144-pin version
5. To select this extra function, refer to Section 40.4.3 “Analog Inputs”.

11.2.2 PIO Controller B Multiplexing

Table 11-3. Multiplexing on PIO Controller B (PIOB)

I/O Line	Peripheral A	Peripheral B	Extra Function	Comments
PB0	PWMH0	A2	WKUP13[1][2][3]	
PB1	PWMH1	A3	WKUP14[1][2][3]	
PB2	PWMH2	A4	WKUP15[1][2][3]	
PB3	PWMH3	A5	AD12B2[4]	
PB4	TCLK1	A6	AD12B3[4]	
PB5	TIOA1	A7	AD0[5]	
PB6	TIOB1	D15	AD1[5]	
PB7	RTS0	A0/NBS0	AD2[5]	
PB8	CTS0	A1	AD3[5]	
PB9	D0	DTR0		
PB10	D1	DSR0		
PB11	D2	DCD0		
PB12	D3	RI0		
PB13	D4	PWMH0		
PB14	D5	PWMH1		
PB15	D6	PWMH2		
PB16	D7	PWMH3		
PB17	NANDOE	PWML0		
PB18	NANDWE	PWML1		
PB19	NRD	PWML2		
PB20	NCS0	PWML3		
PB21	A21/NANDALE	RTS2		
PB22	A22/NANDCLE	CTS2		
PB23	NWR0/NWE	PCK2		
PB24	NANDRDY	PCK1		
PB25	D8	PWML0		144-pin version only
PB26	D9	PWML1		144-pin version only
PB27	D10	PWML2		144-pin version only
PB28	D11	PWML3		144-pin version only
PB29	D12			144-pin version only
PB30	D13			144-pin version only
PB31	D14			144-pin version only

Notes:
1. Wake-Up source in Backup mode (managed by the SUPC)
2. Fast startup source in Wait mode (managed by the PMC)
3. WKUPx can be used if PIO controller defines the I/O line as "input".
4. To select this extra function, refer to Section 40.4.3 “Analog Inputs”.
5. To select this extra function, refer to Section 41.4.3 “Analog Inputs”.

11.2.3 PIO Controller C Multiplexing

Table 11-4. Multiplexing on PIO Controller C (PIOC)

I/O Line	Peripheral A	Peripheral B	Extra Function	Comments
PC0	A2			144-pin version only
PC1	A3			144-pin version only
PC2	A4			144-pin version only
PC3	A5	NPCS1		144-pin version only
PC4	A6	NPCS2		144-pin version only
PC5	A7	NPCS3		144-pin version only
PC6	A8	PWML0		144-pin version only
PC7	A9	PWML1		144-pin version only
PC8	A10	PWML2		144-pin version only
PC9	A11	PWML3		144-pin version only
PC10	A12	CTS3		144-pin version only
PC11	A13	RTS3		144-pin version only
PC12	NCS1	TXD3		144-pin version only
PC13	A2	RXD3		144-pin version only
PC14	A3	NPCS2		144-pin version only
PC15	NWR1/NBS1		AD12B4[1]	144-pin version only
PC16	NCS2	PWML3	AD12B5[1]	144-pin version only
PC17	NCS3		AD12B6[1]	144-pin version only
PC18	NWAIT		AD12B7[1]	144-pin version only
PC19	SCK3	NPCS1		144-pin version only
PC20	A14			144-pin version only
PC21	A15			144-pin version only
PC22	A16			144-pin version only
PC23	A17			144-pin version only
PC24	A18	PWMH0		144-pin version only
PC25	A19	PWMH1		144-pin version only
PC26	A20	PWMH2		144-pin version only
PC27	A23	PWMH3		144-pin version only
PC28		MCDA4	AD4[2]	144-pin version only
PC29	PWML0	MCDA5	AD5[2]	144-pin version only
PC30	PWML1	MCDA6	AD6[2]	144-pin version only
PC31	PWML2	MCDA7	AD7[2]	144-pin version only

Notes: 1. To select this extra function, refer to Section 40.4.3 “Analog Inputs”.
2. To select this extra function, refer to Section 41.4.3 “Analog Inputs”.

12. ARM Cortex-M3 Processor

12.1 About this section

This section provides the information required for application and system-level software development. It does not provide information on debug components, features, or operation.

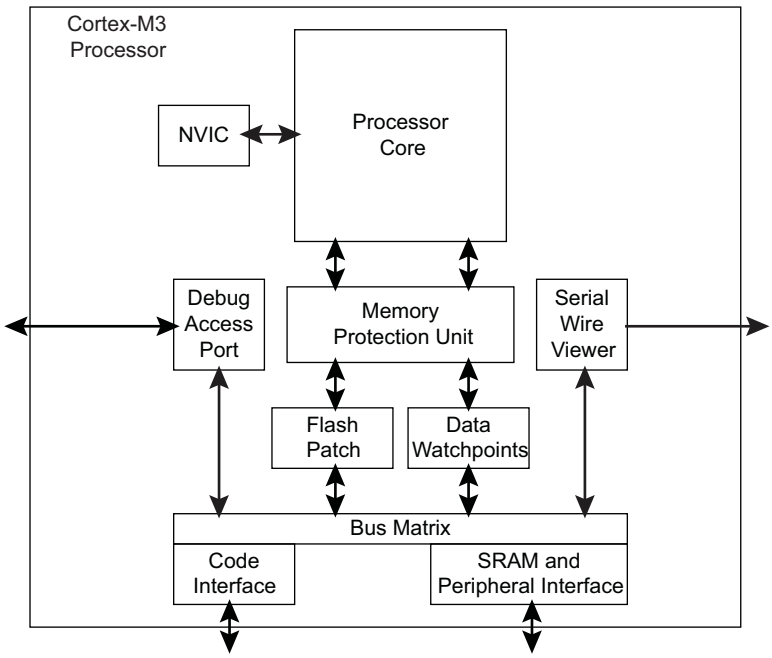
This material is for microcontroller software and hardware engineers, including those who have no experience of ARM products.

Note: The information in this section is reproduced from source material provided to Atmel by ARM Ltd. in terms of Atmel's license for the ARM Cortex-M3 processor core. This information is copyright ARM Ltd., 2008 - 2009.

12.2 About the Cortex-M3 processor and core peripherals

- The Cortex-M3 processor is a high performance 32-bit processor designed for the microcontroller market. It offers significant benefits to developers, including:
- outstanding processing performance combined with fast interrupt handling
- enhanced system debug with extensive breakpoint and trace capabilities
- efficient processor core, system and memories
- ultra-low power consumption with integrated sleep modes
- platform security, with integrated *memory protection unit* (MPU).

Figure 12-1. Typical Cortex-M3 implementation



The Cortex-M3 processor is built on a high-performance processor core, with a 3-stage pipeline Harvard architecture, making it ideal for demanding embedded applications. The processor delivers exceptional power efficiency through an efficient instruction set and extensively optimized design, providing high-end processing hardware including single-cycle 32x32 multiplication and dedicated hardware division.

To facilitate the design of cost-sensitive devices, the Cortex-M3 processor implements tightly-coupled system components that reduce processor area while significantly improving interrupt handling and system debug

capabilities. The Cortex-M3 processor implements a version of the Thumb® instruction set, ensuring high code density and reduced program memory requirements. The Cortex-M3 instruction set provides the exceptional performance expected of a modern 32-bit architecture, with the high code density of 8-bit and 16-bit microcontrollers.

The Cortex-M3 processor closely integrates a configurable *nested interrupt controlle*r (NVIC), to deliver industry-leading interrupt performance. The NVIC provides up to 16 interrupt priority levels. The tight integration of the processor core and NVIC provides fast execution of *interrupt service routines* (ISRs), dramatically reducing the interrupt latency. This is achieved through the hardware stacking of registers, and the ability to suspend load-multiple and store-multiple operations. Interrupt handlers do not require any assembler stubs, removing any code overhead from the ISRs. Tail-chaining optimization also significantly reduces the overhead when switching from one ISR to another.

To optimize low-power designs, the NVIC integrates with the sleep modes, that include a deep sleep function that enables the entire device to be rapidly powered down.

12.2.1 System level interface

The Cortex-M3 processor provides multiple interfaces using AMBA® technology to provide high speed, low latency memory accesses. It supports unaligned data accesses and implements atomic bit manipulation that enables faster peripheral controls, system spinlocks and thread-safe Boolean data handling.

The Cortex-M3 processor has a *memory protection unit* (MPU) that provides fine grain memory control, enabling applications to implement security privilege levels, separating code, data and stack on a task-by-task basis. Such requirements are becoming critical in many embedded applications.

12.2.2 Integrated configurable debug

The Cortex-M3 processor implements a complete hardware debug solution. This provides high system visibility of the processor and memory through either a traditional JTAG port or a 2-pin *Serial Wire Debug* (SWD) port that is ideal for microcontrollers and other small package devices.

For system trace the processor integrates an *Instrumentation Trace Macrocell* (ITM) alongside data watchpoints and a profiling unit. To enable simple and cost-effective profiling of the system events these generate, a *Serial Wire Viewer* (SWV) can export a stream of software-generated messages, data trace, and profiling information through a single pin.

12.2.3 Cortex-M3 processor features and benefits summary

- tight integration of system peripherals reduces area and development costs
- Thumb instruction set combines high code density with 32-bit performance
- code-patch ability for ROM system updates
- power control optimization of system components
- integrated sleep modes for low power consumption
- fast code execution permits slower processor clock or increases sleep mode time
- hardware division and fast multiplier
- deterministic, high-performance interrupt handling for time-critical applications

• *memory protection unit* (MPU) for safety-critical applications

- extensive debug and trace capabilities:
  - Serial Wire Debug and Serial Wire Trace reduce the number of pins required for debugging and tracing.

12.2.4 Cortex-M3 core peripherals

These are:

12.2.4.1 Nested Vectored Interrupt Controller

The *Nested Vectored Interrupt Controller* (NVIC) is an embedded interrupt controller that supports low latency interrupt processing.

12.2.4.2 System control block

The *System control block* (SCB) is the programmers model interface to the processor. It provides system implementation information and system control, including configuration, control, and reporting of system exceptions.

12.2.4.3 System timer

The system timer, SysTick, is a 24-bit count-down timer. Use this as a Real Time Operating System (RTOS) tick timer or as a simple counter.

12.2.4.4 Memory protection unit

The *Memory protection unit* (MPU) improves system reliability by defining the memory attributes for different memory regions. It provides up to eight different regions, and an optional predefined background region.

12.3 Programmers model

This section describes the Cortex-M3 programmers model. In addition to the individual core register descriptions, it contains information about the processor modes and privilege levels for software execution and stacks.

12.3.1 Processor mode and privilege levels for software execution

The processor *modes* are:

12.3.1.1 Thread mode

Used to execute application software. The processor enters Thread mode when it comes out of reset.

12.3.1.2 Handler mode

Used to handle exceptions. The processor returns to Thread mode when it has finished exception processing.

The *privilege levels* for software execution are:

12.3.1.3 Unprivileged

The software:

- has limited access to the MSR and MRS instructions, and cannot use the CPS instruction
- cannot access the system timer, NVIC, or system control block
- might have restricted access to memory or peripherals.

Unprivileged software executes at the unprivileged level.

12.3.1.4 Privileged

The software can use all the instructions and has access to all resources.

Privileged software executes at the privileged level.

In Thread mode, the CONTROL register controls whether software execution is privileged or unprivileged, see “CONTROL register” on page 56. In Handler mode, software execution is always privileged.

Only privileged software can write to the CONTROL register to change the privilege level for software execution in Thread mode. Unprivileged software can use the SVC instruction to make a *supervisor call* to transfer control to privileged software.

12.3.2 Stacks

The processor uses a full descending stack. This means the stack pointer indicates the last stacked item on the stack memory. When the processor pushes a new item onto the stack, it decrements the stack pointer and then writes the item to the new memory location. The processor implements two stacks, the *main stack* and the *process stack*, with independent copies of the stack pointer, see “Stack Pointer” on page 48.

In Thread mode, the CONTROL register controls whether the processor uses the main stack or the process stack, see “CONTROL register” on page 56. In Handler mode, the processor always uses the main stack. The options for processor operations are:

Table 12-1. Summary of processor mode, execution privilege level, and stack use options

Processor mode	Used to execute	Privilege level for software execution	Stack used
Thread	Applications	Privileged or unprivileged (1)	Main stack or process stack(1)
Handler	Exception handlers	Always privileged	Main stack

1. See “CONTROL register” on page 56.

12.3.3 Core registers

The processor core registers are:

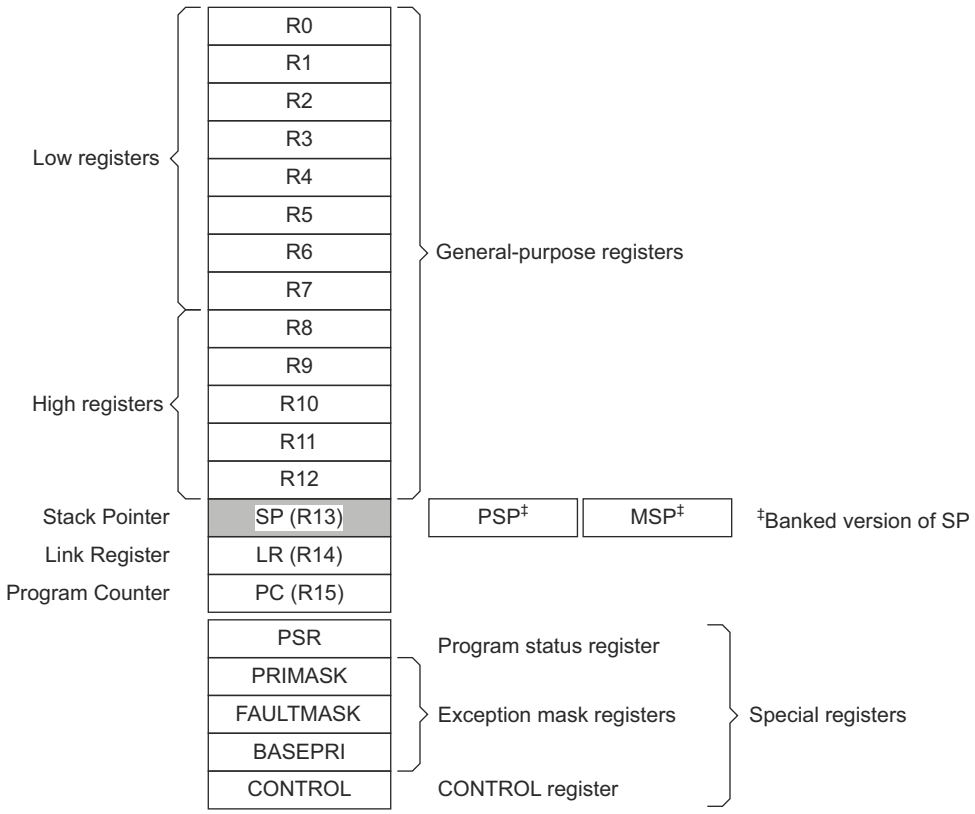


Table 12-2. Core register set summary

Name	Type [1]	Required privilege [2]	Reset value	Description
R0-R12	RW	Either	Unknown	"General-purpose registers" on page 48
MSP	RW	Privileged	See description	"Stack Pointer" on page 48
PSP	RW	Either	Unknown	"Stack Pointer" on page 48
LR	RW	Either	0xFFFFFFFF	"Link Register" on page 48
PC	RW	Either	See description	"Program Counter" on page 48
PSR	RW	Privileged	0x01000000	"Program Status Register" on page 49
ASPR	RW	Either	0x00000000	"Application Program Status Register" on page 50
IPSR	RO	Privileged	0x00000000	"Interrupt Program Status Register" on page 51
EPSR	RO	Privileged	0x01000000	"Execution Program Status Register" on page 52
PRIMASK	RW	Privileged	0x00000000	"Priority Mask Register" on page 53
FAULTMASK	RW	Privileged	0x00000000	"Fault Mask Register" on page 54
BASEPRI	RW	Privileged	0x00000000	"Base Priority Mask Register" on page 55
CONTROL	RW	Privileged	0x00000000	"CONTROL register" on page 56

1. Describes access type during program execution in thread mode and Handler mode. Debug access can differ.
2. An entry of Either means privileged and unprivileged software can access the register.

12.3.3.1 General-purpose registers

R0-R12 are 32-bit general-purpose registers for data operations.

12.3.3.2 Stack Pointer

The *Stack Pointer* (SP) is register R13. In Thread mode, bit[1] of the CONTROL register indicates the stack pointer to use:

- 0 = *Main Stack Pointer* (MSP). This is the reset value.
- 1 = *Process Stack Pointer* (PSP).

On reset, the processor loads the MSP with the value from address 0x00000000.

12.3.3.3 Link Register

The *Link Register* (LR) is register R14. It stores the return information for subroutines, function calls, and exceptions. On reset, the processor loads the LR value 0xFFFFFFFF.

12.3.3.4 Program Counter

The *Program Counter* (PC) is register R15. It contains the current program address. Bit[0] is always 0 because instruction fetches must be halfword aligned. On reset, the processor loads the PC with the value of the reset vector, which is at address 0x00000004.

12.3.3.5 Program Status Register

The *Program Status Register* (PSR) combines:

- *Application Program Status Register* (APSR)
- *Interrupt Program Status Register* (IPSR)
- *Execution Program Status Register* (EPSR).

These registers are mutually exclusive bitfields in the 32-bit PSR. The bit assignments are:

- **APSR:**

31	30	29	28	27	26	25	24
N	Z	C	V	Q	Reserved		

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved							

- **IPSR:**

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							ISR_NUMBER

7	6	5	4	3	2	1	0
ISR_NUMBER							

- **EPSR:**

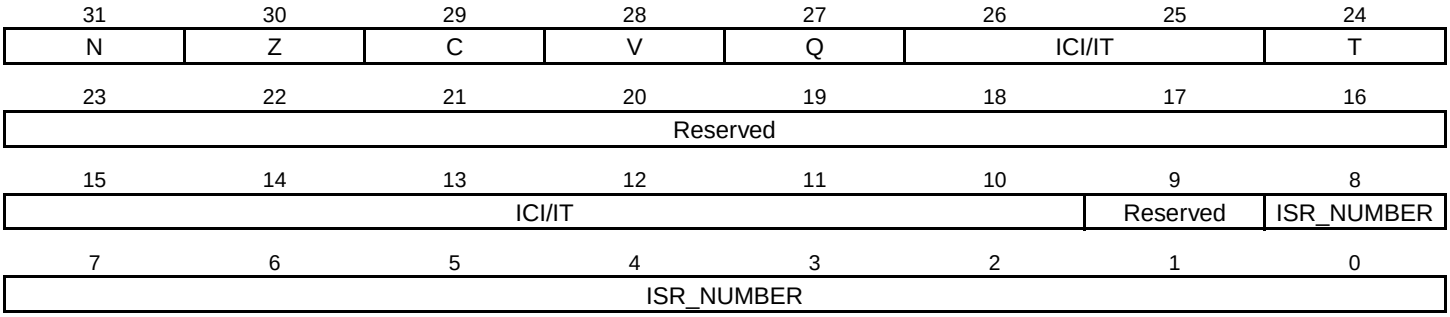
31	30	29	28	27	26	25	24
Reserved					ICI/IT		T

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
ICI/IT						Reserved	

7	6	5	4	3	2	1	0
Reserved							

The PSR bit assignments are:



Access these registers individually or as a combination of any two or all three registers, using the register name as an argument to the MSR or MRS instructions. For example:

- read all of the registers using PSR with the MRS instruction
- write to the APSR using APSR with the MSR instruction.

The PSR combinations and attributes are:

Table 12-3. PSR register combinations

Register	Type	Combination
PSR	RW (1), (2)	APSR, EPSR, and IPSR
IEPSR	RO	EPSR and IPSR
IAPSR	RW(1)	APSR and IPSR
EAPSR	RW(2)	APSR and EPSR

1. The processor ignores writes to the IPSR bits.
2. Reads of the EPSR bits return zero, and the processor ignores writes to the these bits.

See the instruction descriptions “MRS” on page 141 and “MSR” on page 142 for more information about how to access the program status registers.

12.3.3.6 Application Program Status Register

The APSR contains the current state of the condition flags from previous instruction executions. See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

- **N**

Negative or less than flag:

0 = operation result was positive, zero, greater than, or equal

1 = operation result was negative or less than.

- **Z**

Zero flag:

0 = operation result was not zero

1 = operation result was zero.

- **C**

Carry or borrow flag:

0 = add operation did not result in a carry bit or subtract operation resulted in a borrow bit

1 = add operation resulted in a carry bit or subtract operation did not result in a borrow bit.

- **V**

Overflow flag:

0 = operation did not result in an overflow

1 = operation resulted in an overflow.

- **Q**

Sticky saturation flag:

0 = indicates that saturation has not occurred since reset or since the bit was last cleared to zero

1 = indicates when an SSAT or USAT instruction results in saturation.

This bit is cleared to zero by software using an MRS instruction.

12.3.3.7 Interrupt Program Status Register

The IPSR contains the exception type number of the current *Interrupt Service Routine* (ISR). See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

- **ISR_NUMBER**

This is the number of the current exception:

0 = Thread mode

1 = Reserved

2 = NMI

3 = Hard fault

4 = Memory management fault

5 = Bus fault

6 = Usage fault

7-10 = Reserved

11 = SVCall

12 = Reserved for Debug

13 = Reserved

14 = PendSV

15 = SysTick

16 = IRQ0

45 = IRQ29

see “Exception types” on page 67 for more information.

12.3.3.8 Execution Program Status Register

The EPSR contains the Thumb state bit, and the execution state bits for either the:

- *If-Then* (IT) instruction
- *Interruptible-Continuable Instruction* (ICI) field for an interrupted load multiple or store multiple instruction.

See the register summary in Table 12-2 on page 48 for the EPSR attributes. The bit assignments are:

- **ICI**

Interruptible-continuable instruction bits, see "Interruptible-continuable instructions" on page 52.

- **IT**

Indicates the execution state bits of the IT instruction, see "IT" on page 132.

- **T**

Always set to 1.

Attempts to read the EPSR directly through application software using the MSR instruction always return zero. Attempts to write the EPSR using the MSR instruction in application software are ignored. Fault handlers can examine EPSR value in the stacked PSR to indicate the operation that is at fault. See "Exception entry and return" on page 71

12.3.3.9 Interruptible-continuable instructions

When an interrupt occurs during the execution of an LDM or STM instruction, the processor:

- stops the load multiple or store multiple instruction operation temporarily
- stores the next register operand in the multiple operation to EPSR bits[15:12].

After servicing the interrupt, the processor:

- returns to the register pointed to by bits[15:12]
- resumes execution of the multiple load or store instruction.

When the EPSR holds ICI execution state, bits[26:25,11:10] are zero.

12.3.3.10 If-Then block

The If-Then block contains up to four instructions following a 16-bit IT instruction. Each instruction in the block is conditional. The conditions for the instructions are either all the same, or some can be the inverse of others. See "IT" on page 132 for more information.

12.3.3.11 Exception mask registers

The exception mask registers disable the handling of exceptions by the processor. Disable exceptions where they might impact on timing critical tasks.

To access the exception mask registers use the MSR and MRS instructions, or the CPS instruction to change the value of PRIMASK or FAULTMASK. See "MRS" on page 141, "MSR" on page 142, and "CPS" on page 137 for more information.

12.3.3.12 Priority Mask Register

The PRIMASK register prevents activation of all exceptions with configurable priority. See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved							PRIMASK

- **PRIMASK**

0 = no effect

1 = prevents the activation of all exceptions with configurable priority.

12.3.3.13 Fault Mask Register

The FAULTMASK register prevents activation of all exceptions. See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved							FAULTMASK

- **FAULTMASK**

0 = no effect

1 = prevents the activation of all exceptions.

The processor clears the FAULTMASK bit to 0 on exit from any exception handler except the NMI handler.

12.3.3.14 Base Priority Mask Register

The BASEPRI register defines the minimum priority for exception processing. When BASEPRI is set to a nonzero value, it prevents the activation of all exceptions with same or lower priority level as the BASEPRI value. See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
BASEPRI							

- **BASEPRI**

Priority mask bits:

0x0000 = no effect

Nonzero = defines the base priority for exception processing.

The processor does not process any exception with a priority value greater than or equal to BASEPRI.

This field is similar to the priority fields in the interrupt priority registers. The processor implements only bits[7:4] of this field, bits[3:0] read as zero and ignore writes. See “Interrupt Priority Registers” on page 156 for more information. Remember that higher priority field values correspond to lower exception priorities.

12.3.3.15 CONTROL register

The CONTROL register controls the stack used and the privilege level for software execution when the processor is in Thread mode. See the register summary in Table 12-2 on page 48 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved						Active Stack Pointer	Thread Mode Privilege Level

- **Active stack pointer**

Defines the current stack:

0 = MSP is the current stack pointer

1 = PSP is the current stack pointer.

In Handler mode this bit reads as zero and ignores writes.

- **Thread mode privilege level**

Defines the Thread mode privilege level:

0 = privileged

1 = unprivileged.

Handler mode always uses the MSP, so the processor ignores explicit writes to the active stack pointer bit of the CONTROL register when in Handler mode. The exception entry and return mechanisms update the CONTROL register.

In an OS environment, ARM recommends that threads running in Thread mode use the process stack and the kernel and exception handlers use the main stack.

By default, Thread mode uses the MSP. To switch the stack pointer used in Thread mode to the PSP, use the MSR instruction to set the Active stack pointer bit to 1, see “MSR” on page 142.

When changing the stack pointer, software must use an ISB instruction immediately after the MSR instruction. This ensures that instructions after the ISB execute using the new stack pointer. See “ISB” on page 140

12.3.4 Exceptions and interrupts

The Cortex-M3 processor supports interrupts and system exceptions. The processor and the *Nested Vectored Interrupt Controller* (NVIC) prioritize and handle all exceptions. An exception changes the normal flow of software control. The processor uses handler mode to handle all exceptions except for reset. See “Exception entry” on page 72 and “Exception return” on page 72 for more information.

The NVIC registers control interrupt handling. See “Nested Vectored Interrupt Controller” on page 149 for more information.

12.3.5 Data types

The processor:

- supports the following data types:
  - 32-bit words
  - 16-bit halfwords
  - 8-bit bytes
- supports 64-bit data transfer instructions.
- manages all data memory accesses as little-endian. Instruction memory and *Private Peripheral Bus* (PPB) accesses are always little-endian. See “Memory regions, types and attributes” on page 58 for more information.

12.3.6 The Cortex Microcontroller Software Interface Standard

For a Cortex-M3 microcontroller system, the *Cortex Microcontroller Software Interface Standard* (CMSIS) defines:

- a common way to:
  - access peripheral registers
  - define exception vectors
- the names of:
  - the registers of the core peripherals
  - the core exception vectors
- a device-independent interface for RTOS kernels, including a debug channel.

The CMSIS includes address definitions and data structures for the core peripherals in the Cortex-M3 processor. It also includes optional interfaces for middleware components comprising a TCP/IP stack and a Flash file system.

CMSIS simplifies software development by enabling the reuse of template code and the combination of CMSIS-compliant software components from various middleware vendors. Software vendors can expand the CMSIS to include their peripheral definitions and access functions for those peripherals.

This document includes the register names defined by the CMSIS, and gives short descriptions of the CMSIS functions that address the processor core and the core peripherals.

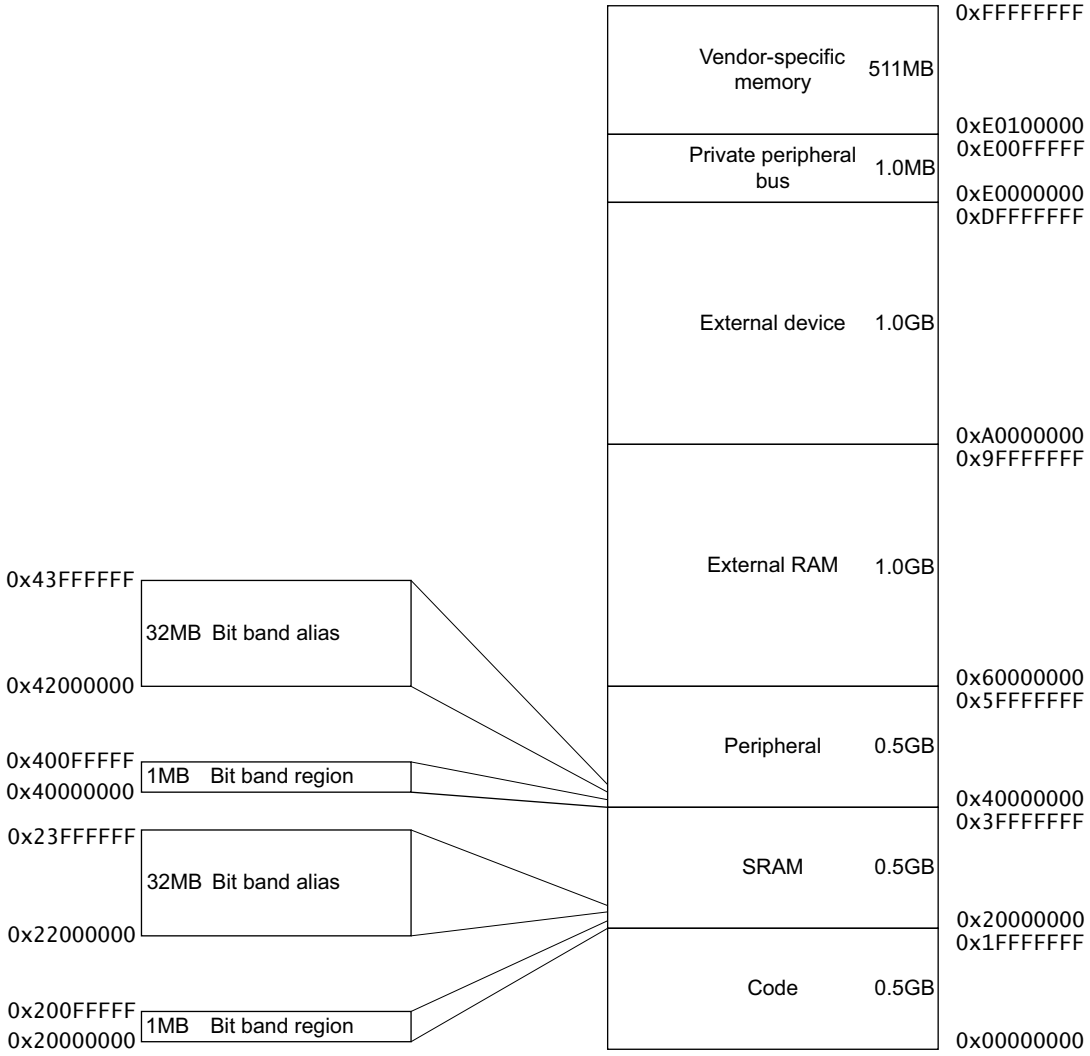
This document uses the register short names defined by the CMSIS. In a few cases these differ from the architectural short names that might be used in other documents.

The following sections give more information about the CMSIS:

- “Power management programming hints” on page 77
- “Intrinsic functions” on page 81
- “The CMSIS mapping of the Cortex-M3 NVIC registers” on page 149
- “NVIC programming hints” on page 159.

12.4 Memory model

This section describes the processor memory map, the behavior of memory accesses, and the bit-banding features. The processor has a fixed memory map that provides up to 4GB of addressable memory. The memory map is:



The regions for SRAM and peripherals include bit-band regions. Bit-banding provides atomic operations to bit data, see “Bit-banding” on page 62.

The processor reserves regions of the *Private peripheral bus* (PPB) address range for core peripheral registers, see “About the Cortex-M3 peripherals” on page 148.

This memory mapping is generic to ARM Cortex-M3 products. To get the specific memory mapping of this product, refer to the Memories section of the datasheet.

12.4.1 Memory regions, types and attributes

The memory map and the programming of the MPU split the memory map into regions. Each region has a defined memory type, and some regions have additional memory attributes. The memory type and attributes determine the behavior of accesses to the region.

The memory types are:

12.4.1.1 Normal

The processor can re-order transactions for efficiency, or perform speculative reads.

12.4.1.2 Device

The processor preserves transaction order relative to other transactions to Device or Strongly-ordered memory.

12.4.1.3 Strongly-ordered

The processor preserves transaction order relative to all other transactions.

The different ordering requirements for Device and Strongly-ordered memory mean that the memory system can buffer a write to Device memory, but must not buffer a write to Strongly-ordered memory.

The additional memory attributes include.

12.4.1.4 Shareable

For a shareable memory region, the memory system provides data synchronization between bus masters in a system with multiple bus masters, for example, a processor with a DMA controller.

Strongly-ordered memory is always shareable.

If multiple bus masters can access a non-shareable memory region, software must ensure data coherency between the bus masters.

12.4.1.5 Execute Never (XN)

Means the processor prevents instruction accesses. Any attempt to fetch an instruction from an XN region causes a memory management fault exception.

12.4.2 Memory system ordering of memory accesses

For most memory accesses caused by explicit memory access instructions, the memory system does not guarantee that the order in which the accesses complete matches the program order of the instructions, providing this does not affect the behavior of the instruction sequence. Normally, if correct program execution depends on two memory accesses completing in program order, software must insert a memory barrier instruction between the memory access instructions, see “Software ordering of memory accesses” on page 61.

However, the memory system does guarantee some ordering of accesses to Device and Strongly-ordered memory. For two memory access instructions A1 and A2, if A1 occurs before A2 in program order, the ordering of the memory accesses caused by two instructions is:

A1 \ A2	Normal access	Device access		Strongly-ordered access
		Non-shareable	Shareable	
Normal access	-	-	-	-
Device access, non-shareable	-	<	-	<
Device access, shareable	-	-	<	<
Strongly-ordered access	-	<	<	<

Where:

- Means that the memory system does not guarantee the ordering of the accesses.

< Means that accesses are observed in program order, that is, A1 is always observed before A2.

12.4.3 Behavior of memory accesses

The behavior of accesses to each region in the memory map is:

Table 12-4. Memory access behavior

Address range	Memory region	Memory type	XN	Description
0x00000000-0x1FFFFFFF	Code	Normal (1)	-	Executable region for program code. You can also put data here.
0x20000000-0x3FFFFFFF	SRAM	Normal (1)	-	Executable region for data. You can also put code here. This region includes bit band and bit band alias areas, see Table 12-6 on page 63.
0x40000000-0x5FFFFFFF	Peripheral	Device (1)	XN	This region includes bit band and bit band alias areas, see Table 12-6 on page 63.
0x60000000-0x9FFFFFFF	External RAM	Normal (1)	-	Executable region for data.
0xA0000000-0xDFFFFFFF	External device	Device (1)	XN	External Device memory
0xE0000000-0xE00FFFFF	Private Peripheral Bus	Strongly- ordered (1)	XN	This region includes the NVIC, System timer, and system control block.
0xE0100000-0xFFFFFFFF	Reserved	Device (1)	XN	Reserved

1. See "Memory regions, types and attributes" on page 58 for more information.

The Code, SRAM, and external RAM regions can hold programs. However, ARM recommends that programs always use the Code region. This is because the processor has separate buses that enable instruction fetches and data accesses to occur simultaneously.

The MPU can override the default memory access behavior described in this section. For more information, see "Memory protection unit" on page 194.

12.4.3.1 Additional memory access constraints for shared memory

When a system includes shared memory, some memory regions have additional access constraints, and some regions are subdivided, as Table 12-5 shows:

Table 12-5. Memory region share ability policies

Address range	Memory region	Memory type	Shareability	
0x00000000-0x1FFFFFFF	Code	Normal (1)	-	
0x20000000-0x3FFFFFFF	SRAM	Normal (1)	-	
0x40000000-0x5FFFFFFF	Peripheral (2)	Device (1)	-	
0x60000000-0x7FFFFFFF	External RAM	Normal (1)	-	WBWA (2)
0x80000000-0x9FFFFFFF				WT (2)
0xA0000000-0xBFFFFFFF	External device	Device (1)	Shareable (1)	-
0xC0000000-0xDFFFFFFF			Non-shareable (1)	
0xE0000000-0xE00FFFFF	Private Peripheral Bus	Strongly- ordered (1)	Shareable (1)	-
0xE0100000-0xFFFFFFFF	Vendor-specific device (2)	Device (1)	-	-

1. See "Memory regions, types and attributes" on page 58 for more information.
2. The Peripheral and Vendor-specific device regions have no additional access constraints.

12.4.4 Software ordering of memory accesses

The order of instructions in the program flow does not always guarantee the order of the corresponding memory transactions. This is because:

- the processor can reorder some memory accesses to improve efficiency, providing this does not affect the behavior of the instruction sequence.
- the processor has multiple bus interfaces
- memory or devices in the memory map have different wait states
- some memory accesses are buffered or speculative.

"Memory system ordering of memory accesses" on page 59 describes the cases where the memory system guarantees the order of memory accesses. Otherwise, if the order of memory accesses is critical, software must include memory barrier instructions to force that ordering. The processor provides the following memory barrier instructions:

12.4.4.1 DMB

The *Data Memory Barrier* (DMB) instruction ensures that outstanding memory transactions complete before subsequent memory transactions. See "DMB" on page 138.

12.4.4.2 DSB

The *Data Synchronization Barrier* (DSB) instruction ensures that outstanding memory transactions complete before subsequent instructions execute. See “DSB” on page 139.

12.4.4.3 ISB

The *Instruction Synchronization Barrier* (ISB) ensures that the effect of all completed memory transactions is recognizable by subsequent instructions. See “ISB” on page 140.

Use memory barrier instructions in, for example:

- MPU programming:
  - Use a DSB instruction to ensure the effect of the MPU takes place immediately at the end of context switching.
  - Use an ISB instruction to ensure the new MPU setting takes effect immediately after programming the MPU region or regions, if the MPU configuration code was accessed using a branch or call. If the MPU configuration code is entered using exception mechanisms, then an ISB instruction is not required.
- Vector table. If the program changes an entry in the vector table, and then enables the corresponding exception, use a DMB instruction between the operations. This ensures that if the exception is taken immediately after being enabled the processor uses the new exception vector.
- Self-modifying code. If a program contains self-modifying code, use an ISB instruction immediately after the code modification in the program. This ensures subsequent instruction execution uses the updated program.
- Memory map switching. If the system contains a memory map switching mechanism, use a DSB instruction after switching the memory map in the program. This ensures subsequent instruction execution uses the updated memory map.
- Dynamic exception priority change. When an exception priority has to change when the exception is pending or active, use DSB instructions after the change. This ensures the change takes effect on completion of the DSB instruction.
- Using a semaphore in multi-master system. If the system contains more than one bus master, for example, if another processor is present in the system, each processor must use a DMB instruction after any semaphore instructions, to ensure other bus masters see the memory transactions in the order in which they were executed.

Memory accesses to Strongly-ordered memory, such as the system control block, do not require the use of DMB instructions.

12.4.5 Bit-banding

A bit-band region maps each word in a *bit-band alias* region to a single bit in the *bit-band region*. The bit-band regions occupy the lowest 1MB of the SRAM and peripheral memory regions.

The memory map has two 32MB alias regions that map to two 1MB bit-band regions:

- accesses to the 32MB SRAM alias region map to the 1MB SRAM bit-band region, as shown in Table 12-6
- accesses to the 32MB peripheral alias region map to the 1MB peripheral bit-band region, as shown in Table 12-7.

Table 12-6. SRAM memory bit-banding regions

Address range	Memory region	Instruction and data accesses
0x20000000-0x200FFFFF	SRAM bit-band region	Direct accesses to this memory range behave as SRAM memory accesses, but this region is also bit addressable through bit-band alias.
0x22000000-0x23FFFFFF	SRAM bit-band alias	Data accesses to this region are remapped to bit band region. A write operation is performed as read-modify-write. Instruction accesses are not remapped.

Table 12-7. Peripheral memory bit-banding regions

Address range	Memory region	Instruction and data accesses
0x40000000-0x400FFFFF	Peripheral bit-band alias	Direct accesses to this memory range behave as peripheral memory accesses, but this region is also bit addressable through bit-band alias.
0x42000000-0x43FFFFFF	Peripheral bit-band region	Data accesses to this region are remapped to bit band region. A write operation is performed as read-modify-write. Instruction accesses are not permitted.

A word access to the SRAM or peripheral bit-band alias regions map to a single bit in the SRAM or peripheral bit-band region.

The following formula shows how the alias region maps onto the bit-band region:

```
bit_word_offset = (byte_offset x 32) + (bit_number x 4)
bit_word_addr = bit_band_base + bit_word_offset
```

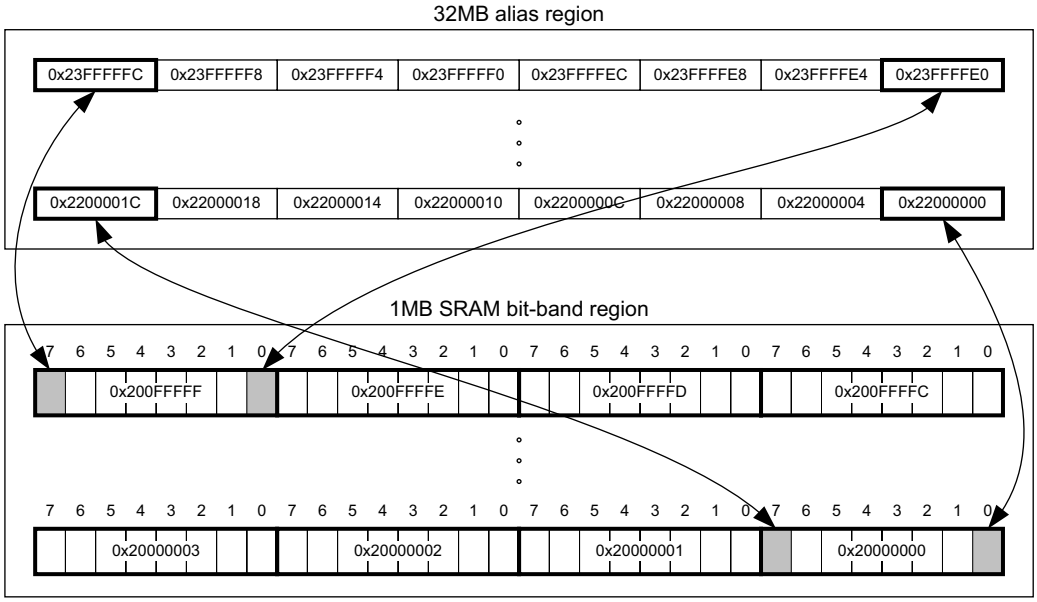
where:

- `Bit_word_offset` is the position of the target bit in the bit-band memory region.
- `Bit_word_addr` is the address of the word in the alias memory region that maps to the targeted bit.
- `Bit_band_base` is the starting address of the alias region.
- `Byte_offset` is the number of the byte in the bit-band region that contains the targeted bit.
- `Bit_number` is the bit position, 0-7, of the targeted bit.

Figure 12-2 shows examples of bit-band mapping between the SRAM bit-band alias region and the SRAM bit-band region:

- The alias word at 0x23FFFFE0 maps to bit[0] of the bit-band byte at 0x200FFFFF: 0x23FFFFE0 = 0x22000000 + (0xFFFFF*32) + (0*4).
- The alias word at 0x23FFFFFC maps to bit[7] of the bit-band byte at 0x200FFFFF: 0x23FFFFFC = 0x22000000 + (0xFFFFF*32) + (7*4).
- The alias word at 0x22000000 maps to bit[0] of the bit-band byte at 0x20000000: 0x22000000 = 0x22000000 + (0*32) + (0 *4).
- The alias word at 0x2200001C maps to bit[7] of the bit-band byte at 0x20000000: 0x2200001C = 0x22000000+ (0*32) + (7*4).

Figure 12-2. Bit-band mapping



12.4.5.1 Directly accessing an alias region

Writing to a word in the alias region updates a single bit in the bit-band region.

Bit[0] of the value written to a word in the alias region determines the value written to the targeted bit in the bit-band region. Writing a value with bit[0] set to 1 writes a 1 to the bit-band bit, and writing a value with bit[0] set to 0 writes a 0 to the bit-band bit.

Bits[31:1] of the alias word have no effect on the bit-band bit. Writing 0x01 has the same effect as writing 0xFF. Writing 0x00 has the same effect as writing 0x0E.

Reading a word in the alias region:

- 0x00000000 indicates that the targeted bit in the bit-band region is set to zero
- 0x00000001 indicates that the targeted bit in the bit-band region is set to 1

12.4.5.2 Directly accessing a bit-band region

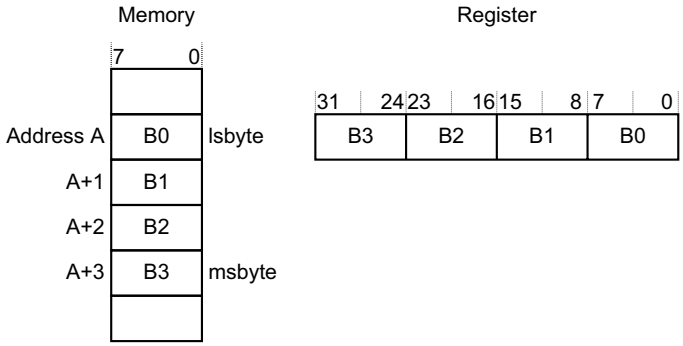
"Behavior of memory accesses" on page 60 describes the behavior of direct byte, halfword, or word accesses to the bit-band regions.

12.4.6 Memory endianness

The processor views memory as a linear collection of bytes numbered in ascending order from zero. For example, bytes 0-3 hold the first stored word, and bytes 4-7 hold the second stored word. or "Little-endian format" describes how words of data are stored in memory.

12.4.6.1 Little-endian format

In little-endian format, the processor stores the least significant byte of a word at the lowest-numbered byte, and the most significant byte at the highest-numbered byte. For example:



12.4.7 Synchronization primitives

The Cortex-M3 instruction set includes pairs of *synchronization primitives*. These provide a non-blocking mechanism that a thread or process can use to obtain exclusive access to a memory location. Software can use them to perform a guaranteed read-modify-write memory update sequence, or for a semaphore mechanism.

A pair of synchronization primitives comprises:

12.4.7.1 A Load-Exclusive instruction

Used to read the value of a memory location, requesting exclusive access to that location.

12.4.7.2 A Store-Exclusive instruction

Used to attempt to write to the same memory location, returning a status bit to a register. If this bit is:

0: it indicates that the thread or process gained exclusive access to the memory, and the write succeeds,

1: it indicates that the thread or process did not gain exclusive access to the memory, and no write is performed,

The pairs of Load-Exclusive and Store-Exclusive instructions are:

- the word instructions LDREX and STREX
- the halfword instructions LDREXH and STREXH
- the byte instructions LDREXB and STREXB.

Software must use a Load-Exclusive instruction with the corresponding Store-Exclusive instruction.

To perform a guaranteed read-modify-write of a memory location, software must:

- Use a Load-Exclusive instruction to read the value of the location.
- Update the value, as required.
- Use a Store-Exclusive instruction to attempt to write the new value back to the memory location, and tests the returned status bit. If this bit is:

  0: The read-modify-write completed successfully,

  1: No write was performed. This indicates that the value returned the first step might be out of date. The software must retry the read-modify-write sequence,

Software can use the synchronization primitives to implement a semaphores as follows:

- Use a Load-Exclusive instruction to read from the semaphore address to check whether the semaphore is free.
- If the semaphore is free, use a Store-Exclusive to write the claim value to the semaphore address.

- If the returned status bit from the second step indicates that the Store-Exclusive succeeded then the software has claimed the semaphore. However, if the Store-Exclusive failed, another process might have claimed the semaphore after the software performed the first step.

The Cortex-M3 includes an exclusive access monitor, that tags the fact that the processor has executed a Load-Exclusive instruction. If the processor is part of a multiprocessor system, the system also globally tags the memory locations addressed by exclusive accesses by each processor.

The processor removes its exclusive access tag if:

- It executes a CLREX instruction
- It executes a Store-Exclusive instruction, regardless of whether the write succeeds.
- An exception occurs. This means the processor can resolve semaphore conflicts between different threads.

In a multiprocessor implementation:

- executing a CLREX instruction removes only the local exclusive access tag for the processor
- executing a Store-Exclusive instruction, or an exception. removes the local exclusive access tags, and all global exclusive access tags for the processor.

For more information about the synchronization primitive instructions, see “LDREX and STREX” on page 102 and “CLREX” on page 104.

12.4.8 Programming hints for the synchronization primitives

ANSI C cannot directly generate the exclusive access instructions. Some C compilers provide intrinsic functions for generation of these instructions:

Table 12-8. C compiler intrinsic functions for exclusive access instructions

Instruction	Intrinsic function
LDREX, LDREXH, or LDREXB	unsigned int __ldrex(volatile void *ptr)
STREX, STREXH, or STREXB	int __strex(unsigned int val, volatile void *ptr)
CLREX	void __clrex(void)

The actual exclusive access instruction generated depends on the data type of the pointer passed to the intrinsic function. For example, the following C code generates the require LDREXB operation:

```
__ldrex((volatile char *) 0xFF);
```

12.5 Exception model

This section describes the exception model.

12.5.1 Exception states

Each exception is in one of the following states:

12.5.1.1 Inactive

The exception is not active and not pending.

12.5.1.2 Pending

The exception is waiting to be serviced by the processor.

An interrupt request from a peripheral or from software can change the state of the corresponding interrupt to pending.

12.5.1.3 Active

An exception that is being serviced by the processor but has not completed.

An exception handler can interrupt the execution of another exception handler. In this case both exceptions are in the active state.

12.5.1.4 Active and pending

The exception is being serviced by the processor and there is a pending exception from the same source.

12.5.2 Exception types

The exception types are:

12.5.2.1 Reset

Reset is invoked on power up or a warm reset. The exception model treats reset as a special form of exception. When reset is asserted, the operation of the processor stops, potentially at any point in an instruction. When reset is deasserted, execution restarts from the address provided by the reset entry in the vector table. Execution restarts as privileged execution in Thread mode.

12.5.2.2 Non Maskable Interrupt (NMI)

A non maskable interrupt (NMI) can be signalled by a peripheral or triggered by software. This is the highest priority exception other than reset. It is permanently enabled and has a fixed priority of -2.

NMIs cannot be:

- Masked or prevented from activation by any other exception.
- Preempted by any exception other than Reset.

12.5.2.3 Hard fault

A hard fault is an exception that occurs because of an error during exception processing, or because an exception cannot be managed by any other exception mechanism. Hard faults have a fixed priority of -1, meaning they have higher priority than any exception with configurable priority.

12.5.2.4 Memory management fault

A memory management fault is an exception that occurs because of a memory protection related fault. The MPU or the fixed memory protection constraints determines this fault, for both instruction and data memory transactions. This fault is used to abort instruction accesses to *Execute Never* (XN) memory regions, even if the MPU is disabled.

12.5.2.5 Bus fault

A bus fault is an exception that occurs because of a memory related fault for an instruction or data memory transaction. This might be from an error detected on a bus in the memory system.

12.5.2.6 Usage fault

A usage fault is an exception that occurs because of a fault related to instruction execution. This includes:

- an undefined instruction
- an illegal unaligned access
- invalid state on instruction execution
- an error on exception return.

The following can cause a usage fault when the core is configured to report them:

- an unaligned address on word and halfword memory access
- division by zero.

12.5.2.7 SVCall

A *supervisor call* (SVC) is an exception that is triggered by the SVC instruction. In an OS environment, applications can use SVC instructions to access OS kernel functions and device drivers.

12.5.2.8 PendSV

PendSV is an interrupt-driven request for system-level service. In an OS environment, use PendSV for context switching when no other exception is active.

12.5.2.9 SysTick

A SysTick exception is an exception the system timer generates when it reaches zero. Software can also generate a SysTick exception. In an OS environment, the processor can use this exception as system tick.

12.5.2.10 Interrupt (IRQ)

A interrupt, or IRQ, is an exception signalled by a peripheral, or generated by a software request. All interrupts are asynchronous to instruction execution. In the system, peripherals use interrupts to communicate with the processor.

Table 12-9. Properties of the different exception types

Exception number (1)	IRQ number (1)	Exception type	Priority	Vector address or offset (2)	Activation
1	-	Reset	-3, the highest	0x00000004	Asynchronous
2	-14	NMI	-2	0x00000008	Asynchronous
3	-13	Hard fault	-1	0x0000000C	-
4	-12	Memory management fault	Configurable (3)	0x00000010	Synchronous
5	-11	Bus fault	Configurable (3)	0x00000014	Synchronous when precise, asynchronous when imprecise
6	-10	Usage fault	Configurable (3)	0x00000018	Synchronous
7-10	-	-	-	Reserved	-
11	-5	SVCall	Configurable (3)	0x0000002C	Synchronous
12-13	-	-	-	Reserved	-
14	-2	PendSV	Configurable (3)	0x00000038	Asynchronous
15	-1	SysTick	Configurable (3)	0x0000003C	Asynchronous
16 and above	0 and above (4)	Interrupt (IRQ)	Configurable (5)	0x00000040 and above (6)	Asynchronous

1. To simplify the software layer, the CMSIS only uses IRQ numbers and therefore uses negative values for exceptions other than interrupts. The IPSR returns the Exception number, see “Interrupt Program Status Register” on page 51.
2. See “Vector table” on page 70 for more information.
3. See “System Handler Priority Registers” on page 173.
4. See the “Peripheral Identifiers” section of the datasheet.
5. See “Interrupt Priority Registers” on page 156.
6. Increasing in steps of 4.

For an asynchronous exception, other than reset, the processor can execute another instruction between when the exception is triggered and when the processor enters the exception handler.

Privileged software can disable the exceptions that Table 12-9 on page 68 shows as having configurable priority, see:

- “System Handler Control and State Register” on page 177
- “Interrupt Clear-enable Registers” on page 152.

For more information about hard faults, memory management faults, bus faults, and usage faults, see “Fault handling” on page 73.

12.5.3 Exception handlers

The processor handles exceptions using:

12.5.3.1 Interrupt Service Routines (ISRs)

Interrupts IRQ0 to IRQ29 are the exceptions handled by ISRs.

12.5.3.2 Fault handlers

Hard fault, memory management fault, usage fault, bus fault are fault exceptions handled by the fault handlers.

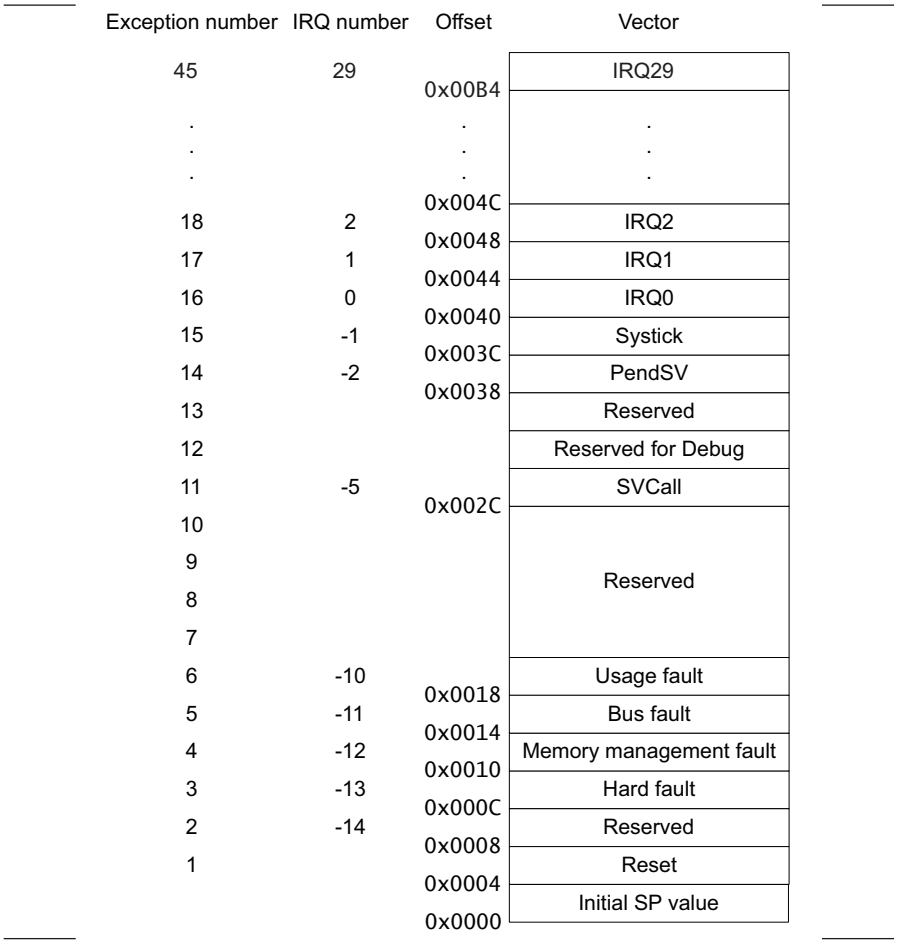
12.5.3.3 System handlers

NMI, PendSV, SVCall SysTick, and the fault exceptions are all system exceptions that are handled by system handlers.

12.5.4 Vector table

The vector table contains the reset value of the stack pointer, and the start addresses, also called exception vectors, for all exception handlers. Figure 12-3 on page 70 shows the order of the exception vectors in the vector table. The least-significant bit of each vector must be 1, indicating that the exception handler is Thumb code.

Figure 12-3. Vector table



On system reset, the vector table is fixed at address 0x00000000. Privileged software can write to the VTOR to relocate the vector table start address to a different memory location, in the range 0x00000080 to 0x3FFFFF80, see "Vector Table Offset Register" on page 167.

12.5.5 Exception priorities

As Table 12-9 on page 68 shows, all exceptions have an associated priority, with:

- a lower priority value indicating a higher priority
- configurable priorities for all exceptions except Reset, Hard fault.

If software does not configure any priorities, then all exceptions with a configurable priority have a priority of 0. For information about configuring exception priorities see

- "System Handler Priority Registers" on page 173
- "Interrupt Priority Registers" on page 156.

Configurable priority values are in the range 0-15. This means that the Reset, Hard fault, and NMI exceptions, with fixed negative priority values, always have higher priority than any other exception.

For example, assigning a higher priority value to IRQ[0] and a lower priority value to IRQ[1] means that IRQ[1] has higher priority than IRQ[0]. If both IRQ[1] and IRQ[0] are asserted, IRQ[1] is processed before IRQ[0].

If multiple pending exceptions have the same priority, the pending exception with the lowest exception number takes precedence. For example, if both IRQ[0] and IRQ[1] are pending and have the same priority, then IRQ[0] is processed before IRQ[1].

When the processor is executing an exception handler, the exception handler is preempted if a higher priority exception occurs. If an exception occurs with the same priority as the exception being handled, the handler is not preempted, irrespective of the exception number. However, the status of the new interrupt changes to pending.

12.5.6 Interrupt priority grouping

To increase priority control in systems with interrupts, the NVIC supports priority grouping. This divides each interrupt priority register entry into two fields:

- an upper field that defines the *group priority*
- a lower field that defines a *subpriority* within the group.

Only the group priority determines preemption of interrupt exceptions. When the processor is executing an interrupt exception handler, another interrupt with the same group priority as the interrupt being handled does not preempt the handler,

If multiple pending interrupts have the same group priority, the subpriority field determines the order in which they are processed. If multiple pending interrupts have the same group priority and subpriority, the interrupt with the lowest IRQ number is processed first.

For information about splitting the interrupt priority fields into group priority and subpriority, see “Application Interrupt and Reset Control Register” on page 168.

12.5.7 Exception entry and return

Descriptions of exception handling use the following terms:

12.5.7.1 Preemption

When the processor is executing an exception handler, an exception can preempt the exception handler if its priority is higher than the priority of the exception being handled. See “Interrupt priority grouping” on page 71 for more information about preemption by an interrupt.

When one exception preempts another, the exceptions are called nested exceptions. See “Exception entry” on page 72 more information.

12.5.7.2 Return

This occurs when the exception handler is completed, and:

- there is no pending exception with sufficient priority to be serviced
- the completed exception handler was not handling a late-arriving exception.

The processor pops the stack and restores the processor state to the state it had before the interrupt occurred. See “Exception return” on page 72 for more information.

12.5.7.3 Tail-chaining

This mechanism speeds up exception servicing. On completion of an exception handler, if there is a pending exception that meets the requirements for exception entry, the stack pop is skipped and control transfers to the new exception handler.

12.5.7.4 Late-arriving

This mechanism speeds up preemption. If a higher priority exception occurs during state saving for a previous exception, the processor switches to handle the higher priority exception and initiates the vector fetch for that exception. State saving is not affected by late arrival because the state saved is the same for both exceptions. Therefore the state saving continues uninterrupted. The processor can accept a late arriving exception until the first instruction of the exception handler of the original exception enters the execute stage of the processor. On return from the exception handler of the late-arriving exception, the normal tail-chaining rules apply.

12.5.7.5 Exception entry

Exception entry occurs when there is a pending exception with sufficient priority and either:

- the processor is in Thread mode
- the new exception is of higher priority than the exception being handled, in which case the new exception preempts the original exception.

When one exception preempts another, the exceptions are nested.

Sufficient priority means the exception has more priority than any limits set by the mask registers, see “Exception mask registers” on page 52. An exception with less priority than this is pending but is not handled by the processor.

When the processor takes an exception, unless the exception is a tail-chained or a late-arriving exception, the processor pushes information onto the current stack. This operation is referred as *stacking* and the structure of eight data words is referred as *stack frame*. The stack frame contains the following information:

- R0-R3, R12
- Return address
- PSR
- LR.

Immediately after stacking, the stack pointer indicates the lowest address in the stack frame. Unless stack alignment is disabled, the stack frame is aligned to a double-word address. If the STKALIGN bit of the *Configuration Control Register* (CCR) is set to 1, stack align adjustment is performed during stacking.

The stack frame includes the return address. This is the address of the next instruction in the interrupted program. This value is restored to the PC at exception return so that the interrupted program resumes.

In parallel to the stacking operation, the processor performs a vector fetch that reads the exception handler start address from the vector table. When stacking is complete, the processor starts executing the exception handler. At the same time, the processor writes an EXC_RETURN value to the LR. This indicates which stack pointer corresponds to the stack frame and what operation mode the was processor was in before the entry occurred.

If no higher priority exception occurs during exception entry, the processor starts executing the exception handler and automatically changes the status of the corresponding pending interrupt to active.

If another higher priority exception occurs during exception entry, the processor starts executing the exception handler for this exception and does not change the pending status of the earlier exception. This is the late arrival case.

12.5.7.6 Exception return

Exception return occurs when the processor is in Handler mode and executes one of the following instructions to load the EXC_RETURN value into the PC:

- a POP instruction that includes the PC
- a BX instruction with any register.
- an LDR or LDM instruction with the PC as the destination.

EXC_RETURN is the value loaded into the LR on exception entry. The exception mechanism relies on this value to detect when the processor has completed an exception handler. The lowest four bits of this value provide information on the return stack and processor mode. Table 12-10 shows the EXC_RETURN[3:0] values with a description of the exception return behavior.

The processor sets EXC_RETURN bits[31:4] to 0xFFFFFFF. When this value is loaded into the PC it indicates to the processor that the exception is complete, and the processor initiates the exception return sequence.

Table 12-10. Exception return behavior

EXC_RETURN[3:0]	Description
bXXX0	Reserved.
b0001	Return to Handler mode. Exception return gets state from MSP. Execution uses MSP after return.
b0011	Reserved.
b01X1	Reserved.
b1001	Return to Thread mode. Exception return gets state from MSP. Execution uses MSP after return.
b1101	Return to Thread mode. Exception return gets state from PSP. Execution uses PSP after return.
b1X11	Reserved.

12.6 Fault handling

Faults are a subset of the exceptions, see “Exception model” on page 66. The following generate a fault:

- a bus error on:
  - an instruction fetch or vector table load
  - a data access
- an internally-detected error such as an undefined instruction or an attempt to change state with a BX instruction
- attempting to execute an instruction from a memory region marked as *Non-Executable* (XN).
- an MPU fault because of a privilege violation or an attempt to access an unmanaged region.

12.6.1 Fault types

Table 12-11 shows the types of fault, the handler used for the fault, the corresponding fault status register, and the register bit that indicates that the fault has occurred. See “Configurable Fault Status Register” on page 179 for more information about the fault status registers.

Table 12-11. Faults

Fault	Handler	Bit name	Fault status register
Bus error on a vector read	Hard fault	VECTTBL	“Hard Fault Status Register” on page 185
Fault escalated to a hard fault		FORCED	
MPU mismatch:	Memory management fault	-	-
on instruction access		IACCVIOL (1)	“Memory Management Fault Address Register” on page 186
on data access		DACCVIOL	
during exception stacking		MSTKERR	
during exception unstacking		MUNSKERR	
Bus error:	Bus fault	-	-
during exception stacking		STKERR	“Bus Fault Status Register” on page 181
during exception unstacking		UNSTKERR	
during instruction prefetch		IBUSERR	
Precise data bus error		PRECISERR	
Imprecise data bus error		IMPRECISERR	
Attempt to access a coprocessor	Usage fault	NOCP	“Usage Fault Status Register” on page 183
Undefined instruction		UNDEFINSTR	
Attempt to enter an invalid instruction set state (2)		INVSTATE	
Invalid EXC_RETURN value		INVPC	
Illegal unaligned load or store		UNALIGNED	
Divide By 0		DIVBYZERO	

1. Occurs on an access to an XN region even if the MPU is disabled.
2. Attempting to use an instruction set other than the Thumb instruction set.

12.6.2 Fault escalation and hard faults

All faults exceptions except for hard fault have configurable exception priority, see “System Handler Priority Registers” on page 173. Software can disable execution of the handlers for these faults, see “System Handler Control and State Register” on page 177.

Usually, the exception priority, together with the values of the exception mask registers, determines whether the processor enters the fault handler, and whether a fault handler can preempt another fault handler. as described in “Exception model” on page 66.

In some situations, a fault with configurable priority is treated as a hard fault. This is called *priority escalation*, and the fault is described as *escalated to hard fault*. Escalation to hard fault occurs when:

- A fault handler causes the same kind of fault as the one it is servicing. This escalation to hard fault occurs because a fault handler cannot preempt itself because it must have the same priority as the current priority level.
- A fault handler causes a fault with the same or lower priority as the fault it is servicing. This is because the handler for the new fault cannot preempt the currently executing fault handler.
- An exception handler causes a fault for which the priority is the same as or lower than the currently executing exception.
- A fault occurs and the handler for that fault is not enabled.

If a bus fault occurs during a stack push when entering a bus fault handler, the bus fault does not escalate to a hard fault. This means that if a corrupted stack causes a fault, the fault handler executes even though the stack push for the handler failed. The fault handler operates but the stack contents are corrupted.

Only Reset and NMI can preempt the fixed priority hard fault. A hard fault can preempt any exception other than Reset, NMI, or another hard fault.

12.6.3 Fault status registers and fault address registers

The fault status registers indicate the cause of a fault. For bus faults and memory management faults, the fault address register indicates the address accessed by the operation that caused the fault, as shown in Table 12-12.

Table 12-12. Fault status and fault address registers

Handler	Status register name	Address register name	Register description
Hard fault	HFSR	-	“Hard Fault Status Register” on page 185
Memory management fault	MMFSR	MMFAR	“Memory Management Fault Status Register” on page 180 “Memory Management Fault Address Register” on page 186
Bus fault	BFSR	BFAR	“Bus Fault Status Register” on page 181 “Bus Fault Address Register” on page 187
Usage fault	UFSR	-	“Usage Fault Status Register” on page 183

12.6.4 Lockup

The processor enters a lockup state if a hard fault occurs when executing the hard fault handlers. When the processor is in lockup state it does not execute any instructions. The processor remains in lockup state until:

- it is reset

12.7 Power management

The Cortex-M3 processor sleep modes reduce power consumption:

- Backup Mode
- Wait Mode
- Sleep Mode

The SLEEPDEEP bit of the SCR selects which sleep mode is used, see “System Control Register” on page 170. For more information about the behavior of the sleep modes see “Low Power Modes” in the PMC section of the datasheet.

This section describes the mechanisms for entering sleep mode, and the conditions for waking up from sleep mode.

12.7.1 Entering sleep mode

This section describes the mechanisms software can use to put the processor into sleep mode.

The system can generate spurious wakeup events, for example a debug operation wakes up the processor. Therefore software must be able to put the processor back into sleep mode after such an event. A program might have an idle loop to put the processor back to sleep mode.

12.7.1.1 Wait for interrupt

The *wait for interrupt* instruction, WFI, causes immediate entry to sleep mode. When the processor executes a WFI instruction it stops executing instructions and enters sleep mode. See “WFI” on page 147 for more information.

12.7.1.2 Wait for event

The *wait for event* instruction, WFE, causes entry to sleep mode conditional on the value of an one-bit event register. When the processor executes a WFE instruction, it checks this register:

- if the register is 0 the processor stops executing instructions and enters sleep mode
- if the register is 1 the processor clears the register to 0 and continues executing instructions without entering sleep mode.

See “WFE” on page 146 for more information.

12.7.1.3 Sleep-on-exit

If the SLEEPONEXIT bit of the SCR is set to 1, when the processor completes the execution of an exception handler it returns to Thread mode and immediately enters sleep mode. Use this mechanism in applications that only require the processor to run when an exception occurs.

12.7.2 Wakeup from sleep mode

The conditions for the processor to wakeup depend on the mechanism that cause it to enter sleep mode.

12.7.2.1 Wakeup from WFI or sleep-on-exit

Normally, the processor wakes up only when it detects an exception with sufficient priority to cause exception entry.

Some embedded systems might have to execute system restore tasks after the processor wakes up, and before it executes an interrupt handler. To achieve this set the PRIMASK bit to 1 and the FAULTMASK bit to 0. If an interrupt arrives that is enabled and has a higher priority than current exception priority, the processor wakes up but does not execute the interrupt handler until the processor sets PRIMASK to zero. For more information about PRIMASK and FAULTMASK see “Exception mask registers” on page 52.

12.7.2.2 Wakeup from WFE

The processor wakes up if:

- it detects an exception with sufficient priority to cause exception entry

In addition, if the SEVONPEND bit in the SCR is set to 1, any new pending interrupt triggers an event and wakes up the processor, even if the interrupt is disabled or has insufficient priority to cause exception entry. For more information about the SCR see “System Control Register” on page 170.

12.7.3 Power management programming hints

ANSI C cannot directly generate the WFI and WFE instructions. The CMSIS provides the following intrinsic functions for these instructions:

```
void __WFE(void) // Wait for Event
void __WFE(void) // Wait for Interrupt
```

12.8 Instruction set summary

The processor implements a version of the Thumb instruction set. Table 12-13 lists the supported instructions.

In Table 12-13:

- angle brackets, <>, enclose alternative forms of the operand
- braces, {}, enclose optional operands
- the Operands column is not exhaustive
- Op2 is a flexible second operand that can be either a register or a constant
- most instructions can use an optional condition code suffix.

For more information on the instructions and operands, see the instruction descriptions.

Table 12-13. Cortex-M3 instructions

Mnemonic	Operands	Brief description	Flags	Page
ADC, ADCS	{Rd,} Rn, Op2	Add with Carry	N,Z,C,V	page 106
ADD, ADDS	{Rd,} Rn, Op2	Add	N,Z,C,V	page 106
ADD, ADDW	{Rd,} Rn, #imm12	Add	N,Z,C,V	page 106
ADR	Rd, label	Load PC-relative address	-	page 91
AND, ANDS	{Rd,} Rn, Op2	Logical AND	N,Z,C	page 108
ASR, ASRS	Rd, Rm, <Rs|#n>	Arithmetic Shift Right	N,Z,C	page 109
B	label	Branch	-	page 129
BFC	Rd, #lsb, #width	Bit Field Clear	-	page 125
BFI	Rd, Rn, #lsb, #width	Bit Field Insert	-	page 125
BIC, BICS	{Rd,} Rn, Op2	Bit Clear	N,Z,C	page 108
BKPT	#imm	Breakpoint	-	page 136
BL	label	Branch with Link	-	page 129
BLX	Rm	Branch indirect with Link	-	page 129
BX	Rm	Branch indirect	-	page 129
CBNZ	Rn, label	Compare and Branch if Non Zero	-	page 131
CBZ	Rn, label	Compare and Branch if Zero	-	page 131
CLREX	-	Clear Exclusive	-	page 104
CLZ	Rd, Rm	Count leading zeros	-	page 111
CMN, CMNS	Rn, Op2	Compare Negative	N,Z,C,V	page 112
CMP, CMPS	Rn, Op2	Compare	N,Z,C,V	page 112
CPSID	iflags	Change Processor State, Disable Interrupts	-	page 137
CPSIE	iflags	Change Processor State, Enable Interrupts	-	page 137
DMB	-	Data Memory Barrier	-	page 138
DSB	-	Data Synchronization Barrier	-	page 139
EOR, EORS	{Rd,} Rn, Op2	Exclusive OR	N,Z,C	page 108
ISB	-	Instruction Synchronization Barrier	-	page 140
IT	-	If-Then condition block	-	page 132
LDM	Rn{!}, reglist	Load Multiple registers, increment after	-	page 99

Table 12-13. Cortex-M3 instructions (Continued)

Mnemonic	Operands	Brief description	Flags	Page
LDMDB, LDMEA	Rn{!}, reglist	Load Multiple registers, decrement before	-	page 99
LDMFD, LDMIA	Rn{!}, reglist	Load Multiple registers, increment after	-	page 99
LDR	Rt, [Rn, #offset]	Load Register with word	-	page 94
LDRB, LDRBT	Rt, [Rn, #offset]	Load Register with byte	-	page 94
LDRD	Rt, Rt2, [Rn, #offset]	Load Register with two bytes	-	page 94
LDREX	Rt, [Rn, #offset]	Load Register Exclusive	-	page 94
LDREXB	Rt, [Rn]	Load Register Exclusive with byte	-	page 94
LDREXH	Rt, [Rn]	Load Register Exclusive with halfword	-	page 94
LDRH, LDRHT	Rt, [Rn, #offset]	Load Register with halfword	-	page 94
LDRSB, LDRSBT	Rt, [Rn, #offset]	Load Register with signed byte	-	page 94
LDRSH, LDRSHT	Rt, [Rn, #offset]	Load Register with signed halfword	-	page 94
LDRT	Rt, [Rn, #offset]	Load Register with word	-	page 94
LSL, LSLS	Rd, Rm, <Rs|#n>	Logical Shift Left	N,Z,C	page 109
LSR, LSRS	Rd, Rm, <Rs|#n>	Logical Shift Right	N,Z,C	page 109
MLA	Rd, Rn, Rm, Ra	Multiply with Accumulate, 32-bit result	-	page 119
MLS	Rd, Rn, Rm, Ra	Multiply and Subtract, 32-bit result	-	page 119
MOV, MOVS	Rd, Op2	Move	N,Z,C	page 113
MOVT	Rd, #imm16	Move Top	-	page 115
MOVW, MOV	Rd, #imm16	Move 16-bit constant	N,Z,C	page 113
MRS	Rd, spec_reg	Move from special register to general register	-	page 141
MSR	spec_reg, Rm	Move from general register to special register	N,Z,C,V	page 142
MUL, MULS	{Rd,} Rn, Rm	Multiply, 32-bit result	N,Z	page 119
MVN, MVNS	Rd, Op2	Move NOT	N,Z,C	page 113
NOP	-	No Operation	-	page 143
ORN, ORNS	{Rd,} Rn, Op2	Logical OR NOT	N,Z,C	page 108
ORR, ORRS	{Rd,} Rn, Op2	Logical OR	N,Z,C	page 108
POP	reglist	Pop registers from stack	-	page 101
PUSH	reglist	Push registers onto stack	-	page 101
RBIT	Rd, Rn	Reverse Bits	-	page 116
REV	Rd, Rn	Reverse byte order in a word	-	page 116
REV16	Rd, Rn	Reverse byte order in each halfword	-	page 116
REVSH	Rd, Rn	Reverse byte order in bottom halfword and sign extend	-	page 116
ROR, RORS	Rd, Rm, <Rs|#n>	Rotate Right	N,Z,C	page 109
RRX, RRXS	Rd, Rm	Rotate Right with Extend	N,Z,C	page 109
RSB, RSBS	{Rd,} Rn, Op2	Reverse Subtract	N,Z,C,V	page 106
SBC, SBCS	{Rd,} Rn, Op2	Subtract with Carry	N,Z,C,V	page 106
SBFX	Rd, Rn, #lsb, #width	Signed Bit Field Extract	-	page 126

Table 12-13. Cortex-M3 instructions (Continued)

Mnemonic	Operands	Brief description	Flags	Page
SDIV	{Rd,} Rn, Rm	Signed Divide	-	page 121
SEV	-	Send Event	-	page 144
SMLAL	RdLo, RdHi, Rn, Rm	Signed Multiply with Accumulate (32 x 32 + 64), 64-bit result	-	page 120
SMULL	RdLo, RdHi, Rn, Rm	Signed Multiply (32 x 32), 64-bit result	-	page 120
SSAT	Rd, #n, Rm {,shift #s}	Signed Saturate	Q	page 122
STM	Rn{!}, reglist	Store Multiple registers, increment after	-	page 99
STMDB, STMEA	Rn{!}, reglist	Store Multiple registers, decrement before	-	page 99
STMFD, STMIA	Rn{!}, reglist	Store Multiple registers, increment after	-	page 99
STR	Rt, [Rn, #offset]	Store Register word	-	page 94
STRB, STRBT	Rt, [Rn, #offset]	Store Register byte	-	page 94
STRD	Rt, Rt2, [Rn, #offset]	Store Register two words	-	page 94
STREX	Rd, Rt, [Rn, #offset]	Store Register Exclusive	-	page 102
STREXB	Rd, Rt, [Rn]	Store Register Exclusive byte	-	page 102
STREXH	Rd, Rt, [Rn]	Store Register Exclusive halfword	-	page 102
STRH, STRHT	Rt, [Rn, #offset]	Store Register halfword	-	page 94
STRT	Rt, [Rn, #offset]	Store Register word	-	page 94
SUB, SUBS	{Rd,} Rn, Op2	Subtract	N,Z,C,V	page 106
SUB, SUBW	{Rd,} Rn, #imm12	Subtract	N,Z,C,V	page 106
SVC	#imm	Supervisor Call	-	page 145
SXTB	{Rd,} Rm {,ROR #n}	Sign extend a byte	-	page 127
SXTH	{Rd,} Rm {,ROR #n}	Sign extend a halfword	-	page 127
TBB	[Rn, Rm]	Table Branch Byte	-	page 134
TBH	[Rn, Rm, LSL #1]	Table Branch Halfword	-	page 134
TEQ	Rn, Op2	Test Equivalence	N,Z,C	page 117
TST	Rn, Op2	Test	N,Z,C	page 117
UBFX	Rd, Rn, #lsb, #width	Unsigned Bit Field Extract	-	page 126
UDIV	{Rd,} Rn, Rm	Unsigned Divide	-	page 121
UMLAL	RdLo, RdHi, Rn, Rm	Unsigned Multiply with Accumulate (32 x 32 + 64), 64-bit result	-	page 120
UMULL	RdLo, RdHi, Rn, Rm	Unsigned Multiply (32 x 32), 64-bit result	-	page 120
USAT	Rd, #n, Rm {,shift #s}	Unsigned Saturate	Q	page 122
UXTB	{Rd,} Rm {,ROR #n}	Zero extend a byte	-	page 127
UXTH	{Rd,} Rm {,ROR #n}	Zero extend a halfword	-	page 127
WFE	-	Wait For Event	-	page 146
WFI	-	Wait For Interrupt	-	page 147

12.9 Intrinsic functions

ANSI cannot directly access some Cortex-M3 instructions. This section describes intrinsic functions that can generate these instructions, provided by the CMIS and that might be provided by a C compiler. If a C compiler does not support an appropriate intrinsic function, you might have to use inline assembler to access some instructions.

The CMSIS provides the following intrinsic functions to generate instructions that ANSI cannot directly access:

Table 12-14. CMSIS intrinsic functions to generate some Cortex-M3 instructions

Instruction	CMSIS intrinsic function
CPSIE I	void __enable_irq(void)
CPSID I	void __disable_irq(void)
CPSIE F	void __enable_fault_irq(void)
CPSID F	void __disable_fault_irq(void)
ISB	void __ISB(void)
DSB	void __DSB(void)
DMB	void __DMB(void)
REV	uint32_t __REV(uint32_t int value)
REV16	uint32_t __REV16(uint32_t int value)
REVSH	uint32_t __REVSH(uint32_t int value)
RBIT	uint32_t __RBIT(uint32_t int value)
SEV	void __SEV(void)
WFE	void __WFE(void)
WFI	void __WFI(void)

The CMSIS also provides a number of functions for accessing the special registers using MRS and MSR instructions:

Table 12-15. CMSIS intrinsic functions to access the special registers

Special register	Access	CMSIS function
PRIMASK	Read	uint32_t __get_PRIMASK (void)
	Write	void __set_PRIMASK (uint32_t value)
FAULTMASK	Read	uint32_t __get_FAULTMASK (void)
	Write	void __set_FAULTMASK (uint32_t value)
BASEPRI	Read	uint32_t __get_BASEPRI (void)
	Write	void __set_BASEPRI (uint32_t value)
CONTROL	Read	uint32_t __get_CONTROL (void)
	Write	void __set_CONTROL (uint32_t value)
MSP	Read	uint32_t __get_MSP (void)
	Write	void __set_MSP (uint32_t TopOfMainStack)
PSP	Read	uint32_t __get_PSP (void)
	Write	void __set_PSP (uint32_t TopOfProcStack)

12.10 About the instruction descriptions

The following sections give more information about using the instructions:

- “Operands” on page 82
- “Restrictions when using PC or SP” on page 82
- “Flexible second operand” on page 82
- “Shift Operations” on page 83
- “Address alignment” on page 86
- “PC-relative expressions” on page 86
- “Conditional execution” on page 87
- “Instruction width selection” on page 88.

12.10.1 Operands

An instruction operand can be an ARM register, a constant, or another instruction-specific parameter. Instructions act on the operands and often store the result in a destination register. When there is a destination register in the instruction, it is usually specified before the operands.

Operands in some instructions are flexible in that they can either be a register or a constant. See “Flexible second operand”.

12.10.2 Restrictions when using PC or SP

Many instructions have restrictions on whether you can use the *Program Counter* (PC) or *Stack Pointer* (SP) for the operands or destination register. See instruction descriptions for more information.

Bit[0] of any address you write to the PC with a BX, BLX, LDM, LDR, or POP instruction must be 1 for correct execution, because this bit indicates the required instruction set, and the Cortex-M3 processor only supports Thumb instructions.

12.10.3 Flexible second operand

Many general data processing instructions have a flexible second operand. This is shown as *Operand2* in the descriptions of the syntax of each instruction.

Operand2 can be a:

- “Constant”
- “Register with optional shift” on page 83

12.10.3.1 Constant

You specify an Operand2 constant in the form:

```
#constant
```

where `constant` can be:

- any constant that can be produced by shifting an 8-bit value left by any number of bits within a 32-bit word
- any constant of the form 0x00XY00XY
- any constant of the form 0xXY00XY00
- any constant of the form 0xXYXYXYXY.

In the constants shown above, X and Y are hexadecimal digits.

In addition, in a small number of instructions, `constant` can take a wider range of values. These are described in the individual instruction descriptions.

When an Operand2 constant is used with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to bit[31] of the constant, if the constant is greater than 255 and can be produced by shifting an 8-bit value. These instructions do not affect the carry flag if Operand2 is any other constant.

12.10.3.2 Instruction substitution

Your assembler might be able to produce an equivalent instruction in cases where you specify a constant that is not permitted. For example, an assembler might assemble the instruction CMP *Rd*, #0xFFFFFFFE as the equivalent instruction CMN *Rd*, #0x2.

12.10.3.3 Register with optional shift

You specify an Operand2 register in the form:

```
Rm {, shift}
```

where:

Rm is the register holding the data for the second operand.

shift is an optional shift to be applied to *Rm*. It can be one of:

ASR #*n*	arithmetic shift right *n* bits, $1 \le n \le 32$.
LSL #*n*	logical shift left *n* bits, $1 \le n \le 31$.
LSR #*n*	logical shift right *n* bits, $1 \le n \le 32$.
ROR #*n*	rotate right *n* bits, $1 \le n \le 31$.
RRX	rotate right one bit, with extend.
-	if omitted, no shift occurs, equivalent to LSL #0.

If you omit the shift, or specify LSL #0, the instruction uses the value in *Rm*.

If you specify a shift, the shift is applied to the value in *Rm*, and the resulting 32-bit value is used by the instruction. However, the contents in the register *Rm* remains unchanged. Specifying a register with shift also updates the carry flag when used with certain instructions. For information on the shift operations and how they affect the carry flag, see “Shift Operations”

12.10.4 Shift Operations

Register shift operations move the bits in a register left or right by a specified number of bits, the *shift length*. Register shift can be performed:

- directly by the instructions ASR, LSR, LSL, ROR, and RRX, and the result is written to a destination register
- during the calculation of *Operand2* by the instructions that specify the second operand as a register with shift, see “Flexible second operand” on page 82. The result is used by the instruction.

The permitted shift lengths depend on the shift type and the instruction, see the individual instruction description or “Flexible second operand” on page 82. If the shift length is 0, no shift occurs. Register shift operations update the carry flag except when the specified shift length is 0. The following sub-sections describe the various shift operations and how they affect the carry flag. In these descriptions, *Rm* is the register containing the value to be shifted, and *n* is the shift length.

12.10.4.1 ASR

Arithmetic shift right by *n* bits moves the left-hand 32-n bits of the register *Rm*, to the right by *n* places, into the right-hand 32-n bits of the result. And it copies the original bit[31] of the register into the left-hand *n* bits of the result. See Figure 12-4 on page 84.

You can use the ASR #n operation to divide the value in the register Rm by 2^n, with the result being rounded towards negative-infinity.

When the instruction is ASRS or when ASR #n is used in *Operand2* with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to the last bit shifted out, bit[*n*-1], of the register *Rm*.

- If *n* is 32 or more, then all the bits in the result are set to the value of bit[31] of *Rm*.
- If *n* is 32 or more and the carry flag is updated, it is updated to the value of bit[31] of *Rm*.

Figure 12-4. ASR #3

12.10.4.2 LSR

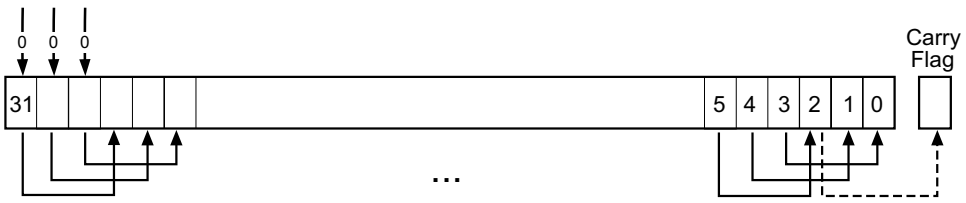
Logical shift right by n bits moves the left-hand 32-n bits of the register Rm, to the right by *n* places, into the right-hand 32-n bits of the result. And it sets the left-hand n bits of the result to 0. See Figure 12-5.

You can use the LSR #n operation to divide the value in the register Rm by 2^n, if the value is regarded as an unsigned integer.

When the instruction is LSRS or when LSR #n is used in *Operand2* with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to the last bit shifted out, bit[n-1], of the register Rm.

- If *n* is 32 or more, then all the bits in the result are cleared to 0.
- If *n* is 33 or more and the carry flag is updated, it is updated to 0.

Figure 12-5. LSR #3



12.10.4.3 LSL

Logical shift left by *n* bits moves the right-hand 32-n bits of the register Rm, to the left by *n* places, into the left-hand 32-n bits of the result. And it sets the right-hand *n* bits of the result to 0. See Figure 12-6 on page 85.

You can use he LSL #n operation to multiply the value in the register *Rm* by 2^n, if the value is regarded as an unsigned integer or a two's complement signed integer. Overflow can occur without warning.

When the instruction is LSLS or when LSL #n, with non-zero *n*, is used in *Operand2* with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to the last bit shifted out, bit[32-*n*], of the register *Rm*. These instructions do not affect the carry flag when used with LSL #0.

- If *n* is 32 or more, then all the bits in the result are cleared to 0.
- If *n* is 33 or more and the carry flag is updated, it is updated to 0.

Figure 12-6. LSL #3

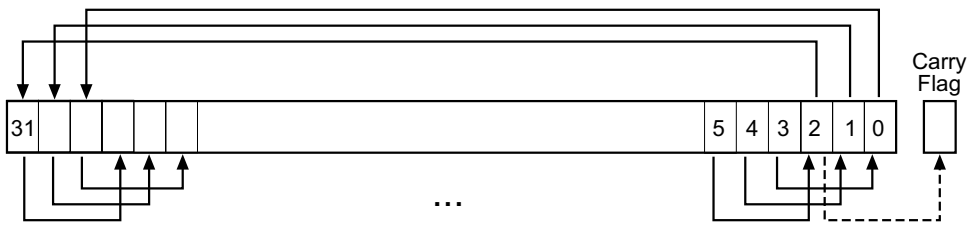
12.10.4.4 ROR

Rotate right by *n* bits moves the left-hand 32-*n* bits of the register *Rm*, to the right by *n* places, into the right-hand 32-*n* bits of the result. And it moves the right-hand *n* bits of the register into the left-hand *n* bits of the result. See Figure 12-7.

When the instruction is RORS or when ROR #*n* is used in *Operand2* with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to the last bit rotation, bit[*n*-1], of the register *Rm*.

- If *n* is 32, then the value of the result is same as the value in *Rm*, and if the carry flag is updated, it is updated to bit[31] of *Rm*.
- ROR with shift length, *n*, more than 32 is the same as ROR with shift length *n*-32.

Figure 12-7. ROR #3

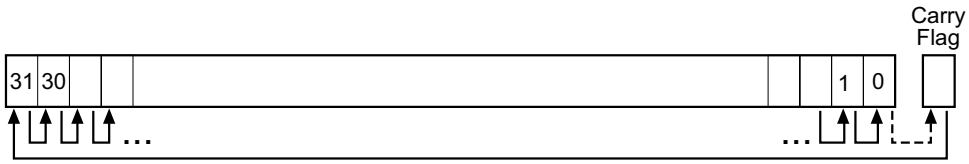


12.10.4.5 RRX

Rotate right with extend moves the bits of the register *Rm* to the right by one bit. And it copies the carry flag into bit[31] of the result. See Figure 12-8 on page 86.

When the instruction is RRXS or when RRX is used in *Operand2* with the instructions MOVS, MVNS, ANDS, ORRS, ORNS, EORS, BICS, TEQ or TST, the carry flag is updated to bit[0] of the register *Rm*.

Figure 12-8. RRX



12.10.5 Address alignment

An aligned access is an operation where a word-aligned address is used for a word, dual word, or multiple word access, or where a halfword-aligned address is used for a halfword access. Byte accesses are always aligned.

The Cortex-M3 processor supports unaligned access only for the following instructions:

- LDR, LDRT
- LDRH, LDRHT
- LDRSH, LDRSHT
- STR, STRT
- STRH, STRHT

All other load and store instructions generate a usage fault exception if they perform an unaligned access, and therefore their accesses must be address aligned. For more information about usage faults see “Fault handling” on page 73.

Unaligned accesses are usually slower than aligned accesses. In addition, some memory regions might not support unaligned accesses. Therefore, ARM recommends that programmers ensure that accesses are aligned. To avoid accidental generation of unaligned accesses, use the UNALIGN_TRP bit in the Configuration and Control Register to trap all unaligned accesses, see “Configuration and Control Register” on page 171.

12.10.6 PC-relative expressions

A PC-relative expression or *label* is a symbol that represents the address of an instruction or literal data. It is represented in the instruction as the PC value plus or minus a numeric offset. The assembler calculates the required offset from the label and the address of the current instruction. If the offset is too big, the assembler produces an error.

- For B, BL, CBNZ, and CBZ instructions, the value of the PC is the address of the current instruction plus 4 bytes.
- For all other instructions that use labels, the value of the PC is the address of the current instruction plus 4 bytes, with bit[1] of the result cleared to 0 to make it word-aligned.
- Your assembler might permit other syntaxes for PC-relative expressions, such as a label plus or minus a number, or an expression of the form [PC, #number].

12.10.7 Conditional execution

Most data processing instructions can optionally update the condition flags in the *Application Program Status Register* (APSR) according to the result of the operation, see “Application Program Status Register” on page 50. Some instructions update all flags, and some only update a subset. If a flag is not updated, the original value is preserved. See the instruction descriptions for the flags they affect.

You can execute an instruction conditionally, based on the condition flags set in another instruction, either:

- immediately after the instruction that updated the flags
- after any number of intervening instructions that have not updated the flags.

Conditional execution is available by using conditional branches or by adding condition code suffixes to instructions. See Table 12-16 on page 88 for a list of the suffixes to add to instructions to make them conditional instructions. The condition code suffix enables the processor to test a condition based on the flags. If the condition test of a conditional instruction fails, the instruction:

- does not execute
- does not write any value to its destination register
- does not affect any of the flags
- does not generate any exception.

Conditional instructions, except for conditional branches, must be inside an If-Then instruction block. See “IT” on page 132 for more information and restrictions when using the IT instruction. Depending on the vendor, the assembler might automatically insert an IT instruction if you have conditional instructions outside the IT block.

Use the CBZ and CBNZ instructions to compare the value of a register against zero and branch on the result.

This section describes:

- “The condition flags”
- “Condition code suffixes”.

12.10.7.1 The condition flags

The APSR contains the following condition flags:

N	Set to 1 when the result of the operation was negative, cleared to 0 otherwise.
Z	Set to 1 when the result of the operation was zero, cleared to 0 otherwise.
C	Set to 1 when the operation resulted in a carry, cleared to 0 otherwise.
V	Set to 1 when the operation caused overflow, cleared to 0 otherwise.

For more information about the APSR see “Program Status Register” on page 49.

A carry occurs:

- if the result of an addition is greater than or equal to 2^{32}
- if the result of a subtraction is positive or zero
- as the result of an inline barrel shifter operation in a move or logical instruction.

Overflow occurs if the result of an add, subtract, or compare is greater than or equal to 2^{31}, or less than -2^{31}.

Most instructions update the status flags only if the S suffix is specified. See the instruction descriptions for more information.

12.10.7.2 Condition code suffixes

The instructions that can be conditional have an optional condition code, shown in syntax descriptions as {cond}. Conditional execution requires a preceding IT instruction. An instruction with a condition code is only executed if the condition code flags in the APSR meet the specified condition. Table 12-16 shows the condition codes to use.

You can use conditional execution with the IT instruction to reduce the number of branch instructions in code.

Table 12-16 also shows the relationship between condition code suffixes and the N, Z, C, and V flags.

Table 12-16. Condition code suffixes

Suffix	Flags	Meaning
EQ	Z = 1	Equal
NE	Z = 0	Not equal
CS or HS	C = 1	Higher or same, unsigned ≥
CC or LO	C = 0	Lower, unsigned <
MI	N = 1	Negative
PL	N = 0	Positive or zero
VS	V = 1	Overflow
VC	V = 0	No overflow
HI	C = 1 and Z = 0	Higher, unsigned >
LS	C = 0 or Z = 1	Lower or same, unsigned ≤
GE	N = V	Greater than or equal, signed ≥
LT	N != V	Less than, signed <
GT	Z = 0 and N = V	Greater than, signed >
LE	Z = 1 and N != V	Less than or equal, signed ≤
AL	Can have any value	Always. This is the default when no suffix is specified.

12.10.7.3 Absolute value

The example below shows the use of a conditional instruction to find the absolute value of a number. R0 = ABS(R1).

```
MOVS    R0, R1          ; R0 = R1, setting flags
IT      MI              ; IT instruction for the negative condition
RSBMI   R0, R1, #0      ; If negative, R0 = -R1
```

12.10.7.4 Compare and update value

The example below shows the use of conditional instructions to update the value of R4 if the signed values R0 is greater than R1 and R2 is greater than R3.

```
CMP     R0, R1        ; Compare R0 and R1, setting flags
ITT     GT            ; IT instruction for the two GT conditions
CMPGT   R2, R3        ; If 'greater than', compare R2 and R3, setting flags
MOVGT   R4, R5        ; If still 'greater than', do R4 = R5
```

12.10.8 Instruction width selection

There are many instructions that can generate either a 16-bit encoding or a 32-bit encoding depending on the operands and destination register specified. For some of these instructions, you can force a specific instruction size by using an instruction width suffix. The .W suffix forces a 32-bit instruction encoding. The .N suffix forces a 16-bit instruction encoding.

If you specify an instruction width suffix and the assembler cannot generate an instruction encoding of the requested width, it generates an error.

In some cases it might be necessary to specify the .W suffix, for example if the operand is the label of an instruction or literal data, as in the case of branch instructions. This is because the assembler might not automatically generate the right size encoding.

12.10.8.1 Instruction width selection

To use an instruction width suffix, place it immediately after the instruction mnemonic and condition code, if any. The example below shows instructions with the instruction width suffix.

```
        BCS.W  label      ; creates a 32-bit instruction even for a short branch

        ADDS.W R0, R0, R1 ; creates a 32-bit instruction even though the same
                          ; operation can be done by a 16-bit instruction
```

12.11 Memory access instructions

Table 12-17 shows the memory access instructions:

Table 12-17. Memory access instructions

Mnemonic	Brief description	See
ADR	Load PC-relative address	“ADR” on page 91
CLREX	Clear Exclusive	“CLREX” on page 104
LDM{mode}	Load Multiple registers	“LDM and STM” on page 99
LDR{type}	Load Register using immediate offset	“LDR and STR, immediate offset” on page 92
LDR{type}	Load Register using register offset	“LDR and STR, register offset” on page 94
LDR{type}T	Load Register with unprivileged access	“LDR and STR, unprivileged” on page 96
LDR	Load Register using PC-relative address	“LDR, PC-relative” on page 97
LDREX{type}	Load Register Exclusive	“LDREX and STREX” on page 102
POP	Pop registers from stack	“PUSH and POP” on page 101
PUSH	Push registers onto stack	“PUSH and POP” on page 101
STM{mode}	Store Multiple registers	“LDM and STM” on page 99
STR{type}	Store Register using immediate offset	“LDR and STR, immediate offset” on page 92
STR{type}	Store Register using register offset	“LDR and STR, register offset” on page 94
STR{type}T	Store Register with unprivileged access	“LDR and STR, unprivileged” on page 96
STREX{type}	Store Register Exclusive	“LDREX and STREX” on page 102

12.11.1 ADR

Load PC-relative address.

12.11.1.1 Syntax

```
ADR{cond} Rd, label
```

where:

cond — is an optional condition code, see “Conditional execution” on page 87.

Rd — is the destination register.

label — is a PC-relative expression. See “PC-relative expressions” on page 86.

12.11.1.2 Operation

ADR determines the address by adding an immediate value to the PC, and writes the result to the destination register.

ADR produces position-independent code, because the address is PC-relative.

If you use ADR to generate a target address for a BX or BLX instruction, you must ensure that bit[0] of the address you generate is set to1 for correct execution.

Values of *label* must be within the range of –4095 to +4095 from the address in the PC.

You might have to use the .W suffix to get the maximum offset range or to generate addresses that are not word-aligned. See “Instruction width selection” on page 88.

12.11.1.3 Restrictions

Rd must not be SP and must not be PC.

12.11.1.4 Condition flags

This instruction does not change the flags.

12.11.1.5 Examples

```
ADR     R1, TextMessage   ; Write address value of a location labelled as
                          ; TextMessage to R1
```

12.11.2 LDR and STR, immediate offset

Load and Store with immediate offset, pre-indexed immediate offset, or post-indexed immediate offset.

12.11.2.1 Syntax

```
op{type}{cond} Rt, [Rn {, #offset}]        ; immediate offset
op{type}{cond} Rt, [Rn, #offset]!          ; pre-indexed
op{type}{cond} Rt, [Rn], #offset           ; post-indexed
opD{cond} Rt, Rt2, [Rn {, #offset}]        ; immediate offset, two words
opD{cond} Rt, Rt2, [Rn, #offset]!          ; pre-indexed, two words
opD{cond} Rt, Rt2, [Rn], #offset           ; post-indexed, two words
```

where:

op is one of:

- LDR Load Register.
- STR Store Register.

type is one of:

- B unsigned byte, zero extend to 32 bits on loads.
- SB signed byte, sign extend to 32 bits (LDR only).
- H unsigned halfword, zero extend to 32 bits on loads.
- SH signed halfword, sign extend to 32 bits (LDR only).
- - omit, for word.

cond is an optional condition code, see “Conditional execution” on page 87.

Rt is the register to load or store.

Rn is the register on which the memory address is based.

offset is an offset from *Rn*. If *offset* is omitted, the address is the contents of *Rn*.

Rt2 is the additional register to load or store for two-word operations.

12.11.2.2 Operation

LDR instructions load one or two registers with a value from memory.

STR instructions store one or two register values to memory.

Load and store instructions with immediate offset can use the following addressing modes:

12.11.2.3 Offset addressing

The offset value is added to or subtracted from the address obtained from the register *Rn*. The result is used as the address for the memory access. The register *Rn* is unaltered. The assembly language syntax for this mode is:

```
[Rn, #offset]
```

12.11.2.4 Pre-indexed addressing

The offset value is added to or subtracted from the address obtained from the register *Rn*. The result is used as the address for the memory access and written back into the register *Rn*. The assembly language syntax for this mode is:

```
[Rn, #offset]!
```

12.11.2.5 Post-indexed addressing

The address obtained from the register *Rn* is used as the address for the memory access. The offset value is added to or subtracted from the address, and written back into the register *Rn*. The assembly language syntax for this mode is:

```
[Rn], #offset
```

The value to load or store can be a byte, halfword, word, or two words. Bytes and halfwords can either be signed or unsigned. See “Address alignment” on page 86.

Table 12-18 shows the ranges of offset for immediate, pre-indexed and post-indexed forms.

Table 12-18. Offset ranges

Instruction type	Immediate offset	Pre-indexed	Post-indexed
Word, halfword, signed halfword, byte, or signed byte	–255 to 4095	–255 to 255	–255 to 255
Two words	multiple of 4 in the range –1020 to 1020	multiple of 4 in the range –1020 to 1020	multiple of 4 in the range –1020 to 1020

12.11.2.6 Restrictions

For load instructions:

- *Rt* can be SP or PC for word loads only
- *Rt* must be different from *Rt2* for two-word loads
- *Rn* must be different from *Rt* and *Rt2* in the pre-indexed or post-indexed forms.

When *Rt* is PC in a word load instruction:

- bit[0] of the loaded value must be 1 for correct execution
- a branch occurs to the address created by changing bit[0] of the loaded value to 0
- if the instruction is conditional, it must be the last instruction in the IT block.

For store instructions:

- *Rt* can be SP for word stores only
- *Rt* must not be PC
- *Rn* must not be PC
- *Rn* must be different from *Rt* and *Rt2* in the pre-indexed or post-indexed forms.

12.11.2.7 Condition flags

These instructions do not change the flags.

12.11.2.8 Examples

```
LDR     R8, [R10]              ; Loads R8 from the address in R10.
LDRNE   R2, [R5, #960]!        ; Loads (conditionally) R2 from a word
                               ; 960 bytes above the address in R5, and
                               ; increments R5 by 960.
STR     R2, [R9,#const-struc]  ; const-struc is an expression evaluating
                               ; to a constant in the range 0-4095.
STRH    R3, [R4], #4           ; Store R3 as halfword data into address in
                               ; R4, then increment R4 by 4
LDRD    R8, R9, [R3, #0x20]    ; Load R8 from a word 32 bytes above the
                               ; address in R3, and load R9 from a word 36
                               ; bytes above the address in R3
STRD    R0, R1, [R8], #-16     ; Store R0 to address in R8, and store R1 to
                               ; a word 4 bytes above the address in R8,
                               ; and then decrement R8 by 16.
```

12.11.3 LDR and STR, register offset

Load and Store with register offset.

12.11.3.1 Syntax

```
op{type}{cond} Rt, [Rn, Rm {, LSL #n}]
```

where:

op — is one of:

- LDR — Load Register.
- STR — Store Register.

type — is one of:

- B — unsigned byte, zero extend to 32 bits on loads.
- SB — signed byte, sign extend to 32 bits (LDR only).
- H — unsigned halfword, zero extend to 32 bits on loads.
- SH — signed halfword, sign extend to 32 bits (LDR only).
- - — omit, for word.

cond — is an optional condition code, see “Conditional execution” on page 87.

Rt — is the register to load or store.

Rn — is the register on which the memory address is based.

Rm — is a register containing a value to be used as the offset.

LSL *#n* — is an optional shift, with *n* in the range 0 to 3.

12.11.3.2 Operation

LDR instructions load a register with a value from memory.

STR instructions store a register value into memory.

The memory address to load from or store to is at an offset from the register *Rn*. The offset is specified by the register *Rm* and can be shifted left by up to 3 bits using LSL.

The value to load or store can be a byte, halfword, or word. For load instructions, bytes and halfwords can either be signed or unsigned. See “Address alignment” on page 86.

12.11.3.3 Restrictions

In these instructions:

- *Rn* must not be PC
- *Rm* must not be SP and must not be PC
- *Rt* can be SP only for word loads and word stores
- *Rt* can be PC only for word loads.

When *Rt* is PC in a word load instruction:

- bit[0] of the loaded value must be 1 for correct execution, and a branch occurs to this halfword-aligned address
- if the instruction is conditional, it must be the last instruction in the IT block.

12.11.3.4 Condition flags

These instructions do not change the flags.

12.11.3.5 Examples

```
STR    R0, [R5, R1]         ; Store value of R0 into an address equal to
                            ; sum of R5 and R1
LDRSB  R0, [R5, R1, LSL #1] ; Read byte value from an address equal to
                            ; sum of R5 and two times R1, sign extended it
                            ; to a word value and put it in R0
STR    R0, [R1, R2, LSL #2] ; Stores R0 to an address equal to sum of R1
                            ; and four times R2
```

12.11.4 LDR and STR, unprivileged

Load and Store with unprivileged access.

12.11.4.1 Syntax

```
op{type}T{cond} Rt, [Rn {, #offset}]      ; immediate offset
```

where:

op is one of:

- LDR Load Register.
- STR Store Register.

type is one of:

- B unsigned byte, zero extend to 32 bits on loads.
- SB signed byte, sign extend to 32 bits (LDR only).
- H unsigned halfword, zero extend to 32 bits on loads.
- SH signed halfword, sign extend to 32 bits (LDR only).
- - omit, for word.

cond is an optional condition code, see “Conditional execution” on page 87.

Rt is the register to load or store.

Rn is the register on which the memory address is based.

offset is an offset from *Rn* and can be 0 to 255.

If *offset* is omitted, the address is the value in *Rn*.

12.11.4.2 Operation

These load and store instructions perform the same function as the memory access instructions with immediate offset, see “LDR and STR, immediate offset” on page 92. The difference is that these instructions have only unprivileged access even when used in privileged software.

When used in unprivileged software, these instructions behave in exactly the same way as normal memory access instructions with immediate offset.

12.11.4.3 Restrictions

In these instructions:

- *Rn* must not be PC
- *Rt* must not be SP and must not be PC.

12.11.4.4 Condition flags

These instructions do not change the flags.

12.11.4.5 Examples

```
STRBTEQ  R4, [R7]       ; Conditionally store least significant byte in
                        ; R4 to an address in R7, with unprivileged access
LDRHT    R2, [R2, #8]   ; Load halfword value from an address equal to
                        ; sum of R2 and 8 into R2, with unprivileged access
```

12.11.5 LDR, PC-relative

Load register from memory.

12.11.5.1 Syntax

```
LDR{type}{cond} Rt, label
LDRD{cond} Rt, Rt2, label          ; Load two words
```

where:

type is one of:

- B unsigned byte, zero extend to 32 bits.
- SB signed byte, sign extend to 32 bits.
- H unsigned halfword, zero extend to 32 bits.
- SH signed halfword, sign extend to 32 bits.
- - omit, for word.

cond is an optional condition code, see “Conditional execution” on page 87.

Rt is the register to load or store.

Rt2 is the second register to load or store.

label is a PC-relative expression. See “PC-relative expressions” on page 86.

12.11.5.2 Operation

LDR loads a register with a value from a PC-relative memory address. The memory address is specified by a label or by an offset from the PC.

The value to load or store can be a byte, halfword, or word. For load instructions, bytes and halfwords can either be signed or unsigned. See “Address alignment” on page 86.

label must be within a limited range of the current instruction. Table 12-19 shows the possible offsets between *label* and the PC.

Table 12-19. Offset ranges

Instruction type	Offset range
Word, halfword, signed halfword, byte, signed byte	–4095 to 4095
Two words	–1020 to 1020

You might have to use the .W suffix to get the maximum offset range. See “Instruction width selection” on page 88.

12.11.5.3 Restrictions

In these instructions:

- *Rt* can be SP or PC only for word loads
- *Rt2* must not be SP and must not be PC
- *Rt* must be different from *Rt2.*

When *Rt* is PC in a word load instruction:

- bit[0] of the loaded value must be 1 for correct execution, and a branch occurs to this halfword-aligned address
- if the instruction is conditional, it must be the last instruction in the IT block.

12.11.5.4 Condition flags

These instructions do not change the flags.

12.11.5.5 Examples

```
LDR     R0, LookUpTable   ; Load R0 with a word of data from an address
                          ; labelled as LookUpTable
LDRSB   R7, localdata     ; Load a byte value from an address labelled
                          ; as localdata, sign extend it to a word
                          ; value, and put it in R7
```

12.11.6 LDM and STM

Load and Store Multiple registers.

12.11.6.1 Syntax

```
op{addr_mode}{cond} Rn{!}, reglist
```

where:

op is one of:

- LDM Load Multiple registers.
- STM Store Multiple registers.

addr_mode is any one of the following:

- IA Increment address After each access. This is the default.
- DB Decrement address Before each access.

cond is an optional condition code, see “Conditional execution” on page 87.

Rn is the register on which the memory addresses are based.

! is an optional writeback suffix.

If ! is present the final address, that is loaded from or stored to, is written back into *Rn*.

reglist is a list of one or more registers to be loaded or stored, enclosed in braces. It can contain register ranges. It must be comma separated if it contains more than one register or register range, see “Examples” on page 100.

LDM and LDMFD are synonyms for LDMIA. LDMFD refers to its use for popping data from Full Descending stacks.

LDMEA is a synonym for LDMDB, and refers to its use for popping data from Empty Ascending stacks.

STM and STMEA are synonyms for STMIA. STMEA refers to its use for pushing data onto Empty Ascending stacks.

STMFD is s synonym for STMDB, and refers to its use for pushing data onto Full Descending stacks

12.11.6.2 Operation

LDM instructions load the registers in *reglist* with word values from memory addresses based on *Rn*.

STM instructions store the word values in the registers in *reglist* to memory addresses based on *Rn*.

For LDM, LDMIA, LDMFD, STM, STMIA, and STMEA the memory addresses used for the accesses are at 4-byte intervals ranging from *Rn* to *Rn* + 4 * (*n*-1), where *n* is the number of registers in *reglist*. The accesses happens in order of increasing register numbers, with the lowest numbered register using the lowest memory address and the highest number register using the highest memory address. If the writeback suffix is specified, the value of *Rn* + 4 * (*n*-1) is written back to *Rn*.

For LDMDB, LDMEA, STMDB, and STMFD the memory addresses used for the accesses are at 4-byte intervals ranging from *Rn* to *Rn* - 4 * (*n*-1), where *n* is the number of registers in *reglist*. The accesses happen in order of decreasing register numbers, with the highest numbered register using the highest memory address and the lowest number register using the lowest memory address. If the writeback suffix is specified, the value of *Rn* - 4 * (*n*-1) is written back to *Rn*.

The PUSH and POP instructions can be expressed in this form. See “PUSH and POP” on page 101 for details.

12.11.6.3 Restrictions

In these instructions:

- *Rn* must not be PC
- *reglist* must not contain SP
- in any STM instruction, *reglist* must not contain PC
- in any LDM instruction, *reglist* must not contain PC if it contains LR
- *reglist* must not contain *Rn* if you specify the writeback suffix.

When PC is in *reglist* in an LDM instruction:

- bit[0] of the value loaded to the PC must be 1 for correct execution, and a branch occurs to this halfword-aligned address
- if the instruction is conditional, it must be the last instruction in the IT block.

12.11.6.4 Condition flags

These instructions do not change the flags.

12.11.6.5 Examples

```
LDM     R8,{R0,R2,R9}      ; LDMIA is a synonym for LDM
STMDB   R1!,{R3-R6,R11,R12}
```

12.11.6.6 Incorrect examples

```
STM     R5!,{R5,R4,R9} ; Value stored for R5 is unpredictable
LDM     R2, {}         ; There must be at least one register in the list
```

12.11.7 PUSH and POP

Push registers onto, and pop registers off a full-descending stack.

12.11.7.1 Syntax

```
PUSH{cond} reglist
POP{cond} reglist
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

reglist is a non-empty list of registers, enclosed in braces. It can contain register ranges. It must be comma separated if it contains more than one register or register range.

PUSH and POP are synonyms for STMDB and LDM (or LDMIA) with the memory addresses for the access based on SP, and with the final address for the access written back to the SP. PUSH and POP are the preferred mnemonics in these cases.

12.11.7.2 Operation

PUSH stores registers on the stack in order of decreasing the register numbers, with the highest numbered register using the highest memory address and the lowest numbered register using the lowest memory address.

POP loads registers from the stack in order of increasing register numbers, with the lowest numbered register using the lowest memory address and the highest numbered register using the highest memory address.

See “LDM and STM” on page 99 for more information.

12.11.7.3 Restrictions

In these instructions:

- *reglist* must not contain SP
- for the PUSH instruction, *reglist* must not contain PC
- for the POP instruction, *reglist* must not contain PC if it contains LR.

When PC is in *reglist* in a POP instruction:

- bit[0] of the value loaded to the PC must be 1 for correct execution, and a branch occurs to this halfword-aligned address
- if the instruction is conditional, it must be the last instruction in the IT block.

12.11.7.4 Condition flags

These instructions do not change the flags.

12.11.7.5 Examples

```
PUSH    {R0,R4-R7}
PUSH    {R2,LR}
POP     {R0,R10,PC}
```

12.11.8 LDREX and STREX

Load and Store Register Exclusive.

12.11.8.1 Syntax

```
LDREX{cond} Rt, [Rn {, #offset}]
STREX{cond} Rd, Rt, [Rn {, #offset}]
LDREXB{cond} Rt, [Rn]
STREXB{cond} Rd, Rt, [Rn]
LDREXH{cond} Rt, [Rn]
STREXH{cond} Rd, Rt, [Rn]
```

where:

cond — is an optional condition code, see “Conditional execution” on page 87.

Rd — is the destination register for the returned status.

Rt — is the register to load or store.

Rn — is the register on which the memory address is based.

offset — is an optional offset applied to the value in *Rn*.

If *offset* is omitted, the address is the value in *Rn*.

12.11.8.2 Operation

LDREX, LDREXB, and LDREXH load a word, byte, and halfword respectively from a memory address.

STREX, STREXB, and STREXH attempt to store a word, byte, and halfword respectively to a memory address. The address used in any Store-Exclusive instruction must be the same as the address in the most recently executed Load-exclusive instruction. The value stored by the Store-Exclusive instruction must also have the same data size as the value loaded by the preceding Load-exclusive instruction. This means software must always use a Load-exclusive instruction and a matching Store-Exclusive instruction to perform a synchronization operation, see “Synchronization primitives” on page 65

If an Store-Exclusive instruction performs the store, it writes 0 to its destination register. If it does not perform the store, it writes 1 to its destination register. If the Store-Exclusive instruction writes 0 to the destination register, it is guaranteed that no other process in the system has accessed the memory location between the Load-exclusive and Store-Exclusive instructions.

For reasons of performance, keep the number of instructions between corresponding Load-Exclusive and Store-Exclusive instruction to a minimum.

The result of executing a Store-Exclusive instruction to an address that is different from that used in the preceding Load-Exclusive instruction is unpredictable.

12.11.8.3 Restrictions

In these instructions:

- do not use PC
- do not use SP for *Rd* and *Rt*
- for STREX, *Rd* must be different from both *Rt* and *Rn*
- the value of *offset* must be a multiple of four in the range 0-1020.

12.11.8.4 Condition flags

These instructions do not change the flags.

12.11.8.5 Examples

```
        MOV     R1, #0x1            ; Initialize the ‘lock taken’ value
    try
        LDREX   R0, [LockAddr]      ; Load the lock value
        CMP     R0, #0              ; Is the lock free?
        ITT     EQ                  ; IT instruction for STREXEQ and CMPEQ
        STREXEQ R0, R1, [LockAddr]  ; Try and claim the lock
        CMPEQ   R0, #0              ; Did this succeed?
        BNE     try                 ; No – try again
        ....                        ; Yes – we have the lock
```

12.11.9 CLREX

Clear Exclusive.

12.11.9.1 Syntax

```
CLREX{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.11.9.2 Operation

Use CLREX to make the next STREX, STREXB, or STREXH instruction write 1 to its destination register and fail to perform the store. It is useful in exception handler code to force the failure of the store exclusive if the exception occurs between a load exclusive instruction and the matching store exclusive instruction in a synchronization operation.

See “Synchronization primitives” on page 65 for more information.

12.11.9.3 Condition flags

These instructions do not change the flags.

12.11.9.4 Examples

```
CLREX
```

12.12 General data processing instructions

Table 12-20 shows the data processing instructions:

Table 12-20. Data processing instructions

Mnemonic	Brief description	See
ADC	Add with Carry	“ADD, ADC, SUB, SBC, and RSB” on page 106
ADD	Add	“ADD, ADC, SUB, SBC, and RSB” on page 106
ADDW	Add	“ADD, ADC, SUB, SBC, and RSB” on page 106
AND	Logical AND	“AND, ORR, EOR, BIC, and ORN” on page 108
ASR	Arithmetic Shift Right	“ASR, LSL, LSR, ROR, and RRX” on page 109
BIC	Bit Clear	“AND, ORR, EOR, BIC, and ORN” on page 108
CLZ	Count leading zeros	“CLZ” on page 111
CMN	Compare Negative	“CMP and CMN” on page 112
CMP	Compare	“CMP and CMN” on page 112
EOR	Exclusive OR	“AND, ORR, EOR, BIC, and ORN” on page 108
LSL	Logical Shift Left	“ASR, LSL, LSR, ROR, and RRX” on page 109
LSR	Logical Shift Right	“ASR, LSL, LSR, ROR, and RRX” on page 109
MOV	Move	“MOV and MVN” on page 113
MOVT	Move Top	“MOVT” on page 115
MOVW	Move 16-bit constant	“MOV and MVN” on page 113
MVN	Move NOT	“MOV and MVN” on page 113
ORN	Logical OR NOT	“AND, ORR, EOR, BIC, and ORN” on page 108
ORR	Logical OR	“AND, ORR, EOR, BIC, and ORN” on page 108
RBIT	Reverse Bits	“REV, REV16, REVSH, and RBIT” on page 116
REV	Reverse byte order in a word	“REV, REV16, REVSH, and RBIT” on page 116
REV16	Reverse byte order in each halfword	“REV, REV16, REVSH, and RBIT” on page 116
REVSH	Reverse byte order in bottom halfword and sign extend	“REV, REV16, REVSH, and RBIT” on page 116
ROR	Rotate Right	“ASR, LSL, LSR, ROR, and RRX” on page 109
RRX	Rotate Right with Extend	“ASR, LSL, LSR, ROR, and RRX” on page 109
RSB	Reverse Subtract	“ADD, ADC, SUB, SBC, and RSB” on page 106
SBC	Subtract with Carry	“ADD, ADC, SUB, SBC, and RSB” on page 106
SUB	Subtract	“ADD, ADC, SUB, SBC, and RSB” on page 106
SUBW	Subtract	“ADD, ADC, SUB, SBC, and RSB” on page 106
TEQ	Test Equivalence	“TST and TEQ” on page 117
TST	Test	“TST and TEQ” on page 117

12.12.1 ADD, ADC, SUB, SBC, and RSB

Add, Add with carry, Subtract, Subtract with carry, and Reverse Subtract.

12.12.1.1 Syntax

```
op{S}{cond} {Rd,} Rn, Operand2
op{cond} {Rd,} Rn, #imm12                ; ADD and SUB only
```

where:

op is one of:

- ADD Add.
- ADC Add with Carry.
- SUB Subtract.
- SBC Subtract with Carry.
- RSB Reverse Subtract.

S is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see “Conditional execution” on page 87.

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register. If *Rd* is omitted, the destination register is *Rn*.

Rn is the register holding the first operand.

Operand2 is a flexible second operand.

See “Flexible second operand” on page 82 for details of the options.

imm12 is any value in the range 0-4095.

12.12.1.2 Operation

The ADD instruction adds the value of *Operand2* or *imm12* to the value in *Rn*.

The ADC instruction adds the values in *Rn* and *Operand2*, together with the carry flag.

The SUB instruction subtracts the value of *Operand2* or *imm12* from the value in *Rn*.

The SBC instruction subtracts the value of *Operand2* from the value in *Rn*. If the carry flag is clear, the result is reduced by one.

The RSB instruction subtracts the value in *Rn* from the value of *Operand2*. This is useful because of the wide range of options for *Operand2*.

Use ADC and SBC to synthesize multiword arithmetic, see “Multiword arithmetic examples” on page 107.

See also “ADR” on page 91.

ADDW is equivalent to the ADD syntax that uses the *imm12* operand. SUBW is equivalent to the SUB syntax that uses the *imm12* operand.

12.12.1.3 Restrictions

In these instructions:

- *Operand2* must not be SP and must not be PC
- *Rd* can be SP only in ADD and SUB, and only with the additional restrictions:
  - *Rn* must also be SP
  - any shift in *Operand2* must be limited to a maximum of 3 bits using LSL
- *Rn* can be SP only in ADD and SUB
- *Rd* can be PC only in the ADD{*cond*} PC, PC, Rm instruction where:
  - you must not specify the S suffix

- *Rm* must not be PC and must not be SP
- if the instruction is conditional, it must be the last instruction in the IT block

- with the exception of the ADD{*cond*} PC, PC, Rm instruction, *Rn* can be PC only in ADD and SUB, and only with the additional restrictions:
  - you must not specify the S suffix
  - the second operand must be a constant in the range 0 to 4095.
  -
  - When using the PC for an addition or a subtraction, bits[1:0] of the PC are rounded to b00 before performing the calculation, making the base address for the calculation word-aligned.
  - If you want to generate the address of an instruction, you have to adjust the constant based on the value of the PC. ARM recommends that you use the ADR instruction instead of ADD or SUB with *Rn* equal to the PC, because your assembler automatically calculates the correct constant for the ADR instruction.

When *Rd* is PC in the ADD{*cond*} PC, PC, Rm instruction:

- bit[0] of the value written to the PC is ignored
- a branch occurs to the address created by forcing bit[0] of that value to 0.

12.12.1.4 Condition flags

If S is specified, these instructions update the N, Z, C and V flags according to the result.

12.12.1.5 Examples

```
ADD     R2, R1, R3
SUBS    R8, R6, #240        ; Sets the flags on the result
RSB     R4, R4, #1280       ; Subtracts contents of R4 from 1280
ADCHI   R11, R0, R3         ; Only executed if C flag set and Z
                            ; flag clear
```

12.12.1.6 Multiword arithmetic examples

12.12.1.7 64-bit addition

The example below shows two instructions that add a 64-bit integer contained in R2 and R3 to another 64-bit integer contained in R0 and R1, and place the result in R4 and R5.

```
ADDS    R4, R0, R2    ; add the least significant words
ADC     R5, R1, R3    ; add the most significant words with carry
```

12.12.1.8 96-bit subtraction

Multiword values do not have to use consecutive registers. The example below shows instructions that subtract a 96-bit integer contained in R9, R1, and R11 from another contained in R6, R2, and R8. The example stores the result in R6, R9, and R2.

```
SUBS    R6, R6, R9     ; subtract the least significant words
SBCS    R9, R2, R1     ; subtract the middle words with carry
SBC     R2, R8, R11    ; subtract the most significant words with carry
```

12.12.2 AND, ORR, EOR, BIC, and ORN

Logical AND, OR, Exclusive OR, Bit Clear, and OR NOT.

12.12.2.1 Syntax

```
op{S}{cond} {Rd,} Rn, Operand2
```

where:

op is one of:

- AND logical AND.
- ORR logical OR, or bit set.
- EOR logical Exclusive OR.
- BIC logical AND NOT, or bit clear.
- ORN logical OR NOT.

S is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see “Conditional execution” on page 87.

cond is an optional condition code, see See “Conditional execution” on page 87..

Rd is the destination register.

Rn is the register holding the first operand.

Operand2 is a flexible second operand. See “Flexible second operand” on page 82 for details of the options.

12.12.2.2 Operation

The AND, EOR, and ORR instructions perform bitwise AND, Exclusive OR, and OR operations on the values in *Rn* and *Operand2*.

The BIC instruction performs an AND operation on the bits in *Rn* with the complements of the corresponding bits in the value of *Operand2*.

The ORN instruction performs an OR operation on the bits in *Rn* with the complements of the corresponding bits in the value of *Operand2*.

12.12.2.3 Restrictions

Do not use SP and do not use PC.

12.12.2.4 Condition flags

If S is specified, these instructions:

- update the N and Z flags according to the result
- can update the C flag during the calculation of *Operand2*, see “Flexible second operand” on page 82
- do not affect the V flag.

12.12.2.5 Examples

```
AND     R9, R2, #0xFF00
ORREQ   R2, R0, R5
ANDS    R9, R8, #0x19
EORS    R7, R11, #0x18181818
BIC     R0, R1, #0xab
ORN     R7, R11, R14, ROR #4
ORNS    R7, R11, R14, ASR #32
```

12.12.3 ASR, LSL, LSR, ROR, and RRX

Arithmetic Shift Right, Logical Shift Left, Logical Shift Right, Rotate Right, and Rotate Right with Extend.

12.12.3.1 Syntax

```
op{S}{cond} Rd, Rm, Rs
op{S}{cond} Rd, Rm, #n
RRX{S}{cond} Rd, Rm
```

where:

op is one of:

- ASR Arithmetic Shift Right.
- LSL Logical Shift Left.
- LSR Logical Shift Right.
- ROR Rotate Right.

S is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see “Conditional execution” on page 87.

Rd is the destination register.

Rm is the register holding the value to be shifted.

Rs is the register holding the shift length to apply to the value in *Rm*. Only the least significant byte is used and can be in the range 0 to 255.

n is the shift length. The range of shift length depends on the instruction:

- ASR shift length from 1 to 32
- LSL shift length from 0 to 31
- LSR shift length from 1 to 32
- ROR shift length from 1 to 31.

MOV{S}{cond} Rd, Rm is the preferred syntax for LSL{S}{cond} Rd, Rm, #0.

12.12.3.2 Operation

ASR, LSL, LSR, and ROR move the bits in the register *Rm* to the left or right by the number of places specified by constant *n* or register *Rs*.

RRX moves the bits in register *Rm* to the right by 1.

In all these instructions, the result is written to *Rd*, but the value in register *Rm* remains unchanged. For details on what result is generated by the different instructions, see “Shift Operations” on page 83.

12.12.3.3 Restrictions

Do not use SP and do not use PC.

12.12.3.4 Condition flags

If S is specified:

- these instructions update the N and Z flags according to the result
- the C flag is updated to the last bit shifted out, except when the shift length is 0, see “Shift Operations” on page 83.

12.12.3.5 Examples

```
ASR    R7, R8, #9  ; Arithmetic shift right by 9 bits
LSLS   R1, R2, #3  ; Logical shift left by 3 bits with flag update
LSR    R4, R5, #6  ; Logical shift right by 6 bits
ROR    R4, R5, R6  ; Rotate right by the value in the bottom byte of R6
RRX    R4, R5      ; Rotate right with extend
```

12.12.4 CLZ

Count Leading Zeros.

12.12.4.1 Syntax

```
CLZ{cond} Rd, Rm
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

Rm is the operand register.

12.12.4.2 Operation

The CLZ instruction counts the number of leading zeros in the value in *Rm* and returns the result in *Rd*. The result value is 32 if no bits are set in the source register, and zero if bit[31] is set.

12.12.4.3 Restrictions

Do not use SP and do not use PC.

12.12.4.4 Condition flags

This instruction does not change the flags.

12.12.4.5 Examples

```
CLZ     R4,R9
CLZNE   R2,R3
```

12.12.5 CMP and CMN

Compare and Compare Negative.

12.12.5.1 Syntax

```
CMP{cond} Rn, Operand2
CMN{cond} Rn, Operand2
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rn is the register holding the first operand.

Operand2 is a flexible second operand. See “Flexible second operand” on page 82 for details of the options.

12.12.5.2 Operation

These instructions compare the value in a register with *Operand2*. They update the condition flags on the result, but do not write the result to a register.

The CMP instruction subtracts the value of *Operand2* from the value in *Rn*. This is the same as a SUBS instruction, except that the result is discarded.

The CMN instruction adds the value of *Operand2* to the value in *Rn*. This is the same as an ADDS instruction, except that the result is discarded.

12.12.5.3 Restrictions

In these instructions:

- do not use PC
- *Operand2* must not be SP.

12.12.5.4 Condition flags

These instructions update the N, Z, C and V flags according to the result.

12.12.5.5 Examples

```
CMP     R2, R9
CMN     R0, #6400
CMPGT   SP, R7, LSL #2
```

12.12.6 MOV and MVN

Move and Move NOT.

12.12.6.1 Syntax

```
MOV{S}{cond} Rd, Operand2
MOV{cond} Rd, #imm16
MVN{S}{cond} Rd, Operand2
```

where:

S is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see “Conditional execution” on page 87.

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

Operand2 is a flexible second operand. See “Flexible second operand” on page 82 for details of the options.

imm16 is any value in the range 0-65535.

12.12.6.2 Operation

The MOV instruction copies the value of *Operand2* into *Rd*.

When *Operand2* in a MOV instruction is a register with a shift other than LSL #0, the preferred syntax is the corresponding shift instruction:

- ASR{S}{cond} Rd, Rm, #n is the preferred syntax for MOV{S}{cond} Rd, Rm, ASR #n
- LSL{S}{cond} Rd, Rm, #n is the preferred syntax for MOV{S}{cond} Rd, Rm, LSL #n if *n* != 0
- LSR{S}{cond} Rd, Rm, #n is the preferred syntax for MOV{S}{cond} Rd, Rm, LSR #n
- ROR{S}{cond} Rd, Rm, #n is the preferred syntax for MOV{S}{cond} Rd, Rm, ROR #n
- RRX{S}{cond} Rd, Rm is the preferred syntax for MOV{S}{cond} Rd, Rm, RRX.

Also, the MOV instruction permits additional forms of *Operand2* as synonyms for shift instructions:

- MOV{S}{cond} Rd, Rm, ASR Rs is a synonym for ASR{S}{cond} Rd, Rm, Rs
- MOV{S}{cond} Rd, Rm, LSL Rs is a synonym for LSL{S}{cond} Rd, Rm, Rs
- MOV{S}{cond} Rd, Rm, LSR Rs is a synonym for LSR{S}{cond} Rd, Rm, Rs
- MOV{S}{cond} Rd, Rm, ROR Rs is a synonym for ROR{S}{cond} Rd, Rm, Rs

See “ASR, LSL, LSR, ROR, and RRX” on page 109.

The MVN instruction takes the value of *Operand2*, performs a bitwise logical NOT operation on the value, and places the result into *Rd*.

The MOVW instruction provides the same function as MOV, but is restricted to using the *imm16* operand.

12.12.6.3 Restrictions

You can use SP and PC only in the MOV instruction, with the following restrictions:

- the second operand must be a register without shift
- you must not specify the S suffix.

When *Rd* is PC in a MOV instruction:

- bit[0] of the value written to the PC is ignored
- a branch occurs to the address created by forcing bit[0] of that value to 0.

Though it is possible to use MOV as a branch instruction, ARM strongly recommends the use of a BX or BLX instruction to branch for software portability to the ARM instruction set.

12.12.6.4 Condition flags

If S is specified, these instructions:

- update the N and Z flags according to the result
- can update the C flag during the calculation of *Operand2*, see “Flexible second operand” on page 82
- do not affect the V flag.

12.12.6.5 Example

```
MOVS  R11, #0x000B    ; Write value of 0x000B to R11, flags get updated
MOV   R1, #0xFA05     ; Write value of 0xFA05 to R1, flags are not updated
MOVS  R10, R12        ; Write value in R12 to R10, flags get updated
MOV   R3, #23         ; Write value of 23 to R3
MOV   R8, SP          ; Write value of stack pointer to R8
MVNS  R2, #0xF        ; Write value of 0xFFFFFFF0 (bitwise inverse of 0xF)
                      ; to the R2 and update flags
```

12.12.7 MOVT

Move Top.

12.12.7.1 Syntax

```
MOVT{cond} Rd, #imm16
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

imm16 is a 16-bit immediate constant.

12.12.7.2 Operation

MOVT writes a 16-bit immediate value, *imm16*, to the top halfword, *Rd*[31:16], of its destination register. The write does not affect *Rd*[15:0].

The MOV, MOVT instruction pair enables you to generate any 32-bit constant.

12.12.7.3 Restrictions

Rd must not be SP and must not be PC.

12.12.7.4 Condition flags

This instruction does not change the flags.

12.12.7.5 Examples

```
MOVT   R3, #0xF123 ; Write 0xF123 to upper halfword of R3, lower halfword
                   ; and APSR are unchanged
```

12.12.8 REV, REV16, REVSH, and RBIT

Reverse bytes and Reverse bits.

12.12.8.1 Syntax

```
op{cond} Rd, Rn
```

where:

op is any of:

- REV Reverse byte order in a word.
- REV16 Reverse byte order in each halfword independently.
- REVSH Reverse byte order in the bottom halfword, and sign extend to 32 bits.
- RBIT Reverse the bit order in a 32-bit word.

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

Rn is the register holding the operand.

12.12.8.2 Operation

Use these instructions to change endianness of data:

REV converts 32-bit big-endian data into little-endian data or 32-bit little-endian data into big-endian data.

REV16 converts 16-bit big-endian data into little-endian data or 16-bit little-endian data into big-endian data.

REVSH converts either:

- 16-bit signed big-endian data into 32-bit signed little-endian data
- 16-bit signed little-endian data into 32-bit signed big-endian data.

12.12.8.3 Restrictions

Do not use SP and do not use PC.

12.12.8.4 Condition flags

These instructions do not change the flags.

12.12.8.5 Examples

```
REV    R3, R7  ; Reverse byte order of value in R7 and write it to R3
REV16  R0, R0  ; Reverse byte order of each 16-bit halfword in R0
REVSH  R0, R5  ; Reverse Signed Halfword
REVHS  R3, R7  ; Reverse with Higher or Same condition
RBIT   R7, R8  ; Reverse bit order of value in R8 and write the result to R7
```

12.12.9 TST and TEQ

Test bits and Test Equivalence.

12.12.9.1 Syntax

```
TST{cond} Rn, Operand2
TEQ{cond} Rn, Operand2
```

where:

cond — is an optional condition code, see “Conditional execution” on page 87.

Rn — is the register holding the first operand.

Operand2 — is a flexible second operand. See “Flexible second operand” on page 82 for details of the options.

12.12.9.2 Operation

These instructions test the value in a register against *Operand2*. They update the condition flags based on the result, but do not write the result to a register.

The TST instruction performs a bitwise AND operation on the value in *Rn* and the value of *Operand2*. This is the same as the ANDS instruction, except that it discards the result.

To test whether a bit of *Rn* is 0 or 1, use the TST instruction with an *Operand2* constant that has that bit set to 1 and all other bits cleared to 0.

The TEQ instruction performs a bitwise Exclusive OR operation on the value in *Rn* and the value of *Operand2*. This is the same as the EORS instruction, except that it discards the result.

Use the TEQ instruction to test if two values are equal without affecting the V or C flags.

TEQ is also useful for testing the sign of a value. After the comparison, the N flag is the logical Exclusive OR of the sign bits of the two operands.

12.12.9.3 Restrictions

Do not use SP and do not use PC.

12.12.9.4 Condition flags

These instructions:

- update the N and Z flags according to the result
- can update the C flag during the calculation of *Operand2*, see “Flexible second operand” on page 82
- do not affect the V flag.

12.12.9.5 Examples

```
TST     R0, #0x3F8  ; Perform bitwise AND of R0 value to 0x3F8,
                    ; APSR is updated but result is discarded
TEQEQ   R10, R9     ; Conditionally test if value in R10 is equal to
                    ; value in R9, APSR is updated but result is discarded
```

12.13 Multiply and divide instructions

Table 12-21 shows the multiply and divide instructions:

Table 12-21. Multiply and divide instructions

Mnemonic	Brief description	See
MLA	Multiply with Accumulate, 32-bit result	"MUL, MLA, and MLS" on page 119
MLS	Multiply and Subtract, 32-bit result	"MUL, MLA, and MLS" on page 119
MUL	Multiply, 32-bit result	"MUL, MLA, and MLS" on page 119
SDIV	Signed Divide	"SDIV and UDIV" on page 121
SMLAL	Signed Multiply with Accumulate (32x32+64), 64-bit result	"UMULL, UMLAL, SMULL, and SMLAL" on page 120
SMULL	Signed Multiply (32x32), 64-bit result	"UMULL, UMLAL, SMULL, and SMLAL" on page 120
UDIV	Unsigned Divide	"SDIV and UDIV" on page 121
UMLAL	Unsigned Multiply with Accumulate (32x32+64), 64-bit result	"UMULL, UMLAL, SMULL, and SMLAL" on page 120
UMULL	Unsigned Multiply (32x32), 64-bit result	"UMULL, UMLAL, SMULL, and SMLAL" on page 120

12.13.1 MUL, MLA, and MLS

Multiply, Multiply with Accumulate, and Multiply with Subtract, using 32-bit operands, and producing a 32-bit result.

12.13.1.1 Syntax

```
MUL{S}{cond} {Rd,} Rn, Rm ; Multiply
MLA{cond} Rd, Rn, Rm, Ra  ; Multiply with accumulate
MLS{cond} Rd, Rn, Rm, Ra  ; Multiply with subtract
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

S is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see “Conditional execution” on page 87.

Rd is the destination register. If *Rd* is omitted, the destination register is *Rn*.

Rn, Rm are registers holding the values to be multiplied.

Ra is a register holding the value to be added or subtracted from.

12.13.1.2 Operation

The MUL instruction multiplies the values from *Rn* and *Rm*, and places the least significant 32 bits of the result in *Rd*.

The MLA instruction multiplies the values from *Rn* and *Rm*, adds the value from *Ra*, and places the least significant 32 bits of the result in *Rd*.

The MLS instruction multiplies the values from *Rn* and *Rm*, subtracts the product from the value from *Ra*, and places the least significant 32 bits of the result in *Rd*.

The results of these instructions do not depend on whether the operands are signed or unsigned.

12.13.1.3 Restrictions

In these instructions, do not use SP and do not use PC.

If you use the S suffix with the MUL instruction:

- *Rd*, *Rn*, and *Rm* must all be in the range R0 to R7
- *Rd* must be the same as *Rm*
- you must not use the *cond* suffix.

12.13.1.4 Condition flags

If S is specified, the MUL instruction:

- updates the N and Z flags according to the result
- does not affect the C and V flags.

12.13.1.5 Examples

```
MUL     R10, R2, R5     ; Multiply, R10 = R2 x R5
MLA     R10, R2, R1, R5 ; Multiply with accumulate, R10 = (R2 x R1) + R5
MULS    R0, R2, R2      ; Multiply with flag update, R0 = R2 x R2
MULLT   R2, R3, R2      ; Conditionally multiply, R2 = R3 x R2
MLS     R4, R5, R6, R7  ; Multiply with subtract, R4 = R7 - (R5 x R6)
```

12.13.2 UMULL, UMLAL, SMULL, and SMLAL

Signed and Unsigned Long Multiply, with optional Accumulate, using 32-bit operands and producing a 64-bit result.

12.13.2.1 Syntax

```
op{cond} RdLo, RdHi, Rn, Rm
```

where:

op is one of:

- UMULL Unsigned Long Multiply.
- UMLAL Unsigned Long Multiply, with Accumulate.
- SMULL Signed Long Multiply.
- SMLAL Signed Long Multiply, with Accumulate.

cond is an optional condition code, see “Conditional execution” on page 87.

RdHi, *RdLo* are the destination registers.

For UMLAL and SMLAL they also hold the accumulating value.

Rn, Rm are registers holding the operands.

12.13.2.2 Operation

The UMULL instruction interprets the values from *Rn* and *Rm* as unsigned integers. It multiplies these integers and places the least significant 32 bits of the result in *RdLo*, and the most significant 32 bits of the result in *RdHi*.

The UMLAL instruction interprets the values from *Rn* and *Rm* as unsigned integers. It multiplies these integers, adds the 64-bit result to the 64-bit unsigned integer contained in *RdHi* and *RdLo*, and writes the result back to *RdHi* and *RdLo*.

The SMULL instruction interprets the values from *Rn* and *Rm* as two’s complement signed integers. It multiplies these integers and places the least significant 32 bits of the result in *RdLo*, and the most significant 32 bits of the result in *RdHi*.

The SMLAL instruction interprets the values from *Rn* and *Rm* as two’s complement signed integers. It multiplies these integers, adds the 64-bit result to the 64-bit signed integer contained in *RdHi* and *RdLo*, and writes the result back to *RdHi* and *RdLo*.

12.13.2.3 Restrictions

In these instructions:

- do not use SP and do not use PC
- *RdHi* and *RdLo* must be different registers.

12.13.2.4 Condition flags

These instructions do not affect the condition code flags.

12.13.2.5 Examples

```
UMULL       R0, R4, R5, R6   ; Unsigned (R4,R0) = R5 x R6
SMLAL       R4, R5, R3, R8   ; Signed (R5,R4) = (R5,R4) + R3 x R8
```

12.13.3 SDIV and UDIV

Signed Divide and Unsigned Divide.

12.13.3.1 Syntax

```
SDIV{cond} {Rd,} Rn, Rm
UDIV{cond} {Rd,} Rn, Rm
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register. If *Rd* is omitted, the destination register is *Rn*.

Rn is the register holding the value to be divided.

Rm is a register holding the divisor.

12.13.3.2 Operation

SDIV performs a signed integer division of the value in *Rn* by the value in *Rm*.

UDIV performs an unsigned integer division of the value in *Rn* by the value in *Rm*.

For both instructions, if the value in *Rn* is not divisible by the value in *Rm*, the result is rounded towards zero.

12.13.3.3 Restrictions

Do not use SP and do not use PC.

12.13.3.4 Condition flags

These instructions do not change the flags.

12.13.3.5 Examples

```
SDIV  R0, R2, R4  ; Signed divide, R0 = R2/R4
UDIV  R8, R8, R1  ; Unsigned divide, R8 = R8/R1
```

12.14 Saturating instructions

This section describes the saturating instructions, SSAT and USAT.

12.14.1 SSAT and USAT

Signed Saturate and Unsigned Saturate to any bit position, with optional shift before saturating.

12.14.1.1 Syntax

```
op{cond} Rd, #n, Rm {, shift #s}
```

where:

op is one of:

- SSAT Saturates a signed value to a signed range.
- USAT Saturates a signed value to an unsigned range.

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

n specifies the bit position to saturate to:

- *n* ranges from 1 to 32 for SSAT
- *n* ranges from 0 to 31 for USAT.

Rm is the register containing the value to saturate.

shift #s is an optional shift applied to *Rm* before saturating. It must be one of the following:

- ASR #*s* where *s* is in the range 1 to 31
- LSL #*s* where *s* is in the range 0 to 31.

12.14.1.2 Operation

These instructions saturate to a signed or unsigned *n*-bit value.

The SSAT instruction applies the specified shift, then saturates to the signed range $-2^{n-1} \le x \le 2^{n-1}-1$.

The USAT instruction applies the specified shift, then saturates to the unsigned range $0 \le x \le 2^{n}-1$.

For signed *n*-bit saturation using SSAT, this means that:

- if the value to be saturated is less than -2^{n-1}, the result returned is -2^{n-1}
- if the value to be saturated is greater than $2^{n-1}-1$, the result returned is $2^{n-1}-1$
- otherwise, the result returned is the same as the value to be saturated.

For unsigned *n*-bit saturation using USAT, this means that:

- if the value to be saturated is less than 0, the result returned is 0
- if the value to be saturated is greater than $2^{n}-1$, the result returned is $2^{n}-1$
- otherwise, the result returned is the same as the value to be saturated.

If the returned result is different from the value to be saturated, it is called *saturation*. If saturation occurs, the instruction sets the Q flag to 1 in the APSR. Otherwise, it leaves the Q flag unchanged. To clear the Q flag to 0, you must use the MSR instruction, see “MSR” on page 142.

To read the state of the Q flag, use the MRS instruction, see “MRS” on page 141.

12.14.1.3 Restrictions

Do not use SP and do not use PC.

12.14.1.4 Condition flags

These instructions do not affect the condition code flags.

If saturation occurs, these instructions set the Q flag to 1.

12.14.1.5 Examples

```
SSAT    R7, #16, R7, LSL #4  ; Logical shift left value in R7 by 4, then
                             ; saturate it as a signed 16-bit value and
                             ; write it back to R7
USATNE  R0, #7, R5           ; Conditionally saturate value in R5 as an
                             ; unsigned 7 bit value and write it to R0
```

12.15 Bitfield instructions

Table 12-22 shows the instructions that operate on adjacent sets of bits in registers or bitfields:

Table 12-22. Packing and unpacking instructions

Mnemonic	Brief description	See
BFC	Bit Field Clear	"BFC and BFI" on page 125
BFI	Bit Field Insert	"BFC and BFI" on page 125
SBFX	Signed Bit Field Extract	"SBFX and UBFX" on page 126
SXTB	Sign extend a byte	"SXT and UXT" on page 127
SXTH	Sign extend a halfword	"SXT and UXT" on page 127
UBFX	Unsigned Bit Field Extract	"SBFX and UBFX" on page 126
UXTB	Zero extend a byte	"SXT and UXT" on page 127
UXTH	Zero extend a halfword	"SXT and UXT" on page 127

12.15.1 BFC and BFI

Bit Field Clear and Bit Field Insert.

12.15.1.1 Syntax

```
BFC{cond} Rd, #lsb, #width
BFI{cond} Rd, Rn, #lsb, #width
```

where:

cond — is an optional condition code, see “Conditional execution” on page 87.

Rd — is the destination register.

Rn — is the source register.

lsb — is the position of the least significant bit of the bitfield.

lsb must be in the range 0 to 31.

width — is the width of the bitfield and must be in the range 1 to 32–*lsb*.

12.15.1.2 Operation

BFC clears a bitfield in a register. It clears *width* bits in *Rd*, starting at the low bit position *lsb*. Other bits in *Rd* are unchanged.

BFI copies a bitfield into one register from another register. It replaces *width* bits in *Rd* starting at the low bit position *lsb*, with *width* bits from *Rn* starting at bit[0]. Other bits in *Rd* are unchanged.

12.15.1.3 Restrictions

Do not use SP and do not use PC.

12.15.1.4 Condition flags

These instructions do not affect the flags.

12.15.1.5 Examples

```
BFC   R4, #8, #12       ; Clear bit 8 to bit 19 (12 bits) of R4 to 0
BFI   R9, R2, #8, #12   ; Replace bit 8 to bit 19 (12 bits) of R9 with
                        ; bit 0 to bit 11 from R2
```

12.15.2 SBFX and UBFX

Signed Bit Field Extract and Unsigned Bit Field Extract.

12.15.2.1 Syntax

```
SBFX{cond} Rd, Rn, #lsb, #width
UBFX{cond} Rd, Rn, #lsb, #width
```

where:

cond — is an optional condition code, see “Conditional execution” on page 87.

Rd — is the destination register.

Rn — is the source register.

lsb — is the position of the least significant bit of the bitfield.

lsb must be in the range 0 to 31.

width — is the width of the bitfield and must be in the range 1 to 32–*lsb*.

12.15.2.2 Operation

SBFX extracts a bitfield from one register, sign extends it to 32 bits, and writes the result to the destination register.

UBFX extracts a bitfield from one register, zero extends it to 32 bits, and writes the result to the destination register.

12.15.2.3 Restrictions

Do not use SP and do not use PC.

12.15.2.4 Condition flags

These instructions do not affect the flags.

12.15.2.5 Examples

```
SBFX  R0, R1, #20, #4  ; Extract bit 20 to bit 23 (4 bits) from R1 and sign
                       ; extend to 32 bits and then write the result to R0.
UBFX  R8, R11, #9, #10 ; Extract bit 9 to bit 18 (10 bits) from R11 and zero
                       ; extend to 32 bits and then write the result to R8
```

12.15.3 SXT and UXT

Sign extend and Zero extend.

12.15.3.1 Syntax

```
SXTextend{cond} {Rd,} Rm {, ROR #n}
UXTextend{cond} {Rd}, Rm {, ROR #n}
```

where:

extend — is one of:

- B — Extends an 8-bit value to a 32-bit value.
- H — Extends a 16-bit value to a 32-bit value.

cond — is an optional condition code, see “Conditional execution” on page 87.

Rd — is the destination register.

Rm — is the register holding the value to extend.

ROR #*n* — is one of:

ROR #8 Value from *Rm* is rotated right 8 bits.

ROR #16 Value from *Rm* is rotated right 16 bits.

ROR #24 Value from *Rm* is rotated right 24 bits.

If ROR #*n* is omitted, no rotation is performed.

12.15.3.2 Operation

These instructions do the following:

- Rotate the value from *Rm* right by 0, 8, 16 or 24 bits.
- Extract bits from the resulting value:

SXTB extracts bits[7:0] and sign extends to 32 bits.

UXTB extracts bits[7:0] and zero extends to 32 bits.

SXTH extracts bits[15:0] and sign extends to 32 bits.

UXTH extracts bits[15:0] and zero extends to 32 bits.

12.15.3.3 Restrictions

Do not use SP and do not use PC.

12.15.3.4 Condition flags

These instructions do not affect the flags.

12.15.3.5 Examples

```
SXTH  R4, R6, ROR #16  ; Rotate R6 right by 16 bits, then obtain the lower
                       ; halfword of the result and then sign extend to
                       ; 32 bits and write the result to R4.
UXTB  R3, R10          ; Extract lowest byte of the value in R10 and zero
                       ; extend it, and write the result to R3
```

12.16 Branch and control instructions

Table 12-23 shows the branch and control instructions:

Table 12-23. Branch and control instructions

Mnemonic	Brief description	See
B	Branch	"B, BL, BX, and BLX" on page 129
BL	Branch with Link	"B, BL, BX, and BLX" on page 129
BLX	Branch indirect with Link	"B, BL, BX, and BLX" on page 129
BX	Branch indirect	"B, BL, BX, and BLX" on page 129
CBNZ	Compare and Branch if Non Zero	"CBZ and CBNZ" on page 131
CBZ	Compare and Branch if Non Zero	"CBZ and CBNZ" on page 131
IT	If-Then	"IT" on page 132
TBB	Table Branch Byte	"TBB and TBH" on page 134
TBH	Table Branch Halfword	"TBB and TBH" on page 134

12.16.1 B, BL, BX, and BLX

Branch instructions.

12.16.1.1 Syntax

```
B{cond} label
BL{cond} label
BX{cond} Rm
BLX{cond} Rm
```

where:

B is branch (immediate).

BL is branch with link (immediate).

BX is branch indirect (register).

BLX is branch indirect with link (register).

cond is an optional condition code, see “Conditional execution” on page 87.

label is a PC-relative expression. See “PC-relative expressions” on page 86.

Rm is a register that indicates an address to branch to. Bit[0] of the value in *Rm* must be 1, but the address to branch to is created by changing bit[0] to 0.

12.16.1.2 Operation

All these instructions cause a branch to *label*, or to the address indicated in *Rm*. In addition:

- The BL and BLX instructions write the address of the next instruction to LR (the link register, R14).
- The BX and BLX instructions cause a UsageFault exception if bit[0] of *Rm* is 0.

B*cond* label is the only conditional instruction that can be either inside or outside an IT block. All other branch instructions must be conditional inside an IT block, and must be unconditional outside the IT block, see “IT” on page 132.

Table 12-24 shows the ranges for the various branch instructions.

Table 12-24. Branch ranges

Instruction	Branch range
B label	–16 MB to +16 MB
B*cond* label (outside IT block)	–1 MB to +1 MB
B*cond* label (inside IT block)	–16 MB to +16 MB
BL{*cond*} label	–16 MB to +16 MB
BX{*cond*} Rm	Any value in register
BLX{*cond*} Rm	Any value in register

You might have to use the .W suffix to get the maximum branch range. See “Instruction width selection” on page 88.

12.16.1.3 Restrictions

The restrictions are:

- do not use PC in the BLX instruction
- for BX and BLX, bit[0] of *Rm* must be 1 for correct execution but a branch occurs to the target address created by changing bit[0] to 0
- when any of these instructions is inside an IT block, it must be the last instruction of the IT block.

B*cond* is the only conditional instruction that is not required to be inside an IT block. However, it has a longer branch range when it is inside an IT block.

12.16.1.4 Condition flags

These instructions do not change the flags.

12.16.1.5 Examples

```
B       loopA  ; Branch to loopA
BLE     ng     ; Conditionally branch to label ng
B.W     target ; Branch to target within 16MB range
BEQ     target ; Conditionally branch to target
BEQ.W   target ; Conditionally branch to target within 1MB
BL      funC   ; Branch with link (Call) to function funC, return address
               ; stored in LR
BX      LR     ; Return from function call
BXNE    R0     ; Conditionally branch to address stored in R0
BLX     R0     ; Branch with link and exchange (Call) to a address stored
               ; in R0
```

12.16.2 CBZ and CBNZ

Compare and Branch on Zero, Compare and Branch on Non-Zero.

12.16.2.1 Syntax

```
CBZ Rn, label
CBNZ Rn, label
```

where:

Rn is the register holding the operand.

label is the branch destination.

12.16.2.2 Operation

Use the CBZ or CBNZ instructions to avoid changing the condition code flags and to reduce the number of instructions.

CBZ Rn, label does not change condition flags but is otherwise equivalent to:

```
CMP     Rn, #0
BEQ     label
```

CBNZ Rn, label does not change condition flags but is otherwise equivalent to:

```
CMP     Rn, #0
BNE     label
```

12.16.2.3 Restrictions

The restrictions are:

- *Rn* must be in the range of R0 to R7
- the branch destination must be within 4 to 130 bytes after the instruction
- these instructions must not be used inside an IT block.

12.16.2.4 Condition flags

These instructions do not change the flags.

12.16.2.5 Examples

```
CBZ    R5, target ; Forward branch if R5 is zero
CBNZ   R0, target ; Forward branch if R0 is not zero
```

12.16.3 IT

If-Then condition instruction.

12.16.3.1 Syntax

```
IT{x{y{z}}} cond
```

where:

x specifies the condition switch for the second instruction in the IT block.

y specifies the condition switch for the third instruction in the IT block.

z specifies the condition switch for the fourth instruction in the IT block.

cond specifies the condition for the first instruction in the IT block.

The condition switch for the second, third and fourth instruction in the IT block can be either:

T Then. Applies the condition *cond* to the instruction.

E Else. Applies the inverse condition of *cond* to the instruction.

It is possible to use AL (the *always* condition) for *cond* in an IT instruction. If this is done, all of the instructions in the IT block must be unconditional, and each of *x*, *y*, and *z* must be T or omitted but not E.

12.16.3.2 Operation

The IT instruction makes up to four following instructions conditional. The conditions can be all the same, or some of them can be the logical inverse of the others. The conditional instructions following the IT instruction form the *IT block*.

The instructions in the IT block, including any branches, must specify the condition in the {*cond*} part of their syntax.

Your assembler might be able to generate the required IT instructions for conditional instructions automatically, so that you do not need to write them yourself. See your assembler documentation for details.

A BKPT instruction in an IT block is always executed, even if its condition fails.

Exceptions can be taken between an IT instruction and the corresponding IT block, or within an IT block. Such an exception results in entry to the appropriate exception handler, with suitable return information in LR and stacked PSR.

Instructions designed for use for exception returns can be used as normal to return from the exception, and execution of the IT block resumes correctly. This is the only way that a PC-modifying instruction is permitted to branch to an instruction in an IT block.

12.16.3.3 Restrictions

The following instructions are not permitted in an IT block:

- IT
- CBZ and CBNZ
- CPSID and CPSIE.

Other restrictions when using an IT block are:

- a branch or any instruction that modifies the PC must either be outside an IT block or must be the last instruction inside the IT block. These are:
  - ADD PC, PC, Rm
  - MOV PC, Rm
  - B, BL, BX, BLX
  - any LDM, LDR, or POP instruction that writes to the PC
  - TBB and TBH

- do not branch to any instruction inside an IT block, except when returning from an exception handler
- all conditional instructions except B*cond* must be inside an IT block. B*cond* can be either outside or inside an IT block but has a larger branch range if it is inside one
- each instruction inside the IT block must specify a condition code suffix that is either the same or logical inverse as for the other instructions in the block.

Your assembler might place extra restrictions on the use of IT blocks, such as prohibiting the use of assembler directives within them.

12.16.3.4 Condition flags

This instruction does not change the flags.

12.16.3.5 Example

```
ITTE   NE           ; Next 3 instructions are conditional
ANDNE  R0, R0, R1   ; ANDNE does not update condition flags
ADDSNE R2, R2, #1   ; ADDSNE updates condition flags
MOVEQ  R2, R3       ; Conditional move


CMP    R0, #9       ; Convert R0 hex value (0 to 15) into ASCII
                    ; ('0'-'9', 'A'-'F')
ITE    GT           ; Next 2 instructions are conditional
ADDGT  R1, R0, #55  ; Convert 0xA -> 'A'
ADDLE  R1, R0, #48  ; Convert 0x0 -> '0'


IT     GT           ; IT block with only one conditional instruction
ADDGT  R1, R1, #1   ; Increment R1 conditionally


ITTEE  EQ           ; Next 4 instructions are conditional
MOVEQ  R0, R1       ; Conditional move
ADDEQ  R2, R2, #10  ; Conditional add
ANDNE  R3, R3, #1   ; Conditional AND
BNE.W  dloop        ; Branch instruction can only be used in the last
                    ; instruction of an IT block


IT     NE           ; Next instruction is conditional
ADD    R0, R0, R1   ; Syntax error: no condition code used in IT block
```

12.16.4 TBB and TBH

Table Branch Byte and Table Branch Halfword.

12.16.4.1 Syntax

```
TBB [Rn, Rm]
TBH [Rn, Rm, LSL #1]
```

where:

Rn is the register containing the address of the table of branch lengths. If *Rn* is PC, then the address of the table is the address of the byte immediately following the TBB or TBH instruction.

Rm is the index register. This contains an index into the table. For halfword tables, LSL #1 doubles the value in *Rm* to form the right offset into the table.

12.16.4.2 Operation

These instructions cause a PC-relative forward branch using a table of single byte offsets for TBB, or halfword offsets for TBH. *Rn* provides a pointer to the table, and *Rm* supplies an index into the table. For TBB the branch offset is twice the unsigned value of the byte returned from the table. and for TBH the branch offset is twice the unsigned value of the halfword returned from the table. The branch occurs to the address at that offset from the address of the byte immediately after the TBB or TBH instruction.

12.16.4.3 Restrictions

The restrictions are:

- *Rn* must not be SP
- *Rm* must not be SP and must not be PC
- when any of these instructions is used inside an IT block, it must be the last instruction of the IT block.

12.16.4.4 Condition flags

These instructions do not change the flags.

12.16.4.5 Examples

```
    ADR.W  R0, BranchTable_Byte
    TBB   [R0, R1]          ; R1 is the index, R0 is the base address of the
                            ; branch table
Case1
; an instruction sequence follows
Case2
; an instruction sequence follows
Case3
; an instruction sequence follows
BranchTable_Byte
    DCB    0                    ; Case1 offset calculation
    DCB    ((Case2-Case1)/2)    ; Case2 offset calculation
    DCB    ((Case3-Case1)/2)    ; Case3 offset calculation
    TBH    [PC, R1, LSL #1]     ; R1 is the index, PC is used as base of the
                                ; branch table
BranchTable_H
    DCI    ((CaseA - BranchTable_H)/2)  ; CaseA offset calculation
    DCI    ((CaseB - BranchTable_H)/2)  ; CaseB offset calculation
    DCI    ((CaseC - BranchTable_H)/2)  ; CaseC offset calculation

CaseA
; an instruction sequence follows
CaseB
; an instruction sequence follows
CaseC
; an instruction sequence follows
```

12.17 Miscellaneous instructions

Table 12-25 shows the remaining Cortex-M3 instructions:

Table 12-25. Miscellaneous instructions

Mnemonic	Brief description	See
BKPT	Breakpoint	"BKPT" on page 136
CPSID	Change Processor State, Disable Interrupts	"CPS" on page 137
CPSIE	Change Processor State, Enable Interrupts	"CPS" on page 137
DMB	Data Memory Barrier	"DMB" on page 138
DSB	Data Synchronization Barrier	"DSB" on page 139
ISB	Instruction Synchronization Barrier	"ISB" on page 140
MRS	Move from special register to register	"MRS" on page 141
MSR	Move from register to special register	"MSR" on page 142
NOP	No Operation	"NOP" on page 143
SEV	Send Event	"SEV" on page 144
SVC	Supervisor Call	"SVC" on page 145
WFE	Wait For Event	"WFE" on page 146
WFI	Wait For Interrupt	"WFI" on page 147

12.17.1 BKPT

Breakpoint.

12.17.1.1 Syntax

```
BKPT #imm
```

where:

imm is an expression evaluating to an integer in the range 0-255 (8-bit value).

12.17.1.2 Operation

The BKPT instruction causes the processor to enter Debug state. Debug tools can use this to investigate system state when the instruction at a particular address is reached.

imm is ignored by the processor. If required, a debugger can use it to store additional information about the breakpoint.

The BKPT instruction can be placed inside an IT block, but it executes unconditionally, unaffected by the condition specified by the IT instruction.

12.17.1.3 Condition flags

This instruction does not change the flags.

12.17.1.4 Examples

```
BKPT 0xAB   ; Breakpoint with immediate value set to 0xAB (debugger can
            ; extract the immediate value by locating it using the PC)
```

12.17.2 CPS

Change Processor State.

12.17.2.1 Syntax

```
CPSeffect iflags
```

where:

effect is one of:

- IE Clears the special purpose register.
- ID Sets the special purpose register.

iflags is a sequence of one or more flags:

- i Set or clear PRIMASK.
- f Set or clear FAULTMASK.

12.17.2.2 Operation

CPS changes the PRIMASK and FAULTMASK special register values. See “Exception mask registers” on page 52 for more information about these registers.

12.17.2.3 Restrictions

The restrictions are:

- use CPS only from privileged software, it has no effect if used in unprivileged software
- CPS cannot be conditional and so must not be used inside an IT block.

12.17.2.4 Condition flags

This instruction does not change the condition flags.

12.17.2.5 Examples

```
CPSID i  ; Disable interrupts and configurable fault handlers (set PRIMASK)
CPSID f  ; Disable interrupts and all fault handlers (set FAULTMASK)
CPSIE i  ; Enable interrupts and configurable fault handlers (clear PRIMASK)
CPSIE f  ; Enable interrupts and fault handlers (clear FAULTMASK)
```

12.17.3 DMB

Data Memory Barrier.

12.17.3.1 Syntax

```
DMB{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.3.2 Operation

DMB acts as a data memory barrier. It ensures that all explicit memory accesses that appear, in program order, before the DMB instruction are completed before any explicit memory accesses that appear, in program order, after the DMB instruction. DMB does not affect the ordering or execution of instructions that do not access memory.

12.17.3.3 Condition flags

This instruction does not change the flags.

12.17.3.4 Examples

```
DMB  ; Data Memory Barrier
```

12.17.4 DSB

Data Synchronization Barrier.

12.17.4.1 Syntax

```
DSB{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.4.2 Operation

DSB acts as a special data synchronization memory barrier. Instructions that come after the DSB, in program order, do not execute until the DSB instruction completes. The DSB instruction completes when all explicit memory accesses before it complete.

12.17.4.3 Condition flags

This instruction does not change the flags.

12.17.4.4 Examples

```
DSB ; Data Synchronisation Barrier
```

12.17.5 ISB

Instruction Synchronization Barrier.

12.17.5.1 Syntax

```
ISB{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.5.2 Operation

ISB acts as an instruction synchronization barrier. It flushes the pipeline of the processor, so that all instructions following the ISB are fetched from memory again, after the ISB instruction has been completed.

12.17.5.3 Condition flags

This instruction does not change the flags.

12.17.5.4 Examples

```
ISB  ; Instruction Synchronisation Barrier
```

12.17.6 MRS

Move the contents of a special register to a general-purpose register.

12.17.6.1 Syntax

```
MRS{cond} Rd, spec_reg
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rd is the destination register.

spec_reg can be any of: APSR, IPSR, EPSR, IEPSR, IAPSR, EAPSR, PSR, MSP, PSP, PRIMASK, BASEPRI, BASEPRI_MAX, FAULTMASK, or CONTROL.

12.17.6.2 Operation

Use MRS in combination with MSR as part of a read-modify-write sequence for updating a PSR, for example to clear the Q flag.

In process swap code, the programmers model state of the process being swapped out must be saved, including relevant PSR contents. Similarly, the state of the process being swapped in must also be restored. These operations use MRS in the state-saving instruction sequence and MSR in the state-restoring instruction sequence.

BASEPRI_MAX is an alias of BASEPRI when used with the MRS instruction.

See “MSR” on page 142.

12.17.6.3 Restrictions

Rd must not be SP and must not be PC.

12.17.6.4 Condition flags

This instruction does not change the flags.

12.17.6.5 Examples

```
MRS  R0, PRIMASK ; Read PRIMASK value and write it to R0
```

12.17.7 MSR

Move the contents of a general-purpose register into the specified special register.

12.17.7.1 Syntax

```
MSR{cond} spec_reg, Rn
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

Rn is the source register.

spec_reg can be any of: APSR, IPSR, EPSR, IEPSR, IAPSR, EAPSR, PSR, MSP, PSP, PRIMASK, BASEPRI, BASEPRI_MAX, FAULTMASK, or CONTROL.

12.17.7.2 Operation

The register access operation in MSR depends on the privilege level. Unprivileged software can only access the APSR, see “Application Program Status Register” on page 50. Privileged software can access all special registers.

In unprivileged software writes to unallocated or execution state bits in the PSR are ignored.

When you write to BASEPRI_MAX, the instruction writes to BASEPRI only if either:

- *Rn* is non-zero and the current BASEPRI value is 0
- *Rn* is non-zero and less than the current BASEPRI value.

See “MRS” on page 141.

12.17.7.3 Restrictions

Rn must not be SP and must not be PC.

12.17.7.4 Condition flags

This instruction updates the flags explicitly based on the value in *Rn*.

12.17.7.5 Examples

```
MSR  CONTROL, R1 ; Read R1 value and write it to the CONTROL register
```

12.17.8 NOP

No Operation.

12.17.8.1 Syntax

```
NOP{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.8.2 Operation

NOP does nothing. NOP is not necessarily a time-consuming NOP. The processor might remove it from the pipeline before it reaches the execution stage.

Use NOP for padding, for example to place the following instruction on a 64-bit boundary.

12.17.8.3 Condition flags

This instruction does not change the flags.

12.17.8.4 Examples

```
NOP  ; No operation
```

12.17.9 SEV

Send Event.

12.17.9.1 Syntax

SEV{*cond*}

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.9.2 Operation

SEV is a hint instruction that causes an event to be signaled to all processors within a multiprocessor system. It also sets the local event register to 1, see “Power management” on page 76.

12.17.9.3 Condition flags

This instruction does not change the flags.

12.17.9.4 Examples

```
SEV ; Send Event
```

12.17.10SVC

Supervisor Call.

12.17.10.1 Syntax

```
SVC{cond} #imm
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

imm is an expression evaluating to an integer in the range 0-255 (8-bit value).

12.17.10.2 Operation

The SVC instruction causes the SVC exception.

imm is ignored by the processor. If required, it can be retrieved by the exception handler to determine what service is being requested.

12.17.10.3 Condition flags

This instruction does not change the flags.

12.17.10.4 Examples

```
SVC  0x32  ; Supervisor Call (SVC handler can extract the immediate value
           ; by locating it via the stacked PC)
```

12.17.11WFE

Wait For Event.

12.17.11.1 Syntax

```
WFE{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.11.2 Operation

WFE is a hint instruction.

If the event register is 0, WFE suspends execution until one of the following events occurs:

- an exception, unless masked by the exception mask registers or the current priority level
- an exception enters the Pending state, if SEVONPEND in the System Control Register is set
- a Debug Entry request, if Debug is enabled
- an event signaled by a peripheral or another processor in a multiprocessor system using the SEV instruction.

If the event register is 1, WFE clears it to 0 and returns immediately.

For more information see “Power management” on page 76.

12.17.11.3 Condition flags

This instruction does not change the flags.

12.17.11.4 Examples

```
WFE  ; Wait for event
```

12.17.12WFI

Wait for Interrupt.

12.17.12.1 Syntax

```
WFI{cond}
```

where:

cond is an optional condition code, see “Conditional execution” on page 87.

12.17.12.2 Operation

WFI is a hint instruction that suspends execution until one of the following events occurs:

- an exception
- a Debug Entry request, regardless of whether Debug is enabled.

12.17.12.3 Condition flags

This instruction does not change the flags.

12.17.12.4 Examples

```
WFI ; Wait for interrupt
```

12.18 About the Cortex-M3 peripherals

The address map of the *Private peripheral bus* (PPB) is:

Table 12-26. Core peripheral register regions

Address	Core peripheral	Description
0xE000E008- 0xE000E00F	System control block	Table 12-30 on page 161
0xE000E010- 0xE000E01F	System timer	Table 12-33 on page 189
0xE000E100- 0xE000E4EF	Nested Vectored Interrupt Controller	Table 12-27 on page 149
0xE000ED00- 0xE000ED3F	System control block	Table 12-30 on page 161
0xE000ED90- 0xE000EDB8	Memory protection unit	Table 12-35 on page 195
0xE000EF00- 0xE000EF03	Nested Vectored Interrupt Controller	Table 12-27 on page 149

In register descriptions:

- the register *type* is described as follows:

  RW Read and write.

  RO Read-only.

  WO Write-only.

- the *required privilege* gives the privilege level required to access the register, as follows:

  Privileged Only privileged software can access the register.

  Unprivileged Both unprivileged and privileged software can access the register.

12.19 Nested Vectored Interrupt Controller

This section describes the Nested Vectored Interrupt Controller (NVIC) and the registers it uses. The NVIC supports:

- 1 to 30 interrupts.
- A programmable priority level of 0-15 for each interrupt. A higher level corresponds to a lower priority, so level 0 is the highest interrupt priority.
- Level detection of interrupt signals.
- Dynamic reprioritization of interrupts.
- Grouping of priority values into group priority and subpriority fields.
- Interrupt tail-chaining.

The processor automatically stacks its state on exception entry and unstacks this state on exception exit, with no instruction overhead. This provides low latency exception handling. The hardware implementation of the NVIC registers is:

Table 12-27. NVIC register summary

Address	Name	Type	Required privilege	Reset value	Description
0xE000E100	ISER0	RW	Privileged	0x00000000	“Interrupt Set-enable Registers” on page 151
0xE000E180	ICER0	RW	Privileged	0x00000000	“Interrupt Clear-enable Registers” on page 152
0xE000E200	ISPR0	RW	Privileged	0x00000000	“Interrupt Set-pending Registers” on page 153
0xE000E280	ICPR0	RW	Privileged	0x00000000	“Interrupt Clear-pending Registers” on page 154
0xE000E300	IABR0	RO	Privileged	0x00000000	“Interrupt Active Bit Registers” on page 155
0xE000E400-0xE000E41C	IPR0-IPR7	RW	Privileged	0x00000000	“Interrupt Priority Registers” on page 156
0xE000EF00	STIR	WO	Configurable (1)	0x00000000	“Software Trigger Interrupt Register” on page 158

1. See the register description for more information.

12.19.1 The CMSIS mapping of the Cortex-M3 NVIC registers

To improve software efficiency, the CMSIS simplifies the NVIC register presentation. In the CMSIS:

- the Set-enable, Clear-enable, Set-pending, Clear-pending and Active Bit registers map to arrays of 32-bit integers, so that:
  - the array ISER[0] corresponds to the registers ISER0
  - the array ICER[0] corresponds to the registers ICER0
  - the array ISPR[0] corresponds to the registers ISPR0
  - the array ICPR[0] corresponds to the registers ICPR0
  - the array IABR[0] corresponds to the registers IABR0
- the 4-bit fields of the Interrupt Priority Registers map to an array of 4-bit integers, so that the array IP[0] to IP[29] corresponds to the registers IPR0-IPR7, and the array entry IP[*n*] holds the interrupt priority for interrupt *n*.

The CMSIS provides thread-safe code that gives atomic access to the Interrupt Priority Registers. For more information see the description of the NVIC_SetPriority function in “NVIC programming hints” on page 159. Table 12-28 shows how the interrupts, or IRQ numbers, map onto the interrupt registers and corresponding CMSIS variables that have one bit per interrupt.

Table 12-28. Mapping of interrupts to the interrupt variables

Interrupts	CMSIS array elements (1)				
	Set-enable	**Clear-enable**	**Set-pending**	**Clear-pending**	**Active Bit**
0-29	ISER[0]	ICER[0]	ISPR[0]	ICPR[0]	IABR[0]

1. Each array element corresponds to a single NVIC register, for example the element ICER[0] corresponds to the ICER0 register.

12.19.2 Interrupt Set-enable Registers

The ISER0 register enables interrupts, and show which interrupts are enabled. See:

- the register summary in Table 12-27 on page 149 for the register attributes
- Table 12-28 on page 150 for which interrupts are controlled by each register.

The bit assignments are:

31	30	29	28	27	26	25	24
SETENA bits							

23	22	21	20	19	18	17	16
SETENA bits							

15	14	13	12	11	10	9	8
SETENA bits							

7	6	5	4	3	2	1	0
SETENA bits							

- **SETENA**

Interrupt set-enable bits.

Write:

0 = no effect

1 = enable interrupt.

Read:

0 = interrupt disabled

1 = interrupt enabled.

If a pending interrupt is enabled, the NVIC activates the interrupt based on its priority. If an interrupt is not enabled, asserting its interrupt signal changes the interrupt state to pending, but the NVIC never activates the interrupt, regardless of its priority.

12.19.3 Interrupt Clear-enable Registers

The ICER0 register disables interrupts, and shows which interrupts are enabled. See:

- the register summary in Table 12-27 on page 149 for the register attributes
- Table 12-28 on page 150 for which interrupts are controlled by each register

The bit assignments are:

31	30	29	28	27	26	25	24
CLRENA							

23	22	21	20	19	18	17	16
CLRENA							

15	14	13	12	11	10	9	8
CLRENA							

7	6	5	4	3	2	1	0
CLRENA							

- **CLRENA**

Interrupt clear-enable bits.

Write:

0 = no effect

1 = disable interrupt.

Read:

0 = interrupt disabled

1 = interrupt enabled.

12.19.4 Interrupt Set-pending Registers

The ISPR0 register forces interrupts into the pending state, and shows which interrupts are pending. See:

- the register summary in Table 12-27 on page 149 for the register attributes
- Table 12-28 on page 150 for which interrupts are controlled by each register.

The bit assignments are:

31	30	29	28	27	26	25	24
SETPEND							

23	22	21	20	19	18	17	16
SETPEND							

15	14	13	12	11	10	9	8
SETPEND							

7	6	5	4	3	2	1	0
SETPEND							

- **SETPEND**

Interrupt set-pending bits.

Write:

0 = no effect.

1 = changes interrupt state to pending.

Read:

0 = interrupt is not pending.

1 = interrupt is pending.

Writing 1 to the ISPR bit corresponding to:

- an interrupt that is pending has no effect
- a disabled interrupt sets the state of that interrupt to pending

12.19.5 Interrupt Clear-pending Registers

The ICPR0 register removes the pending state from interrupts, and show which interrupts are pending. See:

- the register summary in Table 12-27 on page 149 for the register attributes
- Table 12-28 on page 150 for which interrupts are controlled by each register.

The bit assignments are:

31	30	29	28	27	26	25	24
CLRPEND							

23	22	21	20	19	18	17	16
CLRPEND							

15	14	13	12	11	10	9	8
CLRPEND							

7	6	5	4	3	2	1	0
CLRPEND							

- **CLRPEND**

Interrupt clear-pending bits.

Write:

0 = no effect.

1 = removes pending state an interrupt.

Read:

0 = interrupt is not pending.

1 = interrupt is pending.

Writing 1 to an ICPR bit does not affect the active state of the corresponding interrupt.

12.19.6 Interrupt Active Bit Registers

The IABR0 register indicates which interrupts are active. See:

- the register summary in Table 12-27 on page 149 for the register attributes
- Table 12-28 on page 150 for which interrupts are controlled by each register.

The bit assignments are:

31	30	29	28	27	26	25	24
ACTIVE							

23	22	21	20	19	18	17	16
ACTIVE							

15	14	13	12	11	10	9	8
ACTIVE							

7	6	5	4	3	2	1	0
ACTIVE							

- **ACTIVE**

Interrupt active flags:

0 = interrupt not active

1 = interrupt active.

A bit reads as one if the status of the corresponding interrupt is active or active and pending.

12.19.7 Interrupt Priority Registers

The IPR0-IPR7 registers provide a 4-bit priority field for each interrupt (See the “Peripheral Identifiers” section of the datasheet for more details). These registers are byte-accessible. See the register summary in Table 12-27 on page 149 for their attributes. Each register holds four priority fields, that map up to four elements in the CMSIS interrupt priority array IP[0] to IP[29], as shown:

12.19.7.1 IPRm

31	30	29	28	27	26	25	24
IP[4m+3]							
23	22	21	20	19	18	17	16
IP[4m+2]							
15	14	13	12	11	10	9	8
IP[4m+1]							
7	6	5	4	3	2	1	0
IP[4m]							

12.19.7.2 IPR4

31	30	29	28	27	26	25	24
IP[19]							
23	22	21	20	19	18	17	16
IP[18]							
15	14	13	12	11	10	9	8
IP[17]							
7	6	5	4	3	2	1	0
IP[16]							

12.19.7.3 IPR3

31	30	29	28	27	26	25	24
IP[15]							
23	22	21	20	19	18	17	16
IP[14]							
15	14	13	12	11	10	9	8
IP[13]							
7	6	5	4	3	2	1	0
IP[12]							

12.19.7.4 IPR2

31	30	29	28	27	26	25	24
IP[11]							
23	22	21	20	19	18	17	16
IP[10]							
15	14	13	12	11	10	9	8
IP[9]							
7	6	5	4	3	2	1	0
IP[8]							

12.19.7.5 IPR1

31	30	29	28	27	26	25	24
IP[7]							
23	22	21	20	19	18	17	16
IP[6]							
15	14	13	12	11	10	9	8
IP[5]							
7	6	5	4	3	2	1	0
IP[4]							

12.19.7.6 IPR0

31	30	29	28	27	26	25	24
IP[3]							
23	22	21	20	19	18	17	16
IP[2]							
15	14	13	12	11	10	9	8
IP[1]							
7	6	5	4	3	2	1	0
IP[0]							

- **Priority, byte offset 3**
- **Priority, byte offset 2**
- **Priority, byte offset 1**
- **Priority, byte offset 0**

Each priority field holds a priority value, 0-15. The lower the value, the greater the priority of the corresponding interrupt. The processor implements only bits[7:4] of each field, bits[3:0] read as zero and ignore writes.

See “The CMSIS mapping of the Cortex-M3 NVIC registers” on page 149 for more information about the IP[0] to IP[29] interrupt priority array, that provides the software view of the interrupt priorities.

Find the IPR number and byte offset for interrupt *N* as follows:

- the corresponding IPR number, *M*, is given by *M* = *N* DIV 4
- the byte offset of the required Priority field in this register is *N* MOD 4, where:
  - byte offset 0 refers to register bits[7:0]
  - byte offset 1 refers to register bits[15:8]
  - byte offset 2 refers to register bits[23:16]
  - byte offset 3 refers to register bits[31:24].

12.19.8 Software Trigger Interrupt Register

Write to the STIR to generate a *Software Generated Interrupt* (SGI). See the register summary in Table 12-27 on page 149 for the STIR attributes.

When the USERSETMPEND bit in the SCR is set to 1, unprivileged software can access the STIR, see "System Control Register" on page 170.

Only privileged software can enable unprivileged access to the STIR.

The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							INTID

7	6	5	4	3	2	1	0
INTID							

- **INTID**

Interrupt ID of the required SGI, in the range 0-239. For example, a value of b000000011 specifies interrupt IRQ3.

12.19.9 Level-sensitive interrupts

The processor supports level-sensitive interrupts.

A level-sensitive interrupt is held asserted until the peripheral deasserts the interrupt signal. Typically this happens because the ISR accesses the peripheral, causing it to clear the interrupt request.

When the processor enters the ISR, it automatically removes the pending state from the interrupt, see “Hardware and software control of interrupts”. For a level-sensitive interrupt, if the signal is not deasserted before the processor returns from the ISR, the interrupt becomes pending again, and the processor must execute its ISR again. This means that the peripheral can hold the interrupt signal asserted until it no longer needs servicing.

12.19.9.1 Hardware and software control of interrupts

The Cortex-M3 latches all interrupts. A peripheral interrupt becomes pending for one of the following reasons:

- the NVIC detects that the interrupt signal is HIGH and the interrupt is not active
- the NVIC detects a rising edge on the interrupt signal
- software writes to the corresponding interrupt set-pending register bit, see “Interrupt Set-pending Registers” on page 153, or to the STIR to make an SGI pending, see “Software Trigger Interrupt Register” on page 158.

A pending interrupt remains pending until one of the following:

The processor enters the ISR for the interrupt. This changes the state of the interrupt from pending to active. Then:

  - For a level-sensitive interrupt, when the processor returns from the ISR, the NVIC samples the interrupt signal. If the signal is asserted, the state of the interrupt changes to pending, which might cause the processor to immediately re-enter the ISR. Otherwise, the state of the interrupt changes to inactive.
  - If the interrupt signal is not pulsed while the processor is in the ISR, when the processor returns from the ISR the state of the interrupt changes to inactive.
- Software writes to the corresponding interrupt clear-pending register bit.

For a level-sensitive interrupt, if the interrupt signal is still asserted, the state of the interrupt does not change. Otherwise, the state of the interrupt changes to inactive.

12.19.10NVIC design hints and tips

Ensure software uses correctly aligned register accesses. The processor does not support unaligned accesses to NVIC registers. See the individual register descriptions for the supported access sizes.

A interrupt can enter pending state even it is disabled.

Before programming VTOR to relocate the vector table, ensure the vector table entries of the new vector table are setup for fault handlers and all enabled exception like interrupts. For more information see “Vector Table Offset Register” on page 167.

12.19.10.1 NVIC programming hints

Software uses the CPSIE I and CPSID I instructions to enable and disable interrupts. The CMSIS provides the following intrinsic functions for these instructions:

```
void __disable_irq(void) // Disable Interrupts
void __enable_irq(void) // Enable Interrupts
```

In addition, the CMSIS provides a number of functions for NVIC control, including:

Table 12-29. CMSIS functions for NVIC control

CMSIS interrupt control function	Description
void NVIC_SetPriorityGrouping(uint32_t priority_grouping)	Set the priority grouping
void NVIC_EnableIRQ(IRQn_t IRQn)	Enable IRQn
void NVIC_DisableIRQ(IRQn_t IRQn)	Disable IRQn
uint32_t NVIC_GetPendingIRQ (IRQn_t IRQn)	Return true if IRQn is pending
void NVIC_SetPendingIRQ (IRQn_t IRQn)	Set IRQn pending
void NVIC_ClearPendingIRQ (IRQn_t IRQn)	Clear IRQn pending status
uint32_t NVIC_GetActive (IRQn_t IRQn)	Return the IRQ number of the active interrupt
void NVIC_SetPriority (IRQn_t IRQn, uint32_t priority)	Set priority for IRQn
uint32_t NVIC_GetPriority (IRQn_t IRQn)	Read priority of IRQn
void NVIC_SystemReset (void)	Reset the system

For more information about these functions see the CMSIS documentation.

12.20 System control block

The *System control block* (SCB) provides system implementation information, and system control. This includes configuration, control, and reporting of the system exceptions. The system control block registers are:

Table 12-30. Summary of the system control block registers

Address	Name	Type	Required privilege	Reset value	Description
0xE000E008	ACTLR	RW	Privileged	0x00000000	"Auxiliary Control Register" on page 162
0xE000ED00	CPUID	RO	Privileged	0x412FC230	"CPUID Base Register" on page 163
0xE000ED04	ICSR	RW(1)	Privileged	0x00000000	"Interrupt Control and State Register" on page 164
0xE000ED08	VTOR	RW	Privileged	0x00000000	"Vector Table Offset Register" on page 167
0xE000ED0C	AIRCR	RW(1)	Privileged	0xFA050000	"Application Interrupt and Reset Control Register" on page 168
0xE000ED10	SCR	RW	Privileged	0x00000000	"System Control Register" on page 170
0xE000ED14	CCR	RW	Privileged	0x00000200	"Configuration and Control Register" on page 171
0xE000ED18	SHPR1	RW	Privileged	0x00000000	"System Handler Priority Register 1" on page 174
0xE000ED1C	SHPR2	RW	Privileged	0x00000000	"System Handler Priority Register 2" on page 175
0xE000ED20	SHPR3	RW	Privileged	0x00000000	"System Handler Priority Register 3" on page 176
0xE000ED24	SHCRS	RW	Privileged	0x00000000	"System Handler Control and State Register" on page 177
0xE000ED28	CFSR	RW	Privileged	0x00000000	"Configurable Fault Status Register" on page 179
0xE000ED28	MMSR(2)	RW	Privileged	0x00	"Memory Management Fault Address Register" on page 186
0xE000ED29	BFSR(2)	RW	Privileged	0x00	"Bus Fault Status Register" on page 181
0xE000ED2A	UFSR(2)	RW	Privileged	0x0000	"Usage Fault Status Register" on page 183
0xE000ED2C	HFSR	RW	Privileged	0x00000000	"Hard Fault Status Register" on page 185
0xE000ED34	MMAR	RW	Privileged	Unknown	"Memory Management Fault Address Register" on page 186
0xE000ED38	BFAR	RW	Privileged	Unknown	"Bus Fault Address Register" on page 187
0xE000ED3C	AFSR	RW	Privileged	0x00000000	"Auxiliary Fault Status Register" on page 188

Notes: 1. See the register description for more information.
2. A subregister of the CFSR.

12.20.1 The CMSIS mapping of the Cortex-M3 SCB registers

To improve software efficiency, the CMSIS simplifies the SCB register presentation. In the CMSIS, the byte array SHP[0] to SHP[12] corresponds to the registers SHPR1-SHPR3.

12.20.2 Auxiliary Control Register

The ACTLR provides disable bits for the following processor functions:

- IT folding
- write buffer use for accesses to the default memory map
- interruption of multi-cycle instructions.

See the register summary in Table 12-30 on page 161 for the ACTLR attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved					DISFOLD	DISDEFWBUF	DISMCYCINT

- **DISFOLD**

When set to 1, disables IT folding. see "About IT folding" on page 162 for more information.

- **DISDEFWBUF**

When set to 1, disables write buffer use during default memory map accesses. This causes all bus faults to be precise bus faults but decreases performance because any store to memory must complete before the processor can execute the next instruction.

This bit only affects write buffers implemented in the Cortex-M3 processor.

- **DISMCYCINT**

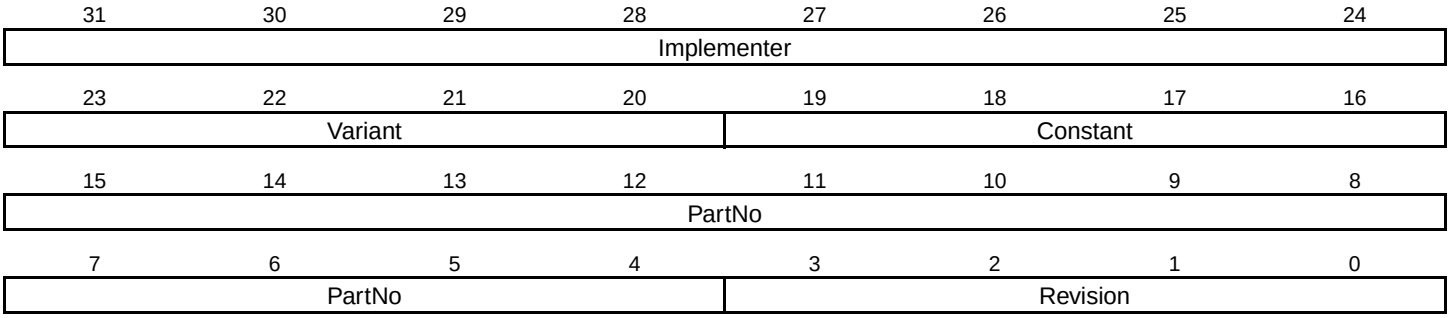
When set to 1, disables interruption of load multiple and store multiple instructions. This increases the interrupt latency of the processor because any LDM or STM must complete before the processor can stack the current state and enter the interrupt handler.

12.20.2.1 About IT folding

In some situations, the processor can start executing the first instruction in an IT block while it is still executing the IT instruction. This behavior is called IT folding, and improves performance, However, IT folding can cause jitter in looping. If a task must avoid jitter, set the DISFOLD bit to 1 before executing the task, to disable IT folding.

12.20.3 CPUID Base Register

The CPUID register contains the processor part number, version, and implementation information. See the register summary in Table 12-30 on page 161 for its attributes. The bit assignments are:



- **Implementer**

Implementer code:

0x41 = ARM

- **Variant**

Variant number, the r value in the r*n*p*n* product revision identifier:

0x2 = r2p0

- **Constant**

Reads as 0xF

- **PartNo**

Part number of the processor:

0xC23 = Cortex-M3

- **Revision**

Revision number, the p value in the r*n*p*n* product revision identifier:

0x0 = r2p0

12.20.4 Interrupt Control and State Register

The ICSR:

- provides:
  - set-pending and clear-pending bits for the PendSV and SysTick exceptions
- indicates:
  - the exception number of the exception being processed
  - whether there are preempted active exceptions
  - the exception number of the highest priority pending exception
  - whether any interrupts are pending.

See the register summary in Table 12-30 on page 161, and the Type descriptions in Table 12-33 on page 189, for the ICSR attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved	Reserved		PENDSVSET	PENDSVCLR	PENDSTSET	PENDSTCLR	Reserved

23	22	21	20	19	18	17	16
Reserved for Debug	ISRPENDING	VECTPENDING					

15	14	13	12	11	10	9	8
VECTPENDING				RETTOBASE	Reserved		VECTACTIVE

7	6	5	4	3	2	1	0
VECTACTIVE							

- **PENDSVSET**

RW

PendSV set-pending bit.

Write:

0 = no effect

1 = changes PendSV exception state to pending.

Read:

0 = PendSV exception is not pending

1 = PendSV exception is pending.

Writing 1 to this bit is the only way to set the PendSV exception state to pending.

- **PENDSVCLR**

WO

PendSV clear-pending bit.

Write:

0 = no effect

1 = removes the pending state from the PendSV exception.

- **PENDSTSET**

RW

SysTick exception set-pending bit.

Write:

0 = no effect

1 = changes SysTick exception state to pending.

Read:

0 = SysTick exception is not pending

1 = SysTick exception is pending.

- **PENDSTCLR**

WO

SysTick exception clear-pending bit.

Write:

0 = no effect

1 = removes the pending state from the SysTick exception.

This bit is WO. On a register read its value is Unknown.

- **Reserved for Debug use**

RO

This bit is reserved for Debug use and reads-as-zero when the processor is not in Debug.

- **ISRPENDING**

RO

Interrupt pending flag, excluding Faults:

0 = interrupt not pending

1 = interrupt pending.

- **VECTPENDING**

RO

Indicates the exception number of the highest priority pending enabled exception:

0 = no pending exceptions

Nonzero = the exception number of the highest priority pending enabled exception.

The value indicated by this field includes the effect of the BASEPRI and FAULTMASK registers, but not any effect of the PRIMASK register.

- **RETTOBASE**

RO

Indicates whether there are preempted active exceptions:

0 = there are preempted active exceptions to execute

1 = there are no active exceptions, or the currently-executing exception is the only active exception.

- **VECTACTIVE**

RO

Contains the active exception number:

0 = Thread mode

Nonzero = The exception number [(1)] of the currently active exception.

Subtract 16 from this value to obtain the IRQ number required to index into the Interrupt Clear-Enable, Set-Enable, Clear-Pending, Set-Pending, or Priority Registers, see “Interrupt Program Status Register” on page 51.

When you write to the ICSR, the effect is Unpredictable if you:

- write 1 to the PENDSVSET bit and write 1 to the PENDSVCLR bit
- write 1 to the PENDSTSET bit and write 1 to the PENDSTCLR bit.

Note: 1. This is the same value as IPSR bits [8:0] see “Interrupt Program Status Register” on page 51.

12.20.5 Vector Table Offset Register

The VTOR indicates the offset of the vector table base address from memory address 0x00000000. See the register summary in Table 12-30 on page 161 for its attributes.

The bit assignments are:

31	30	29	28	27	26	25	24
Reserved		TBLOFF					

23	22	21	20	19	18	17	16
TBLOFF							

15	14	13	12	11	10	9	8
TBLOFF							

7	6	5	4	3	2	1	0
TBLOFF	Reserved						

- **TBLOFF**

Vector table base offset field. It contains bits[29:7] of the offset of the table base from the bottom of the memory map.

Bit[29] determines whether the vector table is in the code or SRAM memory region:

0 = code

1 = SRAM.

Bit[29] is sometimes called the TBLBASE bit.

When setting TBLOFF, you must align the offset to the number of exception entries in the vector table. The minimum alignment is 32 words, enough for up to 16 interrupts. For more interrupts, adjust the alignment by rounding up to the next power of two. For example, if you require 21 interrupts, the alignment must be on a 64-word boundary because the required table size is 37 words, and the next power of two is 64.

Table alignment requirements mean that bits[6:0] of the table offset are always zero.

12.20.6 Application Interrupt and Reset Control Register

The AIRCR provides priority grouping control for the exception model, endian status for data accesses, and reset control of the system. See the register summary in Table 12-30 on page 161 and Table 12-33 on page 189 for its attributes.

To write to this register, you must write 0x05FA to the VECTKEY field, otherwise the processor ignores the write.

The bit assignments are:

31	30	29	28	27	26	25	24
On Read: VECTKEYSTAT, On Write: VECTKEY							

23	22	21	20	19	18	17	16
On Read: VECTKEYSTAT, On Write: VECTKEY							

15	14	13	12	11	10	9	8
ENDIANESS	Reserved				PRIGROUP		

7	6	5	4	3	2	1	0
Reserved					SYSRESETREQ	VECTCLR-ACTIVE	VECTRESET

- **VECTKEYSTAT**

Register Key:

Reads as 0xFA05

- **VECTKEY**

Register key:

On writes, write 0x5FA to VECTKEY, otherwise the write is ignored.

- **ENDIANESS**

RO

Data endianness bit:

0 = Little-endian

ENDIANESS is set from the **BIGEND** configuration signal during reset.

- **PRIGROUP**

R/W

Interrupt priority grouping field. This field determines the split of group priority from subpriority, see “Binary point” on page 169.

- **SYSRESETREQ**

WO

System reset request:

0 = no effect

1 = asserts a proc_reset_signal.

This is intended to force a large system reset of all major components except for debug.

This bit reads as 0.

- **VECTCLRACTIVE**

WO

Reserved for Debug use. This bit reads as 0. When writing to the register you must write 0 to this bit, otherwise behavior is Unpredictable.

- **VECTRESET**

WO

Reserved for Debug use. This bit reads as 0. When writing to the register you must write 0 to this bit, otherwise behavior is Unpredictable.

12.20.6.1 Binary point

The PRIGROUP field indicates the position of the binary point that splits the PRI_*n* fields in the Interrupt Priority Registers into separate *group priority* and *subpriority* fields. Table 12-31 shows how the PRIGROUP value controls this split.

Table 12-31. Priority grouping

	Interrupt priority level value, PRI_*N*[7:0]			Number of	
PRIGROUP	**Binary point [1]**	**Group priority bits**	**Subpriority bits**	**Group priorities**	**Subpriorities**
b011	bxxxx.0000	[7:4]	None	16	1
b100	bxxx.y0000	[7:5]	[4]	8	2
b101	bxx.yy0000	[7:6]	[5:4]	4	4
b110	bx.yyy0000	[7]	[6:4]	2	8
b111	b.yyyy0000	None	[7:4]	1	16

1. PRI_*n*[7:0] field showing the binary point. x denotes a group priority field bit, and y denotes a subpriority field bit.

Determining preemption of an exception uses only the group priority field, see “Interrupt priority grouping” on page 71.

12.20.7 System Control Register

The SCR controls features of entry to and exit from low power state. See the register summary in Table 12-30 on page 161 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved			SEVONPEND	Reserved	SLEEPDEEP	SLEEONEXIT	Reserved

- **SEVONPEND**

Send Event on Pending bit:

0 = only enabled interrupts or events can wakeup the processor, disabled interrupts are excluded

1 = enabled events and all interrupts, including disabled interrupts, can wakeup the processor.

When an event or interrupt enters pending state, the event signal wakes up the processor from WFE. If the processor is not waiting for an event, the event is registered and affects the next WFE.

The processor also wakes up on execution of an SEV instruction or an external event.

- **SLEEPDEEP**

Controls whether the processor uses sleep or deep sleep as its low power mode:

0 = sleep

1 = deep sleep.

- **SLEEPONEXIT**

Indicates sleep-on-exit when returning from Handler mode to Thread mode:

0 = do not sleep when returning to Thread mode.

1 = enter sleep, or deep sleep, on return from an ISR.

Setting this bit to 1 enables an interrupt driven application to avoid returning to an empty main application.

12.20.8 Configuration and Control Register

The CCR controls entry to Thread mode and enables:

- the handlers for hard fault and faults escalated by FAULTMASK to ignore bus faults
- trapping of divide by zero and unaligned accesses
- access to the STIR by unprivileged software, see “Software Trigger Interrupt Register” on page 158.

See the register summary in Table 12-30 on page 161 for the CCR attributes.

The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved						STKALIGN	BFHFNMIGN

7	6	5	4	3	2	1	0
Reserved			DIV_0_TRP	UNALIGN_TRP	Reserved	USERSETMPEND	NONBASETHRDENA

- **STKALIGN**

Indicates stack alignment on exception entry:

0 = 4-byte aligned

1 = 8-byte aligned.

On exception entry, the processor uses bit[9] of the stacked PSR to indicate the stack alignment. On return from the exception it uses this stacked bit to restore the correct stack alignment.

- **BFHFNMIGN**

Enables handlers with priority -1 or -2 to ignore data bus faults caused by load and store instructions. This applies to the hard fault and FAULTMASK escalated handlers:

0 = data bus faults caused by load and store instructions cause a lock-up

1 = handlers running at priority -1 and -2 ignore data bus faults caused by load and store instructions.

Set this bit to 1 only when the handler and its data are in absolutely safe memory. The normal use of this bit is to probe system devices and bridges to detect control path problems and fix them.

- **DIV_0_TRP**

Enables faulting or halting when the processor executes an SDIV or UDIV instruction with a divisor of 0:

0 = do not trap divide by 0

1 = trap divide by 0.

When this bit is set to 0,a divide by zero returns a quotient of 0.

- **UNALIGN_TRP**

Enables unaligned access traps:

0 = do not trap unaligned halfword and word accesses

1 = trap unaligned halfword and word accesses.

If this bit is set to 1, an unaligned access generates a usage fault.

Unaligned LDM, STM, LDRD, and STRD instructions always fault irrespective of whether UNALIGN_TRP is set to 1.

- **USERSETMPEND**

Enables unprivileged software access to the STIR, see “Software Trigger Interrupt Register” on page 158:

0 = disable

1 = enable.

- **NONEBASETHRDENA**

Indicates how the processor enters Thread mode:

0 = processor can enter Thread mode only when no exception is active.

1 = processor can enter Thread mode from any level under the control of an EXC_RETURN value, see “Exception return” on page 72.

12.20.9 System Handler Priority Registers

The SHPR1-SHPR3 registers set the priority level, 0 to 15 of the exception handlers that have configurable priority. SHPR1-SHPR3 are byte accessible. See the register summary in Table 12-30 on page 161 for their attributes.

The system fault handlers and the priority field and register for each handler are:

Table 12-32. System fault handler priority fields

Handler	Field	Register description
Memory management fault	PRI_4	"System Handler Priority Register 1" on page 174
Bus fault	PRI_5	
Usage fault	PRI_6	
SVCall	PRI_11	"System Handler Priority Register 2" on page 175
PendSV	PRI_14	"System Handler Priority Register 3" on page 176
SysTick	PRI_15	

Each PRI_N field is 8 bits wide, but the processor implements only bits[7:4] of each field, and bits[3:0] read as zero and ignore writes.

12.20.9.1 System Handler Priority Register 1

The bit assignments are:

31	30	29	28	27	26	25	24
PRI_7: Reserved							
23	22	21	20	19	18	17	16
PRI_6							
15	14	13	12	11	10	9	8
PRI_5							
7	6	5	4	3	2	1	0
PRI_4							

- **PRI_7**

Reserved

- **PRI_6**

Priority of system handler 6, usage fault

- **PRI_5**

Priority of system handler 5, bus fault

- **PRI_4**

Priority of system handler 4, memory management fault

12.20.9.2 System Handler Priority Register 2

The bit assignments are:

31	30	29	28	27	26	25	24
PRI_11							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved							

- **PRI_11**

Priority of system handler 11, SVCall

12.20.9.3 System Handler Priority Register 3

The bit assignments are:

31	30	29	28	27	26	25	24
PRI_15							
23	22	21	20	19	18	17	16
PRI_14							
15	14	13	12	11	10	9	8
Reserved							
7	6	5	4	3	2	1	0
Reserved							

- **PRI_15**

Priority of system handler 15, SysTick exception

- **PRI_14**

Priority of system handler 14, PendSV

12.20.10System Handler Control and State Register

The SHCSR enables the system handlers, and indicates:

- the pending status of the bus fault, memory management fault, and SVC exceptions
- the active status of the system handlers.

See the register summary in Table 12-30 on page 161 for the SHCSR attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved					USGFAULTENA	BUSFAULTENA	MEMFAULTENA

15	14	13	12	11	10	9	8
SVCALLPENDED	BUSFAULTPENDED	MEMFAULTPENDED	USGFAULTPENDED	SYSTICKACT	PENDSVACT	Reserved	MONITORACT

7	6	5	4	3	2	1	0
SVCALLAVCT	Reserved			USGFAULTACT	Reserved	BUSFAULTACT	MEMFAULTACT

- **USGFAULTENA**

Usage fault enable bit, set to 1 to enable (1)

- **BUSFAULTENA**

Bus fault enable bit, set to 1 to enable(3)

- **MEMFAULTENA**

Memory management fault enable bit, set to 1 to enable(3)

- **SVCALLPENDED**

SVC call pending bit, reads as 1 if exception is pending (2)

- **BUSFAULTPENDED**

Bus fault exception pending bit, reads as 1 if exception is pending(2)

- **MEMFAULTPENDED**

Memory management fault exception pending bit, reads as 1 if exception is pending(2)

- **USGFAULTPENDED**

Usage fault exception pending bit, reads as 1 if exception is pending(2)

- **SYSTICKACT**

SysTick exception active bit, reads as 1 if exception is active (3)

- **PENDSVACT**

PendSV exception active bit, reads as 1 if exception is active

1. Enable bits, set to 1 to enable the exception, or set to 0 to disable the exception.
2. Pending bits, read as 1 if the exception is pending, or as 0 if it is not pending. You can write to these bits to change the pending status of the exceptions.
3. Active bits, read as 1 if the exception is active, or as 0 if it is not active. You can write to these bits to change the active status of the exceptions, but see the Caution in this section.

- **MONITORACT**

Debug monitor active bit, reads as 1 if Debug monitor is active

- **SVCALLACT**

SVC call active bit, reads as 1 if SVC call is active

- **USGFAULTACT**

Usage fault exception active bit, reads as 1 if exception is active

- **BUSFAULTACT**

Bus fault exception active bit, reads as 1 if exception is active

- **MEMFAULTACT**

Memory management fault exception active bit, reads as 1 if exception is active

If you disable a system handler and the corresponding fault occurs, the processor treats the fault as a hard fault.

You can write to this register to change the pending or active status of system exceptions. An OS kernel can write to the active bits to perform a context switch that changes the current exception type.

- Software that changes the value of an active bit in this register without correct adjustment to the stacked content can cause the processor to generate a fault exception. Ensure software that writes to this register retains and subsequently restores the current active status.
- After you have enabled the system handlers, if you have to change the value of a bit in this register you must use a read-modify-write procedure to ensure that you change only the required bit.

12.20.11Configurable Fault Status Register

The CFSR indicates the cause of a memory management fault, bus fault, or usage fault. See the register summary in Table 12-30 on page 161 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Usage Fault Status Register: UFSR							

23	22	21	20	19	18	17	16
Usage Fault Status Register: UFSR							

15	14	13	12	11	10	9	8
Bus Fault Status Register: BFSR							

7	6	5	4	3	2	1	0
Memory Management Fault Status Register: MMFSR							

The following subsections describe the subregisters that make up the CFSR:

- “Memory Management Fault Status Register” on page 180
- “Bus Fault Status Register” on page 181
- “Usage Fault Status Register” on page 183.

The CFSR is byte accessible. You can access the CFSR or its subregisters as follows:

- access the complete CFSR with a word access to 0xE000ED28
- access the MMFSR with a byte access to 0xE000ED28
- access the MMFSR and BFSR with a halfword access to 0xE000ED28
- access the BFSR with a byte access to 0xE000ED29
- access the UFSR with a halfword access to 0xE000ED2A.

12.20.11.1 Memory Management Fault Status Register

The flags in the MMFSR indicate the cause of memory access faults. The bit assignments are:

7	6	5	4	3	2	1	0
MMARVALID	Reserved		MSTKERR	MUNSTKERR	Reserved	DACCVIOL	IACCVIOL

- **MMARVALID**

Memory Management Fault Address Register (MMAR) valid flag:

0 = value in MMAR is not a valid fault address

1 = MMAR holds a valid fault address.

If a memory management fault occurs and is escalated to a hard fault because of priority, the hard fault handler must set this bit to 0. This prevents problems on return to a stacked active memory management fault handler whose MMAR value has been overwritten.

- **MSTKERR**

Memory manager fault on stacking for exception entry:

0 = no stacking fault

1 = stacking for an exception entry has caused one or more access violations.

When this bit is 1, the SP is still adjusted but the values in the context area on the stack might be incorrect. The processor has not written a fault address to the MMAR.

- **MUNSTKERR**

Memory manager fault on unstacking for a return from exception:

0 = no unstacking fault

1 = unstack for an exception return has caused one or more access violations.

This fault is chained to the handler. This means that when this bit is 1, the original return stack is still present. The processor has not adjusted the SP from the failing return, and has not performed a new save. The processor has not written a fault address to the MMAR.

- **DACCVIOL**

Data access violation flag:

0 = no data access violation fault

1 = the processor attempted a load or store at a location that does not permit the operation.

When this bit is 1, the PC value stacked for the exception return points to the faulting instruction. The processor has loaded the MMAR with the address of the attempted access.

- **IACCVIOL**

Instruction access violation flag:

0 = no instruction access violation fault

1 = the processor attempted an instruction fetch from a location that does not permit execution.

This fault occurs on any access to an XN region, even when the MPU is disabled or not present.

When this bit is 1, the PC value stacked for the exception return points to the faulting instruction. The processor has not written a fault address to the MMAR.

12.20.11.2 Bus Fault Status Register

The flags in the BFSR indicate the cause of a bus access fault. The bit assignments are:

7	6	5	4	3	2	1	0
BFRVALID	Reserved		STKERR	UNSTKERR	IMPRECISERR	PRECISERR	IBUSERR

- **BFARVALID**

Bus Fault Address Register (BFAR) valid flag:

0 = value in BFAR is not a valid fault address

1 = BFAR holds a valid fault address.

The processor sets this bit to 1 after a bus fault where the address is known. Other faults can set this bit to 0, such as a memory management fault occurring later.

If a bus fault occurs and is escalated to a hard fault because of priority, the hard fault handler must set this bit to 0. This prevents problems if returning to a stacked active bus fault handler whose BFAR value has been overwritten.

- **STKERR**

Bus fault on stacking for exception entry:

0 = no stacking fault

1 = stacking for an exception entry has caused one or more bus faults.

When the processor sets this bit to 1, the SP is still adjusted but the values in the context area on the stack might be incorrect. The processor does not write a fault address to the BFAR.

- **UNSTKERR**

Bus fault on unstacking for a return from exception:

0 = no unstacking fault

1 = unstack for an exception return has caused one or more bus faults.

This fault is chained to the handler. This means that when the processor sets this bit to 1, the original return stack is still present. The processor does not adjust the SP from the failing return, does not performed a new save, and does not write a fault address to the BFAR.

- **IMPRECISERR**

Imprecise data bus error:

0 = no imprecise data bus error

1 = a data bus error has occurred, but the return address in the stack frame is not related to the instruction that caused the error.

When the processor sets this bit to 1, it does not write a fault address to the BFAR.

This is an asynchronous fault. Therefore, if it is detected when the priority of the current process is higher than the bus fault priority, the bus fault becomes pending and becomes active only when the processor returns from all higher priority processes. If a precise fault occurs before the processor enters the handler for the imprecise bus fault, the handler detects both IMPRECISERR set to 1 and one of the precise fault status bits set to 1.

- **PRECISERR**

Precise data bus error:

0 = no precise data bus error

1 = a data bus error has occurred, and the PC value stacked for the exception return points to the instruction that caused the fault.

When the processor sets this bit is 1, it writes the faulting address to the BFAR.

- **IBUSERR**

Instruction bus error:

0 = no instruction bus error

1 = instruction bus error.

The processor detects the instruction bus error on prefetching an instruction, but it sets the IBUSERR flag to 1 only if it attempts to issue the faulting instruction.

When the processor sets this bit is 1, it does not write a fault address to the BFAR.

12.20.11.3 Usage Fault Status Register

The UFSR indicates the cause of a usage fault. The bit assignments are:

15	14	13	12	11	10	9	8
Reserved						DIVBYZERO	UNALIGNED

7	6	5	4	3	2	1	0
Reserved				NOCP	INVPC	INVSTATE	UNDEFINSTR

- **DIVBYZERO**

Divide by zero usage fault:

0 = no divide by zero fault, or divide by zero trapping not enabled

1 = the processor has executed an SDIV or UDIV instruction with a divisor of 0.

When the processor sets this bit to 1, the PC value stacked for the exception return points to the instruction that performed the divide by zero.

Enable trapping of divide by zero by setting the DIV_0_TRP bit in the CCR to 1, see “Configuration and Control Register” on page 171.

- **UNALIGNED**

Unaligned access usage fault:

0 = no unaligned access fault, or unaligned access trapping not enabled

1 = the processor has made an unaligned memory access.

Enable trapping of unaligned accesses by setting the UNALIGN_TRP bit in the CCR to 1, see “Configuration and Control Register” on page 171.

Unaligned LDM, STM, LDRD, and STRD instructions always fault irrespective of the setting of UNALIGN_TRP.

- **NOCP**

No coprocessor usage fault. The processor does not support coprocessor instructions:

0 = no usage fault caused by attempting to access a coprocessor

1 = the processor has attempted to access a coprocessor.

- **INVPC**

Invalid PC load usage fault, caused by an invalid PC load by EXC_RETURN:

0 = no invalid PC load usage fault

1 = the processor has attempted an illegal load of EXC_RETURN to the PC, as a result of an invalid context, or an invalid EXC_RETURN value.

When this bit is set to 1, the PC value stacked for the exception return points to the instruction that tried to perform the illegal load of the PC.

- **INVSTATE**

Invalid state usage fault:

0 = no invalid state usage fault

1 = the processor has attempted to execute an instruction that makes illegal use of the EPSR.

When this bit is set to 1, the PC value stacked for the exception return points to the instruction that attempted the illegal use of the EPSR.

This bit is not set to 1 if an undefined instruction uses the EPSR.

- **UNDEFINSTR**

Undefined instruction usage fault:

0 = no undefined instruction usage fault

1 = the processor has attempted to execute an undefined instruction.

When this bit is set to 1, the PC value stacked for the exception return points to the undefined instruction.

An undefined instruction is an instruction that the processor cannot decode.

The UFSR bits are sticky. This means as one or more fault occurs, the associated bits are set to 1. A bit that is set to 1 is cleared to 0 only by writing 1 to that bit, or by a reset.

12.20.12Hard Fault Status Register

The HFSR gives information about events that activate the hard fault handler. See the register summary in Table 12-30 on page 161 for its attributes.

This register is read, write to clear. This means that bits in the register read normally, but writing 1 to any bit clears that bit to 0. The bit assignments are:

31	30	29	28	27	26	25	24
DEBUGEVT	FORCED	Reserved					

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved						VECTTBL	Reserved

- **DEBUGEVT**

Reserved for Debug use. When writing to the register you must write 0 to this bit, otherwise behavior is Unpredictable.

- **FORCED**

Indicates a forced hard fault, generated by escalation of a fault with configurable priority that cannot be handles, either because of priority or because it is disabled:

0 = no forced hard fault

1 = forced hard fault.

When this bit is set to 1, the hard fault handler must read the other fault status registers to find the cause of the fault.

- **VECTTBL**

Indicates a bus fault on a vector table read during exception processing:

0 = no bus fault on vector table read

1 = bus fault on vector table read.

This error is always handled by the hard fault handler.

When this bit is set to 1, the PC value stacked for the exception return points to the instruction that was preempted by the exception.

The HFSR bits are sticky. This means as one or more fault occurs, the associated bits are set to 1. A bit that is set to 1 is cleared to 0 only by writing 1 to that bit, or by a reset.

12.20.13Memory Management Fault Address Register

The MMFAR contains the address of the location that generated a memory management fault. See the register summary in Table 12-30 on page 161 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
ADDRESS							
23	22	21	20	19	18	17	16
ADDRESS							
15	14	13	12	11	10	9	8
ADDRESS							
7	6	5	4	3	2	1	0
ADDRESS							

- **ADDRESS**

When the MMARVALID bit of the MMFSR is set to 1, this field holds the address of the location that generated the memory management fault

When an unaligned access faults, the address is the actual address that faulted. Because a single read or write instruction can be split into multiple aligned accesses, the fault address can be any address in the range of the requested access size.

Flags in the MMFSR indicate the cause of the fault, and whether the value in the MMFAR is valid. See “Memory Management Fault Status Register” on page 180.

12.20.14Bus Fault Address Register

The BFAR contains the address of the location that generated a bus fault. See the register summary in Table 12-30 on page 161 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
ADDRESS							

23	22	21	20	19	18	17	16
ADDRESS							

15	14	13	12	11	10	9	8
ADDRESS							

7	6	5	4	3	2	1	0
ADDRESS							

- **ADDRESS**

When the BFARVALID bit of the BFSR is set to 1, this field holds the address of the location that generated the bus fault

When an unaligned access faults the address in the BFAR is the one requested by the instruction, even if it is not the address of the fault.

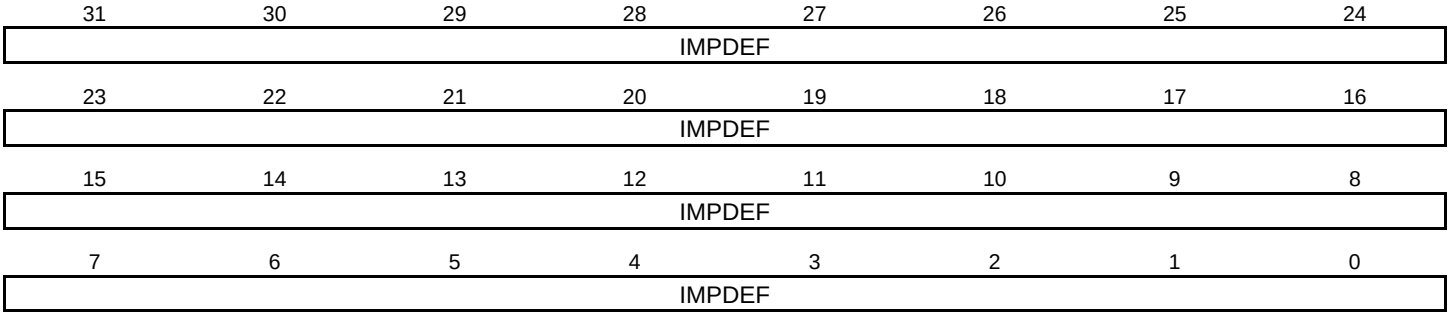
Flags in the BFSR indicate the cause of the fault, and whether the value in the BFAR is valid. See “Bus Fault Status Register” on page 181.

12.20.15Auxiliary Fault Status Register

The AFSR contains additional system fault information. See the register summary in Table 12-30 on page 161 for its attributes.

This register is read, write to clear. This means that bits in the register read normally, but writing 1 to any bit clears that bit to 0.

The bit assignments are:



- **IMPDEF**

Implementation defined. The bits map to the **AUXFAULT** input signals.

Each AFSR bit maps directly to an **AUXFAULT** input of the processor, and a single-cycle HIGH signal on the input sets the corresponding AFSR bit to one. It remains set to 1 until you write 1 to the bit to clear it to zero.

When an AFSR bit is latched as one, an exception does not occur. Use an interrupt if an exception is required.

12.20.16System control block design hints and tips

Ensure software uses aligned accesses of the correct size to access the system control block registers:

- except for the CFSR and SHPR1-SHPR3, it must use aligned word accesses
- for the CFSR and SHPR1-SHPR3 it can use byte or aligned halfword or word accesses.

The processor does not support unaligned accesses to system control block registers.

In a fault handler. to determine the true faulting address:

- Read and save the MMFAR or BFAR value.
- Read the MMARVALID bit in the MMFSR, or the BFARVALID bit in the BFSR. The MMFAR or BFAR address is valid only if this bit is 1.

Software must follow this sequence because another higher priority exception might change the MMFAR or BFAR value. For example, if a higher priority handler preempts the current fault handler, the other fault might change the MMFAR or BFAR value.

12.21 System timer, SysTick

The processor has a 24-bit system timer, SysTick, that counts down from the reload value to zero, reloads (wraps to) the value in the LOAD register on the next clock edge, then counts down on subsequent clocks.

When the processor is halted for debugging the counter does not decrement.

The system timer registers are:

Table 12-33. System timer registers summary

Address	Name	Type	Required privilege	Reset value	Description
0xE000E010	CTRL	RW	Privileged	0x00000004	“SysTick Control and Status Register” on page 190
0xE000E014	LOAD	RW	Privileged	0x00000000	“SysTick Reload Value Register” on page 191
0xE000E018	VAL	RW	Privileged	0x00000000	“SysTick Current Value Register” on page 192
0xE000E01C	CALIB	RO	Privileged	0x0002904 (1)	“SysTick Calibration Value Register” on page 193

1. SysTick calibration value.

12.21.1 SysTick Control and Status Register

The SysTick CTRL register enables the SysTick features. See the register summary in Table 12-33 on page 189 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							COUNTFLAG

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved					CLKSOURCE	TICKINT	ENABLE

- **COUNTFLAG**

Returns 1 if timer counted to 0 since last time this was read.

- **CLKSOURCE**

Indicates the clock source:

0 = MCK/8

1 = MCK

- **TICKINT**

Enables SysTick exception request:

0 = counting down to zero does not assert the SysTick exception request

1 = counting down to zero to asserts the SysTick exception request.

Software can use COUNTFLAG to determine if SysTick has ever counted to zero.

- **ENABLE**

Enables the counter:

0 = counter disabled

1 = counter enabled.

When ENABLE is set to 1, the counter loads the RELOAD value from the LOAD register and then counts down. On reaching 0, it sets the COUNTFLAG to 1 and optionally asserts the SysTick depending on the value of TICKINT. It then loads the RELOAD value again, and begins counting.

12.21.2 SysTick Reload Value Register

The LOAD register specifies the start value to load into the VAL register. See the register summary in Table 12-33 on page 189 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							
23	22	21	20	19	18	17	16
RELOAD							
15	14	13	12	11	10	9	8
RELOAD							
7	6	5	4	3	2	1	0
-RELOAD							

- **RELOAD**

Value to load into the VAL register when the counter is enabled and when it reaches 0, see "Calculating the RELOAD value".

12.21.2.1 Calculating the RELOAD value

The RELOAD value can be any value in the range 0x00000001-0x00FFFFFF. A start value of 0 is possible, but has no effect because the SysTick exception request and COUNTFLAG are activated when counting from 1 to 0.

The RELOAD value is calculated according to its use:

- To generate a multi-shot timer with a period of N processor clock cycles, use a RELOAD value of N-1. For example, if the SysTick interrupt is required every 100 clock pulses, set RELOAD to 99.
- To deliver a single SysTick interrupt after a delay of N processor clock cycles, use a RELOAD of value N. For example, if a SysTick interrupt is required after 400 clock pulses, set RELOAD to 400.

12.21.3 SysTick Current Value Register

The VAL register contains the current value of the SysTick counter. See the register summary in Table 12-33 on page 189 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							
23	22	21	20	19	18	17	16
CURRENT							
15	14	13	12	11	10	9	8
CURRENT							
7	6	5	4	3	2	1	0
CURRENT							

- **CURRENT**

Reads return the current value of the SysTick counter.

A write of any value clears the field to 0, and also clears the SysTick CTRL.COUNTFLAG bit to 0.

12.21.4 SysTick Calibration Value Register

The CALIB register indicates the SysTick calibration properties. See the register summary in Table 12-33 on page 189 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
NOREF	SKEW	Reserved					

23	22	21	20	19	18	17	16
TENMS							

15	14	13	12	11	10	9	8
TENMS							

7	6	5	4	3	2	1	0
TENMS							

- **NOREF**

Reads as zero.

- **SKEW**

Reads as zero

- **TENMS**

Read as 0x0002904. The SysTick calibration value is fixed at 0x0002904 (10500), which allows the generation of a time base of 1 ms with SysTick clock at 10.5 MHz (84/8 = 10.5 MHz)

12.21.5 SysTick design hints and tips

The SysTick counter runs on the processor clock. If this clock signal is stopped for low power mode, the SysTick counter stops.

Ensure software uses aligned word accesses to access the SysTick registers.

12.22 Memory protection unit

This section describes the *Memory protection unit* (MPU).

The MPU divides the memory map into a number of regions, and defines the location, size, access permissions, and memory attributes of each region. It supports:

- independent attribute settings for each region
- overlapping regions
- export of memory attributes to the system.

The memory attributes affect the behavior of memory accesses to the region. The Cortex-M3 MPU defines:

- eight separate memory regions, 0-7
- a background region.

When memory regions overlap, a memory access is affected by the attributes of the region with the highest number. For example, the attributes for region 7 take precedence over the attributes of any region that overlaps region 7.

The background region has the same memory access attributes as the default memory map, but is accessible from privileged software only.

The Cortex-M3 MPU memory map is unified. This means instruction accesses and data accesses have same region settings.

If a program accesses a memory location that is prohibited by the MPU, the processor generates a memory management fault. This causes a fault exception, and might cause termination of the process in an OS environment.

In an OS environment, the kernel can update the MPU region setting dynamically based on the process to be executed. Typically, an embedded OS uses the MPU for memory protection.

Configuration of MPU regions is based on memory types, see “Memory regions, types and attributes” on page 58.

Table 12-34 shows the possible MPU region attributes. These include Share ability and cache behavior attributes that are not relevant to most microcontroller implementations. See “MPU configuration for a microcontroller” on page 206 for guidelines for programming such an implementation.

Table 12-34. Memory attributes summary

Memory type	Shareability	Other attributes	Description
Strongly- ordered	-	-	All accesses to Strongly-ordered memory occur in program order. All Strongly-ordered regions are assumed to be shared.
Device	Shared	-	Memory-mapped peripherals that several processors share.
	Non-shared	-	Memory-mapped peripherals that only a single processor uses.
Normal	Shared		Normal memory that is shared between several processors.
	Non-shared		Normal memory that only a single processor uses.

Use the MPU registers to define the MPU regions and their attributes. The MPU registers are:

Table 12-35. MPU registers summary

Address	Name	Type	Required privilege	Reset value	Description
0xE000ED90	TYPE	RO	Privileged	0x00000800	“MPU Type Register” on page 196
0xE000ED94	CTRL	RW	Privileged	0x00000000	“MPU Control Register” on page 197
0xE000ED98	RNR	RW	Privileged	0x00000000	“MPU Region Number Register” on page 199
0xE000ED9C	RBAR	RW	Privileged	0x00000000	“MPU Region Base Address Register” on page 200
0xE000EDA0	RASR	RW	Privileged	0x00000000	“MPU Region Attribute and Size Register” on page 201
0xE000EDA4	RBAR_A1	RW	Privileged	0x00000000	Alias of RBAR, see “MPU Region Base Address Register” on page 200
0xE000EDA8	RASR_A1	RW	Privileged	0x00000000	Alias of RASR, see “MPU Region Attribute and Size Register” on page 201
0xE000EDAC	RBAR_A2	RW	Privileged	0x00000000	Alias of RBAR, see “MPU Region Base Address Register” on page 200
0xE000EDB0	RASR_A2	RW	Privileged	0x00000000	Alias of RASR, see “MPU Region Attribute and Size Register” on page 201
0xE000EDB4	RBAR_A3	RW	Privileged	0x00000000	Alias of RBAR, see “MPU Region Base Address Register” on page 200
0xE000EDB8	RASR_A3	RW	Privileged	0x00000000	Alias of RASR, see “MPU Region Attribute and Size Register” on page 201

12.22.1 MPU Type Register

The TYPE register indicates whether the MPU is present, and if so, how many regions it supports. See the register summary in Table 12-35 on page 195 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
IREGION							

15	14	13	12	11	10	9	8
DREGION							

7	6	5	4	3	2	1	0
Reserved							SEPARATE

- **IREGION**

Indicates the number of supported MPU instruction regions.

Always contains 0x00. The MPU memory map is unified and is described by the DREGION field.

- **DREGION**

Indicates the number of supported MPU data regions:

0x08 = Eight MPU regions.

- **SEPARATE**

Indicates support for unified or separate instruction and date memory maps:

0 = unified.

12.22.2 MPU Control Register

The MPU CTRL register:

- enables the MPU
- enables the default memory map background region
- enables use of the MPU when in the hard fault, *Non-maskable Interrupt* (NMI), and FAULTMASK escalated handlers.

See the register summary in Table 12-35 on page 195 for the MPU CTRL attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
Reserved					PRIVDEFENA	HFNMIENA	ENABLE

- **PRIVDEFENA**

Enables privileged software access to the default memory map:

0 = If the MPU is enabled, disables use of the default memory map. Any memory access to a location not covered by any enabled region causes a fault.

1 = If the MPU is enabled, enables use of the default memory map as a background region for privileged software accesses.

When enabled, the background region acts as if it is region number -1. Any region that is defined and enabled has priority over this default map.

If the MPU is disabled, the processor ignores this bit.

- **HFNMIENA**

Enables the operation of MPU during hard fault, NMI, and FAULTMASK handlers.

When the MPU is enabled:

0 = MPU is disabled during hard fault, NMI, and FAULTMASK handlers, regardless of the value of the ENABLE bit

1 = the MPU is enabled during hard fault, NMI, and FAULTMASK handlers.

When the MPU is disabled, if this bit is set to 1 the behavior is Unpredictable.

- **ENABLE**

Enables the MPU:

0 = MPU disabled

1 = MPU enabled.

When ENABLE and PRIVDEFENA are both set to 1:

For privileged accesses, the *default memory map* is as described in "Memory model" on page 58. Any access by privileged software that does not address an enabled memory region behaves as defined by the default memory map.

Any access by unprivileged software that does not address an enabled memory region causes a memory management fault.

XN and Strongly-ordered rules always apply to the System Control Space regardless of the value of the ENABLE bit.

When the ENABLE bit is set to 1, at least one region of the memory map must be enabled for the system to function unless the PRIVDEFENA bit is set to 1. If the PRIVDEFENA bit is set to 1 and no regions are enabled, then only privileged software can operate.

When the ENABLE bit is set to 0, the system uses the default memory map. This has the same memory attributes as if the MPU is not implemented, see Table 12-34 on page 194. The default memory map applies to accesses from both privileged and unprivileged software.

When the MPU is enabled, accesses to the System Control Space and vector table are always permitted. Other areas are accessible based on regions and whether PRIVDEFENA is set to 1.

Unless HFNMIENA is set to 1, the MPU is not enabled when the processor is executing the handler for an exception with priority –1 or –2. These priorities are only possible when handling a hard fault or NMI exception, or when FAULTMASK is enabled. Setting the HFNMIENA bit to 1 enables the MPU when operating with these two priorities.

12.22.3 MPU Region Number Register

The RNR selects which memory region is referenced by the RBAR and RASR registers. See the register summary in Table 12-35 on page 195 for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24
Reserved							

23	22	21	20	19	18	17	16
Reserved							

15	14	13	12	11	10	9	8
Reserved							

7	6	5	4	3	2	1	0
REGION							

- **REGION**

Indicates the MPU region referenced by the RBAR and RASR registers.

The MPU supports 8 memory regions, so the permitted values of this field are 0-7.

Normally, you write the required region number to this register before accessing the RBAR or RASR. However you can change the region number by writing to the RBAR with the VALID bit set to 1, see "MPU Region Base Address Register" on page 200. This write updates the value of the REGION field.

12.22.4 MPU Region Base Address Register

The RBAR defines the base address of the MPU region selected by the RNR, and can update the value of the RNR. See the register summary in Table 12-35 on page 195 for its attributes.

Write RBAR with the VALID bit set to 1 to change the current region number and update the RNR. The bit assignments are:

31	30	29	28	27	26	25	24
ADDR							
23	22	21	20	19	18	17	16
ADDR							
15	14	13	12	11	10	9	N
ADDR							
N-1	6	5	4	3	2	1	0
Reserved			VALID	REGION			

- **ADDR**

Region base address field. The value of N depends on the region size. For more information see "The ADDR field".

- **VALID**

MPU Region Number valid bit:

Write:

0 = RNR not changed, and the processor:

updates the base address for the region specified in the RNR

ignores the value of the REGION field

1 = the processor:

updates the value of the RNR to the value of the REGION field

updates the base address for the region specified in the REGION field.

Always reads as zero.

- **REGION**

MPU region field:

For the behavior on writes, see the description of the VALID field.

On reads, returns the current region number, as specified by the RNR.

12.22.4.1 The ADDR field

The ADDR field is bits[31:N] of the RBAR. The region size, as specified by the SIZE field in the RASR, defines the value of N:

$$N = Log_2(\text{Region size in bytes}),$$

If the region size is configured to 4GB, in the RASR, there is no valid ADDR field. In this case, the region occupies the complete memory map, and the base address is 0x00000000.

The base address is aligned to the size of the region. For example, a 64KB region must be aligned on a multiple of 64KB, for example, at 0x00010000 or 0x00020000.

12.22.5 MPU Region Attribute and Size Register

The RASR defines the region size and memory attributes of the MPU region specified by the RNR, and enables that region and any subregions. See the register summary in Table 12-35 on page 195 for its attributes.

RASR is accessible using word or halfword accesses:

- the most significant halfword holds the region attributes
- the least significant halfword holds the region size and the region and subregion enable bits.

The bit assignments are:

31	30	29	28	27	26	25	24
Reserved			XN	Reserved	AP		

23	22	21	20	19	18	17	16
Reserved		TEX			S	C	B

15	14	13	12	11	10	9	8
SRD							

7	6	5	4	3	2	1	0
Reserved		SIZE					ENABLE

- **XN**

Instruction access disable bit:

0 = instruction fetches enabled

1 = instruction fetches disabled.

- **AP**

Access permission field, see Table 12-39 on page 204.

- **TEX, C, B**

Memory access attributes, see Table 12-37 on page 203.

- **S**

Shareable bit, see Table 12-36 on page 202.

- **SRD**

Subregion disable bits. For each bit in this field:

0 = corresponding sub-region is enabled

1 = corresponding sub-region is disabled

See “Subregions” on page 205 for more information.

Region sizes of 128 bytes and less do not support subregions. When writing the attributes for such a region, write the SRD field as 0x00.

- **SIZE**

Specifies the size of the MPU protection region. The minimum permitted value is 3 (b00010), see See “SIZE field values” on page 202 for more information.

- **ENABLE**

Region enable bit.

For information about access permission, see “MPU access permission attributes”.

12.22.5.1 SIZE field values

The SIZE field defines the size of the MPU memory region specified by the RNR. as follows:

$$\text{(Region size in bytes)} = 2^{(SIZE+1)}$$

The smallest permitted region size is 32B, corresponding to a SIZE value of 4. Table 12-36 gives example SIZE values, with the corresponding region size and value of N in the RBAR.

Table 12-36. Example SIZE field values

SIZE value	Region size	Value of N (1)	Note
b00100 (4)	32B	5	Minimum permitted size
b01001 (9)	1KB	10	-
b10011 (19)	1MB	20	-
b11101 (29)	1GB	30	-
b11111 (31)	4GB	b01100	Maximum possible size

1. In the RBAR, see “MPU Region Base Address Register” on page 200.

12.22.6 MPU access permission attributes

This section describes the MPU access permission attributes. The access permission bits, TEX, C, B, S, AP, and XN, of the RASR, control access to the corresponding memory region. If an access is made to an area of memory without the required permissions, then the MPU generates a permission fault.

Table 12-37 shows the encodings for the TEX, C, B, and S access permission bits.

Table 12-37. TEX, C, B, and S encoding

TEX	C	B	S	Memory type	Shareability	Other attributes
b000	0	0	x[1]	Strongly-ordered	Shareable	-
		1	x[1]	Device	Shareable	-
	1	0	0	Normal	Not shareable	Outer and inner write-through. No write allocate.
			1		Shareable	
		1	0	Normal	Not shareable	Outer and inner write-back. No write allocate.
			1		Shareable	
b001	0	0	0	Normal	Not shareable	
			1		Shareable	
		1	x[1]	Reserved encoding		-
	1	0	x[1]	Implementation defined attributes.		-
		1	0	Normal	Not shareable	Outer and inner write-back. Write and read allocate.
			1		Shareable	
b010	0	0	x[1]	Device	Not shareable	Nonshared Device.
		1	x[1]	Reserved encoding		-
	1	x[1]	x[1]	Reserved encoding		-
b1BB	A	A	0	Normal	Not shareable	
			1		Shareable	

1. The MPU ignores the value of this bit.

Table 12-38 shows the cache policy for memory attribute encodings with a TEX value is in the range 4-7.

Table 12-38. Cache policy for memory attribute encoding

Encoding, AA or BB	Corresponding cache policy
00	Non-cacheable
01	Write back, write and read allocate
10	Write through, no write allocate
11	Write back, no write allocate

Table 12-39 shows the AP encodings that define the access permissions for privileged and unprivileged software.

Table 12-39. AP encoding

AP[2:0]	Privileged permissions	Unprivileged permissions	Description
000	No access	No access	All accesses generate a permission fault
001	RW	No access	Access from privileged software only
010	RW	RO	Writes by unprivileged software generate a permission fault
011	RW	RW	Full access
100	Unpredictable	Unpredictable	Reserved
101	RO	No access	Reads by privileged software only
110	RO	RO	Read only, by privileged or unprivileged software
111	RO	RO	Read only, by privileged or unprivileged software

12.22.7 MPU mismatch

When an access violates the MPU permissions, the processor generates a memory management fault, see "Exceptions and interrupts" on page 57. The MMFSR indicates the cause of the fault. See "Memory Management Fault Status Register" on page 180 for more information.

12.22.8 Updating an MPU region

To update the attributes for an MPU region, update the RNR, RBAR and RASR registers. You can program each register separately, or use a multiple-word write to program all of these registers. You can use the RBAR and RASR aliases to program up to four regions simultaneously using an STM instruction.

12.22.8.1 Updating an MPU region using separate words

Simple code to configure one region:

```
; R1 = region number
; R2 = size/enable
; R3 = attributes
; R4 = address
LDR R0,=MPU_RNR         ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]      ; Region Number
STR R4, [R0, #0x4]      ; Region Base Address
STRH R2, [R0, #0x8]     ; Region Size and Enable
STRH R3, [R0, #0xA]     ; Region Attribute
```

Disable a region before writing new region settings to the MPU if you have previously enabled the region being changed. For example:

```
; R1 = region number
; R2 = size/enable
; R3 = attributes
; R4 = address
LDR R0,=MPU_RNR          ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]       ; Region Number
BIC R2, R2, #1           ; Disable
STRH R2, [R0, #0x8]      ; Region Size and Enable
STR R4, [R0, #0x4]       ; Region Base Address
STRH R3, [R0, #0xA]      ; Region Attribute
ORR R2, #1               ; Enable
STRH R2, [R0, #0x8]      ; Region Size and Enable
```

Software must use memory barrier instructions:

- before MPU setup if there might be outstanding memory transfers, such as buffered writes, that might be affected by the change in MPU settings
- after MPU setup if it includes memory transfers that must use the new MPU settings.

However, memory barrier instructions are not required if the MPU setup process starts by entering an exception handler, or is followed by an exception return, because the exception entry and exception return mechanism cause memory barrier behavior.

Software does not need any memory barrier instructions during MPU setup, because it accesses the MPU through the PPB, which is a Strongly-Ordered memory region.

For example, if you want all of the memory access behavior to take effect immediately after the programming sequence, use a DSB instruction and an ISB instruction. A DSB is required after changing MPU settings, such as at the end of context switch. An ISB is required if the code that programs the MPU region or regions is entered using a branch or call. If the programming sequence is entered using a return from exception, or by taking an exception, then you do not require an ISB.

12.22.8.2 Updating an MPU region using multi-word writes

You can program directly using multi-word writes, depending on how the information is divided. Consider the following reprogramming:

```
; R1 = region number
; R2 = address
; R3 = size, attributes in one
LDR R0, =MPU_RNR    ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]  ; Region Number
STR R2, [R0, #0x4]  ; Region Base Address
STR R3, [R0, #0x8]  ; Region Attribute, Size and Enable
```

Use an STM instruction to optimize this:

```
; R1 = region number
; R2 = address
; R3 = size, attributes in one
LDR R0, =MPU_RNR    ; 0xE000ED98, MPU region number register
STM R0, {R1-R3}     ; Region Number, address, attribute, size and enable
```

You can do this in two words for pre-packed information. This means that the RBAR contains the required region number and had the VALID bit set to 1, see “MPU Region Base Address Register” on page 200. Use this when the data is statically packed, for example in a boot loader:

```
; R1 = address and region number in one
; R2 = size and attributes in one
LDR R0, =MPU_RBAR   ; 0xE000ED9C, MPU Region Base register
STR R1, [R0, #0x0]  ; Region base address and
                    ; region number combined with VALID (bit 4) set to 1
STR R2, [R0, #0x4]  ; Region Attribute, Size and Enable
```

Use an STM instruction to optimize this:

```
; R1 = address and region number in one
; R2 = size and attributes in one
LDR R0,=MPU_RBAR    ; 0xE000ED9C, MPU Region Base register
STM R0, {R1-R2}     ; Region base address, region number and VALID bit,
                    ; and Region Attribute, Size and Enable
```

12.22.8.3 Subregions

Regions of 256 bytes or more are divided into eight equal-sized subregions. Set the corresponding bit in the SRD field of the RASR to disable a subregion, see “MPU Region Attribute and Size Register” on page 201. The least significant bit of SRD controls the first subregion, and the most significant bit controls the last subregion. Disabling

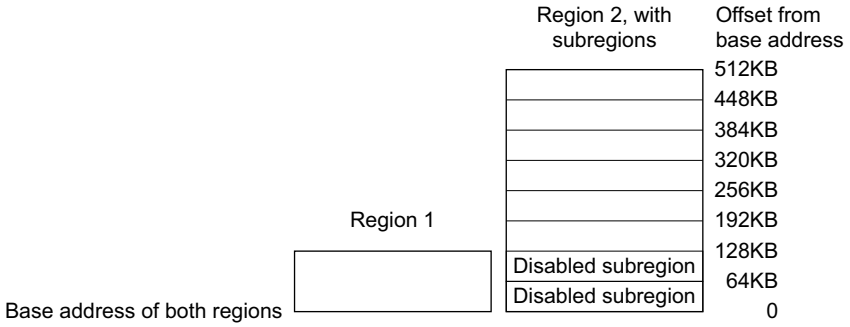
a subregion means another region overlapping the disabled range matches instead. If no other enabled region overlaps the disabled subregion the MPU issues a fault.

Regions of 32, 64, and 128 bytes do not support subregions, With regions of these sizes, you must set the SRD field to 0x00, otherwise the MPU behavior is Unpredictable.

12.22.8.4 Example of SRD use

Two regions with the same base address overlap. Region one is 128KB, and region two is 512KB. To ensure the attributes from region one apply to the first128KB region, set the SRD field for region two to b00000011 to disable the first two subregions, as Figure 12-9 shows

Figure 12-9. SRD use



12.22.9 MPU design hints and tips

To avoid unexpected behavior, disable the interrupts before updating the attributes of a region that the interrupt handlers might access.

Ensure software uses aligned accesses of the correct size to access MPU registers:

- except for the RASR, it must use aligned word accesses
- for the RASR it can use byte or aligned halfword or word accesses.

The processor does not support unaligned accesses to MPU registers.

When setting up the MPU, and if the MPU has previously been programmed, disable unused regions to prevent any previous region settings from affecting the new MPU setup.

12.22.9.1 MPU configuration for a microcontroller

Usually, a microcontroller system has only a single processor and no caches. In such a system, program the MPU as follows:

Table 12-40. Memory region attributes for a microcontroller

Memory region	TEX	C	B	S	Memory type and attributes
Flash memory	b000	1	0	0	Normal memory, Non-shareable, write-through
Internal SRAM	b000	1	0	1	Normal memory, Shareable, write-through
External SRAM	b000	1	1	1	Normal memory, Shareable, write-back, write-allocate
Peripherals	b000	0	1	1	Device memory, Shareable

In most microcontroller implementations, the share ability and cache policy attributes do not affect the system behavior. However, using these settings for the MPU regions can make the application code more portable. The values given are for typical situations. In special systems, such as multiprocessor designs or designs with a separate DMA engine, the share ability attribute might be important. In these cases refer to the recommendations of the memory device manufacturer.

12.23 Glossary

This glossary describes some of the terms used in technical documents from ARM.

Abort

A mechanism that indicates to a processor that the value associated with a memory access is invalid. An abort can be caused by the external or internal memory system as a result of attempting to access invalid instruction or data memory.

Aligned

A data item stored at an address that is divisible by the number of bytes that defines the data size is said to be aligned. Aligned words and halfwords have addresses that are divisible by four and two respectively. The terms word-aligned and halfword-aligned therefore stipulate addresses that are divisible by four and two respectively.

Banked register

A register that has multiple physical copies, where the state of the processor determines which copy is used. The Stack Pointer, SP (R13) is a banked register.

Base register

In instruction descriptions, a register specified by a load or store instruction that is used to hold the base value for the instruction's address calculation. Depending on the instruction and its addressing mode, an offset can be added to or subtracted from the base register value to form the address that is sent to memory.

See also "Index register"

Breakpoint

A breakpoint is a mechanism provided by debuggers to identify an instruction at which program execution is to be halted. Breakpoints are inserted by the programmer to enable inspection of register contents, memory locations, variable values at fixed points in the program execution to test that the program is operating correctly. Breakpoints are removed after the program is successfully tested.

Condition field

A four-bit field in an instruction that specifies a condition under which the instruction can execute.

Conditional execution

If the condition code flags indicate that the corresponding condition is true when the instruction starts executing, it executes normally. Otherwise, the instruction does nothing.

Context

The environment that each process operates in for a multitasking operating system. In ARM processors, this is limited to mean the physical address range that it can access in memory and the associated memory access permissions.

Coprocessor

A processor that supplements the main processor. Cortex-M3 does not support any coprocessors.

Debugger

A debugging system that includes a program, used to detect, locate, and correct software faults, together with custom hardware that supports software debugging.

Direct Memory Access (DMA)

An operation that accesses main memory directly, without the processor performing any accesses to the data concerned.

Doubleword

A 64-bit data item. The contents are taken as being an unsigned integer unless otherwise stated.

Doubleword-aligned

A data item having a memory address that is divisible by eight.

Endianness

Byte ordering. The scheme that determines the order that successive bytes of a data word are stored in memory. An aspect of the system's memory mapping.

See also "Little-endian (LE)"

Exception

An event that interrupts program execution. When an exception occurs, the processor suspends the normal program flow and starts execution at the address indicated by the corresponding exception vector. The indicated address contains the first instruction of the handler for the exception.

An exception can be an interrupt request, a fault, or a software-generated system exception. Faults include attempting an invalid memory access, attempting to execute an instruction in an invalid processor state, and attempting to execute an undefined instruction.

Exception service routine

See "Interrupt handler".

Exception vector

See "Interrupt vector".

Flat address mapping

A system of organizing memory in which each physical address in the memory space is the same as the corresponding virtual address.

Halfword

A 16-bit data item.

Illegal instruction

An instruction that is architecturally Undefined.

Implementation-defined

The behavior is not architecturally defined, but is defined and documented by individual implementations.

Implementation-specific

The behavior is not architecturally defined, and does not have to be documented by individual implementations. Used when there are a number of implementation options available and the option chosen does not affect software compatibility.

Index register

In some load and store instruction descriptions, the value of this register is used as an offset to be added to or subtracted from the base register value to form the address that is sent to memory. Some addressing modes optionally enable the index register value to be shifted prior to the addition or subtraction.

See also "Base register"

Instruction cycle count

The number of cycles that an instruction occupies the Execute stage of the pipeline.

Interrupt handler

A program that control of the processor is passed to when an interrupt occurs.

Interrupt vector

One of a number of fixed addresses in low memory, or in high memory if high vectors are configured, that contains the first instruction of the corresponding interrupt handler.

Little-endian (LE)

Byte ordering scheme in which bytes of increasing significance in a data word are stored at increasing addresses in memory.

See also “Condition field”, “Endianness”.

Little-endian memory

Memory in which:

a byte or halfword at a word-aligned address is the least significant byte or halfword within the word at that address

a byte at a halfword-aligned address is the least significant byte within the halfword at that address.

Load/store architecture

A processor architecture where data-processing operations only operate on register contents, not directly on memory contents.

Memory Protection Unit (MPU)

Hardware that controls access permissions to blocks of memory. An MPU does not perform any address translation.

Prefetching

In pipelined processors, the process of fetching instructions from memory to fill up the pipeline before the preceding instructions have finished executing. Prefetching an instruction does not mean that the instruction has to be executed.

Read

Reads are defined as memory operations that have the semantics of a load. Reads include the Thumb instructions LDM, LDR, LDRSH, LDRH, LDRSB, LDRB, and POP.

Region

A partition of memory space.

Reserved

A field in a control register or instruction format is reserved if the field is to be defined by the implementation, or produces Unpredictable results if the contents of the field are not zero. These fields are reserved for use in future extensions of the architecture or are implementation-specific. All reserved bits not used by the implementation must be written as 0 and read as 0.

Should Be One (SBO)

Write as 1, or all 1s for bit fields, by software. Writing as 0 produces Unpredictable results.

Should Be Zero (SBZ)

Write as 0, or all 0s for bit fields, by software. Writing as 1 produces Unpredictable results.

Should Be Zero or Preserved (SBZP)

Write as 0, or all 0s for bit fields, by software, or preserved by writing the same value back that has been previously read from the same field on the same processor.

Thread-safe

In a multi-tasking environment, thread-safe functions use safeguard mechanisms when accessing shared resources, to ensure correct operation without the risk of shared access conflicts.

Thumb instruction

One or two halfwords that specify an operation for a processor to perform. Thumb instructions must be halfword-aligned.

Unaligned

A data item stored at an address that is not divisible by the number of bytes that defines the data size is said to be unaligned. For example, a word stored at an address that is not divisible by four.

Undefined

Indicates an instruction that generates an Undefined instruction exception.

Unpredictable (UNP)

You cannot rely on the behavior. Unpredictable behavior must not represent security holes. Unpredictable behavior must not halt or hang the processor, or any parts of the system.

Warm reset

Also known as a core reset. Initializes the majority of the processor excluding the debug controller and debug logic. This type of reset is useful if you are using the debugging features of a processor.

Word

A 32-bit data item.

Write

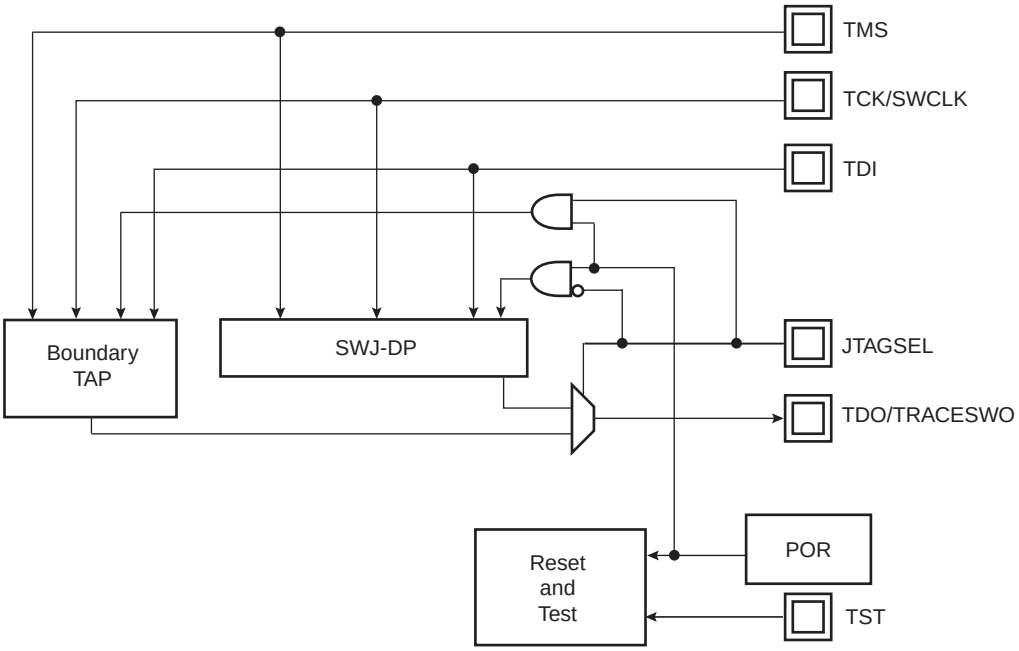
Writes are defined as operations that have the semantics of a store. Writes include the Thumb instructions STM, STR, STRH, STRB, and PUSH.

13. Debug and Test Features

13.1 Overview

The SAM3U Series microcontrollers feature a number of complementary debug and test capabilities. The Serial Wire/JTAG Debug Port (SWJ-DP) combining a Serial Wire Debug Port (SW-DP) and JTAG Debug (JTAG-DP) port is used for standard debugging functions, such as downloading code and single-stepping through programs. It also embeds a serial wire trace.

Figure 13-1. Debug and Test Block Diagram



13.2 Embedded Characteristics

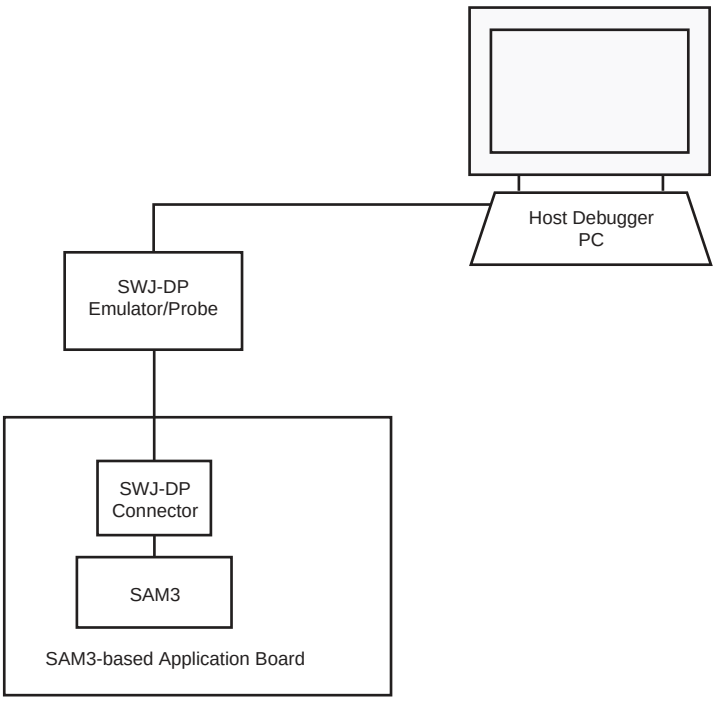
- Debug access to all memory and registers in the system, including Cortex-M3 register bank when the core is running, halted, or held in reset
- Serial Wire Debug Port (SW-DP) and Serial Wire JTAG Debug Port (SWJ-DP) debug access
- Flash Patch and Breakpoint (FPB) unit for implementing break points and code patches
- Data Watchpoint and Trace (DWT) unit for implementing watch points, data tracing, and system profiling
- Instrumentation Trace Macrocell (ITM) for support of **printf** style debugging
- IEEE® 1149.1 JTAG Boundary-scan on all digital pins

13.3 Application Examples

13.3.1 Debug Environment

Figure 13-2 shows a complete debug environment example. The SWJ-DP interface is used for standard debugging functions, such as downloading code and single-stepping through the program and viewing core and peripheral registers.

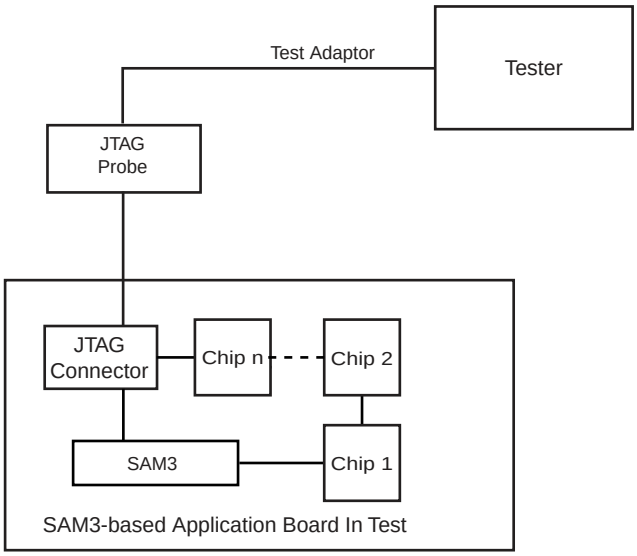
Figure 13-2. Application Debug Environment Example



13.3.2 Test Environment

Figure 13-3 shows a test environment example (JTAG Boundary scan). Test vectors are sent and interpreted by the tester. In this example, the “board in test” is designed using a number of JTAG-compliant devices. These devices can be connected to form a single scan chain.

Figure 13-3. Application Test Environment Example



13.4 Debug and Test Pin Description

Table 13-1. Debug and Test Signal List

Signal Name	Function	Type	Active Level
Reset/Test			
NRST	Microcontroller Reset	Input/Output	Low
TST	Test Select	Input	
SWD/JTAG			
TCK/SWCLK	Test Clock/Serial Wire Clock	Input	
TDI	Test Data In	Input	
TDO/TRACESWO	Test Data Out/Trace Asynchronous Data Out	Output(1)	
TMS/SWDIO	Test Mode Select/Serial Wire Input/Output	Input	
JTAGSEL	JTAG Selection	Input	High

Note: 1. TDO pin is set in input mode when the Cortex-M3 Core is not in debug mode. Thus an external pull-up (100 kΩ) must be added to avoid current consumption due to floating input.

13.5 Functional Description

13.5.1 Test Pin

One dedicated pin, TST, is used to define the device operating mode. When this pin is at low level during power-up, the device is in normal operating mode. When at high level, the device is in test mode or FFPI mode. The TST pin integrates a permanent pull-down resistor of about 15 kΩ,so that it can be left unconnected for normal operation. Note that when setting the TST pin to low or high level at power up, it must remain in the same state during the duration of the whole operation.

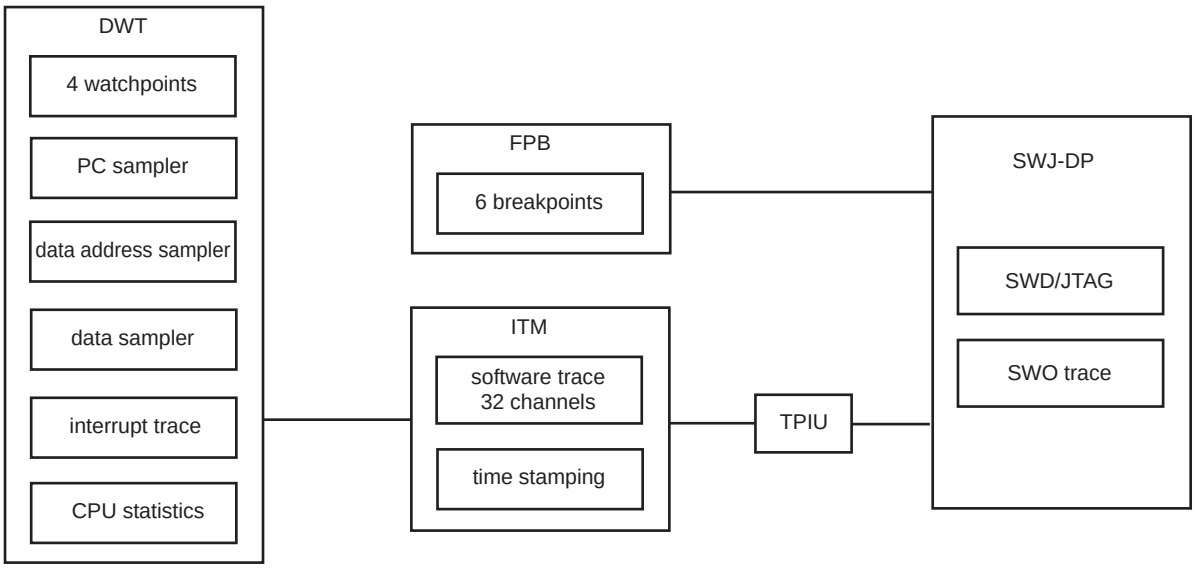
13.5.2 Debug Architecture

Figure 13-4 shows the Debug Architecture used in the SAM3. The Cortex-M3 embeds five functional units for debug:

- SWJ-DP (Serial Wire/JTAG Debug Port)
- FPB (Flash Patch Breakpoint)
- DWT (Data Watchpoint and Trace)
- ITM (Instrumentation Trace Macrocell)
- TPIU (Trace Port Interface Unit)

The debug architecture information that follows is mainly dedicated to developers of SWJ-DP Emulators/Probes and debugging tool vendors for Cortex M3-based microcontrollers. For further details on SWJ-DP see the Cortex M3 technical reference manual.

Figure 13-4. Debug Architecture



13.5.3 Serial Wire/JTAG Debug Port (SWJ-DP)

The Cortex-M3 embeds a SWJ-DP Debug port which is the standard CoreSight™ debug port. It combines Serial Wire Debug Port (SW-DP), from 2 to 3 pins and JTAG debug Port (JTAG-DP), 5 pins.

By default, the JTAG Debug Port is active. If the host debugger wants to switch to the Serial Wire Debug Port, it must provide a dedicated JTAG sequence on TMS/SWDIO and TCK/SWCLK which disables JTAG-DP and enables SW-DP.

When the Serial Wire Debug Port is active, TDO/TRACESWO can be used for trace. The asynchronous TRACE output (TRACESWO) is multiplexed with TDO. The asynchronous trace can only be used with SW-DP, not JTAG-DP.

Table 13-2. SWJ-DP Pin List

Pin Name	JTAG Port	Serial Wire Debug Port
TMS/SWDIO	TMS	SWDIO
TCK/SWCLK	TCK	SWCLK
TDI	TDI	–
TDO/TRACESWO	TDO	TRACESWO (optional: trace)

SW-DP or JTAG-DP mode is selected when JTAGSEL is low. It is not possible to switch directly between SWJ-DP and JTAG boundary scan operations. A chip reset must be performed after JTAGSEL is changed.

13.5.3.1 SW-DP and JTAG-DP Selection Mechanism

Debug port selection mechanism is done by sending specific **SWDIOTMS** sequence. The JTAG-DP is selected by default after reset.

- Switch from JTAG-DP to SW-DP. The sequence is:
  - Send more than 50 **SWCLKTCK** cycles with **SWDIOTMS** = 1
  - Send the 16-bit sequence on **SWDIOTMS** = 0111100111100111 (0x79E7 MSB first)
  - Send more than 50 **SWCLKTCK** cycles with **SWDIOTMS** = 1
- Switch from SWD to JTAG. The sequence is:
  - Send more than 50 **SWCLKTCK** cycles with **SWDIOTMS** = 1
  - Send the 16-bit sequence on **SWDIOTMS** = 0011110011100111 (0x3CE7 MSB first)
  - Send more than 50 **SWCLKTCK** cycles with **SWDIOTMS** = 1

13.5.4 FPB (Flash Patch Breakpoint)

The FPB:

- Implements hardware breakpoints
- Patches code and data from code space to system space.

The FPB unit contains:

- Two literal comparators for matching against literal loads from Code space, and remapping to a corresponding area in System space.
- Six instruction comparators for matching against instruction fetches from Code space and remapping to a corresponding area in System space.
- Alternatively, comparators can also be configured to generate a Breakpoint instruction to the processor core on a match.

13.5.5 DWT (Data Watchpoint and Trace)

The DWT contains four comparators which can be configured to generate the following:

- PC sampling packets at set intervals
- PC or Data watchpoint packets
- Watchpoint event to halt core

The DWT contains counters for the items that follow:

- Clock cycle (CYCCNT)
- Folded instructions
- Load Store Unit (LSU) operations
- Sleep Cycles
- CPI (all instruction cycles except for the first cycle)
- Interrupt overhead

13.5.6 ITM (Instrumentation Trace Macrocell)

The ITM is an application driven trace source that supports printf style debugging to trace Operating System (OS) and application events, and emits diagnostic system information. The ITM emits trace information as packets which can be generated by three different sources with several priority levels:

- **Software trace**: Software can write directly to ITM stimulus registers. This can be done thanks to the “printf” function. For more information, refer to Section 13.5.6.1 “How to Configure the ITM”.
- **Hardware trace**: The ITM emits packets generated by the DWT.
- **Time stamping**: Timestamps are emitted relative to packets. The ITM contains a 21-bit counter to generate the timestamp.

13.5.6.1 How to Configure the ITM

The following example describes how to output trace data in asynchronous trace mode.

- Configure the TPIU for asynchronous trace mode (refer to Section 13.5.6.3 “5.4.3. How to Configure the TPIU”)
- Enable the write accesses into the ITM registers by writing “0xC5ACCE55” into the Lock Access Register (Address: 0xE0000FB0)
- Write 0x00010015 into the Trace Control Register:
  - Enable ITM
  - Enable Synchronization packets
  - Enable SWO behavior
  - Fix the ATB ID to 1
- Write 0x1 into the Trace Enable Register:
  - Enable the Stimulus port 0
- Write 0x1 into the Trace Privilege Register:
  - Stimulus port 0 only accessed in privileged mode (Clearing a bit in this register will result in the corresponding stimulus port being accessible in user mode.)
- Write into the Stimulus port 0 register: TPIU (Trace Port Interface Unit)

  The TPIU acts as a bridge between the on-chip trace data and the Instruction Trace Macrocell (ITM).

  The TPIU formats and transmits trace data off-chip at frequencies asynchronous to the core.

13.5.6.2 Asynchronous Mode

The TPIU is configured in asynchronous mode, trace data are output using the single TRACESWO pin. The TRACESWO signal is multiplexed with the TDO signal of the JTAG Debug Port. As a consequence, asynchronous trace mode is only available when the Serial Wire Debug mode is selected since TDO signal is used in JTAG debug mode.

Two encoding formats are available for the single pin output:

- Manchester encoded stream. This is the reset value.
- NRZ_based UART byte structure

13.5.6.3 5.4.3. How to Configure the TPIU

This example only concerns the asynchronous trace mode.

- Set the TRCENA bit to 1 into the Debug Exception and Monitor Register (0xE000EDFC) to enable the use of trace and debug blocks.
- Write 0x2 into the Selected Pin Protocol Register
  - Select the Serial Wire Output – NRZ
- Write 0x100 into the Formatter and Flush Control Register
- Set the suitable clock prescaler value into the Async Clock Prescaler Register to scale the baud rate of the asynchronous output (this can be done automatically by the debugging tool).

13.5.7 IEEE 1149.1 JTAG Boundary Scan

IEEE 1149.1 JTAG Boundary Scan allows pin-level access independent of the device packaging technology.

IEEE 1149.1 JTAG Boundary Scan is enabled when FWUP, NRST, NRSTB and JTAGSEL are high while TST is tied low during power-up and must be kept in this state during the whole boundary scan operation. The SAMPLE, EXTEST and BYPASS functions are implemented. In SWD/JTAG debug mode, the ARM processor responds with a non-JTAG chip ID that identifies the processor. This is not IEEE 1149.1 JTAG-compliant.

It is not possible to switch directly between JTAG Boundary Scan and SWJ Debug Port operations. A chip reset must be performed after JTAGSEL is changed.

A Boundary-scan Descriptor Language (BSDL) file to set up the test is provided on www.atmel.com.

13.5.7.1 JTAG Boundary-scan Register

The Boundary-scan Register (BSR) contains a number of bits which correspond to active pins and associated control signals.

Each SAM3 input/output pin corresponds to a 3-bit register in the BSR. The OUTPUT bit contains data that can be forced on the pad. The INPUT bit facilitates the observability of data applied to the pad. The CONTROL bit selects the direction of the pad.

For more information, please refer to BDSL files available for the SAM3U Series.

13.5.8 ID Code Register

Access: Read-only

31	30	29	28	27	26	25	24
VERSION				PART NUMBER			

23	22	21	20	19	18	17	16
PART NUMBER							

15	14	13	12	11	10	9	8
PART NUMBER				MANUFACTURER IDENTITY			

7	6	5	4	3	2	1	0
MANUFACTURER IDENTITY							1

- **VERSION[31:28]: Product Version Number**

Set to 0x0.

- **PART NUMBER[27:12]: Product Part Number**

Chip Name	Chip ID
SAM3U	0x5B2A

- **MANUFACTURER IDENTITY[11:1]**

Set to 0x01F.

- **Bit[0] Required by IEEE Std. 1149.1**

Set to 0x1.

Chip Name	JTAG ID Code
SAM3U	05B2_A03F

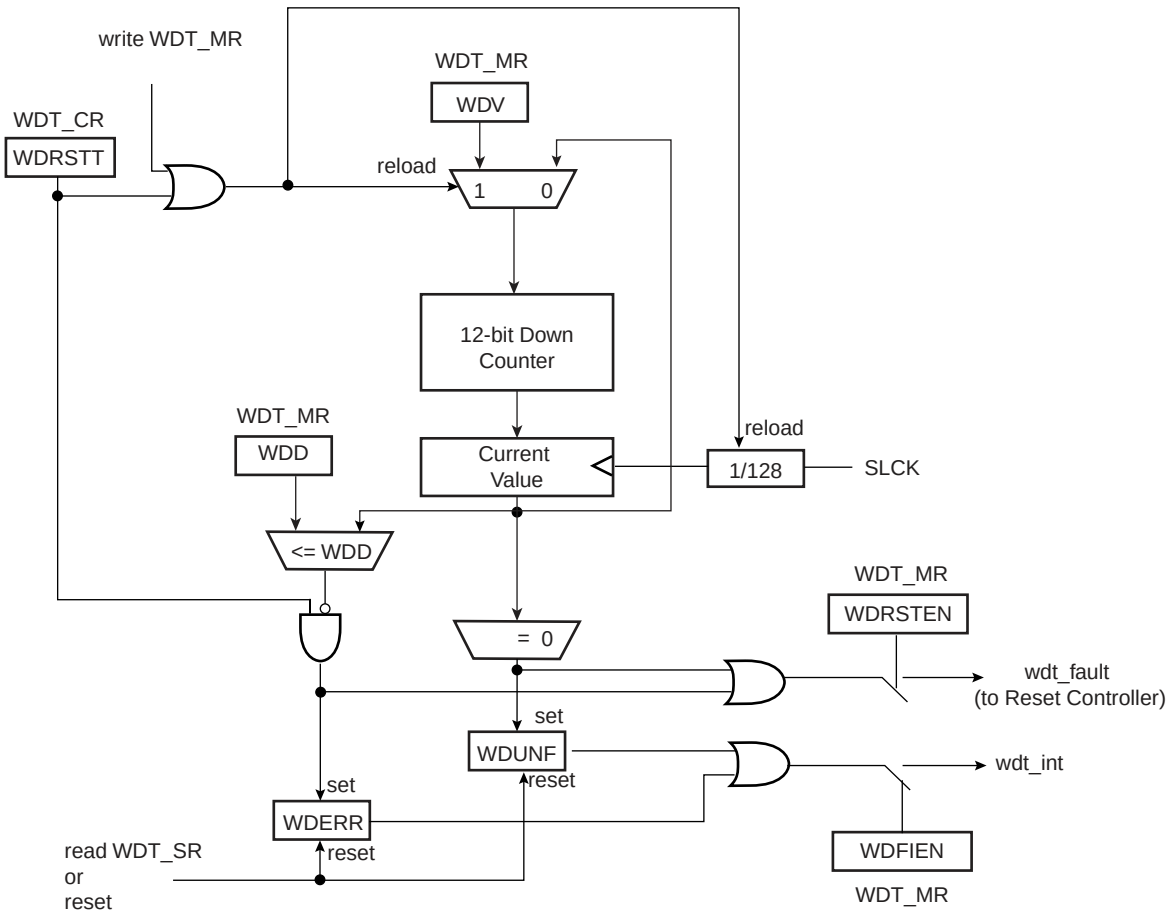
14. Watchdog Timer (WDT)

14.1 Description

The Watchdog Timer can be used to prevent system lock-up if the software becomes trapped in a deadlock. It features a 12-bit down counter that allows a watchdog period of up to 16 seconds (slow clock at 32.768 kHz). It can generate a general reset or a processor reset only. In addition, it can be stopped while the processor is in debug mode or idle mode.

14.2 Block Diagram

Figure 14-1. Watchdog Timer Block Diagram



14.3 Functional Description

The Watchdog Timer can be used to prevent system lock-up if the software becomes trapped in a deadlock. It is supplied with VDDCORE. It restarts with initial values on processor reset.

The Watchdog is built around a 12-bit down counter, which is loaded with the value defined in the field WDV of the Mode Register (WDT_MR). The Watchdog Timer uses the Slow Clock divided by 128 to establish the maximum Watchdog period to be 16 seconds (with a typical Slow Clock of 32.768 kHz).

After a Processor Reset, the value of WDV is 0xFFF, corresponding to the maximum value of the counter with the external reset generation enabled (field WDRSTEN at 1 after a Backup Reset). This means that a default Watchdog is running at reset, i.e., at power-up. The user must either disable it (by setting the WDDIS bit in WDT_MR) if he does not expect to use it or must reprogram it to meet the maximum Watchdog period the application requires.

The Watchdog Mode Register (WDT_MR) can be written only once. Only a processor reset resets it. Writing the WDT_MR register reloads the timer with the newly programmed mode parameters.

In normal operation, the user reloads the Watchdog at regular intervals before the timer underflow occurs, by writing the Control Register (WDT_CR) with the bit WDRSTT to 1. The Watchdog counter is then immediately reloaded from WDT_MR and restarted, and the Slow Clock 128 divider is reset and restarted. The WDT_CR register is write-protected. As a result, writing WDT_CR without the correct hard-coded key has no effect. If an underflow does occur, the “wdt_fault” signal to the Reset Controller is asserted if the bit WDRSTEN is set in the Mode Register (WDT_MR). Moreover, the bit WDUNF is set in the Watchdog Status Register (WDT_SR).

To prevent a software deadlock that continuously triggers the Watchdog, the reload of the Watchdog must occur while the Watchdog counter is within a window between 0 and WDD, WDD is defined in the WatchDog Mode Register WDT_MR.

Any attempt to restart the Watchdog while the Watchdog counter is between WDV and WDD results in a Watchdog error, even if the Watchdog is disabled. The bit WDERR is updated in the WDT_SR and the “wdt_fault” signal to the Reset Controller is asserted.

Note that this feature can be disabled by programming a WDD value greater than or equal to the WDV value. In such a configuration, restarting the Watchdog Timer is permitted in the whole range [0; WDV] and does not generate an error. This is the default configuration on reset (the WDD and WDV values are equal).

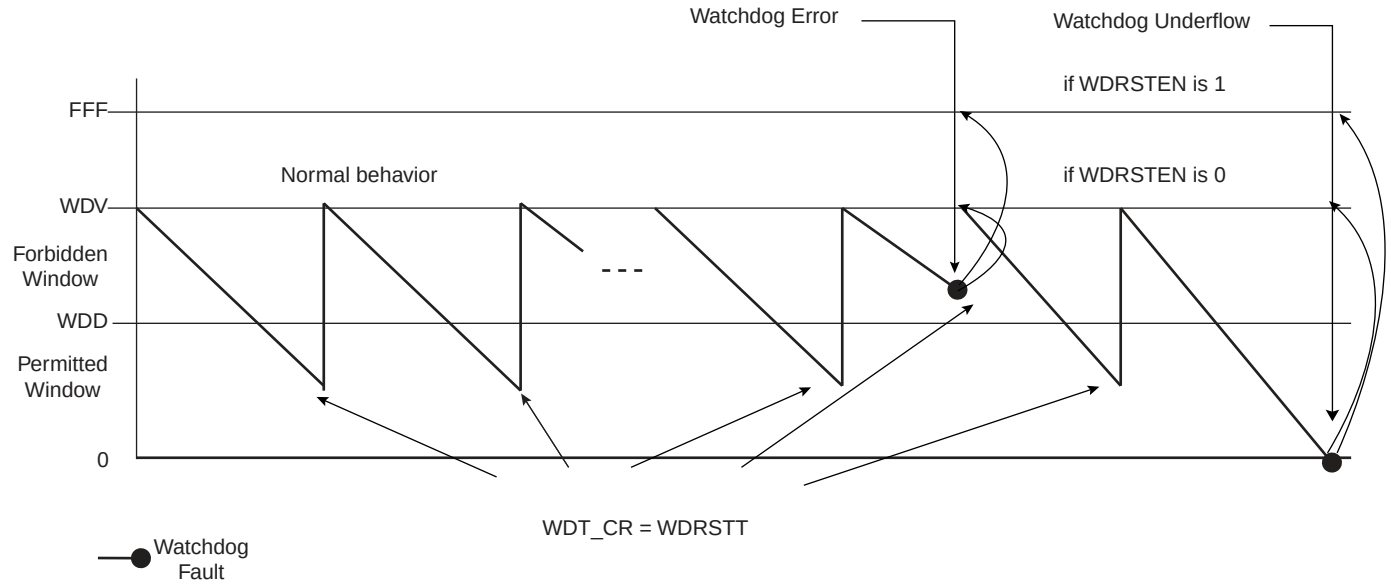
The status bits WDUNF (Watchdog Underflow) and WDERR (Watchdog Error) trigger an interrupt, provided the bit WDFIEN is set in the mode register. The signal “wdt_fault” to the reset controller causes a Watchdog reset if the WDRSTEN bit is set as already explained in the reset controller programmer Datasheet. In that case, the processor and the Watchdog Timer are reset, and the WDERR and WDUNF flags are reset.

If a reset is generated or if WDT_SR is read, the status bits are reset, the interrupt is cleared, and the “wdt_fault” signal to the reset controller is deasserted.

Writing the WDT_MR reloads and restarts the down counter.

While the processor is in debug state or in idle mode, the counter may be stopped depending on the value programmed for the bits WDIDLEHLT and WDDBGHLT in the WDT_MR.

Figure 14-2. Watchdog Behavior



14.4 Watchdog Timer (WDT) User Interface

Table 14-1. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	WDT_CR	Write-only	-
0x04	Mode Register	WDT_MR	Read-write Once	0x3FFF_2FFF
0x08	Status Register	WDT_SR	Read-only	0x0000_0000

14.4.1 Watchdog Timer Control Register

Register Name: WDT_CR

Address: 0x400E1250

Access Type: Write-only

31	30	29	28	27	26	25	24
KEY							

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WDRSTT

- **WDRSTT: Watchdog Restart**

0: No effect.

1: Restarts the Watchdog.

- **KEY: Password**

Should be written at value 0xA5. Writing any other value in this field aborts the write operation.

14.4.2 Watchdog Timer Mode Register

Register Name: WDT_MR

Address: 0x400E1254

Access Type: Read-write Once

31	30	29	28	27	26	25	24
		WDIDLEHLT	WDDBGHLT	WDD			
23	22	21	20	19	18	17	16
WDD							
15	14	13	12	11	10	9	8
WDDIS	WDRPROC	WDRSTEN	WDFIEN	WDV			
7	6	5	4	3	2	1	0
WDV							

- **WDV: Watchdog Counter Value**

Defines the value loaded in the 12-bit Watchdog Counter.

- **WDFIEN: Watchdog Fault Interrupt Enable**

0: A Watchdog fault (underflow or error) has no effect on interrupt.

1: A Watchdog fault (underflow or error) asserts interrupt.

- **WDRSTEN: Watchdog Reset Enable**

0: A Watchdog fault (underflow or error) has no effect on the resets.

1: A Watchdog fault (underflow or error) triggers a Watchdog reset.

- **WDRPROC: Watchdog Reset Processor**

0: If WDRSTEN is 1, a Watchdog fault (underflow or error) activates all resets.

1: If WDRSTEN is 1, a Watchdog fault (underflow or error) activates the processor reset.

- **WDD: Watchdog Delta Value**

Defines the permitted range for reloading the Watchdog Timer.

If the Watchdog Timer value is less than or equal to WDD, writing WDT_CR with WDRSTT = 1 restarts the timer.

If the Watchdog Timer value is greater than WDD, writing WDT_CR with WDRSTT = 1 causes a Watchdog error.

- **WDDBGHLT: Watchdog Debug Halt**

0: The Watchdog runs when the processor is in debug state.

1: The Watchdog stops when the processor is in debug state.

- **WDIDLEHLT: Watchdog Idle Halt**

0: The Watchdog runs when the system is in idle mode.

1: The Watchdog stops when the system is in idle state.

- **WDDIS: Watchdog Disable**

0: Enables the Watchdog Timer.

1: Disables the Watchdog Timer.

14.4.3 Watchdog Timer Status Register

Register Name: WDT_SR

Address: 0x400E1258

Access Type: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	WDERR	WDUNF

- **WDUNF: Watchdog Underflow**

0: No Watchdog underflow occurred since the last read of WDT_SR.

1: At least one Watchdog underflow occurred since the last read of WDT_SR.

- **WDERR: Watchdog Error**

0: No Watchdog error occurred since the last read of WDT_SR.

1: At least one Watchdog error occurred since the last read of WDT_SR.

15. Reset Controller (RSTC)

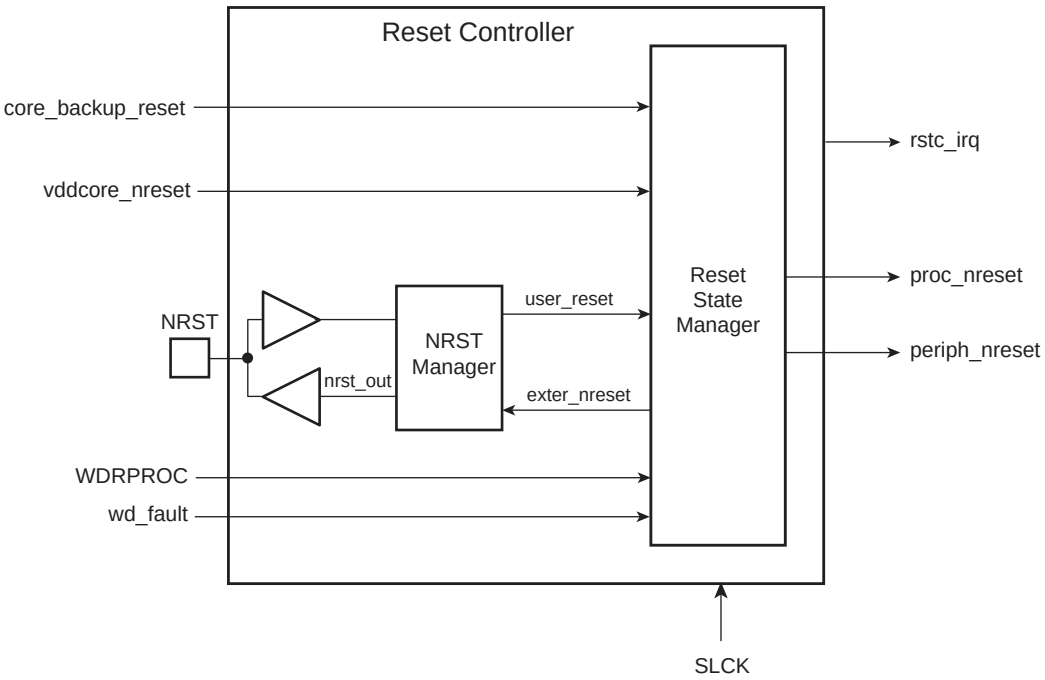
15.1 Overview

The Reset Controller (RSTC), based on power-on reset cells, handles all the resets of the system without any external components. It reports which reset occurred last.

The Reset Controller also drives independently or simultaneously the external reset and the peripheral and processor resets.

15.2 Block Diagram

Figure 15-1. Reset Controller Block Diagram



15.3 Functional Description

15.3.1 Reset Controller Overview

The Reset Controller is made up of an NRST Manager and a Reset State Manager. It runs at Slow Clock and generates the following reset signals:

- proc_nreset: Processor reset line. It also resets the Watchdog Timer.
- periph_nreset: Affects the whole set of embedded peripherals.
- nrst_out: Drives the NRST pin.

These reset signals are asserted by the Reset Controller, either on external events or on software action. The Reset State Manager controls the generation of reset signals and provides a signal to the NRST Manager when an assertion of the NRST pin is required.

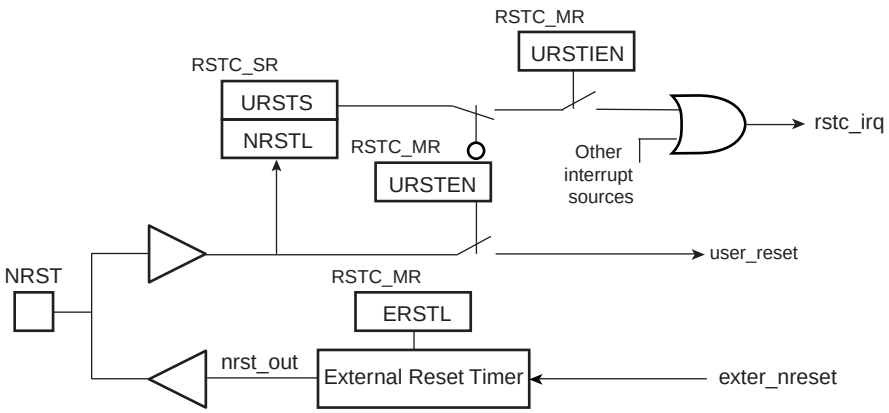
The NRST Manager shapes the NRST assertion during a programmable time, thus controlling external device resets.

The Reset Controller Mode Register (RSTC_MR), allowing the configuration of the Reset Controller, is powered with VDDBU, so that its configuration is saved as long as VDDBU is on.

15.3.2 NRST Manager

The NRST Manager samples the NRST input pin and drives this pin low when required by the Reset State Manager. Figure 15-2 shows the block diagram of the NRST Manager.

Figure 15-2. NRST Manager



15.3.2.1 NRST Signal or Interrupt

The NRST Manager samples the NRST pin at Slow Clock speed. When the line is detected low, a User Reset is reported to the Reset State Manager.

However, the NRST Manager can be programmed to not trigger a reset when an assertion of NRST occurs. Writing the bit URSTEN at 0 in RSTC_MR disables the User Reset trigger.

The level of the pin NRST can be read at any time in the bit NRSTL (NRST level) in RSTC_SR. As soon as the pin NRST is asserted, the bit URSTS in RSTC_SR is set. This bit clears only when RSTC_SR is read.

The Reset Controller can also be programmed to generate an interrupt instead of generating a reset. To do so, the bit URSTIEN in RSTC_MR must be written at 1.

15.3.2.2 NRST External Reset Control

The Reset State Manager asserts the signal ext_nreset to assert the NRST pin. When this occurs, the “nrst_out” signal is driven low by the NRST Manager for a time programmed by the field ERSTL in RSTC_MR. This assertion duration, named EXTERNAL_RESET_LENGTH, lasts $2^{(ERSTL+1)}$ Slow Clock cycles. This gives the approximate duration of an assertion between 60 µs and 2 seconds. Note that ERSTL at 0 defines a two-cycle duration for the NRST pulse.

This feature allows the Reset Controller to shape the NRST pin level, and thus to guarantee that the NRST line is driven low for a time compliant with potential external devices connected on the system reset.

As the ERSTL field is within RSTC_MR register, which is backed-up, it can be used to shape the system power-up reset for devices requiring a longer startup time than the Slow Clock Oscillator.

Please note that the NRST output is in high impedance state when the chip is in OFF mode.

15.3.3 Brownout Manager

The Brownout manager is embedded within the Supply Controller, please refer to the Supply Controller section for a detailed description.

15.3.4 Reset States

The Reset State Manager handles the different reset sources and generates the internal reset signals. It reports the reset status in the field RSTTYP of the Status Register (RSTC_SR). The update of the field RSTTYP is performed when the processor reset is released.

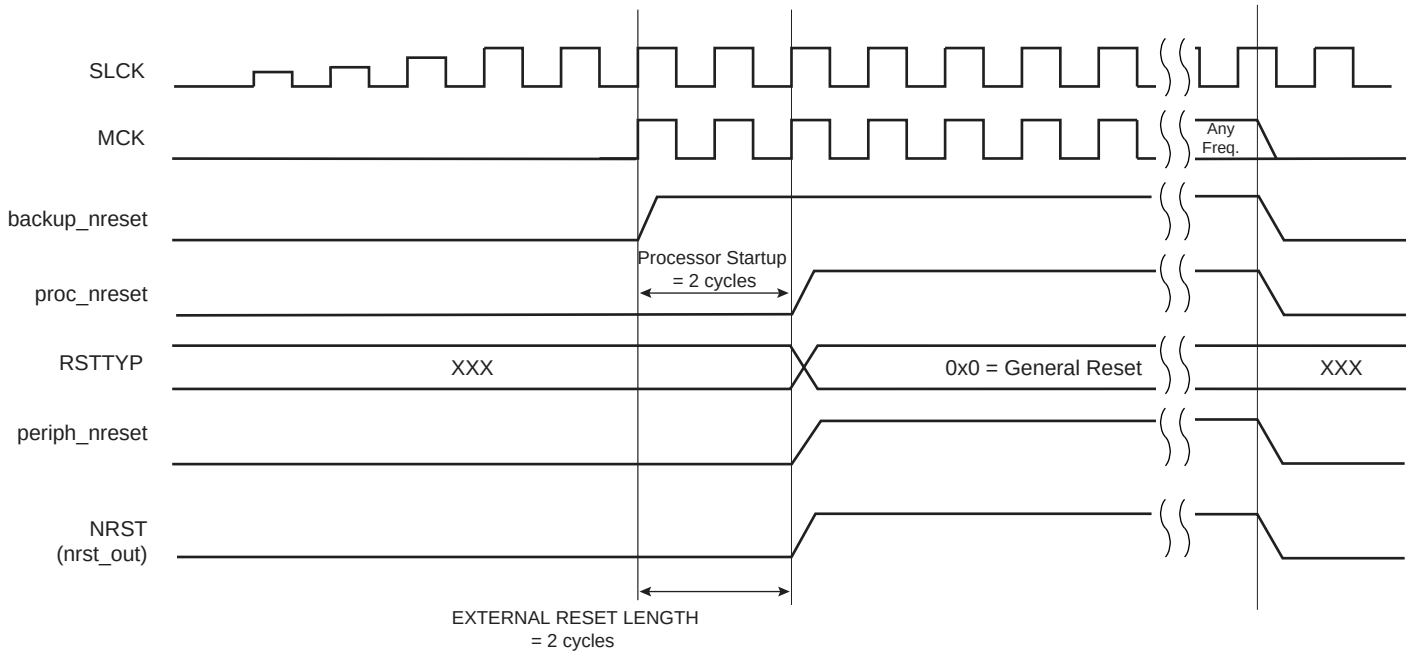
15.3.4.1 General Reset

A general reset occurs when a Power-on-reset is detected, an Asynchronous Master Reset (NRSTB pin) is requested, a Brownout or a Voltage regulation loss is detected by the Supply controller. The vddcore_nreset signal is asserted by the Supply Controller when a general reset occurs.

All the reset signals are released and the field RSTTYP in RSTC_SR reports a General Reset. As the RSTC_MR is reset, the NRST line rises 2 cycles after the vddcore_nreset, as ERSTL defaults at value 0x0.

Figure 15-3 shows how the General Reset affects the reset signals.

Figure 15-3. General Reset State



15.3.4.2 Backup Reset

A Backup reset occurs when the chip returns from Backup mode. The vddcore_nreset signal is asserted by the Supply Controller when a Backup reset occurs.

The field RSTTYP in RSTC_SR is updated to report a Backup Reset.

15.3.4.3 User Reset

The User Reset is entered when a low level is detected on the NRST pin and the bit URSTEN in RSTC_MR is at 1. The NRST input signal is resynchronized with SLCK to insure proper behavior of the system.

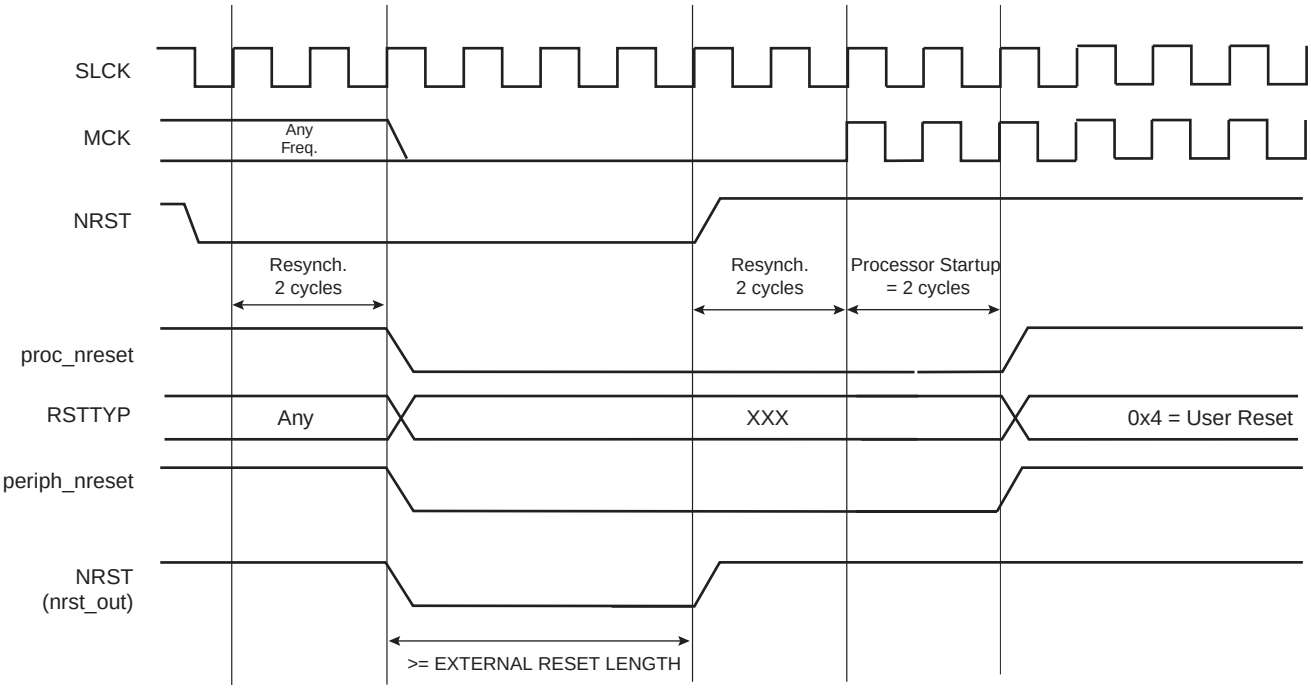
The User Reset is entered as soon as a low level is detected on NRST. The Processor Reset and the Peripheral Reset are asserted.

The User Reset is left when NRST rises, after a two-cycle resynchronization time and a 3-cycle processor startup. The processor clock is re-enabled as soon as NRST is confirmed high.

When the processor reset signal is released, the RSTTYP field of the Status Register (RSTC_SR) is loaded with the value 0x4, indicating a User Reset.

The NRST Manager guarantees that the NRST line is asserted for EXTERNAL_RESET_LENGTH Slow Clock cycles, as programmed in the field ERSTL. However, if NRST does not rise after EXTERNAL_RESET_LENGTH because it is driven low externally, the internal reset lines remain asserted until NRST actually rises.

Figure 15-4. User Reset State



15.3.4.4 Software Reset

The Reset Controller offers several commands used to assert the different reset signals. These commands are performed by writing the Control Register (RSTC_CR) with the following bits at 1:

- PROCRST: Writing PROCRST at 1 resets the processor and the watchdog timer.
- PERRST: Writing PERRST at 1 resets all the embedded peripherals, including the memory system, and, in particular, the Remap Command. The Peripheral Reset is generally used for debug purposes.
- EXTRST: Writing EXTRST at 1 asserts low the NRST pin during a time defined by the field ERSTL in the Mode Register (RSTC_MR).

The software reset is entered if at least one of these bits is set by the software. All these commands can be performed independently or simultaneously. The software reset lasts 3 Slow Clock cycles.

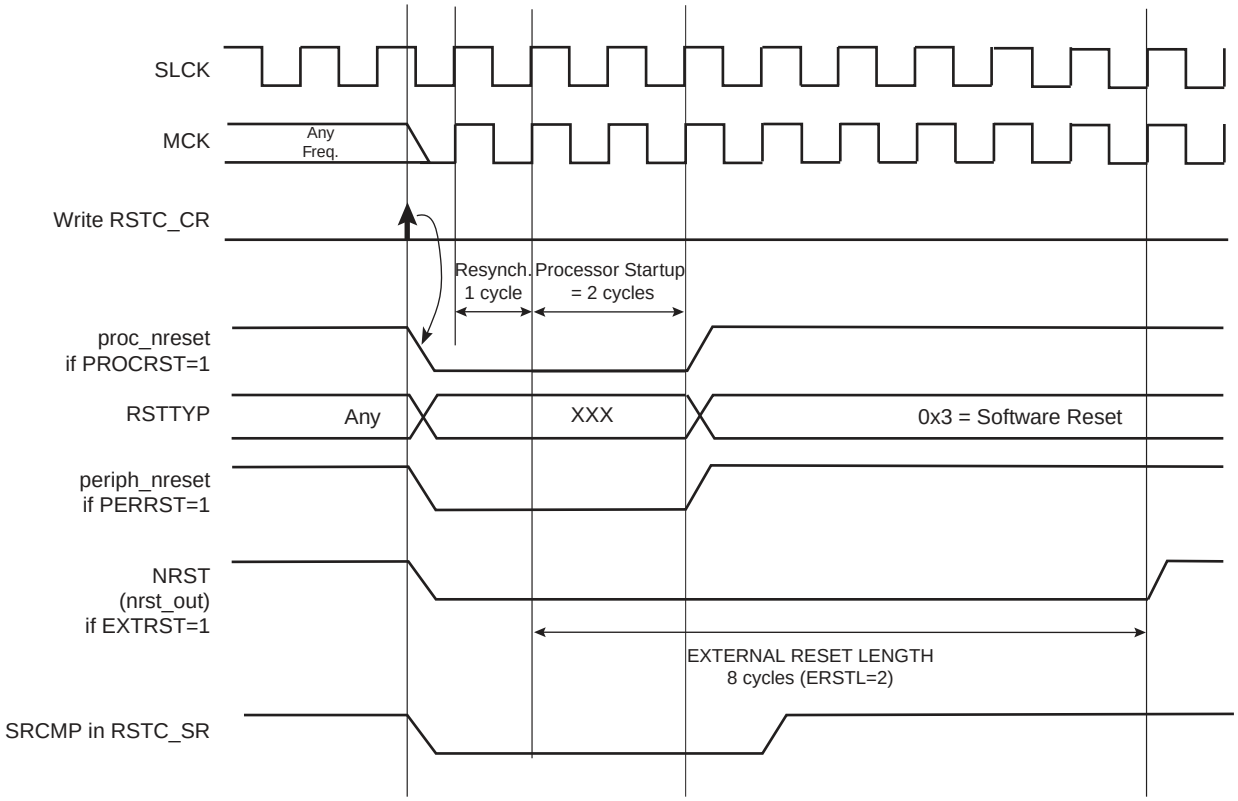
The internal reset signals are asserted as soon as the register write is performed. This is detected on the Master Clock (MCK). They are released when the software reset is left, i.e., synchronously to SLCK.

If EXTRST is set, the nrst_out signal is asserted depending on the programming of the field ERSTL. However, the resulting falling edge on NRST does not lead to a User Reset.

If and only if the PROCRST bit is set, the Reset Controller reports the software status in the field RSTTYP of the Status Register (RSTC_SR). Other Software Resets are not reported in RSTTYP.

As soon as a software operation is detected, the bit SRCMP (Software Reset Command in Progress) is set in the Status Register (RSTC_SR). It is cleared as soon as the software reset is left. No other software reset can be performed while the SRCMP bit is set, and writing any value in RSTC_CR has no effect.

Figure 15-5. Software Reset



15.3.4.5 Watchdog Reset

The Watchdog Reset is entered when a watchdog fault occurs. This state lasts 3 Slow Clock cycles.

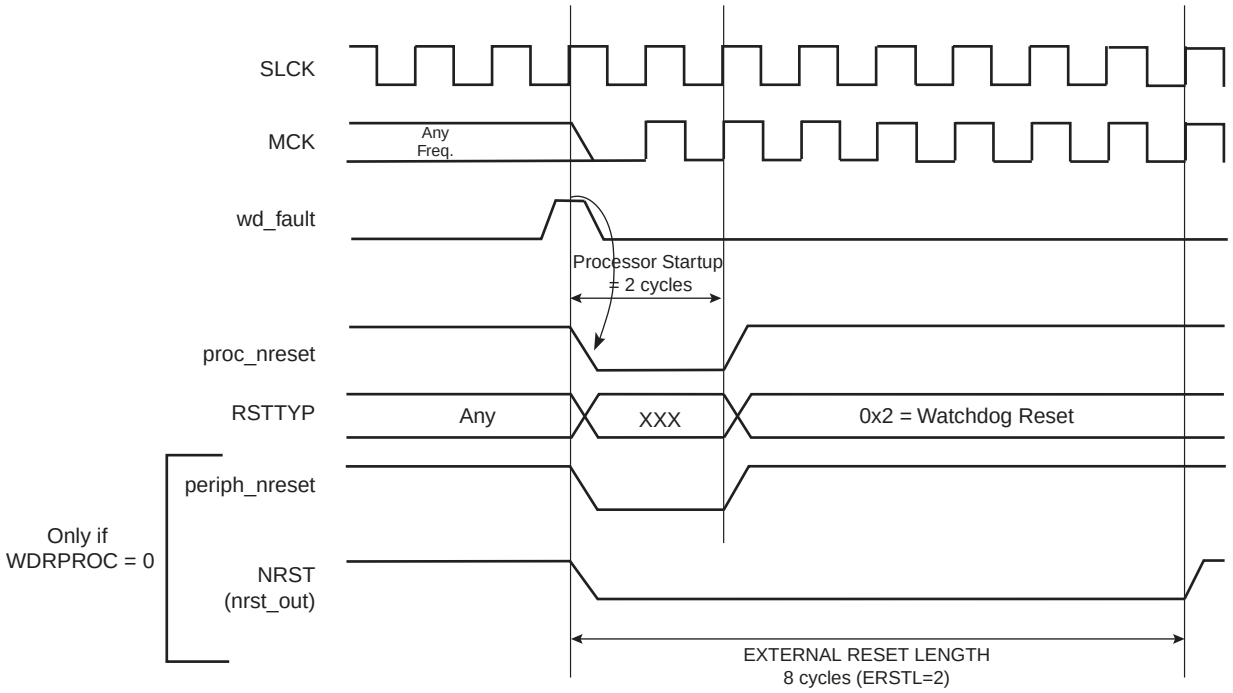
When in Watchdog Reset, assertion of the reset signals depends on the WDRPROC bit in WDT_MR:

- If WDRPROC is 0, the Processor Reset and the Peripheral Reset are asserted. The NRST line is also asserted, depending on the programming of the field ERSTL. However, the resulting low level on NRST does not result in a User Reset state.
- If WDRPROC = 1, only the processor reset is asserted.

The Watchdog Timer is reset by the proc_nreset signal. As the watchdog fault always causes a processor reset if WDRSTEN is set, the Watchdog Timer is always reset after a Watchdog Reset, and the Watchdog is enabled by default and with a period set to a maximum.

When the WDRSTEN in WDT_MR bit is reset, the watchdog fault has no impact on the reset controller.

Figure 15-6. Watchdog Reset



15.3.5 Reset State Priorities

The Reset State Manager manages the following priorities between the different reset sources, given in descending order:

- General Reset
- Backup Reset
- Watchdog Reset
- Software Reset
- User Reset

Particular cases are listed below:

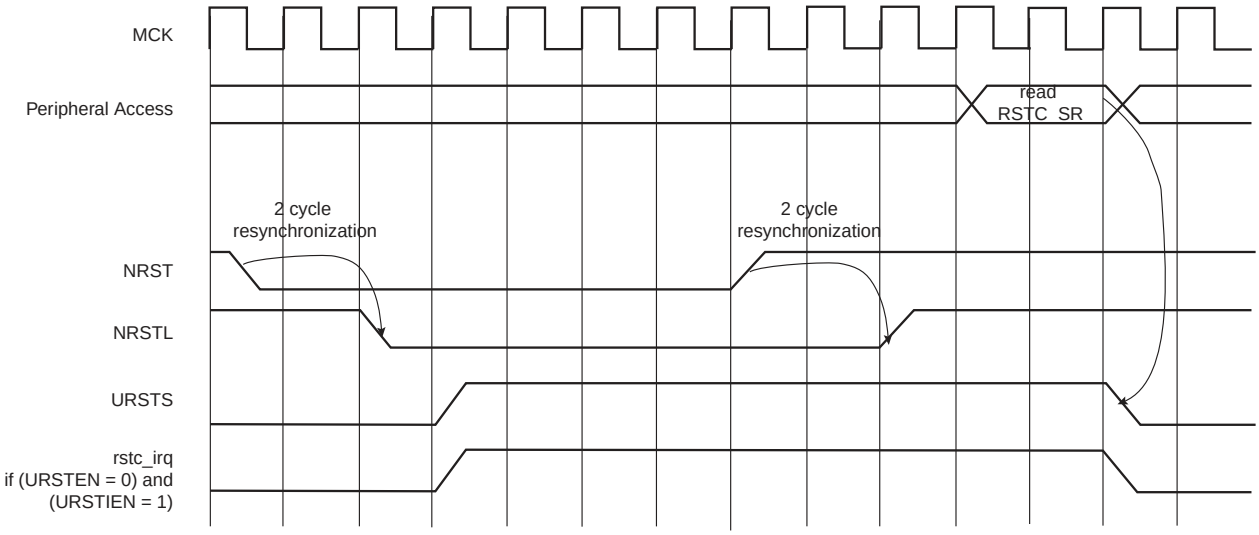
- When in User Reset:
  - A watchdog event is impossible because the Watchdog Timer is being reset by the proc_nreset signal.
  - A software reset is impossible, since the processor reset is being activated.
- When in Software Reset:
  - A watchdog event has priority over the current state.
  - The NRST has no effect.
- When in Watchdog Reset:
  - The processor reset is active and so a Software Reset cannot be programmed.
  - A User Reset cannot be entered.

15.3.6 Reset Controller Status Register

The Reset Controller status register (RSTC_SR) provides several status fields:

- RSTTYP field: This field gives the type of the last reset, as explained in previous sections.
- SRCMP bit: This field indicates that a Software Reset Command is in progress and that no further software reset should be performed until the end of the current one. This bit is automatically cleared at the end of the current software reset.
- NRSTL bit: The NRSTL bit of the Status Register gives the level of the NRST pin sampled on each MCK rising edge.
- URSTS bit: A high-to-low transition of the NRST pin sets the URSTS bit of the RSTC_SR register. This transition is also detected on the Master Clock (MCK) rising edge (see Figure 15-7). If the User Reset is disabled (URSTEN = 0) and if the interruption is enabled by the URSTIEN bit in the RSTC_MR register, the URSTS bit triggers an interrupt. Reading the RSTC_SR status register resets the URSTS bit and clears the interrupt.

Figure 15-7. Reset Controller Status and Interrupt



15.4 Reset Controller (RSTC) User Interface

Table 15-1. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	RSTC_CR	Write-only	-
0x04	Status Register	RSTC_SR	Read-only	0x0000_0000
0x08	Mode Register	RSTC_MR	Read-write	0x0000_0000

15.4.1 Reset Controller Control Register

Name: RSTC_CR

Address: 0x400E1200

Access Type: Write-only

31	30	29	28	27	26	25	24
KEY							

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–		–

7	6	5	4	3	2	1	0
–	–	–	–	EXTRST	PERRST	–	PROCRST

- **PROCRST: Processor Reset**

0 = No effect.

1 = If KEY is correct, resets the processor.

- **PERRST: Peripheral Reset**

0 = No effect.

1 = If KEY is correct, resets the peripherals.

- **EXTRST: External Reset**

0 = No effect.

1 = If KEY is correct, asserts the NRST pin.

- **KEY: Password**

Should be written at value 0xA5. Writing any other value in this field aborts the write operation.

15.4.2 Reset Controller Status Register

Name: RSTC_SR

Address: 0x400E1204

Access Type: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	SRCMP	NRSTL
15	14	13	12	11	10	9	8
–	–	–	–	–	RSTTYP		
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	URSTS

- **URSTS: User Reset Status**

0 = No high-to-low edge on NRST happened since the last read of RSTC_SR.

1 = At least one high-to-low transition of NRST has been detected since the last read of RSTC_SR.

- **RSTTYP: Reset Type**

Reports the cause of the last processor reset. Reading this RSTC_SR does not reset this field.

RSTTYP			Reset Type	Comments
0	0	0	General Reset	First power-up Reset
0	0	1	Backup Reset	Return from Backup mode
0	1	0	Watchdog Reset	Watchdog fault occurred
0	1	1	Software Reset	Processor reset required by the software
1	0	0	User Reset	NRST pin detected low

- **NRSTL: NRST Pin Level**

Registers the NRST Pin Level at Master Clock (MCK).

- **SRCMP: Software Reset Command in Progress**

0 = No software command is being performed by the reset controller. The reset controller is ready for a software command.

1 = A software reset command is being performed by the reset controller. The reset controller is busy.

15.4.3 Reset Controller Mode Register

Name: RSTC_MR

Address: 0x400E1208

Access Type: Read-write

31	30	29	28	27	26	25	24
KEY							

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	ERSTL			

7	6	5	4	3	2	1	0
–	–		URSTIEN	–	–	–	URSTEN

- **URSTEN: User Reset Enable**

0 = The detection of a low level on the pin NRST does not generate a User Reset.

1 = The detection of a low level on the pin NRST triggers a User Reset.

- **URSTIEN: User Reset Interrupt Enable**

0 = USRTS bit in RSTC_SR at 1 has no effect on rstc_irq.

1 = USRTS bit in RSTC_SR at 1 asserts rstc_irq if URSTEN = 0.

- **ERSTL: External Reset Length**

This field defines the external reset length. The external reset is asserted during a time of $2^{(ERSTL+1)}$ Slow Clock cycles. This allows assertion duration to be programmed between 60 µs and 2 seconds.

- **KEY: Password**

Should be written at value 0xA5. Writing any other value in this field aborts the write operation.

16. Real-time Timer (RTT)

16.1 Description

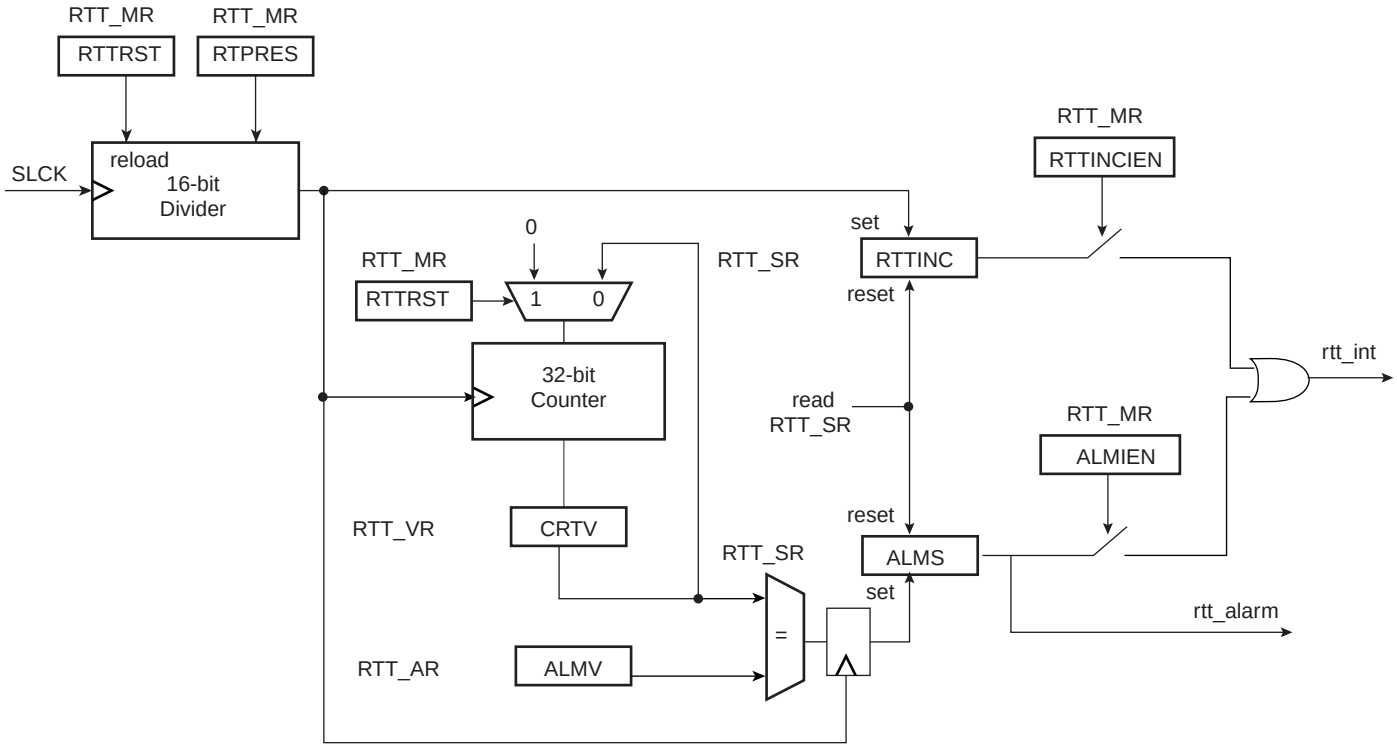
The Real-time Timer is built around a 32-bit counter used to count roll-over events of the programmable 16-bit prescaler which enables counting elapsed seconds from a 32 kHz slow clock source. It generates a periodic interrupt and/or triggers an alarm on a programmed value.

16.2 Embedded Characteristics

- 32-bit Free-running Counter on prescaled slow clock
- 16-bit Configurable Prescaler
- Interrupt on Alarm

16.3 Block Diagram

Figure 16-1. Real-time Timer



16.4 Functional Description

The Real-time Timer can be used to count elapsed seconds. It is built around a 32-bit counter fed by Slow Clock divided by a programmable 16-bit value. The value can be programmed in the field RTPRES of the Real-time Mode Register (RTT_MR).

Programming RTPRES at 0x00008000 corresponds to feeding the real-time counter with a 1 Hz signal (if the Slow Clock is 32.768 kHz). The 32-bit counter can count up to 2^{32} seconds, corresponding to more than 136 years, then roll over to 0.

The Real-time Timer can also be used as a free-running timer with a lower time-base. The best accuracy is achieved by writing RTPRES to 3. Programming RTPRES to 1 or 2 is possible, but may result in losing status events because the status register is cleared two Slow Clock cycles after read. Thus if the RTT is configured to trigger an interrupt, the interrupt occurs during 2 Slow Clock cycles after reading RTT_SR. To prevent several executions of the interrupt handler, the interrupt must be disabled in the interrupt handler and re-enabled when the status register is clear.

The Real-time Timer value (CRTV) can be read at any time in the register RTT_VR (Real-time Value Register). As this value can be updated asynchronously from the Master Clock, it is advisable to read this register twice at the same value to improve accuracy of the returned value.

The current value of the counter is compared with the value written in the alarm register RTT_AR (Real-time Alarm Register). If the counter value matches the alarm, the bit ALMS in RTT_SR is set. The alarm register is set to its maximum value, corresponding to 0xFFFF_FFFF, after a reset.

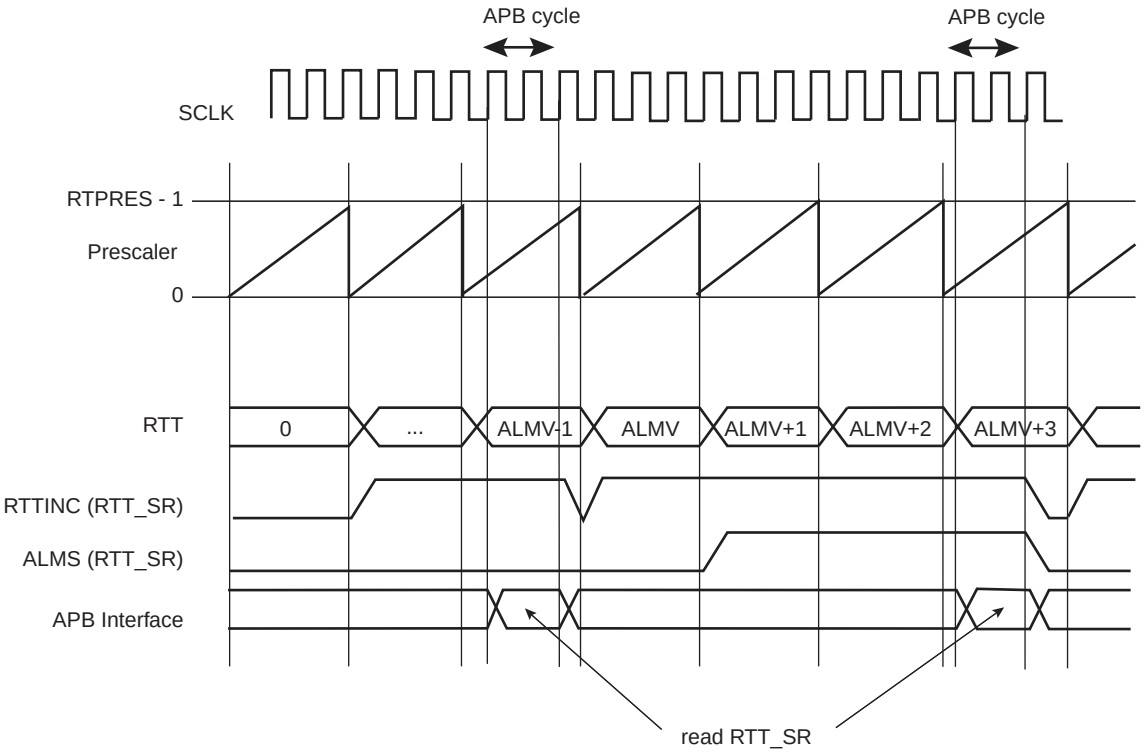
The bit RTTINC in RTT_SR is set each time the Real-time Timer counter is incremented. This bit can be used to start a periodic interrupt, the period being one second when the RTPRES is programmed with 0x8000 and Slow Clock equal to 32.768 Hz.

Reading the RTT_SR status register resets the RTTINC and ALMS fields.

Writing the bit RTTRST in RTT_MR immediately reloads and restarts the clock divider with the new programmed value. This also resets the 32-bit counter.

Note: Because of the asynchronism between the Slow Clock (SCLK) and the System Clock (MCK):
1) The restart of the counter and the reset of the RTT_VR current value register is effective only 2 slow clock cycles after the write of the RTTRST bit in the RTT_MR register.
2) The status register flags reset is taken into account only 2 slow clock cycles after the read of the RTT_SR (Status Register).

Figure 16-2. RTT Counting



16.5 Real-time Timer (RTT) User Interface

Table 16-1. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Mode Register	RTT_MR	Read-write	0x0000_8000
0x04	Alarm Register	RTT_AR	Read-write	0xFFFF_FFFF
0x08	Value Register	RTT_VR	Read-only	0x0000_0000
0x0C	Status Register	RTT_SR	Read-only	0x0000_0000

16.5.1 Real-time Timer Mode Register

Name: RTT_MR

Address: 0x400E1230

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	RTTRST	RTTINCIEN	ALMIEN

15	14	13	12	11	10	9	8
RTPRES							

7	6	5	4	3	2	1	0
RTPRES							

- **RTPRES: Real-time Timer Prescaler Value**

Defines the number of SLCK periods required to increment the Real-time timer. RTPRES is defined as follows:

RTPRES = 0: The prescaler period is equal to 2^{16} * SCLK period.

RTPRES ≠ 0: The prescaler period is equal to RTPRES * SCLK period.

- **ALMIEN: Alarm Interrupt Enable**

0 = The bit ALMS in RTT_SR has no effect on interrupt.

1 = The bit ALMS in RTT_SR asserts interrupt.

- **RTTINCIEN: Real-time Timer Increment Interrupt Enable**

0 = The bit RTTINC in RTT_SR has no effect on interrupt.

1 = The bit RTTINC in RTT_SR asserts interrupt.

- **RTTRST: Real-time Timer Restart**

0 = No effect.

1 = Reloads and restarts the clock divider with the new programmed value. This also resets the 32-bit counter.

16.5.2 Real-time Timer Alarm Register

Name: RTT_AR

Address: 0x400E1234

Access: Read-write

31	30	29	28	27	26	25	24
ALMV							

23	22	21	20	19	18	17	16
ALMV							

15	14	13	12	11	10	9	8
ALMV							

7	6	5	4	3	2	1	0
ALMV							

- **ALMV: Alarm Value**

Defines the alarm value (ALMV+1) compared with the Real-time Timer.

16.5.3 Real-time Timer Value Register

Name: RTT_VR

Address: 0x400E1238

Access: Read-only

31	30	29	28	27	26	25	24
CRTV							

23	22	21	20	19	18	17	16
CRTV							

15	14	13	12	11	10	9	8
CRTV							

7	6	5	4	3	2	1	0
CRTV							

- **CRTV: Current Real-time Value**

Returns the current value of the Real-time Timer.

16.5.4 Real-time Timer Status Register

Name: RTT_SR

Address: 0x400E123C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	RTTINC	ALMS

- **ALMS: Real-time Alarm Status**

0 = The Real-time Alarm has not occurred since the last read of RTT_SR.

1 = The Real-time Alarm occurred since the last read of RTT_SR.

- **RTTINC: Real-time Timer Increment**

0 = The Real-time Timer has not been incremented since the last read of the RTT_SR.

1 = The Real-time Timer has been incremented since the last read of the RTT_SR.

17. Real Time Clock (RTC)

17.1 Description

The Real-time Clock (RTC) peripheral is designed for very low power consumption.

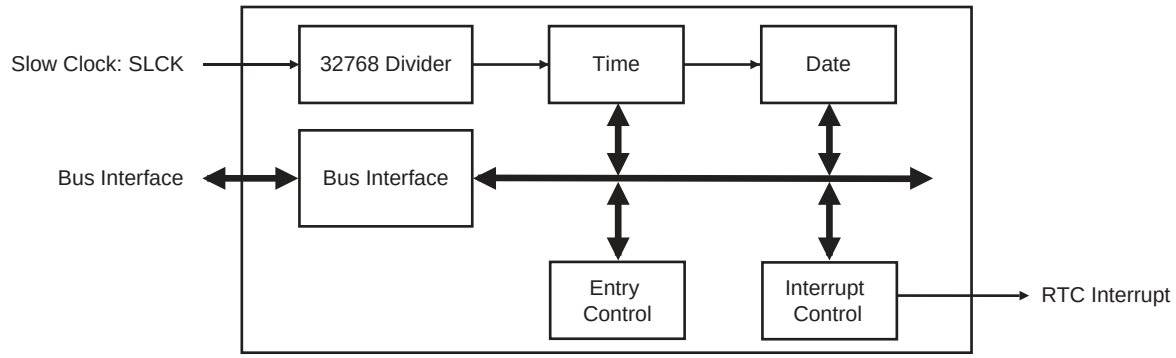
It combines a complete time-of-day clock with alarm and a two-hundred-year Gregorian calendar, complemented by a programmable periodic interrupt. The alarm and calendar registers are accessed by a 32-bit data bus.

The time and calendar values are coded in binary-coded decimal (BCD) format. The time format can be 24-hour mode or 12-hour mode with an AM/PM indicator.

Updating time and calendar fields and configuring the alarm fields are performed by a parallel capture on the 32-bit data bus. An entry control is performed to avoid loading registers with incompatible BCD format data or with an incompatible date according to the current month/year/century.

17.2 Block Diagram

Figure 17-1. RTC Block Diagram



17.3 Product Dependencies

17.3.1 Power Management

The Real-time Clock is continuously clocked at 32768 Hz. The Power Management Controller has no effect on RTC behavior.

17.3.2 Interrupt

RTC interrupt line is connected on one of the internal sources of the interrupt controller. RTC interrupt requires the interrupt controller to be programmed first.

17.4 Functional Description

The RTC provides a full binary-coded decimal (BCD) clock that includes century (19/20), year (with leap years), month, date, day, hours, minutes and seconds.

The valid year range is 1900 to 2099 in Gregorian mode, a two-hundred-year calendar.

The RTC can operate in 24-hour mode or in 12-hour mode with an AM/PM indicator.

Corrections for leap years are included (all years divisible by 4 being leap years). This is correct up to the year 2099.

17.4.1 Reference Clock

The reference clock is Slow Clock (SLCK). It can be driven internally or by an external 32.768 kHz crystal.

During low power modes of the processor, the oscillator runs and power consumption is critical. The crystal selection has to take into account the current consumption for power saving and the frequency drift due to temperature effect on the circuit for time accuracy.

17.4.2 Timing

The RTC is updated in real time at one-second intervals in normal mode for the counters of seconds, at one-minute intervals for the counter of minutes and so on.

Due to the asynchronous operation of the RTC with respect to the rest of the chip, to be certain that the value read in the RTC registers (century, year, month, date, day, hours, minutes, seconds) are valid and stable, it is necessary to read these registers twice. If the data is the same both times, then it is valid. Therefore, a minimum of two and a maximum of three accesses are required.

17.4.3 Alarm

The RTC has five programmable fields: month, date, hours, minutes and seconds.

Each of these fields can be enabled or disabled to match the alarm condition:

- If all the fields are enabled, an alarm flag is generated (the corresponding flag is asserted and an interrupt generated if enabled) at a given month, date, hour/minute/second.
- If only the “seconds” field is enabled, then an alarm is generated every minute.

Depending on the combination of fields enabled, a large number of possibilities are available to the user ranging from minutes to 365/366 days.

17.4.4 Error Checking

Verification on user interface data is performed when accessing the century, year, month, date, day, hours, minutes, seconds and alarms. A check is performed on illegal BCD entries such as illegal date of the month with regard to the year and century configured.

If one of the time fields is not correct, the data is not loaded into the register/counter and a flag is set in the validity register. The user can not reset this flag. It is reset as soon as an acceptable value is programmed. This avoids any further side effects in the hardware. The same procedure is done for the alarm.

The following checks are performed:

1. Century (check if it is in range 19 - 20)
2. Year (BCD entry check)
3. Date (check range 01 - 31)
4. Month (check if it is in BCD range 01 - 12, check validity regarding “date”)
5. Day (check range 1 - 7)

6. Hour (BCD checks: in 24-hour mode, check range 00 - 23 and check that AM/PM flag is not set if RTC is set in 24-hour mode; in 12-hour mode check range 01 - 12)
7. Minute (check BCD and range 00 - 59)
8. Second (check BCD and range 00 - 59)

Note: If the 12-hour mode is selected by means of the RTC_MODE register, a 12-hour value can be programmed and the returned value on RTC_TIME will be the corresponding 24-hour value. The entry control checks the value of the AM/PM indicator (bit 22 of RTC_TIME register) to determine the range to be checked.

17.4.5 Updating Time/Calendar

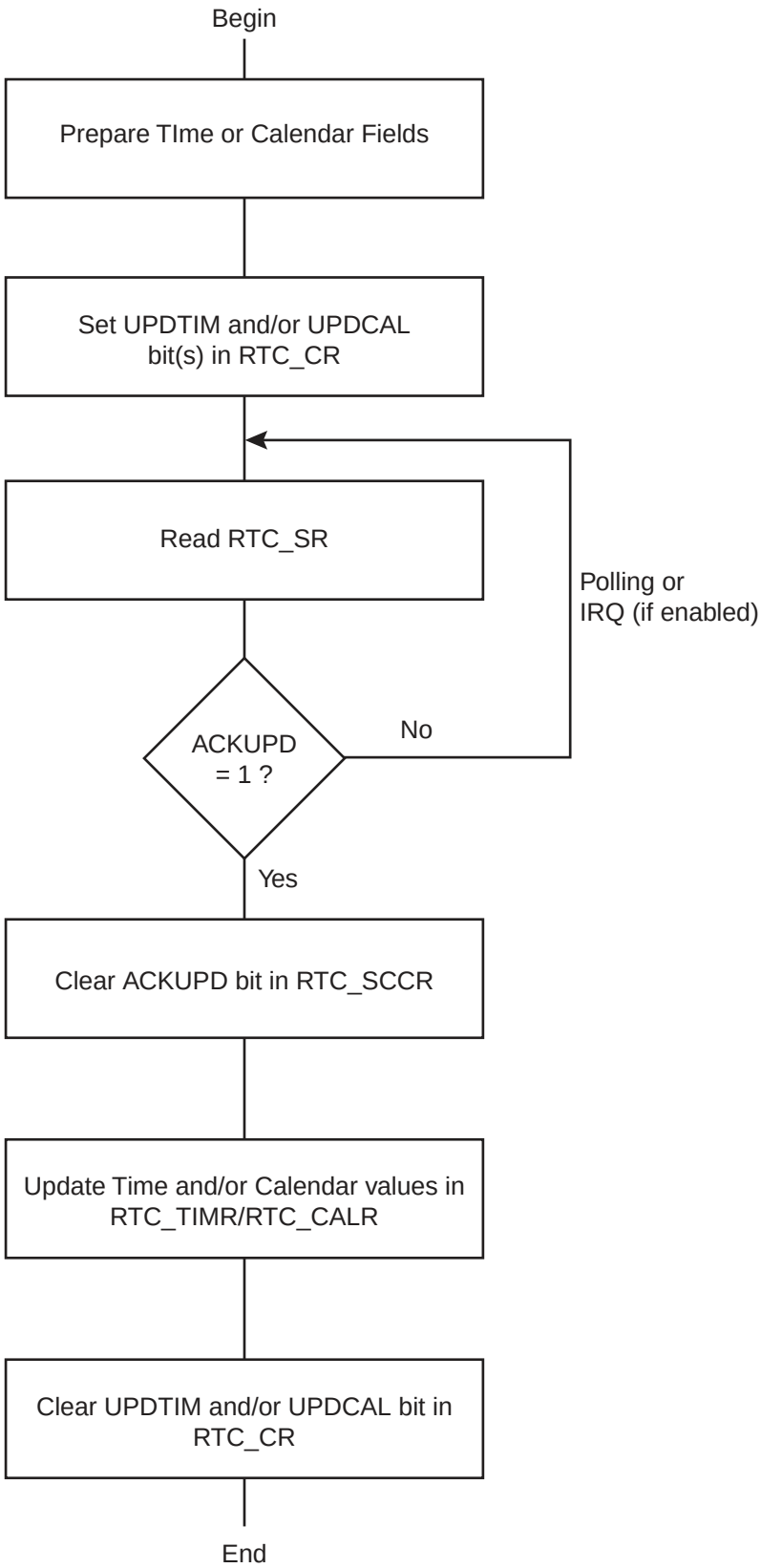
To update any of the time/calendar fields, the user must first stop the RTC by setting the corresponding field in the Control Register. Bit UPDTIM must be set to update time fields (hour, minute, second) and bit UPDCAL must be set to update calendar fields (century, year, month, date, day).

Then the user must poll or wait for the interrupt (if enabled) of bit ACKUPD in the Status Register. Once the bit reads 1, it is mandatory to clear this flag by writing the corresponding bit in RTC_SCCR. The user can now write to the appropriate Time and Calendar register.

Once the update is finished, the user must reset (0) UPDTIM and/or UPDCAL in the Control

When entering programming mode of the calendar fields, the time fields remain enabled. When entering the programming mode of the time fields, both time and calendar fields are stopped. This is due to the location of the calendar logic circuity (downstream for low-power considerations). It is highly recommended to prepare all the fields to be updated before entering programming mode. In successive update operations, the user must wait at least one second after resetting the UPDTIM/UPDCAL bit in the RTC_CR (Control Register) before setting these bits again. This is done by waiting for the SEC flag in the Status Register before setting UPDTIM/UPDCAL bit. After resetting UPDTIM/UPDCAL, the SEC flag must also be cleared.

Figure 17-2. Update Sequence



17.5 Real Time Clock (RTC) User Interface

Table 17-1. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	RTC_CR	Read-write	0x0
0x04	Mode Register	RTC_MR	Read-write	0x0
0x08	Time Register	RTC_TIMR	Read-write	0x0
0x0C	Calendar Register	RTC_CALR	Read-write	0x01210720
0x10	Time Alarm Register	RTC_TIMALR	Read-write	0x0
0x14	Calendar Alarm Register	RTC_CALALR	Read-write	0x01010000
0x18	Status Register	RTC_SR	Read-only	0x0
0x1C	Status Clear Command Register	RTC_SCCR	Write-only	–
0x20	Interrupt Enable Register	RTC_IER	Write-only	–
0x24	Interrupt Disable Register	RTC_IDR	Write-only	–
0x28	Interrupt Mask Register	RTC_IMR	Read-only	0x0
0x2C	Valid Entry Register	RTC_VER	Read-only	0x0
0x30–0xE0	Reserved Register	–	–	–
0xE4	Write Protect Mode Register	RTC_WPMR	Read-write	0x00000000
0xE8–0xF8	Reserved Register	–	–	–
0xFC	Reserved Register	–	–	–

Note: if an offset is not listed in the table it must be considered as reserved.

17.5.1 RTC Control Register

Name: RTC_CR

Address: 0x400E1260

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	CALEVSEL	
15	14	13	12	11	10	9	8
–	–	–	–	–	–	TIMEVSEL	
7	6	5	4	3	2	1	0
–	–	–	–	–	–	UPDCAL	UPDTIM

This register can only be written if the WPEN bit is cleared in “RTC Write Protect Mode Register” on page 263.

- **UPDTIM: Update Request Time Register**

0 = No effect.

1 = Stops the RTC time counting.

Time counting consists of second, minute and hour counters. Time counters can be programmed once this bit is set and acknowledged by the bit ACKUPD of the Status Register.

- **UPDCAL: Update Request Calendar Register**

0 = No effect.

1 = Stops the RTC calendar counting.

Calendar counting consists of day, date, month, year and century counters. Calendar counters can be programmed once this bit is set.

- **TIMEVSEL: Time Event Selection**

The event that generates the flag TIMEV in RTC_SR (Status Register) depends on the value of TIMEVSEL.

Value	Name	Description
0	MINUTE	Minute change
1	HOUR	Hour change
2	MIDNIGHT	Every day at midnight
3	NOON	Every day at noon

- **CALEVSEL: Calendar Event Selection**

The event that generates the flag CALEV in RTC_SR depends on the value of CALEVSEL

Value	Name	Description
0	WEEK	Week change (every Monday at time 00:00:00)
1	MONTH	Month change (every 01 of each month at time 00:00:00)
2	YEAR	Year change (every January 1 at time 00:00:00)
3	–	

17.5.2 RTC Mode Register

Name: RTC_MR

Address: 0x400E1264

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	HRMOD

- **HRMOD: 12-/24-hour Mode**

0 = 24-hour mode is selected.

1 = 12-hour mode is selected.

All non-significant bits read zero.

17.5.3 RTC Time Register

Name: RTC_TIMR

Address: 0x400E1268

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	AMPM	HOUR					
15	14	13	12	11	10	9	8
–	MIN						
7	6	5	4	3	2	1	0
–	SEC						

- **SEC: Current Second**

The range that can be set is 0 - 59 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

- **MIN: Current Minute**

The range that can be set is 0 - 59 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

- **HOUR: Current Hour**

The range that can be set is 1 - 12 (BCD) in 12-hour mode or 0 - 23 (BCD) in 24-hour mode.

- **AMPM: Ante Meridiem Post Meridiem Indicator**

This bit is the AM/PM indicator in 12-hour mode.

0 = AM.

1 = PM.

All non-significant bits read zero.

17.5.4 RTC Calendar Register

Name: RTC_CALR

Address: 0x400E126C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	DATE					

23	22	21	20	19	18	17	16
DAY			MONTH				

15	14	13	12	11	10	9	8
YEAR							

7	6	5	4	3	2	1	0
–	CENT						

- **CENT: Current Century**

The range that can be set is 19 - 20 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

- **YEAR: Current Year**

The range that can be set is 00 - 99 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

- **MONTH: Current Month**

The range that can be set is 01 - 12 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

- **DAY: Current Day in Current Week**

The range that can be set is 1 - 7 (BCD).

The coding of the number (which number represents which day) is user-defined as it has no effect on the date counter.

- **DATE: Current Day in Current Month**

The range that can be set is 01 - 31 (BCD).

The lowest four bits encode the units. The higher bits encode the tens.

All non-significant bits read zero.

17.5.5 RTC Time Alarm Register

Name: RTC_TIMALR

Address: 0x400E1270

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
HOUREN	AMPM	HOUR					
15	14	13	12	11	10	9	8
MINEN	MIN						
7	6	5	4	3	2	1	0
SECEN	SEC						

This register can only be written if the WPEN bit is cleared in “RTC Write Protect Mode Register” on page 263.

- **SEC: Second Alarm**

This field is the alarm field corresponding to the BCD-coded second counter.

- **SECEN: Second Alarm Enable**

0 = The second-matching alarm is disabled.

1 = The second-matching alarm is enabled.

- **MIN: Minute Alarm**

This field is the alarm field corresponding to the BCD-coded minute counter.

- **MINEN: Minute Alarm Enable**

0 = The minute-matching alarm is disabled.

1 = The minute-matching alarm is enabled.

- **HOUR: Hour Alarm**

This field is the alarm field corresponding to the BCD-coded hour counter.

- **AMPM: AM/PM Indicator**

This field is the alarm field corresponding to the BCD-coded hour counter.

- **HOUREN: Hour Alarm Enable**

0 = The hour-matching alarm is disabled.

1 = The hour-matching alarm is enabled.

17.5.6 RTC Calendar Alarm Register

Name: RTC_CALALR

Address: 0x400E1274

Access: Read-write

31	30	29	28	27	26	25	24
DATEEN	–	DATE					
23	22	21	20	19	18	17	16
MTHEN	–	–	MONTH				
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

This register can only be written if the WPEN bit is cleared in “RTC Write Protect Mode Register” on page 263.

- **MONTH: Month Alarm**

This field is the alarm field corresponding to the BCD-coded month counter.

- **MTHEN: Month Alarm Enable**

0 = The month-matching alarm is disabled.

1 = The month-matching alarm is enabled.

- **DATE: Date Alarm**

This field is the alarm field corresponding to the BCD-coded date counter.

- **DATEEN: Date Alarm Enable**

0 = The date-matching alarm is disabled.

1 = The date-matching alarm is enabled.

17.5.7 RTC Status Register

Name: RTC_SR

Address: 0x400E1278

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	CALEV	TIMEV	SEC	ALARM	ACKUPD

- **ACKUPD: Acknowledge for Update**

0 = Time and calendar registers cannot be updated.

1 = Time and calendar registers can be updated.

- **ALARM: Alarm Flag**

0 = No alarm matching condition occurred.

1 = An alarm matching condition has occurred.

- **SEC: Second Event**

0 = No second event has occurred since the last clear.

1 = At least one second event has occurred since the last clear.

- **TIMEV: Time Event**

0 = No time event has occurred since the last clear.

1 = At least one time event has occurred since the last clear.

The time event is selected in the TIMEVSEL field in RTC_CR (Control Register) and can be any one of the following events: minute change, hour change, noon, midnight (day change).

- **CALEV: Calendar Event**

0 = No calendar event has occurred since the last clear.

1 = At least one calendar event has occurred since the last clear.

The calendar event is selected in the CALEVSEL field in RTC_CR and can be any one of the following events: week change, month change and year change.

17.5.8 RTC Status Clear Command Register

Name: RTC_SCCR

Address: 0x400E127C

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	CALCLR	TIMCLR	SECCLR	ALRCLR	ACKCLR

- **ACKCLR: Acknowledge Clear**

0 = No effect.

1 = Clears corresponding status flag in the Status Register (RTC_SR).

- **ALRCLR: Alarm Clear**

0 = No effect.

1 = Clears corresponding status flag in the Status Register (RTC_SR).

- **SECCLR: Second Clear**

0 = No effect.

1 = Clears corresponding status flag in the Status Register (RTC_SR).

- **TIMCLR: Time Clear**

0 = No effect.

1 = Clears corresponding status flag in the Status Register (RTC_SR).

- **CALCLR: Calendar Clear**

0 = No effect.

1 = Clears corresponding status flag in the Status Register (RTC_SR).

17.5.9 RTC Interrupt Enable Register

Name: RTC_IER

Address: 0x400E1280

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	CALEN	TIMEN	SECEN	ALREN	ACKEN

- **ACKEN: Acknowledge Update Interrupt Enable**

0 = No effect.

1 = The acknowledge for update interrupt is enabled.

- **ALREN: Alarm Interrupt Enable**

0 = No effect.

1 = The alarm interrupt is enabled.

- **SECEN: Second Event Interrupt Enable**

0 = No effect.

1 = The second periodic interrupt is enabled.

- **TIMEN: Time Event Interrupt Enable**

0 = No effect.

1 = The selected time event interrupt is enabled.

- **CALEN: Calendar Event Interrupt Enable**

0 = No effect.

- 1 = The selected calendar event interrupt is enabled.

17.5.10 RTC Interrupt Disable Register

Name: RTC_IDR

Address: 0x400E1284

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	CALDIS	TIMDIS	SECDIS	ALRDIS	ACKDIS

- **ACKDIS: Acknowledge Update Interrupt Disable**

0 = No effect.

1 = The acknowledge for update interrupt is disabled.

- **ALRDIS: Alarm Interrupt Disable**

0 = No effect.

1 = The alarm interrupt is disabled.

- **SECDIS: Second Event Interrupt Disable**

0 = No effect.

1 = The second periodic interrupt is disabled.

- **TIMDIS: Time Event Interrupt Disable**

0 = No effect.

1 = The selected time event interrupt is disabled.

- **CALDIS: Calendar Event Interrupt Disable**

0 = No effect.

1 = The selected calendar event interrupt is disabled.

17.5.11 RTC Interrupt Mask Register

Name: RTC_IMR

Address: 0x400E1288

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	CAL	TIM	SEC	ALR	ACK

- **ACK: Acknowledge Update Interrupt Mask**

0 = The acknowledge for update interrupt is disabled.

1 = The acknowledge for update interrupt is enabled.

- **ALR: Alarm Interrupt Mask**

0 = The alarm interrupt is disabled.

1 = The alarm interrupt is enabled.

- **SEC: Second Event Interrupt Mask**

0 = The second periodic interrupt is disabled.

1 = The second periodic interrupt is enabled.

- **TIM: Time Event Interrupt Mask**

0 = The selected time event interrupt is disabled.

1 = The selected time event interrupt is enabled.

- **CAL: Calendar Event Interrupt Mask**

0 = The selected calendar event interrupt is disabled.

1 = The selected calendar event interrupt is enabled.

17.5.12 RTC Valid Entry Register

Name: RTC_VER

Address: 0x400E128C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	NVCALALR	NVTIMALR	NVCAL	NVTIM

- **NVTIM: Non-valid Time**

0 = No invalid data has been detected in RTC_TIMR (Time Register).

1 = RTC_TIMR has contained invalid data since it was last programmed.

- **NVCAL: Non-valid Calendar**

0 = No invalid data has been detected in RTC_CALR (Calendar Register).

1 = RTC_CALR has contained invalid data since it was last programmed.

- **NVTIMALR: Non-valid Time Alarm**

0 = No invalid data has been detected in RTC_TIMALR (Time Alarm Register).

1 = RTC_TIMALR has contained invalid data since it was last programmed.

- **NVCALALR: Non-valid Calendar Alarm**

0 = No invalid data has been detected in RTC_CALALR (Calendar Alarm Register).

1 = RTC_CALALR has contained invalid data since it was last programmed.

17.5.13 RTC Write Protect Mode Register

Name: RTC_WPMR

Address: 0x400E1344

Access: Read-write

31	30	29	28	27	26	25	24
WPKEY							

23	22	21	20	19	18	17	16
WPKEY							

15	14	13	12	11	10	9	8
WPKEY							

7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPEN

- **WPEN: Write Protect Enable**

0 = Disables the Write Protect if WPKEY corresponds to 0x525443 (“RTC” in ASCII).

1 = Enables the Write Protect if WPKEY corresponds to 0x525443 (“RTC” in ASCII).

Protects the registers:

“RTC Mode Register” on page 252

“RTC Time Alarm Register” on page 255

“RTC Calendar Alarm Register” on page 256

18. Supply Controller (SUPC)

18.1 Description

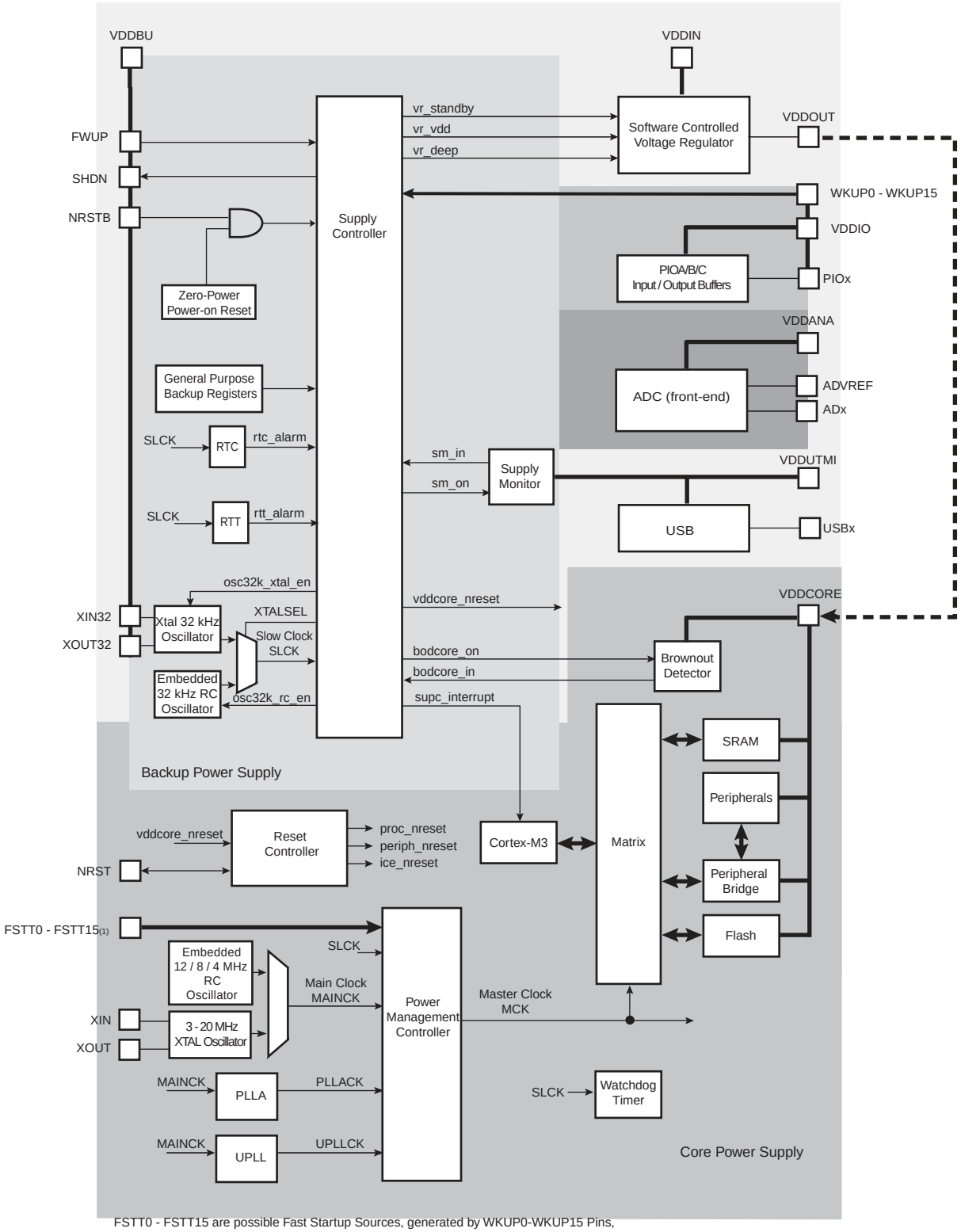
The Supply Controller (SUPC) controls the supply voltage of the Core of the system and manages the Backup Low Power Mode. In this mode, the current consumption is reduced to a few microamps for Backup power retention. Exit from this mode is possible on multiple wake-up sources including events on FWUP or WKUP pins, or a Clock alarm. The SUPC also generates the Slow Clock by selecting either the Low Power RC oscillator or the Low Power Crystal oscillator.

18.2 Embedded Characteristics

- Manages the Core Power Supply VDDCORE and the Backup Low Power Mode by Controlling the Embedded Voltage Regulator
- Generates the Slow Clock SLCK, by Selecting Either the 22-42 kHz Low Power RC Oscillator or the 32 kHz Low Power Crystal Oscillator
- Supports Multiple Wake Up Sources, for Exit from Backup Low Power Mode
  - Force Wake Up Pin, with Programmable Debouncing
  - 16 Wake Up Inputs, with Programmable Debouncing
  - Real Time Clock Alarm
  - Real Time Timer Alarm
  - Supply Monitor Detection on VDDUTMI, with Programmable Scan Period and Voltage Threshold
- A Supply Monitor Detection on VDDUTMI or a Brownout Detection on VDDCORE can Trigger a Core Reset
- Embeds:
  - One 22 to 42 kHz Low Power RC Oscillator
  - One 32 kHz Low Power Crystal Oscillator
  - One Zero-Power Power-On Reset Cell
  - One Software Programmable Supply Monitor, on VDDUTMI Located in Backup Section
  - One Brownout Detector on VDDCORE Located in the Core

18.3 Block Diagram

Figure 18-1. Supply Controller Block Diagram



FSTT0 - FSTT15 are possible Fast Startup Sources, generated by WKUP0-WKUP15 Pins, but are not physical pins.

18.4 Supply Controller Functional Description

18.4.1 Supply Controller Overview

The device can be divided into two power supply areas:

- The Backup VDDBU Power Supply: including the Supply Controller, a part of the Reset Controller, the Slow Clock switch, the General Purpose Backup Registers, the Supply Monitor and the Clock which includes the Real Time Timer and the Real Time Clock
- The Core Power Supply: including the other part of the Reset Controller, the Brownout Detector, the Processor, the SRAM memory, the FLASH memory and the Peripherals

The Supply Controller (SUPC) controls the supply voltage of the core power supply. The SUPC intervenes when the VDDUTMI power supply rises (when the system is starting) or when the Backup Low Power Mode is entered.

The SUPC also integrates the Slow Clock generator which is based on a 32 kHz crystal oscillator and an embedded 32 kHz RC oscillator. The Slow Clock defaults to the RC oscillator, but the software can enable the crystal oscillator and select it as the Slow Clock source.

The Supply Controller and the VDDUTMI power supply have a reset circuitry based on the NRSTB pin and a zero-power power-on reset cell. The zero-power power-on reset allows the SUPC to start properly as soon as the VDDUTMI voltage becomes valid. The NRSTB pin allows to reset the system from outside.

At startup of the system, once the backup voltage VDDUTMI is valid and the reset pin NRSTB is not driven low and the embedded 32 kHz RC oscillator is stabilized, the SUPC starts up the core by sequentially enabling the internal Voltage Regulator, waiting that the core voltage VDDCORE is valid, then releasing the reset signal of the core “vddcore_nreset” signal.

Once the system has started, the user can program a supply monitor and/or a brownout detector. If the supply monitor detects a voltage on VDDUTMI that is too low, the SUPC can assert the reset signal of the core “vddcore_nreset” signal until VDDUTMI is valid. Likewise, if the brownout detector detects a core voltage VDDCORE that is too low, the SUPC can assert the reset signal “vddcore_nreset” until VDDCORE is valid.

When the Backup Low Power Mode is entered, the SUPC sequentially asserts the reset signal of the core power supply “vddcore_nreset” and disables the voltage regulator, in order to supply only the VDDUTMI power supply. In this mode the current consumption is reduced to a few microamps for Backup part retention. Exit from this mode is possible on multiple wake-up sources including an event on FWUP pin or WKUP pins, or a Clock alarm. To exit this mode, the SUPC operates in the same way as system startup.

18.4.2 Slow Clock Generator

The Supply Controller embeds a slow clock generator that is supplied with the VDDUTMI power supply. As soon as the VDDUTMI is supplied, both the crystal oscillator and the embedded RC oscillator are powered up, but only the embedded RC oscillator is enabled. This allows the slow clock to be valid in a short time (about 100 µs).

The user can select the crystal oscillator to be the source of the slow clock, as it provides a more accurate frequency. The command is made by writing the Supply Controller Control Register (SUPC_CR) with the XTALSEL bit at 1. This results in a sequence which first enables the crystal oscillator, then waits for 32,768 slow clock cycles, then switches the slow clock on the output of the crystal oscillator and then disables the RC oscillator to save power. The switch of the slow clock source is glitch free. The OSCSEL bit of the Supply Controller Status Register (SUPC_SR) allows knowing when the switch sequence is done.

Coming back on the RC oscillator is only possible by shutting down the VDDUTMI power supply.

If the user does not need the crystal oscillator, the XIN32 and XOUT32 pins should be left unconnected.

The user can also set the crystal oscillator in bypass mode instead of connecting a crystal. In this case, the user has to provide the external clock signal on XIN32. The input characteristics of the XIN32 pin are given in the product electrical characteristics section. In order to set the bypass mode, the OSCBYPASS bit of the Supply Controller Mode Register (SUPC_MR) needs to be set at 1.

18.4.3 Voltage Regulator Control/Backup Low Power Mode

The Supply Controller can be used to control the embedded 1.8V voltage regulator.

The voltage regulator automatically adapts its quiescent current depending on the required load current. Please refer to the electrical characteristics section.

The programmer can switch off the voltage regulator, and thus put the device in Backup mode, by writing the Supply Controller Control Register (SUPC_CR) with the VROFF bit at 1.

This can be done also by using WFE (Wait for Event) Cortex-M3 instruction with the deep mode bit set to 1.

The Backup mode can also be entered by executing the WFI (Wait for Interrupt) or WFE (Wait for Event) Cortex-M3 instructions. To select the Backup mode entry mechanism, two options are available, depending on the SLEEPONEXIT bit in the Cortex-M3 System Control register:

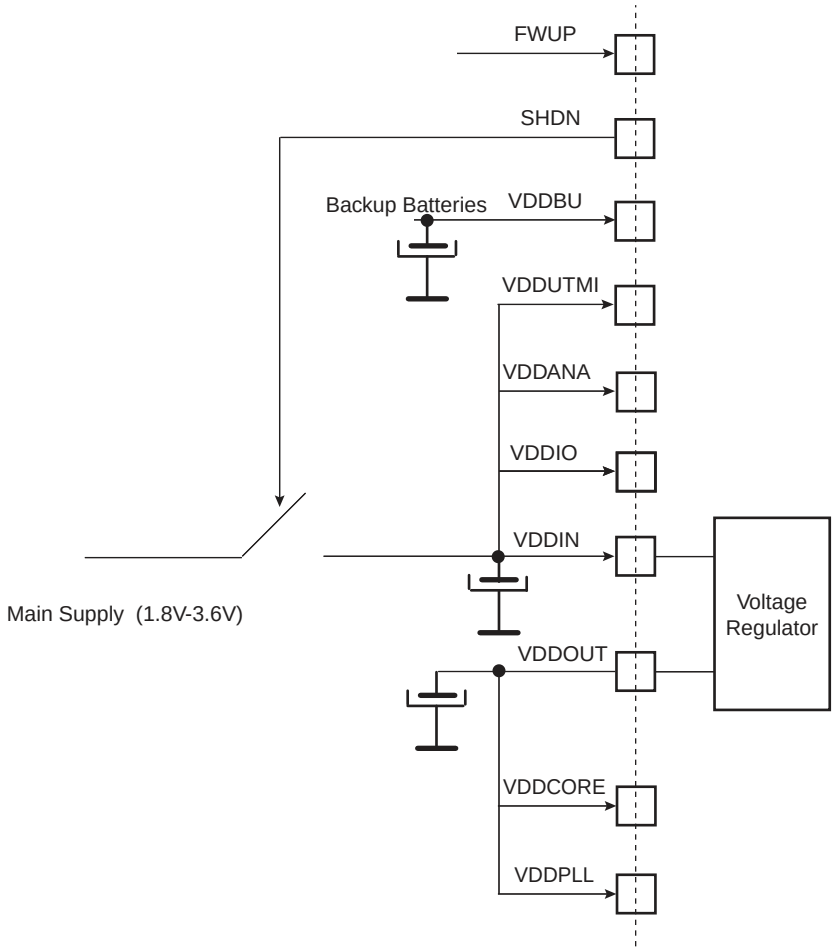
- Sleep-now: if the SLEEPONEXIT bit is cleared, the device enters Backup mode as soon as the WFI or WFE instruction is executed.
- Sleep-on-exit: if the SLEEPONEXIT bit is set when the WFI instruction is executed, the device enters Backup mode as soon as it exits the lowest priority ISR.

This asserts the vddcore_nreset signal after the write resynchronization time which lasts, in the worse case, two slow clock cycles. Once the vddcore_nreset signal is asserted, the processor and the peripherals are stopped one slow clock cycle before the core power supply shuts off.

18.4.4 Using Backup Batteries/Backup Supply

The product can be used with or without backup batteries, or more generally a backup supply. When a backup supply is used (See Figure 18-2), only VDDBU voltage is present in Backup mode and no other external supply is applied on the chip. In this case the user needs to clear VDDIORDY bit in the Supply Controller Mode Register (SUPC_MR) at least two slow clock periods before VDDIO voltage is removed. When waking up from Backup mode, the programmer needs to set VDDIORDY.

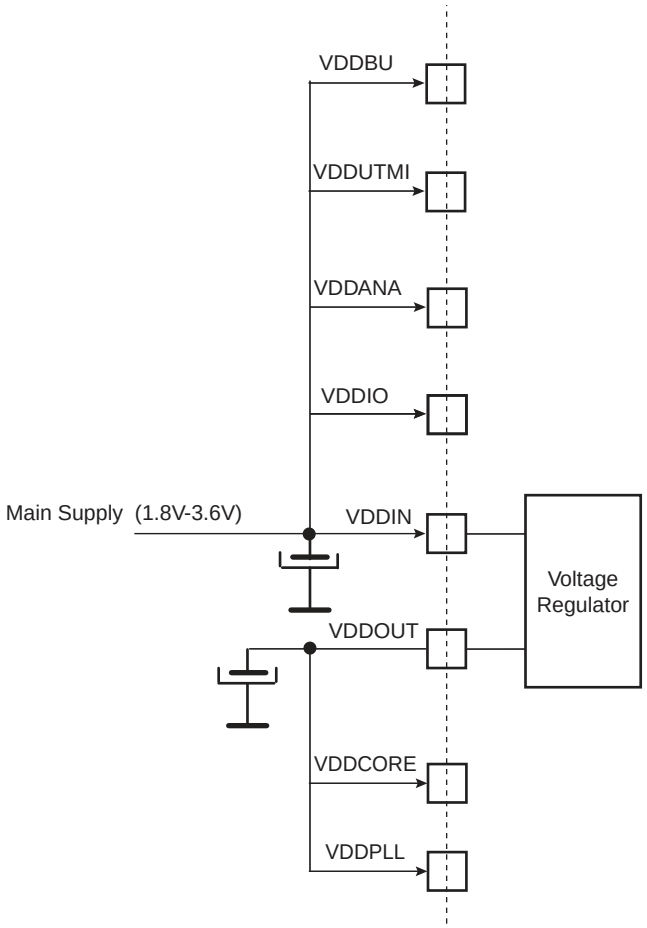
Figure 18-2. Separated Backup Supply Powering Scheme



Note: Restrictions: With Main Supply < 3V, some peripherals such as USB and ADC might not be operational. Refer to the DC Characteristics of the product for actual possible ranges for such peripherals.

When a separated backup supply for VDDBU is not used (See Figure 18-3), since the external voltage applied on VDDIO is kept, all of the I/O configurations (i.e. WKUP pin configuration) are kept during backup mode. When not using backup batteries, VDDIORDY is set so the user does not need to program it.

Figure 18-3. No Separated Backup Supply Powering Scheme



Note: Restrictions: With Main Supply < 3V, some peripherals such as USB and ADC might not be operational. Refer to the DC Characteristics of the product for actual possible ranges for such peripherals.

18.4.5 Supply Monitor

The Supply Controller embeds a supply monitor which is located in the VDDBU Backup Power Supply and which monitors VDDUTMI power supply.

The supply monitor can be used to prevent the processor from falling into an unpredictable state if the Main power supply drops below a certain level.

The threshold of the supply monitor is programmable. It can be selected from 1.9V to 3.4V by steps of 100 mV. This threshold is programmed in the SMTH field of the Supply Controller Supply Monitor Mode Register (SUPC_SMMR).

The supply monitor can also be enabled during one slow clock period on every one of **either** 32, 256 or 2048 slow clock periods, according to the choice of the user. This can be configured by programming the SMSMPL field in SUPC_SMMR.

Enabling the supply monitor for such reduced times allows to divide the typical supply monitor power consumption respectively by factors of 32, 256 or 2048, if the user does not need a continuous monitoring of the VDDUTMI power supply.

A supply monitor detection can either generate a reset of the core power supply or a wake up of the core power supply. Generating a core reset when a supply monitor detection occurs is enabled by writing the SMRSTEN bit to 1 in SUPC_SMMR.

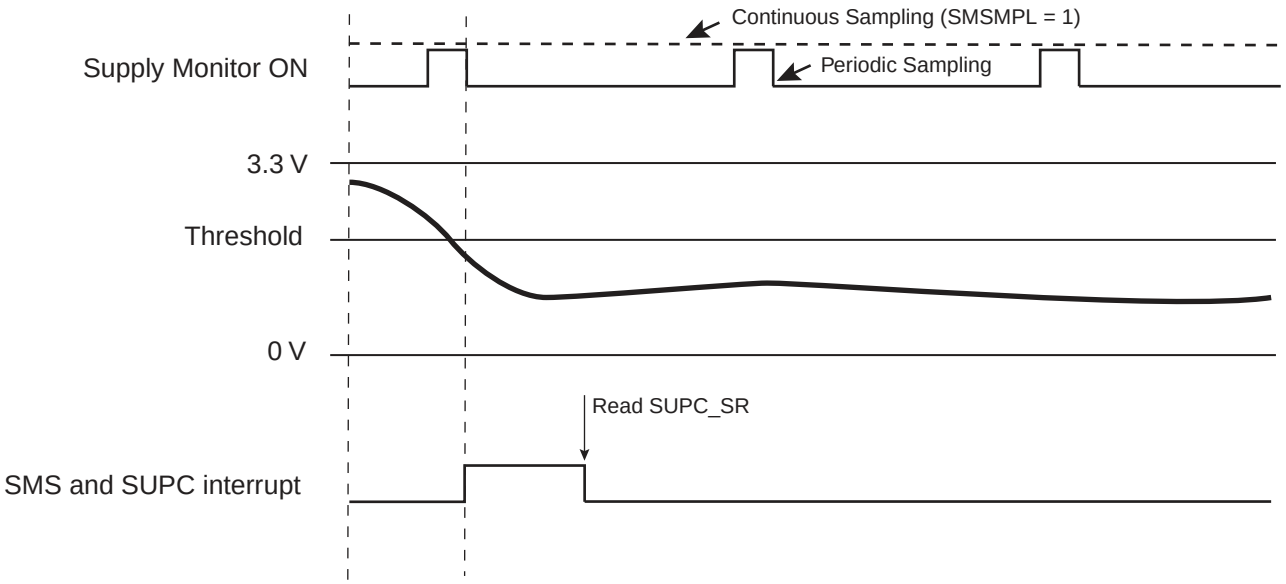
Waking up the core power supply when a supply monitor detection occurs can be enabled by programming the SMEN bit to 1 in the Supply Controller Wake Up Mode Register (SUPC_WUMR).

The Supply Controller provides two status bits in the Supply Controller Status Register for the supply monitor which allows to determine whether the last wake up was due to the supply monitor:

- The SMOS bit provides real time information, which is updated at each measurement cycle or updated at each Slow Clock cycle, if the measurement is continuous.
- The SMS bit provides saved information and shows a supply monitor detection has occurred since the last read of SUPC_SR.

The SMS bit can generate an interrupt if the SMIEN bit is set to 1 in the Supply Controller Supply Monitor Mode Register (SUPC_SMMR).

Figure 18-4. Supply Monitor Status Bit and Associated Interrupt



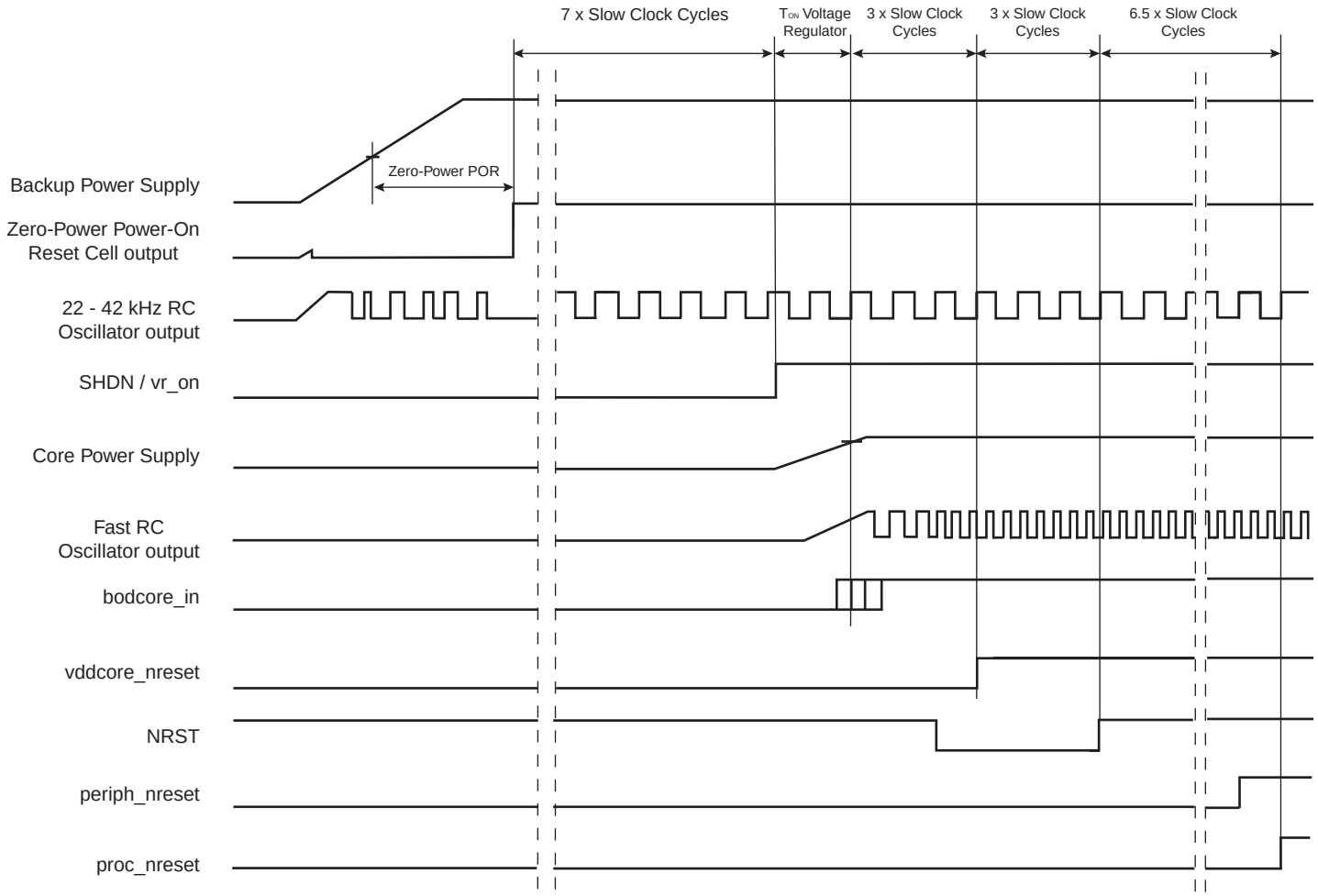
18.4.6 Backup Power Supply Reset

18.4.6.1 Raising the Backup Power Supply

As soon as the backup voltage VDDUTMI rises, the RC oscillator is powered up and the zero-power power-on reset cell maintains its output low as long as VDDUTMI has not reached its target voltage. During this time, the Supply Controller is entirely reset. When the VDDUTMI voltage becomes valid and zero-power power-on reset signal is released, a counter is started for 5 slow clock cycles. This is the time it takes for the 32 kHz RC oscillator to stabilize.

After this time, the SHDN pin is asserted and the voltage regulator is enabled. The core power supply rises and the brownout detector provides the bodcore_in signal as soon as the core voltage VDDCORE is valid. This results in releasing the vddcore_nreset signal to the Reset Controller after the bodcore_in signal has been confirmed as being valid for at least one slow clock cycle.

Figure 18-5. Raising the VDDUTMI Power Supply



Note: After “proc_nreset” rising, the core starts fecthing instructions from Flash at 4 MHz.

18.4.6.2 NRSTB Asynchronous Reset Pin

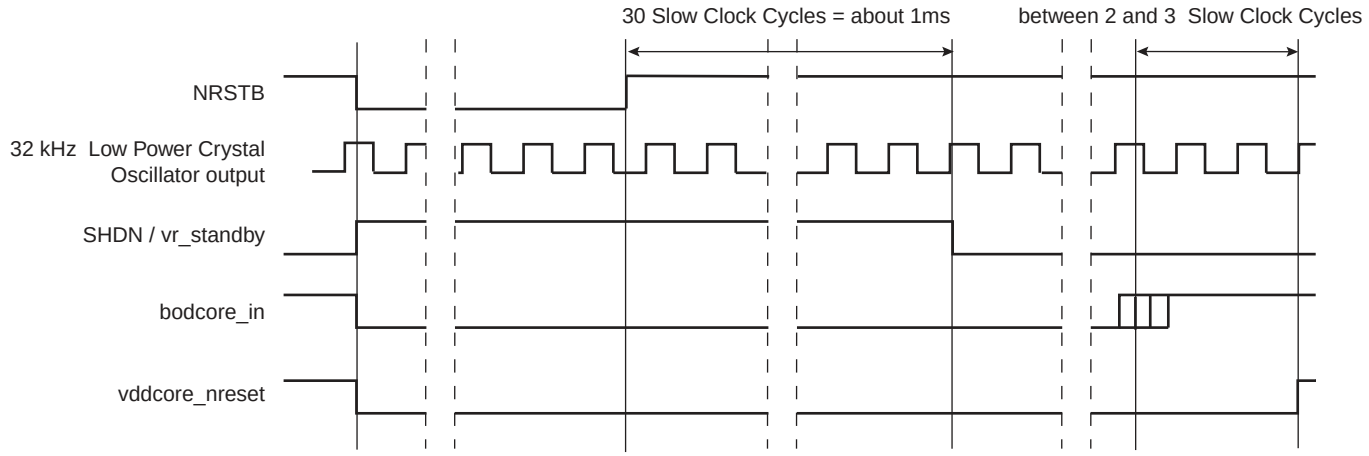
The NRSTB pin is an asynchronous reset input, which acts exactly like the zero-power power-on reset cell.

As soon as NRSTB is tied to GND, the supply controller is reset generating in turn, a reset of the whole system.

When NRSTB is released, the system can start as described in Section 18.4.6.1 "Raising the Backup Power Supply".

The NRSTB pin does not need to be driven during power-up phase to allow a reset of the system, it is done by the zero-power power-on cell.

Figure 18-6. NRSTB Reset



Note: periph_nreset, ice_reset and proc_nreset are not shown, but are asserted low thanks to the vddcore_nreset signal controlling the Reset controller.

18.4.6.3 SHDN output pin

As shown in Figure 18-6, the SHDN pin acts like the vr_standby signal making it possible to use the SHDN pin to control external voltage regulator with shutdown capabilities.

18.4.7 Core Reset

The Supply Controller manages the vddcore_nreset signal to the Reset Controller, as described previously in Section 18.4.6 "Backup Power Supply Reset". The vddcore_nreset signal is normally asserted before shutting down the core power supply and released as soon as the core power supply is correctly regulated.

There are two additional sources which can be programmed to activate vddcore_nreset:

- a supply monitor detection
- a brownout detection

18.4.7.1 Supply Monitor Reset

The supply monitor is capable of generating a reset of the system. This can be enabled by setting the SMRSTEN bit in the Supply Controller Supply Monitor Mode Register (SUPC_SMMR).

If SMRSTEN is set and if a supply monitor detection occurs, the vddcore_nreset signal is immediately activated for a minimum of 1 slow clock cycle.

18.4.7.2 Brownout Detector Reset

The brownout detector provides the bodcore_in signal to the SUPC which indicates that the voltage regulation is operating as programmed. If this signal is lost for longer than 1 slow clock period while the voltage regulator is enabled, the Supply Controller can assert vddcore_nreset. This feature is enabled by writing the bit, BODRSTEN (Brownout Detector Reset Enable) to 1 in the Supply Controller Mode Register (SUPC_MR).

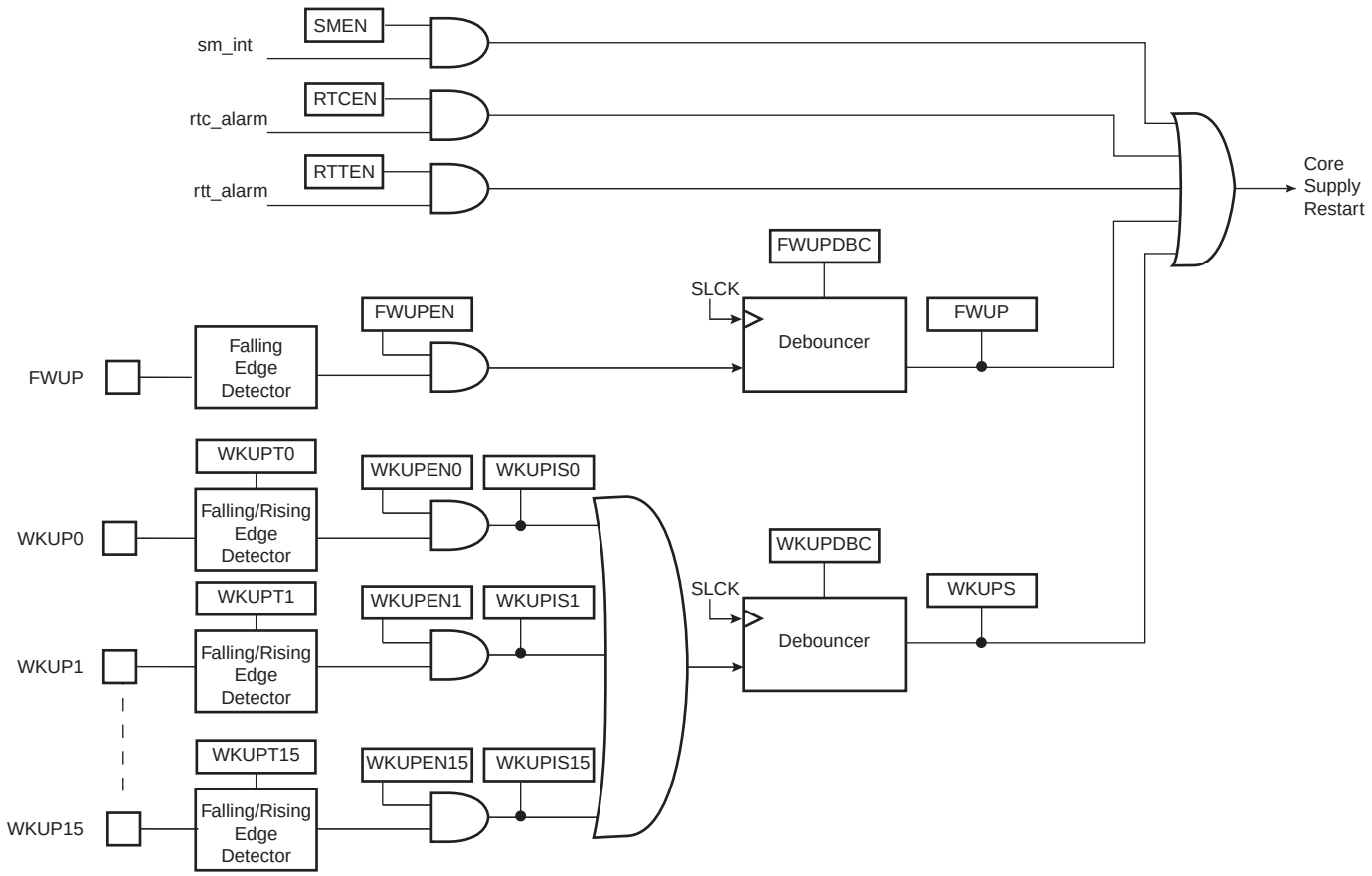
If BODRSTEN is set and the voltage regulation is lost (output voltage of the regulator too low), the vddcore_nreset signal is asserted for a minimum of 1 slow clock cycle and then released if bodcore_in has been reactivated. The BODRSTS bit is set in the Supply Controller Status Register (SUPC_SR) so that the user can know the source of the last reset.

Until bodcore_in is deactivated, the vddcore_nreset signal remains active.

18.4.8 Wake Up Sources

The wake up events allow the device to exit backup mode. When a wake up event is detected, the Supply Controller performs a sequence which automatically reenables the core power supply.

Figure 18-7. Wake Up Sources



18.4.8.1 Force Wake Up

The FWUP pin is enabled as a wake up source by writing the FWUPEN bit to 1 in the Supply Controller Wake Up Mode Register (SUPC_WUMR). Then, the FWUPDBC field in the same register selects the debouncing period, which can be selected between 3, 32, 512, 4,096 or 32,768 slow clock cycles. This corresponds respectively to about 100 µs, about 1 ms, about 16 ms, about 128 ms and about 1 second (for a typical slow clock frequency of 32 kHz). Programming FWUPDBC to 0x0 selects an immediate wake up, i.e., the FWUP must be low during a minimum of one slow clock period to wake up the core power supply.

If the FWUP pin is asserted for a time longer than the debouncing period, a wake up of the core power supply is started and the FWUP bit in the Supply Controller Status Register (SUPC_SR) is set and remains high until the register is read.

18.4.8.2 Wake Up Inputs

The wake up inputs, WKUP0 to WKUP15, can be programmed to perform a wake up of the core power supply. Each input can be enabled by writing to 1 the corresponding bit, WKUPEN0 to WKUPEN 15, in the Wake Up Inputs Register (SUPC_WUIR). The wake up level can be selected with the corresponding polarity bit, WKUPPL0 to WKUPPL15, also located in SUPC_WUIR.

All the resulting signals are wired-ORed to trigger a debounce counter, which can be programmed with the WKUPDBC field in the Supply Controller Wake Up Mode Register (SUPC_WUMR). The WKUPDBC field can select a debouncing period of 3, 32, 512, 4,096 or 32,768 slow clock cycles. This corresponds respectively to about 100 µs, about 1 ms, about 16 ms, about 128 ms and about 1 second (for a typical slow clock frequency of 32 kHz). Programming WKUPDBC to 0x0 selects an immediate wake up, i.e., an enabled WKUP pin must be active according to its polarity during a minimum of one slow clock period to wake up the core power supply.

If an enabled WKUP pin is asserted for a time longer than the debouncing period, a wake up of the core power supply is started and the signals, WKUP0 to WKUP15 as shown in Figure 18-7, are latched in the Supply Controller Status Register (SUPC_SR). This allows the user to identify the source of the wake up, however, if a new wake up condition occurs, the primary information is lost. No new wake up can be detected since the primary wake up condition has disappeared.

18.4.8.3 Clock Alarms

The RTC and the RTT alarms can generate a wake up of the core power supply. This can be enabled by writing respectively, the bits RTCEN and RTTEN to 1 in the Supply Controller Wake Up Mode Register (SUPC_WUMR).

The Supply Controller does not provide any status as the information is available in the User Interface of either the Real Time Timer or the Real Time Clock.

18.4.8.4 Supply Monitor Detection

The supply monitor can generate a wakeup of the core power supply. See Section 18.4.5 ”Supply Monitor”.

18.5 Supply Controller (SUPC) User Interface

The User Interface of the Supply Controller is part of the System Controller User Interface.

18.5.1 System Controller (SYSC) User Interface

Table 18-1. System Controller Registers

Offset	System Controller Peripheral	Name
0x00-0x0c	Reset Controller	RSTC
0x10-0x2C	Supply Controller	SUPC
0x30-0x3C	Real Time Timer	RTT
0x50-0x5C	Watchdog Tiler	WDT
0x60-0x7C	Real Time Clock	RTC
0x90-0xDC	General Purpose Backup Register	GPBR

18.5.2 Supply Controller (SUPC) User Interface

Table 18-2. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Supply Controller Control Register	SUPC_CR	Write-only	N/A
0x04	Supply Controller Supply Monitor Mode Register	SUPC_SMMR	Read-write	0x0000_0000
0x08	Supply Controller Mode Register	SUPC_MR	Read-write	0x0000_5A00
0x0C	Supply Controller Wake Up Mode Register	SUPC_WUMR	Read-write	0x0000_0000
0x10	Supply Controller Wake Up Inputs Register	SUPC_WUIR	Read-write	0x0000_0000
0x14	Supply Controller Status Register	SUPC_SR	Read-only	0x0000_0800
0x18	Reserved			

18.5.3 Supply Controller Control Register

Name: SUPC_CR

Address: 0x400E1210

Access: Write-only

31	30	29	28	27	26	25	24
KEY							

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–		–

7	6	5	4	3	2	1	0
–	–	–	–	XTALSEL	VROFF	–	–

- **VROFF: Voltage Regulator Off**

0 (NO_EFFECT) = no effect.

1 (STOP_VREG) = if KEY is correct, asserts vddcore_nreset and stops the voltage regulator.

- **XTALSEL: Crystal Oscillator Select**

0 (NO_EFFECT) = no effect.

1 (CRYSTAL_SEL) = if KEY is correct, switches the slow clock on the crystal oscillator output.

- **KEY: Password**

Should be written to value 0xA5. Writing any other value in this field aborts the write operation.

18.5.4 Supply Controller Supply Monitor Mode Register

Name: SUPC_SMMR

Address: 0x400E1214

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	SMIEN	SMRSTEN	–	SMSMPL		

7	6	5	4	3	2	1	0
–	–	–	–	SMTH			

- **SMTH: Supply Monitor Threshold**

Value	Name	Description
0x0	1_9V	1.9 V
0x1	2_0V	2.0 V
0x2	2_1V	2.1 V
0x3	2_2V	2.2 V
0x4	2_3V	2.3 V
0x5	2_4V	2.4 V
0x6	2_5V	2.5 V
0x7	2_6V	2.6 V
0x8	2_7V	2.7 V
0x9	2_8V	2.8 V
0xA	2_9V	2.9 V
0xB	3_0V	3.0 V
0xC	3_1V	3.1 V
0xD	3_2V	3.2 V
0xE	3_3V	3.3 V
0xF	3_4V	3.4 V

- **SMSMPL: Supply Monitor Sampling Period**

Value	Name	Description
0x0	SMD	Supply Monitor disabled
0x1	CSM	Continuous Supply Monitor
0x2	32SLCK	Supply Monitor enabled one SLCK period every 32 SLCK periods
0x3	256SLCK	Supply Monitor enabled one SLCK period every 256 SLCK periods
0x4	2048SLCK	Supply Monitor enabled one SLCK period every 2,048 SLCK periods
0x5-0x7	Reserved	Reserved

- **SMRSTEN: Supply Monitor Reset Enable**

0 (NOT_ENABLE) = the core reset signal “vddcore_nreset” is not affected when a supply monitor detection occurs.

1 (ENABLE) = the core reset signal, vddcore_nreset is asserted when a supply monitor detection occurs.

- **SMIEN: Supply Monitor Interrupt Enable**

0 (NOT_ENABLE) = the SUPC interrupt signal is not affected when a supply monitor detection occurs.

1 (ENABLE) = the SUPC interrupt signal is asserted when a supply monitor detection occurs.

18.5.5 Supply Controller Mode Register

Name: SUPC_MR

Address: 0x400E1218

Access: Read-write

31	30	29	28	27	26	25	24
KEY							

23	22	21	20	19	18	17	16
–	–	–	OSCBYPASS	–	–	–	–

15	14	13	12	11	10	9	8
–	VDDIORDY	BODDIS	BODRSTEN	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **BODRSTEN: Brownout Detector Reset Enable**

0 (NOT_ENABLE) = the core reset signal “vddcore_nreset” is not affected when a brownout detection occurs.

1 (ENABLE) = the core reset signal, vddcore_nreset is asserted when a brownout detection occurs.

- **BODDIS: Brownout Detector Disable**

0 (ENABLE) = the core brownout detector is enabled.

1 (DISABLE) = the core brownout detector is disabled.

- **VDDIORDY: VDDIO Ready**

0 (VDDIO_REMOVED) = VDDIO is removed (used before going to backup mode when backup batteries are used)

1 (VDDIO_PRESENT) = VDDIO is present (used before going to backup mode when backup batteries are used)

If the backup batteries are not used, VDDIORDY must be kept set to 1.

- **OSCBYPASS: Oscillator Bypass**

0 (NO_EFFECT) = no effect. Clock selection depends on XTALSEL value.

1 (BYPASS) = the 32-KHz XTAL oscillator is selected and is put in bypass mode.

- **KEY: Password Key**

Should be written to value 0xA5. Writing any other value in this field aborts the write operation.

18.5.6 Supply Controller Wake Up Mode Register

Name: SUPC_WUMR

Address: 0x400E121C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	WKUPDBC			–	FWUPDBC		

7	6	5	4	3	2	1	0
–	–	–	–	RTCEN	RTTEN	SMEN	FWUPEN

- **FWUPEN: Force Wake Up Enable**

0 (NOT_ENABLE) = the Force Wake Up pin has no wake up effect.

1 (ENABLE) = the Force Wake Up pin low forces the wake up of the core power supply.

- **SMEN: Supply Monitor Wake Up Enable**

0 (NOT_ENABLE) = the supply monitor detection has no wake up effect.

1 (ENABLE) = the supply monitor detection forces the wake up of the core power supply.

- **RTTEN: Real Time Timer Wake Up Enable**

0 (NOT_ENABLE) = the RTT alarm signal has no wake up effect.

1 (ENABLE) = the RTT alarm signal forces the wake up of the core power supply.

- **RTCEN: Real Time Clock Wake Up Enable**

0 (NOT_ENABLE) = the RTC alarm signal has no wake up effect.

1 (ENABLE) = the RTC alarm signal forces the wake up of the core power supply.

- **FWUPDBC: Force Wake Up Debouncer Period**

Value	Name	Description
0	IMMEDIATE	Immediate, no debouncing, detected active at least on one Slow Clock edge.
1	3_SCLK	FWUP shall be low for at least 3 SLCK periods
2	32_SCLK	FWUP shall be low for at least 32 SLCK periods
3	512_SCLK	FWUP shall be low for at least 512 SLCK periods
4	4096_SCLK	FWUP shall be low for at least 4,096 SLCK periods
5	32768_SCLK	FWUP shall be low for at least 32,768 SLCK periods
6	Reserved	Reserved
7	Reserved	Reserved

- **WKUPDBC: Wake Up Inputs Debouncer Period**

Value	Name	Description
0	IMMEDIATE	Immediate, no debouncing, detected active at least on one Slow Clock edge.
1	3_SCLK	WKUPx shall be in its active state for at least 3 SLCK periods
2	32_SCLK	WKUPx shall be in its active state for at least 32 SLCK periods
3	512_SCLK	WKUPx shall be in its active state for at least 512 SLCK periods
4	4096_SCLK	WKUPx shall be in its active state for at least 4,096 SLCK periods
5	32768_SCLK	WKUPx shall be in its active state for at least 32,768 SLCK periods
6	Reserved	Reserved
7	Reserved	Reserved

18.5.7 System Controller Wake Up Inputs Register

Name: SUPC_WUIR

Address: 0x400E1220

Access: Read-write

31	30	29	28	27	26	25	24
WKUPT15	WKUPT14	WKUPT13	WKUPT12	WKUPT11	WKUPT10	WKUPT9	WKUPT8
23	22	21	20	19	18	17	16
WKUPT7	WKUPT6	WKUPT5	WKUPT4	WKUPT3	WKUPT2	WKUPT1	WKUPT0
15	14	13	12	11	10	9	8
WKUPEN15	WKUPEN14	WKUPEN13	WKUPEN12	WKUPEN11	WKUPEN10	WKUPEN9	WKUPEN8
7	6	5	4	3	2	1	0
WKUPEN7	WKUPEN6	WKUPEN5	WKUPEN4	WKUPEN3	WKUPEN2	WKUPEN1	WKUPEN0

- **WKUPEN0 - WKUPEN15: Wake Up Input Enable 0 to 15**

0 (NOT_ENABLE) = the corresponding wake-up input has no wake up effect.

1 (ENABLE) = the corresponding wake-up input forces the wake up of the core power supply.

- **WKUPT0 - WKUPT15: Wake Up Input Transition 0 to 15**

0 (HIGH_TO_LOW) = a high to low level transition on the corresponding wake-up input forces the wake up of the core power supply.

1 (LOW_TO_HIGH) = a low to high level transition on the corresponding wake-up input forces the wake up of the core power supply.

18.5.8 Supply Controller Status Register

Name: SUPC_SR

Address: 0x400E1224

Access: Read-write

31	30	29	28	27	26	25	24
WKUPIS15	WKUPIS14	WKUPIS13	WKUPIS12	WKUPIS11	WKUPIS10	WKUPIS9	WKUPIS8
23	22	21	20	19	18	17	16
WKUPIS7	WKUPIS6	WKUPIS5	WKUPIS4	WKUPIS3	WKUPIS2	WKUPIS1	WKUPIS0
15	14	13	12	11	10	9	8
–	–	–	FWUPIS	–	–	–	–
7	6	5	4	3	2	1	0
OSCSEL	SMOS	SMS	SMRSTS	BODRSTS	SMWS	WKUPS	FWUPS

Note: Because of the asynchronism between the Slow Clock (SCLK) and the System Clock (MCK), the status register flag reset is taken into account only 2 slow clock cycles after the read of the SUPC_SR.

- **FWUPS: FWUP Wake Up Status**

0 (NO) = no wake up due to the assertion of the FWUP pin has occurred since the last read of SUPC_SR.

1 (PRESENT) = at least one wake up due to the assertion of the FWUP pin has occurred since the last read of SUPC_SR.

- **WKUPS: WKUP Wake Up Status**

0 (NO) = no wake up due to the assertion of the WKUP pins has occurred since the last read of SUPC_SR.

1 (PRESENT) = at least one wake up due to the assertion of the WKUP pins has occurred since the last read of SUPC_SR.

- **SMWS: Supply Monitor Detection Wake Up Status**

0 (NO) = no wake up due to a supply monitor detection has occurred since the last read of SUPC_SR.

1 (PRESENT) = at least one wake up due to a supply monitor detection has occurred since the last read of SUPC_SR.

- **BODRSTS: Brownout Detector Reset Status**

0 (NO) = no core brownout rising edge event has been detected since the last read of the SUPC_SR.

1 (PRESENT) = at least one brownout output rising edge event has been detected since the last read of the SUPC_SR.

When the voltage remains below the defined threshold, there is no rising edge event at the output of the brownout detection cell. The rising edge event occurs only when there is a voltage transition below the threshold.

- **SMRSTS: Supply Monitor Reset Status**

0 (NO) = no supply monitor detection has generated a core reset since the last read of the SUPC_SR.

1 (PRESENT) = at least one supply monitor detection has generated a core reset since the last read of the SUPC_SR.

- **SMS: Supply Monitor Status**

0 (NO) = no supply monitor detection since the last read of SUPC_SR.

1 (PRESENT) = at least one supply monitor detection since the last read of SUPC_SR.

- **SMOS: Supply Monitor Output Status**

0 (HIGH) = the supply monitor detected VDDUTMI higher than its threshold at its last measurement.

1 (LOW) = the supply monitor detected VDDUTMI lower than its threshold at its last measurement.

- **OSCSEL: 32-kHz Oscillator Selection Status**

0 (RC) = the slow clock, SLCK is generated by the embedded 32-kHz RC oscillator.

1 (CRYST) = the slow clock, SLCK is generated by the 32-kHz crystal oscillator.

- **FWUPIS: FWUP Input Status**

0 (LOW) = FWUP input is tied low.

1 (HIGH) = FWUP input is tied high.

- **WKUPIS0-WKUPIS15: WKUP Input Status 0 to 15**

0 (DIS) = the corresponding wake-up input is disabled, or was inactive at the time the debouncer triggered a wake up event.

1 (EN) = the corresponding wake-up input was active at the time the debouncer triggered a wake up event.

19. General Purpose Backup Registers (GPBR)

19.1 Embedded Characteristics

- eight 32-bit General Purpose Backup Registers

19.2 Description

The System Controller embeds eight general-purpose backup registers.

19.2.1 Power Management Controller (PMC) User Interface

Table 19-1. Register Mapping

Offset	Register	Name	Access	Reset
0x0	General Purpose Backup Register 0	SYS_GPBR0	Read-write	–
...	...	...	...	...
0x1c	General Purpose Backup Register 7	SYS_GPBR7	Read-write	–

19.2.1.1 General Purpose Backup Register x

Name: SYS_GPBRx

Address: 0x400E1290 [0] .. 0x400E12AC [7]

Access: Read-write

31	30	29	28	27	26	25	24
GPBR_VALUEx							
23	22	21	20	19	18	17	16
GPBR_VALUEx							
15	14	13	12	11	10	9	8
GPBR_VALUEx							
7	6	5	4	3	2	1	0
GPBR_VALUEx							

- **GPBR_VALUEx: Value of GPBR x**

20. Enhanced Embedded Flash Controller (EEFC)

20.1 Description

The Enhanced Embedded Flash Controller (EEFC) ensures the interface of the Flash block with the 32-bit internal bus.

Its 128-bit or 64-bit wide memory interface increases performance. It also manages the programming, erasing, locking and unlocking sequences of the Flash using a full set of commands. One of the commands returns the embedded Flash descriptor definition that informs the system about the Flash organization, thus making the software generic.

20.2 Embedded Characteristics

- Interface of the Flash Block with the 32-bit Internal Bus
- Increases Performance in Thumb2 Mode with 128-bit or -64 bit Wide Memory Interface up to 24 MHz
- 32 Lock Bits, Each Protecting a Lock Region
- GPNVMx General-purpose GPNVM Bits
- One-by-one Lock Bit Programming
- Commands Protected by a Keyword
- Erases the Entire Flash
- Erases by Plane
- Possibility of Erasing before Programming
- Locking and Unlocking Operations
- Consecutive Programming and Locking Operations

20.3 Product Dependencies

20.3.1 Power Management

The Enhanced Embedded Flash Controller (EEFC) is continuously clocked. The Power Management Controller has no effect on its behavior.

20.3.2 Interrupt Sources

The Enhanced Embedded Flash Controller (EEFC) interrupt line is connected to the Nested Vectored Interrupt Controller (NVIC). Using the Enhanced Embedded Flash Controller (EEFC) interrupt requires the NVIC to be programmed first. The EEFC interrupt is generated only on FRDY bit rising.

20.4 Functional Description

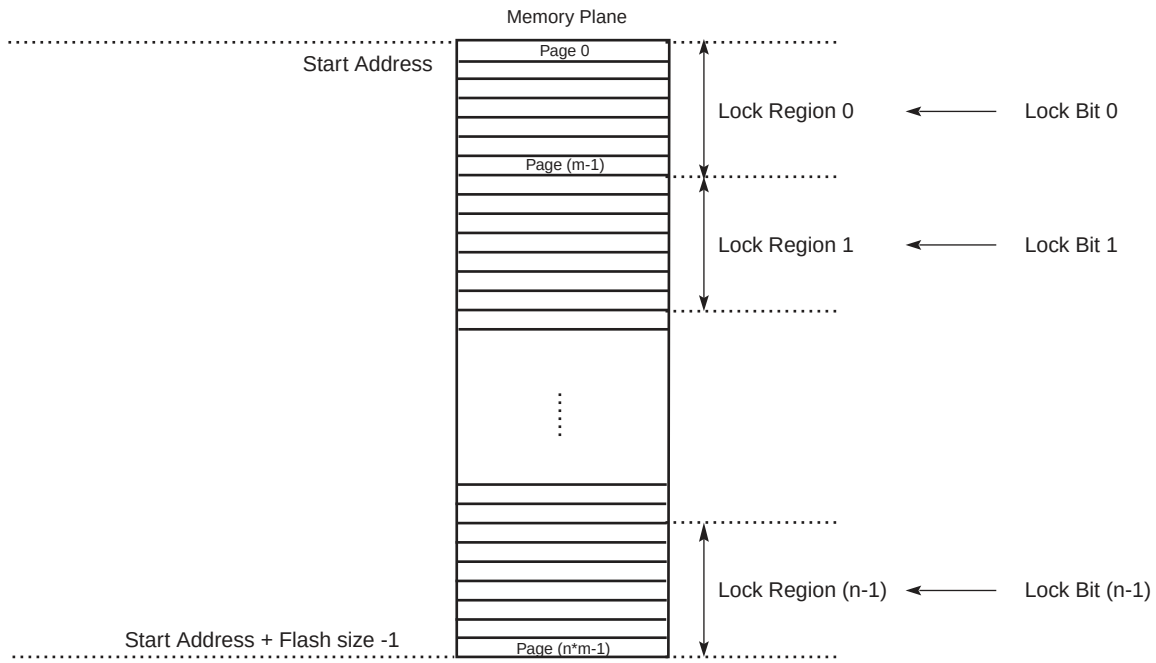
20.4.1 Embedded Flash Organization

The embedded Flash interfaces directly with the 32-bit internal bus. The embedded Flash is composed of:

- One memory plane organized in several pages of the same size.
- Two 128-bit or 64-bit read buffers used for code read optimization.
- One 128-bit or 64-bit read buffer used for data read optimization.
- One write buffer that manages page programming. The write buffer size is equal to the page size. This buffer is write-only and accessible all along the 1 MByte address space, so that each word can be written to its final address.
- Several lock bits used to protect write/erase operation on several pages (lock region). A lock bit is associated with a lock region composed of several pages in the memory plane.
- Several bits that may be set and cleared through the Enhanced Embedded Flash Controller (EEFC) interface, called General Purpose Non Volatile Memory bits (GPNVM bits).

The embedded Flash size, the page size, the lock regions organization and GPNVM bits definition are described in the product definition section. The Enhanced Embedded Flash Controller (EEFC) returns a descriptor of the Flash controlled after a get descriptor command issued by the application (see “Getting Embedded Flash Descriptor” on page 292).

Figure 20-1. Embedded Flash Organization



20.4.2 Read Operations

An optimized controller manages embedded Flash reads, thus increasing performance when the processor is running in Thumb2 mode by means of the 128- or 64- bit wide memory interface.

The Flash memory is accessible through 8-, 16- and 32-bit reads.

As the Flash block size is smaller than the address space reserved for the internal memory area, the embedded Flash wraps around the address space and appears to be repeated within it.

The read operations can be performed with or without wait states. Wait states must be programmed in the field FWS (Flash Read Wait State) in the Flash Mode Register (EEFC_FMR). Defining FWS to be 0 enables the single-cycle access of the embedded Flash. Refer to the Electrical Characteristics for more details.

20.4.2.1 128-bit or 64-bit Access Mode

By default the read accesses of the Flash are performed through a 128-bit wide memory interface. It enables better system performance especially when 2 or 3 wait state needed.

For systems requiring only 1 wait state, or to privilege current consumption rather than performance, the user can select a 64-bit wide memory access via the FAM bit in the Flash Mode Register (EEFC_FMR)

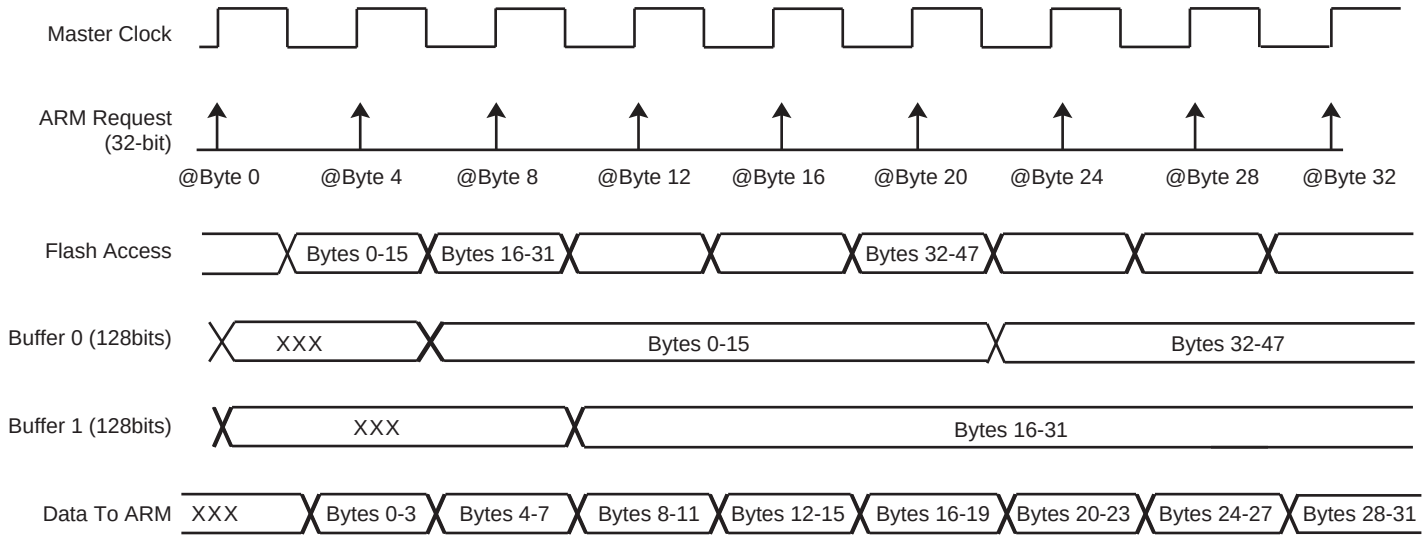
Please refer to the electrical characteristics section of the product datasheet for more details.

20.4.2.2 Code Read Optimization

A system of 2 x 128-bit or 2 x 64-bit buffers is added in order to optimize sequential Code Fetch.

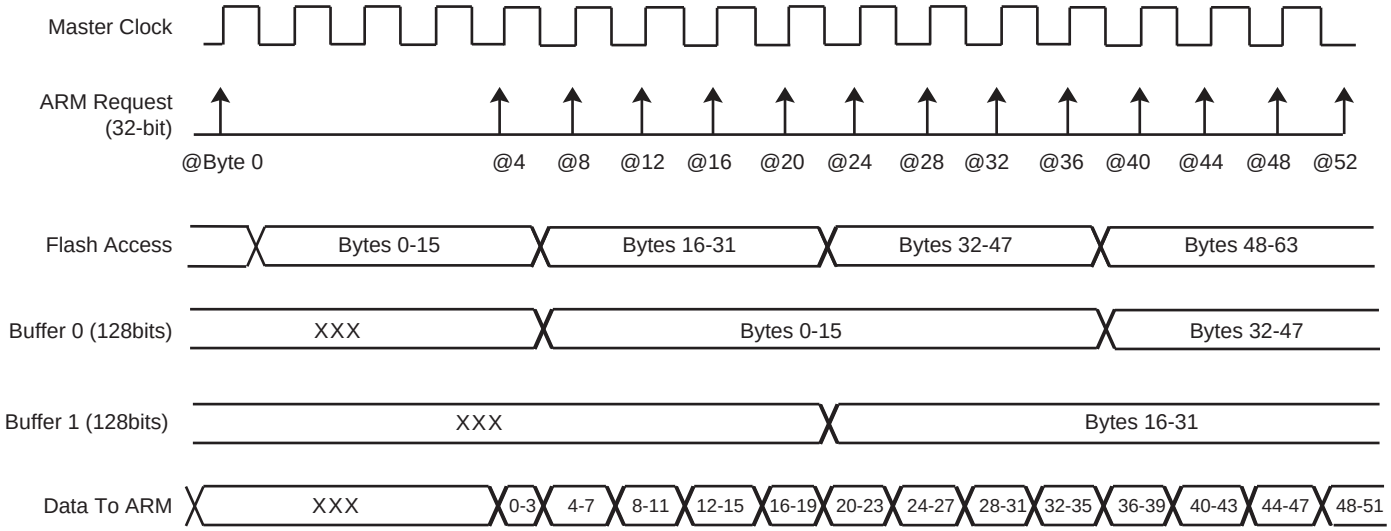
Note: Immediate consecutive code read accesses are not mandatory to benefit from this optimization.

Figure 20-2. Code Read Optimization for FWS = 0



Note: When FWS is equal to 0, all the accesses are performed in a single-cycle access.

Figure 20-3. Code Read Optimization for FWS = 3



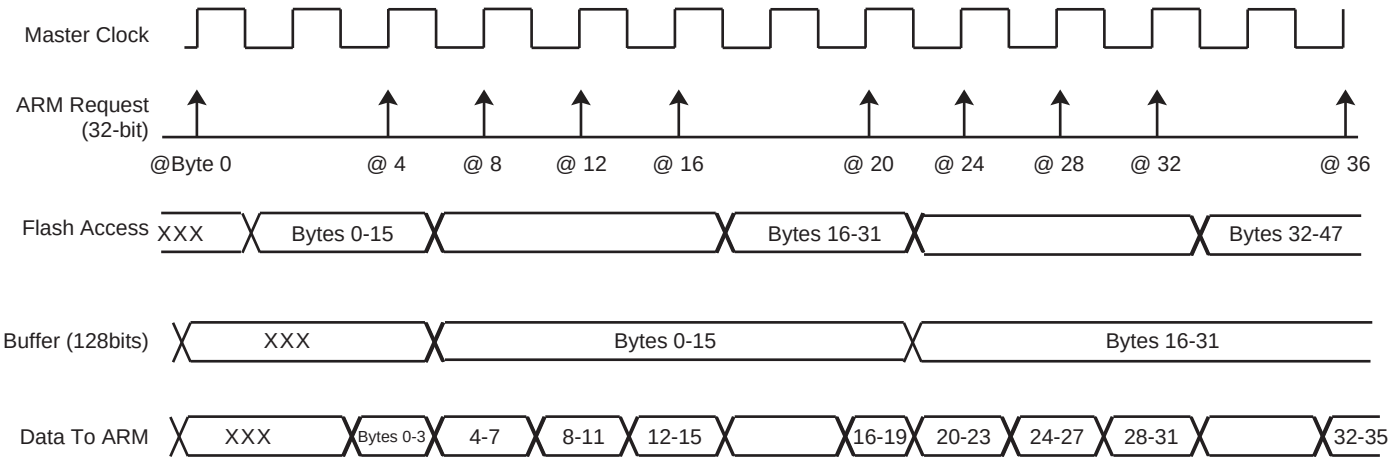
Note: When FWS is included between 1 and 3, in case of sequential reads, the first access takes (FWS+1) cycles, the other ones only 1 cycle.

20.4.2.3 Data Read Optimization

The organization of the Flash in 128 bits (or 64 bits) is associated with two 128-bit (or 64-bit) prefetch buffers and one 128-bit (or 64-bit) data read buffer, thus providing maximum system performance. This buffer is added in order to store the requested data plus all the data contained in the 128-bit (64-bit) aligned data. This speeds up sequential data reads if, for example, FWS is equal to 1 (see Figure 20-4).

Note: No consecutive data read accesses are mandatory to benefit from this optimization.

Figure 20-4. Data Read Optimization for FWS = 1



20.4.3 Flash Commands

The Enhanced Embedded Flash Controller (EEFC) offers a set of commands such as programming the memory Flash, locking and unlocking lock regions, consecutive programming and locking and full Flash erasing, etc.

Table 20-1. Set of Commands

Command	Value	Mnemonic
Get Flash Descriptor	0x00	GETD
Write page	0x01	WP
Write page and lock	0x02	WPL
Erase page and write page	0x03	EWP
Erase page and write page then lock	0x04	EWPL
Erase all	0x05	EA
Set Lock Bit	0x08	SLB
Clear Lock Bit	0x09	CLB
Get Lock Bit	0x0A	GLB
Set GPNVM Bit	0x0B	SGPB
Clear GPNVM Bit	0x0C	CGPB
Get GPNVM Bit	0x0D	GGPB
Start Read Unique Identifier	0x0E	STUI
Stop Read Unique Identifier	0x0F	SPUI

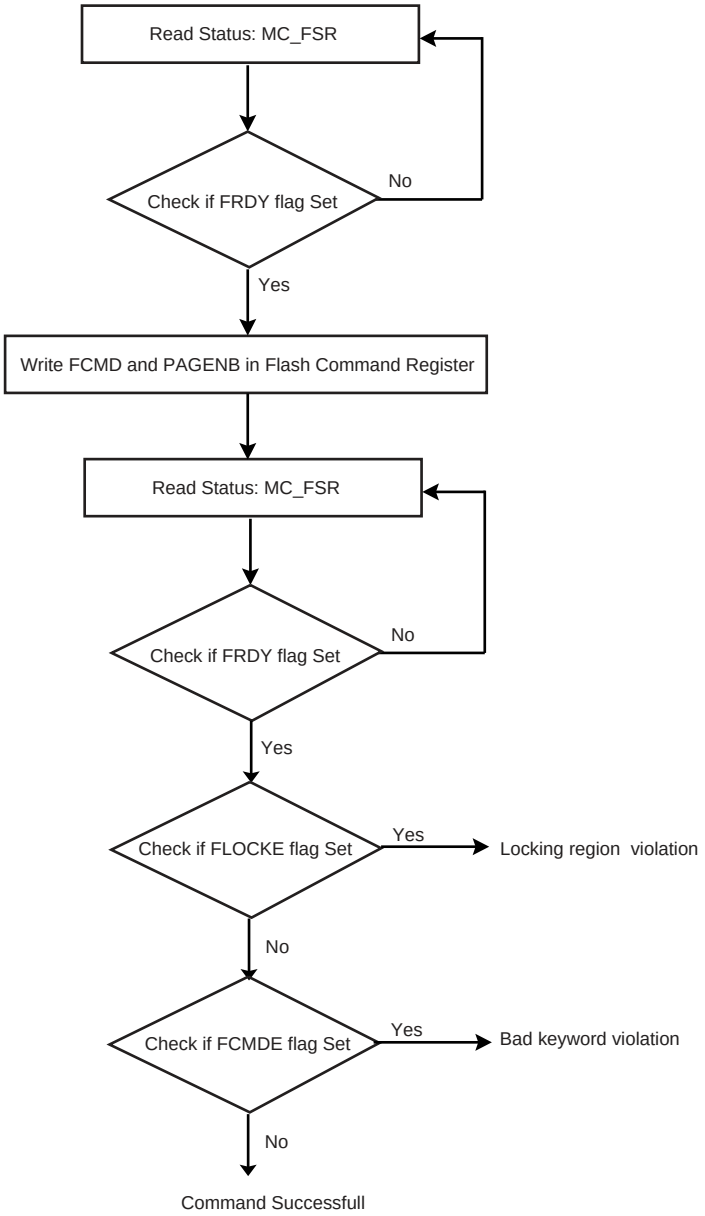
In order to perform one of these commands, the Flash Command Register (EEFC_FCR) has to be written with the correct command using the FCMD field. As soon as the EEFC_FCR register is written, **the FRDY flag and the FVALUE field in the EEFC_FRR register are automatically cleared**. Once the current command is achieved, then the FRDY flag is automatically set. If an interrupt has been enabled by setting the FRDY bit in EEFC_FMR, the corresponding interrupt line of the NVIC is activated. (Note that this is true for all commands except for the STUI Command. The FRDY flag is not set when the STUI command is achieved.)

All the commands are protected by the same keyword, which has to be written in the 8 highest bits of the EEFC_FCR register.

Writing EEFC_FCR with data that does not contain the correct key and/or with an invalid command has no effect on the whole memory plane, but the FCMDE flag is set in the EEFC_FSR register. This flag is automatically cleared by a read access to the EEFC_FSR register.

When the current command writes or erases a page in a locked region, the command has no effect on the whole memory plane, but the FLOCKE flag is set in the EEFC_FSR register. This flag is automatically cleared by a read access to the EEFC_FSR register.

Figure 20-5. Command State Chart



20.4.3.1 Getting Embedded Flash Descriptor

This command allows the system to learn about the Flash organization. The system can take full advantage of this information. For instance, a device could be replaced by one with more Flash capacity, and so the software is able to adapt itself to the new configuration.

To get the embedded Flash descriptor, the application writes the GETD command in the EEFC_FCR register. The first word of the descriptor can be read by the software application in the EEFC_FRR register as soon as the FRDY flag in the EEFC_FSR register rises. The next reads of the EEFC_FRR register provide the following word of the descriptor. If extra read operations to the EEFC_FRR register are done after the last word of the descriptor has been returned, then the EEFC_FRR register value is 0 until the next valid command.

Table 20-2. Flash Descriptor Definition

Symbol	Word Index	Description
FL_ID	0	Flash Interface Description
FL_SIZE	1	Flash size in bytes
FL_PAGE_SIZE	2	Page size in bytes
FL_NB_PLANE	3	Number of planes.
FL_PLANE[0]	4	Number of bytes in the first plane.
...		
FL_PLANE[FL_NB_PLANE-1]	4 + FL_NB_PLANE - 1	Number of bytes in the last plane.
FL_NB_LOCK	4 + FL_NB_PLANE	Number of lock bits. A bit is associated with a lock region. A lock bit is used to prevent write or erase operations in the lock region.
FL_LOCK[0]	4 + FL_NB_PLANE + 1	Number of bytes in the first lock region.
...		

20.4.3.2 Write Commands

Several commands can be used to program the Flash.

Flash technology requires that an erase be done before programming. The full memory plane can be erased at the same time, or several pages can be erased at the same time (refer to Figure 20-6, "Example of Partial Page Programming", and the paragraph below the figure.). Also, a page erase can be automatically done before a page write using EWP or EWPL commands.

After programming, the page (the whole lock region) can be locked to prevent miscellaneous write or erase sequences. The lock bit can be automatically set after page programming using WPL or EWPL commands.

Data to be written are stored in an internal latch buffer. The size of the latch buffer corresponds to the page size. The latch buffer wraps around within the internal memory area address space and is repeated as many times as the number of pages within this address space.

Note: Writing of 8-bit and 16-bit data is not allowed and may lead to unpredictable data corruption.

Write operations are performed in a number of wait states equal to the number of wait states for read operations.

Data are written to the latch buffer before the programming command is written to the Flash Command Register EEFC_FCR. The sequence is as follows:

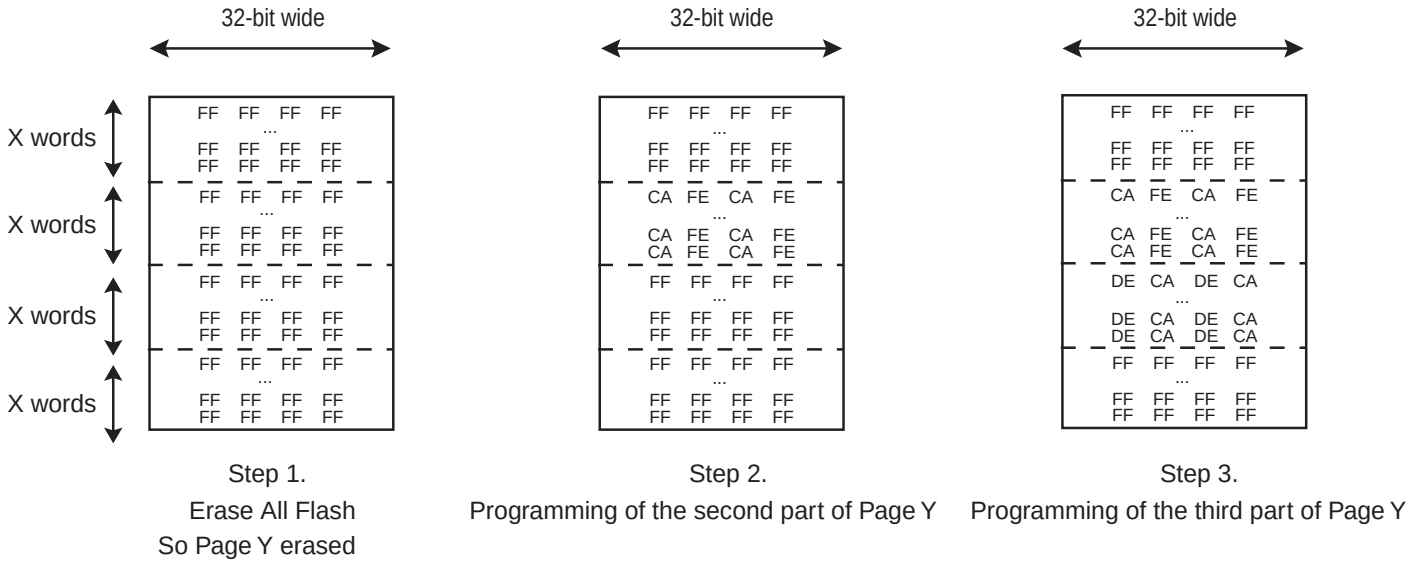
- Write the full page, at any page address, within the internal memory area address space.
- Programming starts as soon as the page number and the programming command are written to the Flash Command Register. The FRDY bit in the Flash Programming Status Register (EEFC_FSR) is automatically cleared.
- When programming is completed, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt has been enabled by setting the bit FRDY in EEFC_FMR, the corresponding interrupt line of the NVIC is activated.

Two errors can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.
- Lock Error: the page to be programmed belongs to a locked region. A command must be previously run to unlock the corresponding region.

By using the WP command, a page can be programmed in several steps if it has been erased before (see Figure 20-6 below).

Figure 20-6. Example of Partial Page Programming



The Partial Programming mode works only with 128-bit (or higher) boundaries. It cannot be used with boundaries lower than 128 bits (8, 16 or 32-bit for example).

20.4.3.3 Erase Commands

Erase commands are allowed only on unlocked regions. Depending on the Flash memory, several commands can be used to erase the Flash:

- Erase all memory (EA): all memory is erased. The processor must not fetch code from the Flash memory.

The erase sequence is:

- Erase starts as soon as one of the erase commands and the FARG field are written in the Flash Command Register.
- When the programming completes, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt has been enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.

Two errors can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.
- Lock Error: at least one page to be erased belongs to a locked region. The erase command has been refused, no page has been erased. A command must be run previously to unlock the corresponding region.

20.4.3.4 Lock Bit Protection

Lock bits are associated with several pages in the embedded Flash memory plane. This defines lock regions in the embedded Flash memory plane. They prevent writing/erasing protected pages.

The lock sequence is:

- The Set Lock command (SLB) and a page number to be protected are written in the Flash Command Register.
- When the locking completes, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt has been enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.

- If the lock bit number is greater than the total number of lock bits, then the command has no effect. The result of the SLB command can be checked running a GLB (Get Lock Bit) command.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

It is possible to clear lock bits previously set. Then the locked region can be erased or programmed. The unlock sequence is:

- The Clear Lock command (CLB) and a page number to be unprotected are written in the Flash Command Register.
- When the unlock completes, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt has been enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.
- If the lock bit number is greater than the total number of lock bits, then the command has no effect.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

The status of lock bits can be returned by the Enhanced Embedded Flash Controller (EEFC). The Get Lock Bit status sequence is:

- The Get Lock Bit command (GLB) is written in the Flash Command Register, FARG field is meaningless.
- Lock bits can be read by the software application in the EEFC_FRR register. The first word read corresponds to the 32 first lock bits, next reads providing the next 32 lock bits as long as it is meaningful. Extra reads to the EEFC_FRR register return 0.

For example, if the third bit of the first word read in the EEFC_FRR is set, then the third lock region is locked.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

Note: Access to the Flash in read is permitted when a set, clear or get lock bit command is performed.

20.4.3.5 GPNVM Bit

GPNVM bits do not interfere with the embedded Flash memory plane. Refer to the product definition section for information on the GPNVM Bit Action.

The set GPNVM bit sequence is:

- Start the Set GPNVM Bit command (SGPB) by writing the Flash Command Register with the SGPB command and the number of the GPNVM bit to be set.
- When the GPVNM bit is set, the bit FRDY in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt was enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.
- If the GPNVM bit number is greater than the total number of GPNVM bits, then the command has no effect. The result of the SGPB command can be checked by running a GGPB (Get GPNVM Bit) command.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

It is possible to clear GPNVM bits previously set. The clear GPNVM bit sequence is:

- Start the Clear GPNVM Bit command (CGPB) by writing the Flash Command Register with CGPB and the number of the GPNVM bit to be cleared.
- When the clear completes, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt has been enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.
- If the GPNVM bit number is greater than the total number of GPNVM bits, then the command has no effect.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

The status of GPNVM bits can be returned by the Enhanced Embedded Flash Controller (EEFC). The sequence is:

- Start the Get GPNVM bit command by writing the Flash Command Register with GGPB. The FARG field is meaningless.
- GPNVM bits can be read by the software application in the EEFC_FRR register. The first word read corresponds to the 32 first GPNVM bits, following reads provide the next 32 GPNVM bits as long as it is meaningful. Extra reads to the EEFC_FRR register return 0.

For example, if the third bit of the first word read in the EEFC_FRR is set, then the third GPNVM bit is active.

One error can be detected in the EEFC_FSR register after a programming sequence:

- Command Error: a bad keyword has been written in the EEFC_FCR register.

Note: Access to the Flash in read is permitted when a set, clear or get GPNVM bit command is performed.

20.4.3.6 Security Bit Protection

When the security is enabled, access to the Flash, either through the JTAG/SWD interface or through the Fast Flash Programming Interface, is forbidden. This ensures the confidentiality of the code programmed in the Flash.

The security bit is GPNVM0.

Disabling the security bit can only be achieved by asserting the ERASE pin at 1, and after a full Flash erase is performed. When the security bit is deactivated, all accesses to the Flash are permitted.

20.4.3.7 Unique Identifier

Each part is programmed with a 128-bit Unique Identifier. It can be used to generate keys for example.

To read the Unique Identifier the sequence is:

- Send the Start Read unique Identifier command (STUI) by writing the Flash Command Register with the STUI command.
- When the Unique Identifier is ready to be read, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) falls.
- The Unique Identifier is located in the first 128 bits of the Flash memory mapping, thus, at the address 0x80000-0x8000F.
- To stop the Unique Identifier mode, the user needs to send the Stop Read unique Identifier command (SPUI) by writing the Flash Command Register with the SPUI command.
- When the Stop read Unique Identifier command (SPUI) has been performed, the FRDY bit in the Flash Programming Status Register (EEFC_FSR) rises. If an interrupt was enabled by setting the FRDY bit in EEFC_FMR, the interrupt line of the NVIC is activated.

Note that during the sequence, the software can not run out of Flash (or the second plane in case of dual plane).

20.5 Enhanced Embedded Flash Controller (EEFC) User Interface

The User Interface of the Enhanced Embedded Flash Controller (EEFC) is integrated within the System Controller with base address 0x400E0800.

Table 20-3. Register Mapping

Offset	Register	Name	Access	Reset State
0x00	EEFC Flash Mode Register	EEFC_FMR	Read-write	0x0
0x04	EEFC Flash Command Register	EEFC_FCR	Write-only	–
0x08	EEFC Flash Status Register	EEFC_FSR	Read-only	0x00000001
0x0C	EEFC Flash Result Register	EEFC_FRR	Read-only	0x0
0x10	Reserved	–	–	–

20.5.1 EEFC Flash Mode Register

Name: EEFC_FMR

Address: 0x400E0800 (0), 0x400E0A00 (1)

Access: Read-write

Offset: 0x00

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	FAM
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	SCOD
15	14	13	12	11	10	9	8
–	–	–	–	FWS			
7	6	5	4	3	2	1	0
–		–	–	–	–	–	FRDY

- **FRDY: Ready Interrupt Enable**

0: Flash Ready does not generate an interrupt.

1: Flash Ready (to accept a new command) generates an interrupt.

- **FWS: Flash Wait State**

This field defines the number of wait states for read and write operations:

Number of cycles for Read/Write operations = FWS+1

- **SCOD: Sequential Code Optimization Disable**

0: The sequential code optimization is enabled.

1: The sequential code optimization is disabled.

No Flash read should be done during change of this register.

- **FAM: Flash Access Mode**

0: 128-bit access in read Mode only, to enhance access speed.

1: 64-bit access in read Mode only, to enhance power consumption.

No Flash read should be done during change of this register.

20.5.2 EEFC Flash Command Register

Name: EEFC_FCR

Address: 0x400E0804 (0), 0x400E0A04 (1)

Access: Write-only

Offset: 0x04

31	30	29	28	27	26	25	24
FKEY							
23	22	21	20	19	18	17	16
FARG							
15	14	13	12	11	10	9	8
FARG							
7	6	5	4	3	2	1	0
FCMD							

- **FCMD: Flash Command**

This field defines the Flash commands. Refer to “Flash Commands” on page 291.

- **FARG: Flash Command Argument**

Erase all command	Field is meaningless.
Programming command	FARG defines the page number to be programmed.
Lock command	FARG defines the page number to be locked.

- **FKEY: Flash Writing Protection Key**

This field should be written with the value 0x5A to enable the command defined by the bits of the register. If the field is written with a different value, the write is not performed and no action is started.

20.5.3 EEFC Flash Status Register

Name: EEFC_FSR

Address: 0x400E0808 (0), 0x400E0A08 (1)

Access: Read-only

Offset: 0x08

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	FLOCKE	FCMDE	FRDY

- **FRDY: Flash Ready Status**

0: The Enhanced Embedded Flash Controller (EEFC) is busy.

1: The Enhanced Embedded Flash Controller (EEFC) is ready to start a new command.

When it is set, this flags triggers an interrupt if the FRDY flag is set in the EEFC_FMR register.

This flag is automatically cleared when the Enhanced Embedded Flash Controller (EEFC) is busy.

- **FCMDE: Flash Command Error Status**

0: No invalid commands and no bad keywords were written in the Flash Mode Register EEFC_FMR.

1: An invalid command and/or a bad keyword was/were written in the Flash Mode Register EEFC_FMR.

This flag is automatically cleared when EEFC_FSR is read or EEFC_FCR is written.

- **FLOCKE: Flash Lock Error Status**

0: No programming/erase of at least one locked region has happened since the last read of EEFC_FSR.

1: Programming/erase of at least one locked region has happened since the last read of EEFC_FSR.

This flag is automatically cleared when EEFC_FSR is read or EEFC_FCR is written.

20.5.4 EEFC Flash Result Register

Name: EEFC_FRR

Address: 0x400E080C (0), 0x400E0A0C (1)

Access: Read-only

Offset: 0x0C

31	30	29	28	27	26	25	24
FVALUE							
23	22	21	20	19	18	17	16
FVALUE							
15	14	13	12	11	10	9	8
FVALUE							
7	6	5	4	3	2	1	0
FVALUE							

- **FVALUE: Flash Result Value**

The result of a Flash command is returned in this register. If the size of the result is greater than 32 bits, then the next resulting value is accessible at the next register read.

21. Fast Flash Programming Interface (FFPI)

21.1 Overview

The Fast Flash Programming Interface provides solutions for high-volume programming using a standard gang programmer. The parallel interface is fully handshaked and the device is considered to be a standard EEPROM. Additionally, the parallel protocol offers an optimized access to all the embedded Flash functionalities.

Although the Fast Flash Programming Mode is a dedicated mode for high volume programming, this mode is not designed for in-situ programming.

21.2 Parallel Fast Flash Programming

21.2.1 Device Configuration

In Fast Flash Programming Mode, the device is in a specific test mode. Only a certain set of pins is significant. Other pins must be left unconnected.

Figure 21-1. Parallel Programming Interface

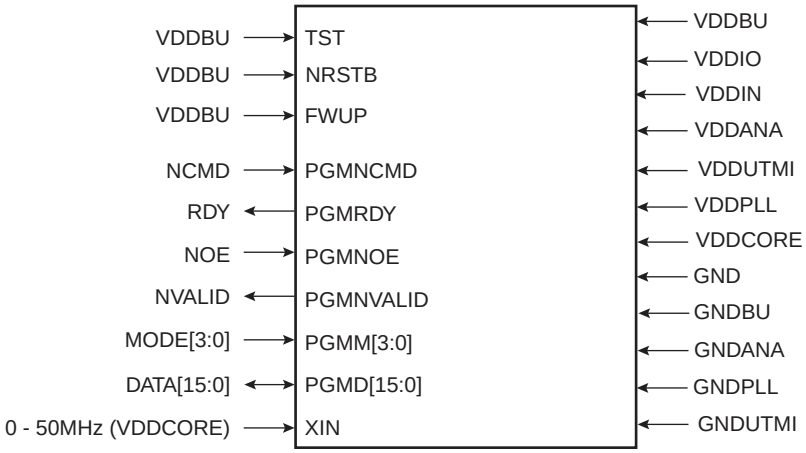


Table 21-1. Signal Description List

Signal Name	Function	Type	Active Level	Comments
Power				
VDDIO	I/O Lines Power Supply	Power		Apply external 3.0V-3.6V
VDDBU	Backup I/O Lines Power Supply	Power		Apply external 3.0V-3.6V
VDDUTMI	UTMI+ Interface Power Supply	Power		Apply external 3.0V-3.6V
VDDANA	ADC Analog Power Supply	Power		Apply external 3.0V-3.6V
VDDIN	Voltage Regulator Input	Power		Apply external 3.0V-3.6V
VDDCORE	Core Power Supply	Power		Apply external 1.65V-1.95V
VDDPLL	PLLs and Oscillator Power Supply	Power		Apply external 1.65V-1.95V
GND	Ground	Ground		
GNDPLL	Ground	Ground		
GNDBU	Ground	Ground		
GNDANA	Ground	Ground		
GNDUTMI	Ground	Ground		
Clocks				
XIN	Clock Input	Input		0 to 50MHz (0-VDDCORE square wave)
Test				
TST	Test Mode Select	Input	High	Must be connected to VDDIO
NRSTB	Asynchronous Microcontroller Reset	Input	High	Must be connected to VDDIO
FWUP	Wake-up pin	Input	High	Must be connected to VDDIO
PIO				
PGMNCMD	Valid command available	Input	Low	Pulled-up input at reset
PGMRDY	0: Device is busy 1: Device is ready for a new command	Output	High	Pulled-up input at reset
PGMNOE	Output Enable (active high)	Input	Low	Pulled-up input at reset
PGMNVALID	0: DATA[15:0] is in input mode 1: DATA[15:0] is in output mode	Output	Low	Pulled-up input at reset
PGMM[3:0]	Specifies DATA type (See Table 21-2)	Input		Pulled-up input at reset
PGMD[15:0]	Bi-directional data bus	Input/Output		Pulled-up input at reset

21.2.2 Signal Names

Depending on the MODE settings, DATA is latched in different internal registers.

Table 21-2. Mode Coding

MODE[3:0]	Symbol	Data
0000	CMDE	Command Register
0001	ADDR0	Address Register LSBs
0010	ADDR1	Address Register MSBs
0101	DATA	Data Register
Default	IDLE	No register

When MODE is equal to CMDE, then a new command (strobed on DATA[15:0] signals) is stored in the command register.

Table 21-3. Command Bit Coding

DATA[15:0]	Symbol	Command Executed
0x0011	READ	Read Flash
0x0012	WP	Write Page Flash
0x0022	WPL	Write Page and Lock Flash
0x0032	EWP	Erase Page and Write Page
0x0042	EWPL	Erase Page and Write Page then Lock
0x0013	EA	Erase All
0x0014	SLB	Set Lock Bit
0x0024	CLB	Clear Lock Bit
0x0015	GLB	Get Lock Bit
0x0034	SGPB	Set General Purpose NVM bit
0x0044	CGPB	Clear General Purpose NVM bit
0x0025	GGPB	Get General Purpose NVM bit
0x0054	SSE	Set Security Bit
0x0035	GSE	Get Security Bit
0x001F	WRAM	Write Memory
0x0016	SEFC	Select EEFC Controller(1)
0x001E	GVE	Get Version

Note: 1. Applies to 256 kbytes Flash version (dual EEFC)

21.2.3 Entering Programming Mode

The following algorithm puts the device in Parallel Programming Mode:

- Apply GND, TST, NRTSB, FWUP and the supplies as described in Table 21-1, “Signal Description List,” on page 303.
- Apply XIN clock
- Wait for 20 ms
- Start a read or write handshaking.

21.2.4 Programmer Handshaking

A handshake is defined for read and write operations. When the device is ready to start a new operation (RDY signal set), the programmer starts the handshake by clearing the NCMD signal. The handshaking is achieved once NCMD signal is high and RDY is high.

21.2.4.1 Write Handshaking

For details on the write handshaking sequence, refer to Figure 21-2 and Table 21-4.

Figure 21-2. Parallel Programming Timing, Write Sequence

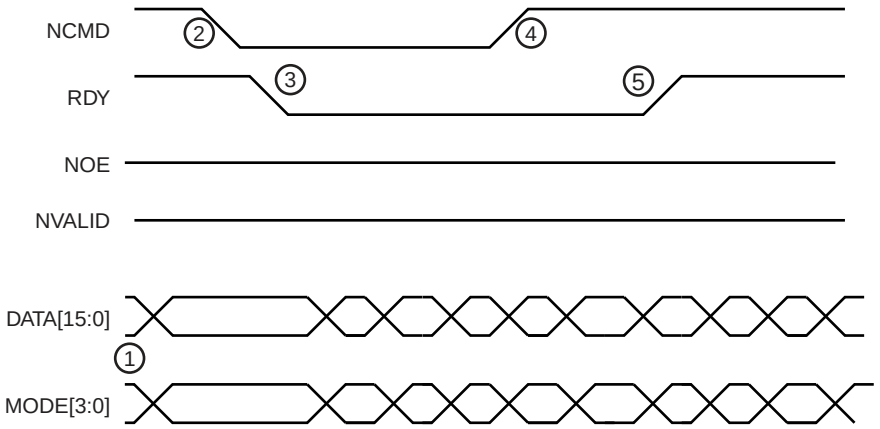


Table 21-4. Write Handshake

Step	Programmer Action	Device Action	Data I/O
1	Sets MODE and DATA signals	Waits for NCMD low	Input
2	Clears NCMD signal	Latches MODE and DATA	Input
3	Waits for RDY low	Clears RDY signal	Input
4	Releases MODE and DATA signals	Executes command and polls NCMD high	Input
5	Sets NCMD signal	Executes command and polls NCMD high	Input
6	Waits for RDY high	Sets RDY	Input

21.2.4.2 Read Handshaking

For details on the read handshaking sequence, refer to Figure 21-3 and Table 21-5.

Figure 21-3. Parallel Programming Timing, Read Sequence

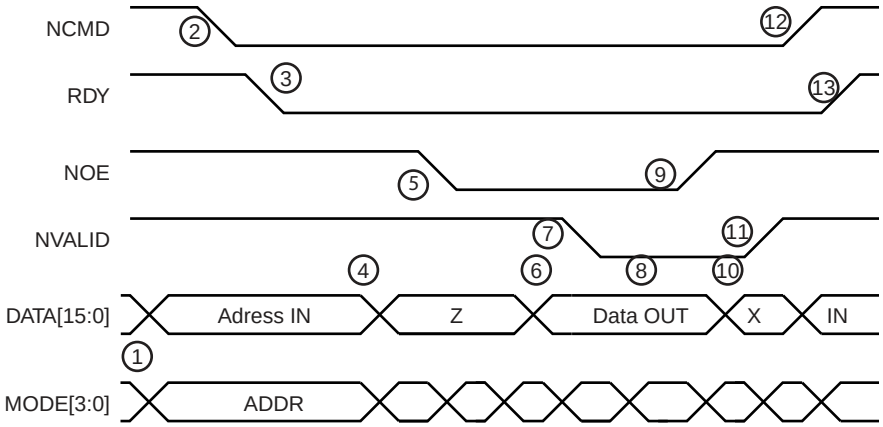


Table 21-5. Read Handshake

Step	Programmer Action	Device Action	DATA I/O
1	Sets MODE and DATA signals	Waits for NCMD low	Input
2	Clears NCMD signal	Latch MODE and DATA	Input
3	Waits for RDY low	Clears RDY signal	Input
4	Sets DATA signal in tristate	Waits for NOE Low	Input
5	Clears NOE signal		Tristate
6	Waits for NVALID low	Sets DATA bus in output mode and outputs the flash contents.	Output
7		Clears NVALID signal	Output
8	Reads value on DATA Bus	Waits for NOE high	Output
9	Sets NOE signal		Output
10	Waits for NVALID high	Sets DATA bus in input mode	X
11	Sets DATA in output mode	Sets NVALID signal	Input
12	Sets NCMD signal	Waits for NCMD high	Input
13	Waits for RDY high	Sets RDY signal	Input

21.2.5 Device Operations

Several commands on the Flash memory are available. These commands are summarized in Table 21-3 on page 304. Each command is driven by the programmer through the parallel interface running several read/write handshaking sequences.

When a new command is executed, the previous one is automatically achieved. Thus, chaining a read command after a write automatically flushes the load buffer in the Flash.

21.2.5.1 Flash Read Command

This command is used to read the contents of the Flash memory. The read command can start at any valid address in the memory plane and is optimized for consecutive reads. Read handshaking can be chained; an internal address buffer is automatically increased.

Table 21-6. Read Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	READ
2	Write handshaking	ADDR0	Memory Address LSB
3	Write handshaking	ADDR1	Memory Address
4	Read handshaking	DATA	*Memory Address++
5	Read handshaking	DATA	*Memory Address++
...	...	...	...
n	Write handshaking	ADDR0	Memory Address LSB
n+1	Write handshaking	ADDR1	Memory Address
n+2	Read handshaking	DATA	*Memory Address++
n+3	Read handshaking	DATA	*Memory Address++
...	...	...	...

21.2.5.2 Flash Write Command

This command is used to write the Flash contents.

The Flash memory plane is organized into several pages. Data to be written are stored in a load buffer that corresponds to a Flash memory page. The load buffer is automatically flushed to the Flash:

- before access to any page other than the current one
- when a new command is validated (MODE = CMDE)

The **Write Page** command **(WP)** is optimized for consecutive writes. Write handshaking can be chained; an internal address buffer is automatically increased.

Table 21-7. Write Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	WP or WPL or EWP or EWPL
2	Write handshaking	ADDR0	Memory Address LSB
3	Write handshaking	ADDR1	Memory Address
4	Write handshaking	DATA	*Memory Address++
5	Write handshaking	DATA	*Memory Address++
...	...	...	...
n	Write handshaking	ADDR0	Memory Address LSB
n+1	Write handshaking	ADDR1	Memory Address
n+2	Write handshaking	DATA	*Memory Address++
n+3	Write handshaking	DATA	*Memory Address++
...	...	...	...

The Flash command **Write Page and Lock (WPL)** is equivalent to the Flash Write Command. However, the lock bit is automatically set at the end of the Flash write operation. As a lock region is composed of several pages, the

programmer writes to the first pages of the lock region using Flash write commands and writes to the last page of the lock region using a Flash write and lock command.

The Flash command **Erase Page and Write (EWP)** is equivalent to the Flash Write Command. However, before programming the load buffer, the page is erased.

The Flash command **Erase Page and Write the Lock (EWPL)** combines EWP and WPL commands.

21.2.5.3 Flash Full Erase Command

This command is used to erase the Flash memory planes.

All lock regions must be unlocked before the Full Erase command by using the CLB command. Otherwise, the erase command is aborted and no page is erased.

Table 21-8. Full Erase Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	EA
2	Write handshaking	DATA	0

21.2.5.4 Flash Lock Commands

Lock bits can be set using WPL or EWPL commands. They can also be set by using the **Set Lock** command **(SLB)**. With this command, several lock bits can be activated. A Bit Mask is provided as argument to the command. When bit 0 of the bit mask is set, then the first lock bit is activated.

Likewise, the **Clear Lock** command **(CLB)** is used to clear lock bits.

Table 21-9. Set and Clear Lock Bit Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	SLB or CLB
2	Write handshaking	DATA	Bit Mask

Lock bits can be read using **Get Lock Bit** command **(GLB)**. The n^{th} lock bit is active when the bit n of the bit mask is set..

Table 21-10. Get Lock Bit Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	GLB
2	Read handshaking	DATA	Lock Bit Mask Status 0 = Lock bit is cleared 1 = Lock bit is set

21.2.5.5 Flash General-purpose NVM Commands

General-purpose NVM bits (GP NVM bits) can be set using the **Set GPNVM** command **(SGPB)**. This command also activates GP NVM bits. A bit mask is provided as argument to the command. When bit 0 of the bit mask is set, then the first GP NVM bit is activated.

Likewise, the **Clear GPNVM** command **(CGPB)** is used to clear general-purpose NVM bits. All the general-purpose NVM bits are also cleared by the EA command. The general-purpose NVM bit is deactivated when the corresponding bit in the pattern value is set to 1.

Table 21-11. Set/Clear GP NVM Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	SGPB or CGPB
2	Write handshaking	DATA	GP NVM bit pattern value

General-purpose NVM bits can be read using the **Get GPNVM Bit** command **(GGPB)**. The n^{th} GP NVM bit is active when bit n of the bit mask is set..

Table 21-12. Get GP NVM Bit Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	GGPB
2	Read handshaking	DATA	GP NVM Bit Mask Status 0 = GP NVM bit is cleared 1 = GP NVM bit is set

21.2.5.6 Flash Security Bit Command

A security bit can be set using the **Set Security Bit** command (SSE). Once the security bit is active, the Fast Flash programming is disabled. No other command can be run. An event on the Erase pin can erase the security bit once the contents of the Flash have been erased.

The AT9SAM3U256 security bit is controlled by the EEFC0. To use the **Set Security Bit** command, the EEFC0 must be selected using the **Select EFC** command.

Table 21-13. Set Security Bit Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	SSE
2	Write handshaking	DATA	0

Once the security bit is set, it is not possible to access FFPI. The only way to erase the security bit is to erase the Flash.

In order to erase the Flash, the user must perform the following:

- Power-off the chip
- Power-on the chip with TST = 0
- Assert Erase during a period of more than 220 ms
- Power-off the chip

Then it is possible to return to FFPI mode and check that Flash is erased.

21.2.5.7 SAM3U 256 Kbytes Flash Select EEFC Command

The commands WPx, EA, xLB, xFB are executed using the current EFC controller. The default EEFC controller is EEFC0. The **Select EEFC** command (SEFC) allows selection of the current EEFC controller.

Table 21-14. Select EFC Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	SEFC
2	Write handshaking	DATA	0 = Select EEFC0 1 = Select EEFC1

21.2.5.8 Memory Write Command

This command is used to perform a write access to any memory location.

The **Memory Write** command **(WRAM)** is optimized for consecutive writes. Write handshaking can be chained; an internal address buffer is automatically increased.

Table 21-15. Write Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	WRAM
2	Write handshaking	ADDR0	Memory Address LSB
3	Write handshaking	ADDR1	Memory Address
4	Write handshaking	DATA	*Memory Address++
5	Write handshaking	DATA	*Memory Address++
...	...	...	...
n	Write handshaking	ADDR0	Memory Address LSB
n+1	Write handshaking	ADDR1	Memory Address
n+2	Write handshaking	DATA	*Memory Address++
n+3	Write handshaking	DATA	*Memory Address++
...	...	...	...

21.2.5.9 Get Version Command

The **Get Version** (GVE) command retrieves the version of the FFPI interface.

Table 21-16. Get Version Command

Step	Handshake Sequence	MODE[3:0]	DATA[15:0]
1	Write handshaking	CMDE	GVE
2	Write handshaking	DATA	Version

22. SAM3U4/2/1 Boot Program

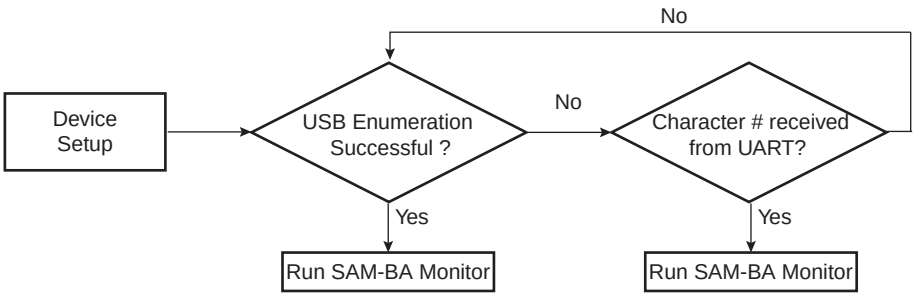
22.1 Description

The SAM-BA Boot Program integrates an array of programs permitting download and/or upload into the different memories of the product.

22.2 Flow Diagram

The Boot Program implements the algorithm illustrated in Figure 22-1.

Figure 22-1. Boot Program Algorithm Flow Diagram



The SAM-BA Boot program seeks to detect a source clock either from the embedded main oscillator with external crystal (main osccillator enabled) or from a 12 MHz signal applied to the XIN pin (main oscillator in Bypass mode).

If a clock is found from the two possible sources above, the boot program checks to verify that the frequency is 12 MHz (taking into account the frequency range of the 32 kHz RC oscillator). If the frequency is 12 MHz, USB activation is allowed, else (no clock or frequency other than 12 MHz), the internal 12 MHz RC oscilator is used as main clock and USB clock is not allowed due to frequency drift of the 12 MHz RC oscillator.

22.3 Device Initialization

The initialization sequence is the following:

1. Stack setup
2. Set up the Embedded Flash Controller
3. External Clock detection (quartz or external clock on XIN)
4. If quartz or external clock is 12 MHz, allow USB activation
5. Else, does not allow USB activation and use internal RC 12 MHz
6. Main oscillator frequency detection if no external clock detected
7. Switch Master Clock on Main Oscillator
8. C variable initialization
9. PLLA setup: PLLA is initialized to generate a 48 MHz clock
10. UPLL setup in case of USB activation allowed
11. Disable of the Watchdog
12. Initialization of the UART (115200 bauds, 8, N, 1)
13. Initialization of the USB Device Port (in case of USB activation allowed)
14. Wait for one of the following events:
    a. Check if USB device enumeration has occured
    b. Check if characters have been received in the UART
15. Jump to SAM-BA Monitor (see Section 22.4 ”SAM-BA Monitor”)

22.4 SAM-BA Monitor

Once the communication interface is identified, the monitor runs in an infinite loop waiting for different commands as shown in Table 22-1.

Table 22-1. Commands Available Through the SAM-BA Boot

Command	Action	Argument(s)	Example
O	write a byte	Address, Value#	**O**200001,CA#
o	read a byte	Address,#	**o**200001,#
H	write a half word	Address, Value#	**H**200002,CAFE#
h	read a half word	Address,#	**h**200002,#
W	write a word	Address, Value#	**W**200000,CAFEDECA#
w	read a word	Address,#	**w**200000,#
S	send a file	Address,#	**S**200000,#
R	receive a file	Address, NbOfBytes#	**R**200000,1234#
G	go	Address#	**G**200200#
V	display version	No argument	**V**#

- Write commands: Write a byte (**O**), a halfword (**H**) or a word (**W**) to the target.
  - *Address*: Address in hexadecimal.
  - *Value*: Byte, halfword or word to write in hexadecimal.
  - *Output*: '>'.
- Read commands: Read a byte (**o**), a halfword (**h**) or a word (**w**) from the target.
  - *Address*: Address in hexadecimal
  - *Output*: The byte, halfword or word read in hexadecimal following by '>'
- Send a file (**S**): Send a file to a specified address
  - *Address*: Address in hexadecimal
  - *Output*: '>'.

Note: There is a time-out on this command which is reached when the prompt '>' appears before the end of the command execution.

- Receive a file (**R**): Receive data into a file from a specified address
  - *Address*: Address in hexadecimal
  - *NbOfBytes*: Number of bytes in hexadecimal to receive
  - *Output*: '>'
- Go (**G**): Jump to a specified address and execute the code
  - *Address*: Address to jump in hexadecimal
  - *Output*: '>'
- Get Version (**V**): Return the SAM-BA boot version
  - *Output*: '>'

22.4.1 UART Serial Port

Communication is performed through the UART initialized to 115200 Baud, 8, n, 1.

The Send and Receive File commands use the Xmodem protocol to communicate. Any terminal performing this protocol can be used to send the application file to the target. The size of the binary file to send depends on the SRAM size embedded in the product. In all cases, the size of the binary file must be lower than the SRAM size because the Xmodem protocol requires some SRAM memory to work. See Section 22.5 ”Hardware and Software Constraints”.

22.4.2 Xmodem Protocol

The Xmodem protocol supported is the 128-byte length block. This protocol uses a two-character CRC-16 to guarantee detection of a maximum bit error.

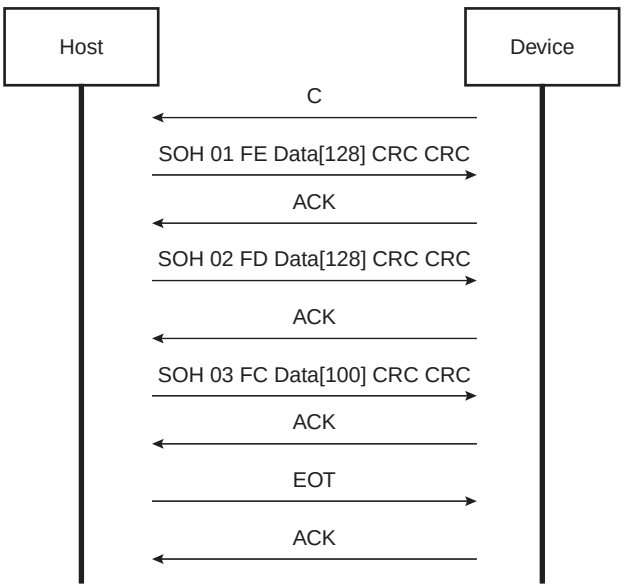
Xmodem protocol with CRC is accurate provided both sender and receiver report successful transmission. Each block of the transfer looks like:

<SOH><blk #><255-blk #><--128 data bytes--><checksum> in which:

- <SOH> = 01 hex
- <blk #> = binary number, starts at 01, increments by 1, and wraps 0FFH to 00H (not to 01)
- <255-blk #> = 1’s complement of the blk#.
- <checksum> = 2 bytes CRC16

Figure 22-2 shows a transmission using this protocol.

Figure 22-2. Xmodem Transfer Example



22.4.3 USB Device Port

A 12.000 MHz Crystal (or 12.000 MHz external clock on XIN) is necessary to use the USB Device Port.

The device uses the USB communication device class (CDC) drivers to take advantage of the installed PC RS-232 software to talk over the USB. The CDC class is implemented in all releases of Windows® beginning with Windows 98SE. The CDC document, available at www.usb.org, describes a way to implement devices such as ISDN modems and virtual COM ports.

The Vendor ID (VID) is Atmel's vendor ID 0x03EB. The product ID (PID) is 0x6124. These references are used by the host operating system to mount the correct driver. On Windows systems, the INF files contain the correspondence between vendor ID and product ID.

For more details about VID/PID for End Product/Systems, please refer to the Vendor ID form available from the USB Implementers Forum on www.usb.org.

Atmel provides an INF example to see the device as a new serial port and also provides another custom driver used by the SAM-BA application: atm6124.sys. Refer to the application note *Basic USB Application* (Atmel literature number 6123) available on www.atmel.com) for more details.

22.4.3.1 Enumeration Process

The USB protocol is a master/slave protocol. This is the host that starts the enumeration sending requests to the device through the control endpoint. The device handles standard requests as defined in the USB Specification.

Table 22-2. Handled Standard Requests

Request	Definition
GET_DESCRIPTOR	Returns the current device configuration value.
SET_ADDRESS	Sets the device address for all future device access.
SET_CONFIGURATION	Sets the device configuration.
GET_CONFIGURATION	Returns the current device configuration value.
GET_STATUS	Returns status for the specified recipient.
SET_FEATURE	Set or Enable a specific feature.
CLEAR_FEATURE	Clear or Disable a specific feature.

The device also handles some class requests defined in the CDC class.

Table 22-3. Handled Class Requests

Request	Definition
SET_LINE_CODING	Configures DTE rate, stop bits, parity and number of character bits.
GET_LINE_CODING	Requests current DTE rate, stop bits, parity and number of character bits.
SET_CONTROL_LINE_STATE	RS-232 signal used to tell the DCE device the DTE device is now present.

Unhandled requests are STALLed.

22.4.3.2 Communication Endpoints

There are two communication endpoints and endpoint 0 is used for the enumeration process. Endpoint 1 is a 64-byte Bulk OUT endpoint and endpoint 2 is a 64-byte Bulk IN endpoint. SAM-BA Boot commands are sent by the host through endpoint 1. If required, the message is split by the host into several data payloads by the host driver.

If the command requires a response, the host can send IN transactions to pick up the response.

22.4.4 In Application Programming (IAP) Feature

The IAP feature is a function located in ROM that can be called by any software application.

When called, this function sends the desired FLASH command to the EEFC and waits for the Flash to be ready (looping while the FRDY bit is not set in the EEFC_FSR).

Since this function is executed from ROM, this allows Flash programming (such as sector write) to be done by code running in Flash.

The IAP function entry point is retrieved by reading the NMI vector in ROM (0x00180008).

This function takes one argument in parameter: the command to be sent to the EEFC.

This function returns the value of the EEFC_FSR.

IAP software code example:

```
(unsigned int) (*IAP_Function)(unsigned long);
void main (void){

                  unsigned long FlashSectorNum = 200; //
                  unsigned long flash_cmd = 0;
                  unsigned long flash_status = 0;
                  unsigned long EFCIndex = 0; // 0:EEFC0, 1: EEFC1

/* Initialize the function pointer (retrieve function address from NMI vector)
*/

                  IAP_Function = ((unsigned long) (*)(unsigned long))
0x00180008;

/* Send your data to the sector here */

/* build the command to send to EEFC */

                  flash_cmd =  (0x5A << 24) | (FlashSectorNum << 8) |
AT91C_MC_FCMD_EWP;

/* Call the IAP function with appropriate command */

                  flash_status = IAP_Function (EFCIndex, flash_cmd);

}
```

22.5 Hardware and Software Constraints

- SAM-BA Boot uses the first 2048 bytes of the SRAM for variables and stacks. The remaining available size can be used for user's code.
- USB requirements:
  - 12.000 MHz Quartz or 12.000 MHz external clock on XIN. 12 MHz must be ±500 ppm and 1.8V Square Wave Signal.

Table 22-4. Pins Driven during Boot Program Execution

Peripheral	Pin	PIO Line
UART	URXD	PA11
UART	UTXD	PA12

23. Bus Matrix (MATRIX)

23.1 Description

Bus Matrix implements a multi-layer AHB, based on AHB-Lite protocol, that enables parallel access paths between multiple AHB masters and slaves in a system, which increases the overall bandwidth. Bus Matrix interconnects 5 AHB Masters to 10 AHB Slaves. The normal latency to connect a master to a slave is one cycle except for the default master of the accessed slave which is connected directly (zero cycle latency).

The Bus Matrix user interface is compliant with ARM® Advance Peripheral Bus and provides a Chip Configuration User Interface with Registers that allow the Bus Matrix to support application specific features.

23.2 Memory Mapping

Bus Matrix provides one decoder for every AHB Master Interface. The decoder offers each AHB Master several memory mappings. In fact, depending on the product, each memory area may be assigned to several slaves. Booting at the same address while using different AHB slaves (i.e. internal ROM or internal Flash) becomes possible.

The Bus Matrix user interface provides Master Remap Control Register (MATRIX_MRCR) that allows to perform remap action for every master independently.

23.3 Special Bus Granting Techniques

The Bus Matrix provides some speculative bus granting techniques in order to anticipate access requests from some masters. This mechanism allows to reduce latency at first accesses of a burst or single transfer. The bus granting mechanism allows to set a default master for every slave.

At the end of the current access, if no other request is pending, the slave remains connected to its associated default master. A slave can be associated with three kinds of default masters: no default master, last access master and fixed default master.

23.3.1 No Default Master

At the end of the current access, if no other request is pending, the slave is disconnected from all masters. No Default Master suits low power mode.

23.3.2 Last Access Master

At the end of the current access, if no other request is pending, the slave remains connected to the last master that performed an access request.

23.3.3 Fixed Default Master

At the end of the current access, if no other request is pending, the slave connects to its fixed default master. Unlike last access master, the fixed master doesn't change unless the user modifies it by a software action (field FIXED_DEFMSTR of the related MATRIX_SCFG).

To change from one kind of default master to another, the Bus Matrix user interface provides the Slave Configuration Registers, one for each slave, that allow to set a default master for each slave. The Slave Configuration Register contains two fields:

DEFMSTR_TYPE and FIXED_DEFMSTR. The 2-bit DEFMSTR_TYPE field allows to choose the default master type (no default, last access master, fixed default master) whereas the 4-bit FIXED_DEFMSTR field allows to choose a fixed default master provided that DEFMSTR_TYPE is set to fixed default master. Please refer to the Bus Matrix user interface description.

23.4 Arbitration

The Bus Matrix provides an arbitration mechanism that allows to reduce latency when conflict cases occur, basically when two or more masters try to access the same slave at the same time. One arbiter per AHB slave is provided, allowing to arbitrate each slave differently.

The Bus Matrix provides to the user the possibility to choose between 2 arbitration types, and this for each slave:

1. Round-Robin Arbitration (the default)

2. Fixed Priority Arbitration

This choice is given through the field ARBT of the Slave Configuration Registers (MATRIX_SCFG).

Each algorithm may be complemented by selecting a default master configuration for each slave.

When a re-arbitration has to be done, it is realized only under some specific conditions detailed in the following paragraph.

23.4.1 Arbitration Rules

Each arbiter has the ability to arbitrate between two or more different master's requests. In order to avoid burst breaking and also to provide the maximum throughput for slave interfaces, arbitration may only take place during the following cycles:

1. Idle Cycles: when a slave is not connected to any master or is connected to a master which is not currently accessing it.

2. Single Cycles: when a slave is currently doing a single access.

3. End of Burst Cycles: when the current cycle is the last cycle of a burst transfer. For defined length burst, predicted end of burst matches the size of the transfer but is managed differently for undefined length burst (See Section 23.4.1.1 "Undefined Length Burst Arbitration" on page 318").

4. Slot Cycle Limit: when the slot cycle counter has reached the limit value indicating that the current master access is too long and must be broken (See Section 23.4.1.2 "Slot Cycle Limit Arbitration" on page 318).

23.4.1.1 Undefined Length Burst Arbitration

In order to avoid too long slave handling during undefined length bursts (INCR), the Bus Matrix provides specific logic in order to re-arbitrate before the end of the INCR transfer.

A predicted end of burst is used as for defined length burst transfer, which is selected between the following:

1. Infinite: no predicted end of burst is generated and therefore INCR burst transfer will never be broken.

2. Four beat bursts: predicted end of burst is generated at the end of each four beat boundary inside INCR transfer.

3. Eight beat bursts: predicted end of burst is generated at the end of each eight beat boundary inside INCR transfer.

4. Sixteen beat bursts: predicted end of burst is generated at the end of each sixteen beat boundary inside INCR transfer.

This selection can be done through the field ULBT of the Master Configuration Registers (MATRIX_MCFG).

23.4.1.2 Slot Cycle Limit Arbitration

The Bus Matrix contains specific logic to break too long accesses such as very long bursts on a very slow slave (e.g. an external low speed memory). At the beginning of the burst access, a counter is loaded with the value previously written in the SLOT_CYCLE field of the related Slave Configuration Register (MATRIX_SCFG) and decreased at each clock cycle. When the counter reaches zero, the arbiter has the ability to re-arbitrate at the end of the current byte, half word or word transfer.

23.4.2 Round-Robin Arbitration

This algorithm allows the Bus Matrix arbiters to dispatch the requests from different masters to the same slave in a round-robin manner. If two or more master's requests arise at the same time, the master with the lowest number is first serviced then the others are serviced in a round-robin manner.

There are three round-robin algorithm implemented:

- Round-Robin arbitration without default master
- Round-Robin arbitration with last access master
- Round-Robin arbitration with fixed default master

23.4.2.1 Round-Robin arbitration without default master

This is the main algorithm used by Bus Matrix arbiters. It allows the Bus Matrix to dispatch requests from different masters to the same slave in a pure round-robin manner. At the end of the current access, if no other request is pending, the slave is disconnected from all masters. This configuration incurs one latency cycle for the first access of a burst. Arbitration without default master can be used for masters that perform significant bursts.

23.4.2.2 Round-Robin arbitration with last access master

This is a biased round-robin algorithm used by Bus Matrix arbiters. It allows the Bus Matrix to remove the one latency cycle for the last master that accessed the slave. In fact, at the end of the current transfer, if no other master request is pending, the slave remains connected to the last master that performs the access. Other non privileged masters will still get one latency cycle if they want to access the same slave. This technique can be used for masters that mainly perform single accesses.

23.4.2.3 Round-Robin arbitration with fixed default master

This is another biased round-robin algorithm, it allows the Bus Matrix arbiters to remove the one latency cycle for the fixed default master per slave. At the end of the current access, the slave remains connected to its fixed default master. Every request attempted by this fixed default master will not cause any latency whereas other non privileged masters will still get one latency cycle. This technique can be used for masters that mainly perform single accesses.

23.4.3 Fixed Priority Arbitration

This algorithm allows the Bus Matrix arbiters to dispatch the requests from different masters to the same slave by using the fixed priority defined by the user. If two or more master's requests are active at the same time, the master with the highest priority number is serviced first. If two or more master's requests with the same priority are active at the same time, the master with the highest number is serviced first.

For each slave, the priority of each master may be defined through the Priority Registers for Slaves (MATRIX_PRAS and MATRIX_PRBS).

23.5 Write Protect Registers

To prevent any single software error that may corrupt MATRIX behavior, the entire MATRIX address space from address offset 0x000 to 0x1FC can be write-protected by setting the WPEN bit in the MATRIX Write Protect Mode Register (MATRIX_WPMR).

If a write access to anywhere in the MATRIX address space from address offset 0x000 to 0x1FC is detected, then the WPVS flag in the MATRIX Write Protect Status Register (MATRIX_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is reset by writing the MATRIX Write Protect Mode Register (MATRIX_WPMR) with the appropriate access key WPKEY.

The protected registers are:

"Bus Matrix Master Configuration Registers"

"Bus Matrix Slave Configuration Registers"

"Bus Matrix Priority Registers For Slaves"

"Bus Matrix Master Remap Control Register"

"Bus Matrix Master Remap Control Register"

23.6 Bus Matrix (MATRIX) User Interface

Table 23-1. Register Mapping

Offset	Register	Name	Access	Reset
0x0000	Master Configuration Register 0	MATRIX_MCFG0	Read-write	0x00000000
0x0004	Master Configuration Register 1	MATRIX_MCFG1	Read-write	0x00000000
0x0008	Master Configuration Register 2	MATRIX_MCFG2	Read-write	0x00000000
0x000C	Master Configuration Register 3	MATRIX_MCFG3	Read-write	0x00000000
0x0010	Master Configuration Register 4	MATRIX_MCFG4	Read-write	0x00000000
0x0014 - 0x003C	Reserved	–	–	–
0x0040	Slave Configuration Register 0	MATRIX_SCFG0	Read-write	0x00010010
0x0044	Slave Configuration Register 1	MATRIX_SCFG1	Read-write	0x00050010
0x0048	Slave Configuration Register 2	MATRIX_SCFG2	Read-write	0x00000010
0x004C	Slave Configuration Register 3	MATRIX_SCFG3	Read-write	0x00000010
0x0050	Slave Configuration Register 4	MATRIX_SCFG4	Read-write	0x00000010
0x0054	Slave Configuration Register 5	MATRIX_SCFG5	Read-write	0x00000010
0x0058	Slave Configuration Register 6	MATRIX_SCFG6	Read-write	0x00000010
0x005C	Slave Configuration Register 7	MATRIX_SCFG7	Read-write	0x00000010
0x0060	Slave Configuration Register 8	MATRIX_SCFG8	Read-write	0x00000010
0x0064	Slave Configuration Register 9	MATRIX_SCFG9	Read-write	0x00000010
0x0068 - 0x007C	Reserved	–	–	–
0x0080	Priority Register A for Slave 0	MATRIX_PRAS0	Read-write	0x00000000
0x0084	Reserved	–	–	–
0x0088	Priority Register A for Slave 1	MATRIX_PRAS1	Read-write	0x00000000
0x008C	Reserved	–	–	–
0x0090	Priority Register A for Slave 2	MATRIX_PRAS2	Read-write	0x00000000
0x0094	Reserved	–	–	–
0x0098	Priority Register A for Slave 3	MATRIX_PRAS3	Read-write	0x00000000
0x009C	Reserved	–	–	–
0x00A0	Priority Register A for Slave 4	MATRIX_PRAS4	Read-write	0x00000000
0x00A4	Reserved	–	–	–
0x00A8	Priority Register A for Slave 5	MATRIX_PRAS5	Read-write	0x00000000
0x00AC	Reserved	–	–	–
0x00B0	Priority Register A for Slave 6	MATRIX_PRAS6	Read-write	0x00000000
0x00B4	Reserved	–	–	–
0x00B8	Priority Register A for Slave 7	MATRIX_PRAS7	Read-write	0x00000000
0x00BC	Reserved	–	–	–
0x00C0	Priority Register A for Slave 8	MATRIX_PRAS8	Read-write	0x00000000

Table 23-1. Register Mapping (Continued)

Offset	Register	Name	Access	Reset
0x00C4	Reserved	–	–	–
0x00C8	Priority Register A for Slave 9	MATRIX_PRAS9	Read-write	0x00000000
0x00CC- 0x00FC	Reserved	–	–	–
0x0100	Master Remap Control Register	MATRIX_MRCR	Read-write	0x00000000
0x0104 - 0x010C	Reserved	–	–	–
0x1E4	Write Protect Mode Register	MATRIX_WPMR	Read-write	0x0
0x1E8	Write Protect Status Register	MATRIX_WPSR	Read-only	0x0
0x0110 - 0x01FC	Reserved	–	–	–

23.6.1 Bus Matrix Master Configuration Registers

Name: MATRIX_MCFG0..MATRIX_MCFG4

Address: 0x400E0200

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	ULBT		

This register can only be written if the WPEN bit is cleared in the “Write Protect Mode Register”.

- **ULBT: Undefined Length Burst Type**

0: Infinite Length Burst

No predicted end of burst is generated and therefore INCR bursts coming from this master cannot be broken.

1: Single Access

The undefined length burst is treated as a succession of single access allowing rearbitration at each beat of the INCR burst.

2: Four Beat Burst

The undefined length burst is split into 4 beats burst allowing rearbitration at each 4 beats burst end.

3: Eight Beat Burst

The undefined length burst is split into 8 beats burst allowing rearbitration at each 8 beats burst end.

4: Sixteen Beat Burst

The undefined length burst is split into 16 beats burst allowing rearbitration at each 16 beats burst end.

23.6.2 Bus Matrix Slave Configuration Registers

Name: MATRIX_SCFG0..MATRIX_SCFG9

Address: 0x400E0240

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	ARBT	

23	22	21	20	19	18	17	16
–	–	–	FIXED_DEFMSTR			DEFMSTR_TYPE	

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
SLOT_CYCLE							

This register can only be written if the WPEN bit is cleared in the “Write Protect Mode Register”.

- **SLOT_CYCLE: Maximum Number of Allowed Cycles for a Burst**

When the SLOT_CYCLE limit is reach for a burst it may be broken by another master trying to access this slave.

This limit has been placed to avoid locking very slow slave by when very long burst are used.

This limit should not be very small though. Unreasonable small value will break every burst and Bus Matrix will spend its time to arbitrate without performing any data transfer. 16 cycles is a reasonable value for SLOT_CYCLE.

- **DEFMSTR_TYPE: Default Master Type**

0: No Default Master

At the end of current slave access, if no other master request is pending, the slave is disconnected from all masters.

This results in having a one cycle latency for the first acccess of a burst transfer or for a single access.

1: Last Default Master

At the end of current slave access, if no other master request is pending, the slave stay connected with the last master having accessed it.

This results in not having the one cycle latency when the last master re-tries access on the slave again.

2: Fixed Default Master

At the end of the current slave access, if no other master request is pending, the slave connects to the fixed master which number has been written in the FIXED_DEFMSTR field.

This results in not having the one cycle latency when the fixed master re-tries access on the slave again.

- **FIXED_DEFMSTR: Fixed Default Master**

This is the number of the Default Master for this slave. Only used if DEFMSTR_TYPE is 2. Specifying the number of a master which is not connected to the selected slave is equivalent to setting DEFMSTR_TYPE to 0.

- **ARBT: Arbitration Type**

0: Round-Robin Arbitration

1: Fixed Priority Arbitration

2: Reserved

3: Reserved

23.6.3 Bus Matrix Priority Registers For Slaves

Name: MATRIX_PRAS0..MATRIX_PRAS9

Addresses: 0x400E0280 [0], 0x400E0288 [1], 0x400E0290 [2], 0x400E0298 [3], 0x400E02A0 [4], 0x400E02A8 [5], 0x400E02B0 [6], 0x400E02B8 [7], 0x400E02C0 [8], 0x400E02C8 [9]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	M4PR	

15	14	13	12	11	10	9	8
–	–	M3PR		–	–	M2PR	

7	6	5	4	3	2	1	0
–	–	M1PR		–	–	M0PR	

This register can only be written if the WPEN bit is cleared in the “Write Protect Mode Register”.

- **MxPR: Master x Priority**

Fixed prority of Master x for accessing to the selected slave.The higher the number, the higher the priority.

23.6.4 Bus Matrix Master Remap Control Register

Name: MATRIX_MRCR

Address: 0x400E0300

Access: Read-write

Reset: 0x0000_0000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	RCB4	RCB3	RCB2	RCB1	RCB0

This register can only be written if the WPEN bit is cleared in the “Write Protect Mode Register”.

- **RCBx: Remap Command Bit for AHB Master x**

0: Disable remaped address decoding for the selected Master

1: Enable remaped address decoding for the selected Master

23.6.5 Write Protect Mode Register

Name: MATRIX_WPMR

Address: 0x400E03E4

Access: Read-write

31	30	29	28	27	26	25	24
WPKEY							

23	22	21	20	19	18	17	16
WPKEY							

15	14	13	12	11	10	9	8
WPKEY							

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WPEN

For more details on MATRIX_WPMR, refer to Section 23.5 “Write Protect Registers” on page 320.

- **WPEN: Write Protect ENable**

0 = Disables the Write Protect if WPKEY corresponds to 0x4D4154 (“MAT” in ASCII).

1 = Enables the Write Protect if WPKEY corresponds to 0x4D4154 (“MAT” in ASCII).

Protects the entire MATRIX address space from address offset 0x000 to 0x1FC.

- **WPKEY: Write Protect KEY** (Write-only)

Should be written at value 0x4D4154 (“MAT”in ASCII). Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

23.6.6 Write Protect Status Register

Name: MATRIX_WPSR

Address: 0x400E03E8

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
WPVSRC							

15	14	13	12	11	10	9	8
WPVSRC							

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WPVS

For more details on MATRIX_WPSR, refer to Section 23.5 “Write Protect Registers” on page 320.

- **WPVS: Write Protect Violation Status**

0: No Write Protect Violation has occurred since the last write of MATRIX_WPMR.

1: At least one Write Protect Violation has occurred since the last write of MATRIX_WPMR.

- **WPVSRC: Write Protect Violation Source**

Should be written at value 0x4D4154 (“MAT”in ASCII). Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

The protected registers are:

- “Bus Matrix Master Configuration Registers”
- “Bus Matrix Slave Configuration Registers”
- “Bus Matrix Priority Registers For Slaves”
- “Bus Matrix Master Remap Control Register”
- “Bus Matrix Master Remap Control Register”

24. Static Memory Controller (SMC)

24.1 Description

The External Bus Interface is designed to ensure the successful data transfer between several external devices and the Cortex-M3 based device. The External Bus Interface of the SAM3U consists of a Static Memory Controller (SMC).

This SMC is capable of handling several types of external memory and peripheral devices, such as SRAM, PSRAM, PROM, EPROM, EEPROM, LCD Module, NOR Flash and NAND Flash.

The SMC generates the signals that control the access to external memory devices or peripheral devices. It has 4 Chip Selects and a 24-bit address bus. The 16-bit data bus can be configured to interface with 8- or 16-bit external devices. Separate read and write control signals allow for direct memory and peripheral interfacing. Read and write signal waveforms are fully parametrizable.

The SMC can manage wait requests from external devices to extend the current access. The SMC is provided with an automatic slow clock mode. In slow clock mode, it switches from user-programmed waveforms to slow-rate specific waveforms on read and write signals.

The SMC embeds a NAND Flash Controller (NFC). The NFC can handle automatic transfers, sending the commands and address cycles to the NAND Flash and transferring the contents of the page (for read and write) to the NFC SRAM. It minimizes the CPU overhead.

The SMC includes programmable hardware error correcting code with one bit error correction capability and supports two bits error detection. In order to improve overall system performance the DATA phase of the transfer can be DMA assisted.

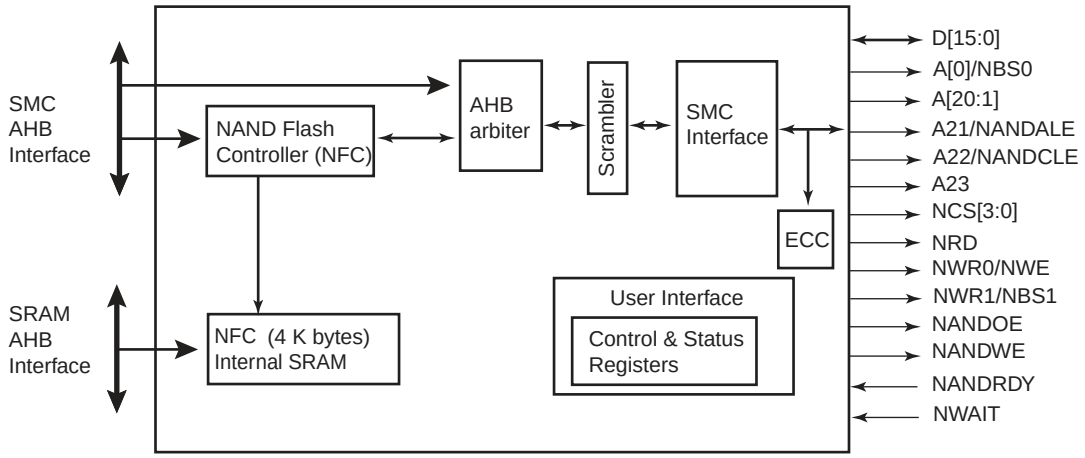
The External Data Bus can be scrambled/unscrambled by means of user keys.

24.2 Embedded Characteristics

- 16-Mbyte Address Space per Chip Select
- 8- or 16-bit Data Bus
- Word, Halfword, Byte Transfers
- Byte Write or Byte Select Lines
- Programmable Setup, Pulse and Hold Time for Read Signals per Chip Select
- Programmable Setup, Pulse and Hold Time for Write Signals per Chip Select
- Programmable Data Float Time per Chip Select
- External Data Bus Scrambling/Unscrambling Function
- External Wait Request
- Automatic Switch to Slow Clock Mode
- NAND Flash Controller Supporting NAND Flash with Multiplexed Data/Address Buses
- Supports SLC NAND Flash Technology
- Hardware Configurable Number of Chip Selects from 1 to 4
- Programmable Timing on a per Chip Select Basis
- AHB Slave Interface
- Atmel APB Configuration Interface
- Programmable Flash Data Width 8 Bits or 16 Bits
- Supports Hardware Error Correcting Code (ECC), 1-bit Error Correction, 2-bit Error Detection
- Detection and Correction by Software
- Supports NAND Flash and SmartMedia™ Devices with 8- or 16-bit Data Path
- Supports NAND Flash/SmartMedia with Page Sizes of 528, 1056, 2112 and 4224 Bytes, Specified by Software
- **Supports 1-bit Correction for a Page of 512, 1024, 2048 and 4096 Bytes** with 8- or 16-bit Data Path
- Supports 1-bit Correction per 512 Bytes of Data for a Page Size of 512, 2048 and 4096 Bytes with 8-bit Data Path
- Supports 1-bit Correction per 256 Bytes of Data for a Page Size of 512, 2048 and 4096 Bytes with 8-bit Data Path

24.3 Block Diagram

Figure 24-1. Block Diagram



24.4 I/O Lines Description

Table 24-1. I/O Line Description

Name	Description	Type	Active Level
NCS[3:0]	Static Memory Controller Chip Select Lines	Output	Low
NRD	Read Signal	Output	Low
NWR0/NWE	Write 0/Write Enable Signal	Output	Low
A0/NBS0	Address Bit 0/Byte 0 Select Signal	Output	Low
NWR1/NBS1	Write 1/Byte 1 Select Signal	Output	Low
A1	Address Bit 1	Output	Low
A[23:2]	Address Bus	Output	
D[15:0]	Data Bus	I/O	
NWAIT	External Wait Signal	Input	Low
NANDRDY	NAND Flash Ready/Busy	Input	
NANDWE	NAND Flash Write Enable	Output	Low
NANDOE	NAND Flash Output Enable	Output	Low
NANDALE	NAND Flash Address Latch Enable	Output	
NANDCLE	NAND Flash Command Latch Enable	Output	

24.5 Multiplexed Signals

Table 24-2. Static Memory Controller (SMC) Multiplexed Signals

Multiplexed Signals		Related Function
NWR0	NWE	Byte-write or byte-select access, see Figure 24-4 "Memory Connection for an 8-bit Data Bus" and Figure 24-5 "Memory Connection for a 16-bit Data Bus"
A0	NBS0	8-bit or 16-bit data bus, see Section 24.9.1 ”Data Bus Width”
A22	NANDCLE	NAND Flash Command Latch Enable
A21	NANDALE	NAND Flash Address Latch Enable
NWR1	NBS1	Byte-write or byte-select access, see Figure 24-4 and Figure 24-5
A1	–	8-/16-bit data bus, see Section 24.9.1 ”Data Bus Width” Byte-write or byte-select access, see Figure 24-4 and Figure 24-5

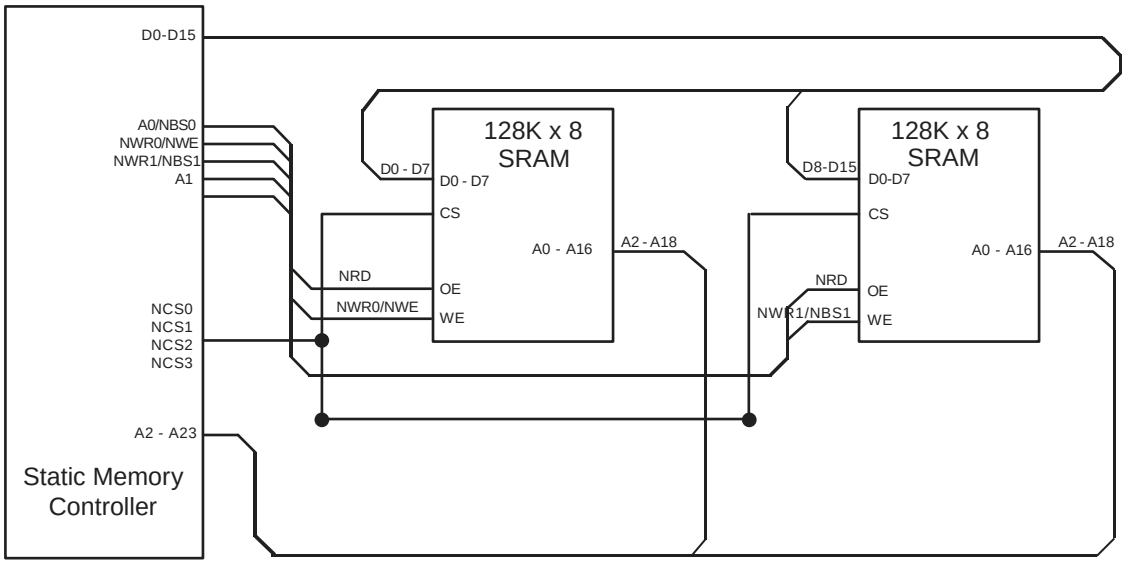
24.6 Application Example

24.6.1 Implementation Examples

For Hardware implementation examples, refer to ATSAM3U-EK schematics which show examples of connection to an LCD module, PSRAM and NAND Flash.

24.6.2 Hardware Interface

Figure 24-2. SMC Connections to Static Memory Devices



24.7 Product Dependencies

24.7.1 I/O Lines

The pins used for interfacing the Static Memory Controller are multiplexed with the PIO lines. The programmer must first program the PIO controller to assign the Static Memory Controller pins to their peripheral function. If I/O Lines of the SMC are not used by the application, they can be used for other purposes by the PIO Controller.

24.7.2 Power Management

The SMC is clocked through the Power Management Controller (PMC), thus the programmer must first configure the PMC to enable the SMC clock.

24.7.3 Interrupt

The SMC has an interrupt line connected to the Nested Vector Interrupt Controller (NVIC). Handling the SMC interrupt requires programming the NVIC before configuring the SMC.

Table 24-3. Peripheral IDs

Instance	ID
SMC	9

24.8 External Memory Mapping

Table 24-4. External Memory Mapping

Address	Use	Access
0x60000000-0x60FFFFFF	Chip Select 0 (16 MB)	Read-write
0x61000000-0x61FFFFFF	Chip Select 1	Read-write
0x62000000-0x62FFFFFF	Chip Select 2	Read-write
0x63000000-0x63FFFFFF	Chip Select 3	Read-write
0x04000000-0x07FFFFFF	Undefined Area	
0x68000000-0x6FFFFFFF	NFC Command Registers(1)	Read-write

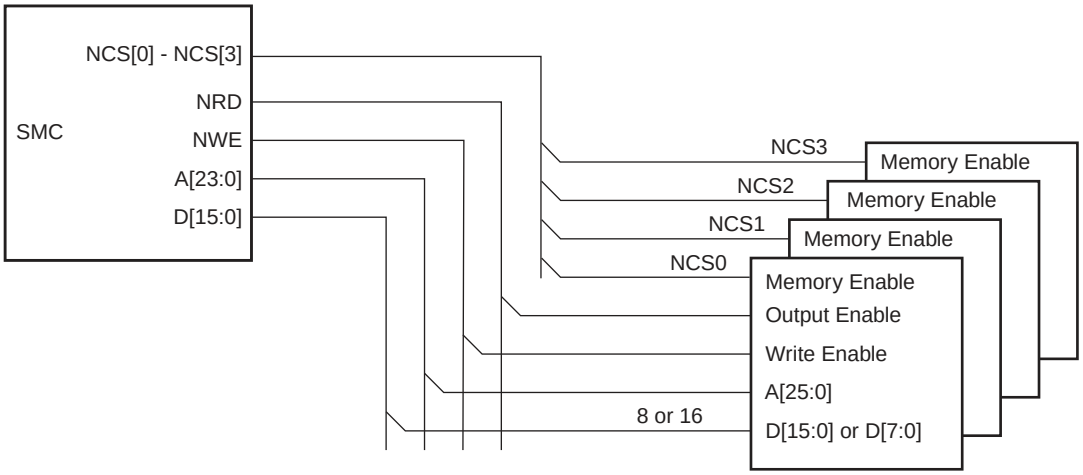
Note: 1. See Section 24.16.2 ”NFC Control Registers”, i.e., CMD_ADDR description.

The SMC provides up to 24 address lines, A[23:0]. This allows each chip select line to address up to 16 Mbytes of memory.

If the physical memory device connected on one chip select is smaller than 16 Mbytes, it wraps around and appears to be repeated within this space. The SMC correctly handles any valid access to the memory device within the page (see Figure).

A[23:0] is only significant for 8-bit memory, A[23:1] is used for 16-bit memory.

Figure 24-3. Memory Connections for External Devices



24.9 Connection to External Devices

24.9.1 Data Bus Width

A data bus width of 8 or 16 bits can be selected for each chip select. This option is controlled by the field DBW in SMC_MODE (Mode Register) for the corresponding chip select.

Figure 24-4 shows how to connect a 512K x 8-bit memory on NCS2. Figure 24-5 shows how to connect a 512K x 16-bit memory on NCS2.

24.9.2 Byte Write or Byte Select Access

Each chip select with a 16-bit data bus can operate with one of two different types of write access: byte write or byte select access. This is controlled by the BAT field of the SMC_MODE register for the corresponding chip select.

Figure 24-4. Memory Connection for an 8-bit Data Bus

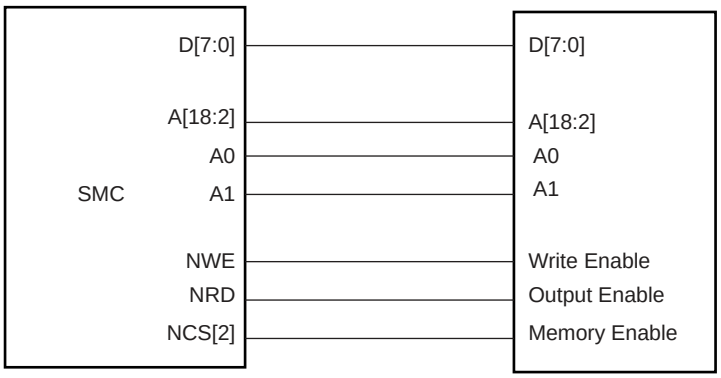
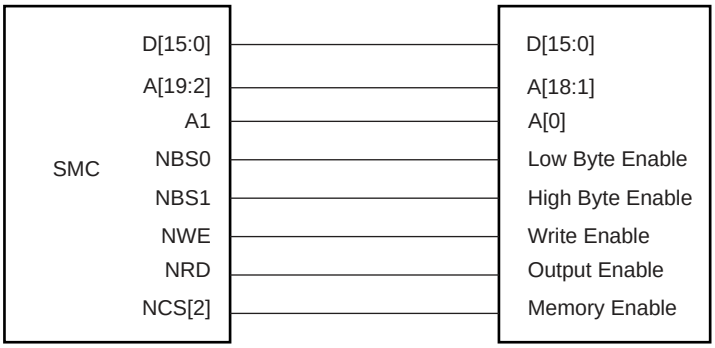


Figure 24-5. Memory Connection for a 16-bit Data Bus



24.9.2.1 Byte Write Access

Byte write access supports one byte write signal per byte of the data bus and a single read signal.

Note that the SMC does not allow boot in Byte Write Access mode.

- For 16-bit devices: the SMC provides NWR0 and NWR1 write signals for respectively, byte0 (lower byte) and byte1 (upper byte) of a 16-bit bus. One single read signal (NRD) is provided.

  Byte Write Access is used to connect 2 x 8-bit devices as a 16-bit memory.

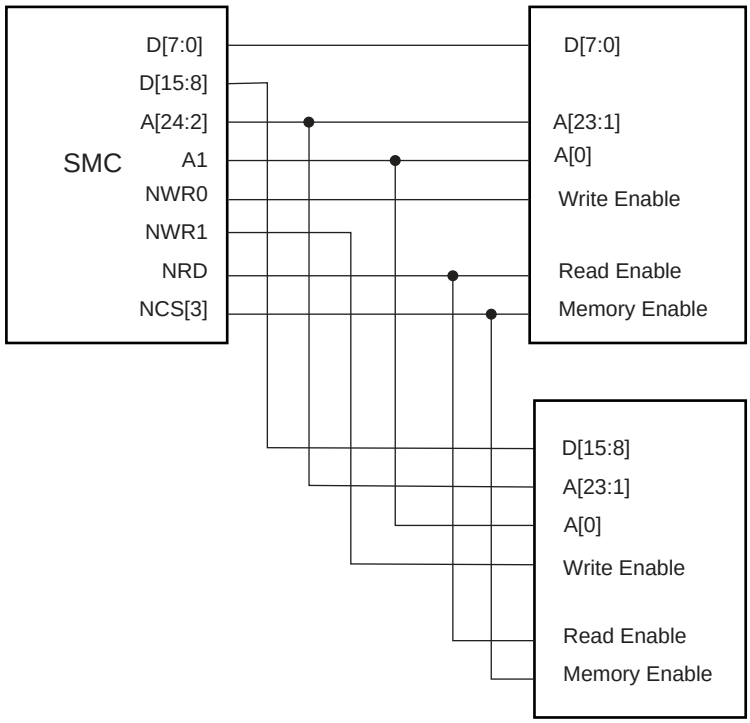
24.9.2.2 Byte Select Access

In this mode, read/write operations can be enabled/disabled at byte level. One byte-select line per byte of the data bus is provided. One NRD and one NWE signal control read and write.

- For 16-bit devices: the SMC provides NBS0 and NBS1 selection signals for respectively byte0 (lower byte) and byte1 (upper byte) of a 16-bit bus.

  Byte Select Access is used to connect one 16-bit device.

Figure 24-6. Connection of 2 x 8-bit Devices on a 16-bit Bus: Byte Write Option



24.9.2.3 Signal Multiplexing

Depending on the byte access type (BAT), only the write signals or the byte select signals are used. To save IOs at the external bus interface, control signals at the SMC interface are multiplexed. Table 24-5 shows signal multiplexing depending on the data bus width and the byte access type.

For 16-bit devices, bit A0 of address is unused. When Byte Select Option is selected, NWR1 is unused. When Byte Write option is selected, NBS0 is unused.

Table 24-5. SMC Multiplexed Signal Translation

Signal Name	16-bit Bus		8-bit Bus
Device Type	**1x16-bit**	**2 x 8-bit**	**1 x 8-bit**
Byte Access Type (BAT)	Byte Select	Byte Write	
NBS0_A0	NBS0		A0
NWE_NWR0	NWE	NWR0	NWE
NBS1_NWR1	NBS1	NWR1	
A1	A1	A1	A1

24.10 Standard Read and Write Protocols

In the following sections, the byte access type is not considered. Byte select lines (NBS0 to NBS1) always have the same timing as the A address bus. NWE represents either the NWE signal in byte select access type or one of the byte write lines (NWR0 to NWR1) in byte write access type. NWR0 to NWR3 have the same timings and protocol as NWE. In the same way, NCS represents one of the NCS[0..3] chip select lines.

24.10.1 Read Waveforms

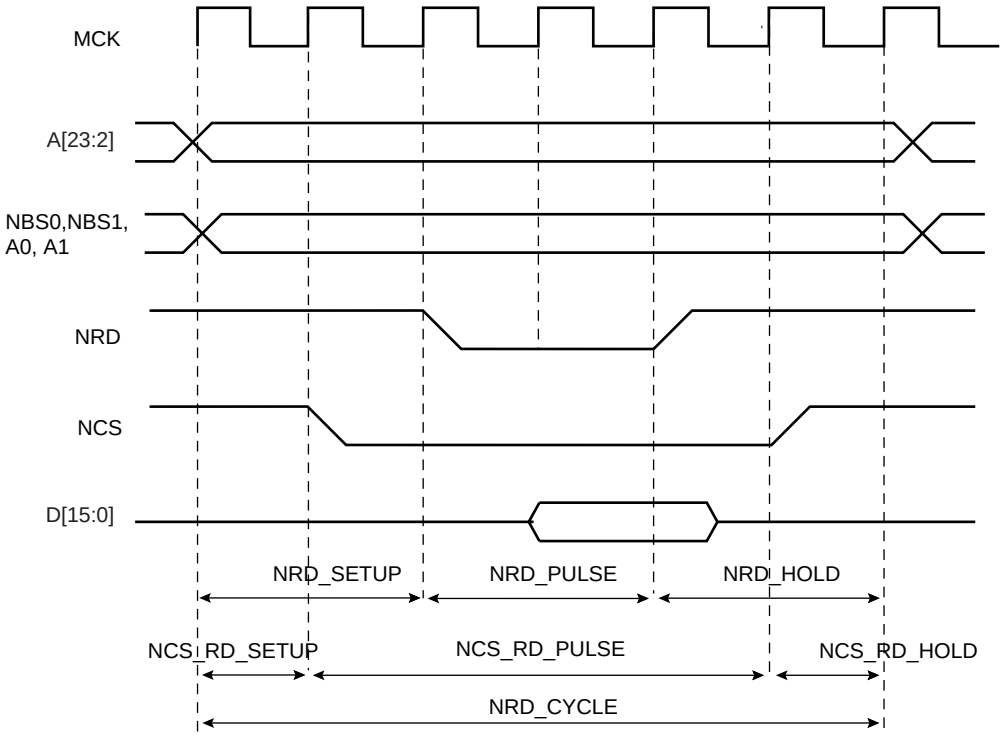
The read cycle is shown on Figure 24-7.

The read cycle starts with the address setting on the memory address bus, i.e.:

{A[23:2], A1, A0} for 8-bit devices

{A[23:2], A1} for 16-bit devices

Figure 24-7. Standard Read Cycle



24.10.1.1 NRD Waveform

The NRD signal is characterized by a setup timing, a pulse width and a hold timing.

1. NRD_SETUP: the NRD setup time is defined as the setup of address before the NRD falling edge.
2. NRD_PULSE: the NRD pulse length is the time between NRD falling edge and NRD rising edge.
3. NRD_HOLD: the NRD hold time is defined as the hold time of address after the NRD rising edge.

24.10.1.2 NCS Waveform

Similarly, the NCS signal can be divided into a setup time, pulse length and hold time:

1. NCS_RD_SETUP: the NCS setup time is defined as the setup time of address before the NCS falling edge.
2. NCS_RD_PULSE: the NCS pulse length is the time between NCS falling edge and NCS rising edge.
3. NCS_RD_HOLD: the NCS hold time is defined as the hold time of address after the NCS rising edge.

24.10.1.3 Read Cycle

The NRD_CYCLE time is defined as the total duration of the read cycle, i.e., from the time where address is set on the address bus to the point where address may change. The total read cycle time is equal to:

NRD_CYCLE = NRD_SETUP + NRD_PULSE + NRD_HOLD

= NCS_RD_SETUP + NCS_RD_PULSE + NCS_RD_HOLD

All NRD and NCS timings are defined separately for each chip select as an integer number of Master Clock cycles. To ensure that the NRD and NCS timings are coherent, the user must define the total read cycle instead of the hold timing. NRD_CYCLE implicitly defines the NRD hold time and NCS hold time as:

NRD_HOLD = NRD_CYCLE - NRD SETUP - NRD PULSE

NCS_RD_HOLD = NRD_CYCLE - NCS_RD_SETUP - NCS_RD_PULSE

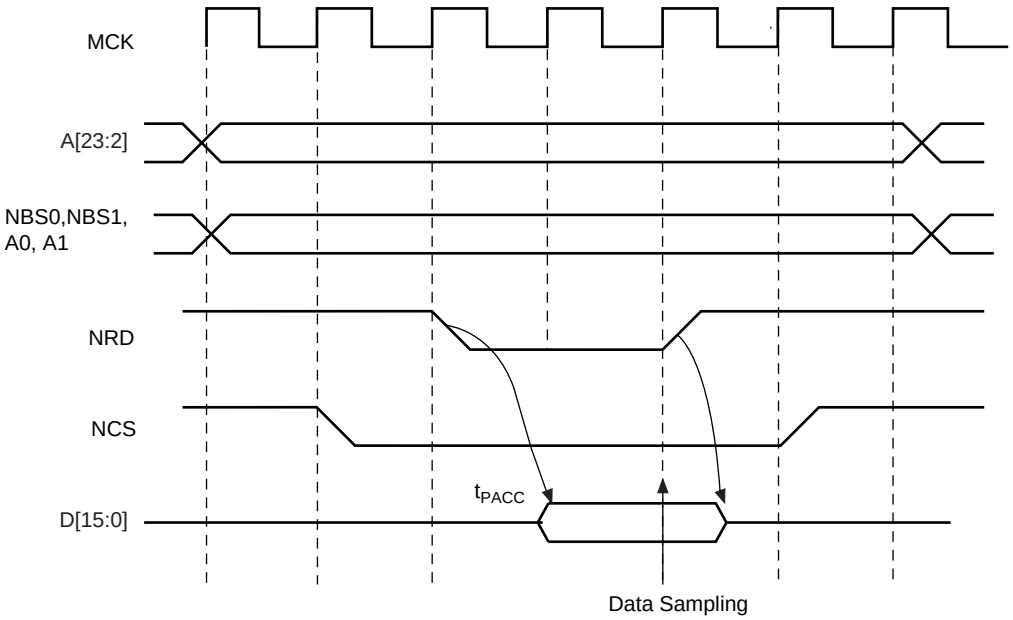
24.10.2 Read Mode

As NCS and NRD waveforms are defined independently of one other, the SMC needs to know when the read data is available on the data bus. The SMC does not compare NCS and NRD timings to know which signal rises first. The READ_MODE parameter in the SMC_MODE register of the corresponding chip select indicates which signal of NRD and NCS controls the read operation.

24.10.2.1 Read is Controlled by NRD (READ_MODE = 1):

Figure 24-8 shows the waveforms of a read operation of a typical asynchronous RAM. The read data is available t_{PACC} after the falling edge of NRD, and turns to 'Z' after the rising edge of NRD. In this case, the READ_MODE must be set to 1 (read is controlled by NRD), to indicate that data is available with the rising edge of NRD. The SMC samples the read data internally on the rising edge of Master Clock that generates the rising edge of NRD, whatever the programmed waveform of NCS may be.

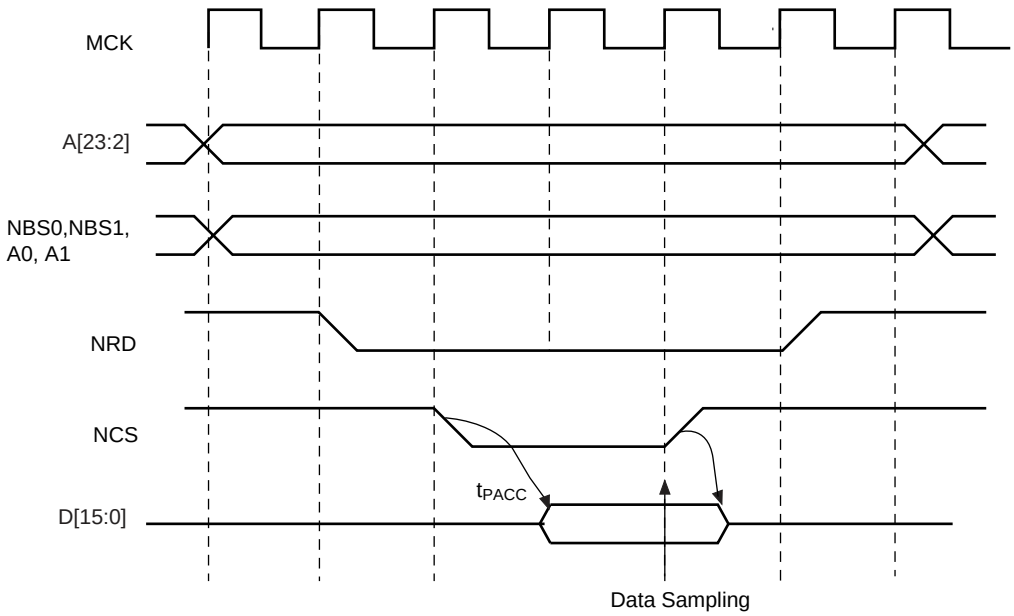
Figure 24-8. READ_MODE = 1: Data is sampled by SMC before the rising edge of NRD



24.10.2.2 Read is Controlled by NCS (READ_MODE = 0)

Figure 24-9 shows the typical read cycle. The read data is valid t_{PACC} after the falling edge of the NCS signal and remains valid until the rising edge of NCS. Data must be sampled when NCS is raised. In that case, the READ_MODE must be set to 0 (read is controlled by NCS): the SMC internally samples the data on the rising edge of Master Clock that generates the rising edge of NCS, whatever the programmed waveform of NRD may be.

Figure 24-9. READ_MODE = 0: Data is sampled by SMC before the rising edge of NCS



24.10.3 Write Waveforms

The write protocol is similar to the read protocol. It is depicted in Figure 24-10. The write cycle starts with the address setting on the memory address bus.

24.10.3.1 NWE Waveforms

The NWE signal is characterized by a setup timing, a pulse width and a hold timing.

1. NWE_SETUP: the NWE setup time is defined as the setup of address and data before the NWE falling edge.
2. NWE_PULSE: The NWE pulse length is the time between NWE falling edge and NWE rising edge.
3. NWE_HOLD: The NWE hold time is defined as the hold time of address and data after the NWE rising edge.

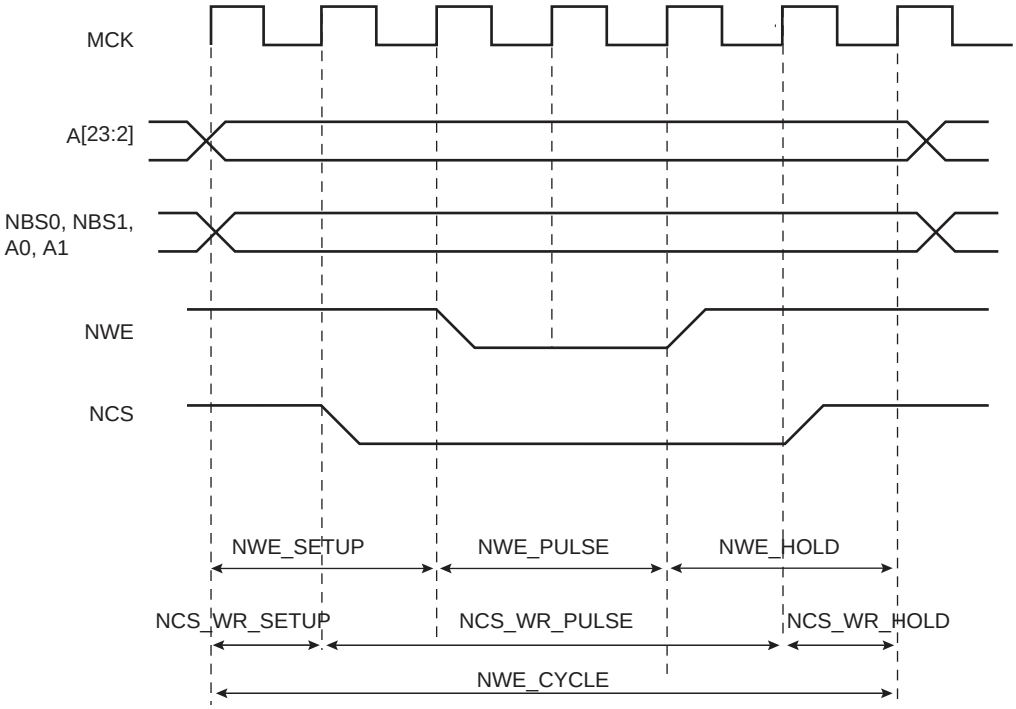
The NWE waveforms apply to all byte-write lines in Byte Write access mode: NWR0 to NWR3.

24.10.3.2 NCS Waveforms

The NCS signal waveforms in write operation are not the same as those applied in read operations, but are separately defined:

1. NCS_WR_SETUP: the NCS setup time is defined as the setup time of address before the NCS falling edge.
2. NCS_WR_PULSE: the NCS pulse length is the time between NCS falling edge and NCS rising edge.
3. NCS_WR_HOLD: the NCS hold time is defined as the hold time of address after the NCS rising edge.

Figure 24-10. Write Cycle



24.10.3.3 Write Cycle

The write cycle time is defined as the total duration of the write cycle, that is, from the time where address is set on the address bus to the point where address may change. The total write cycle time is equal to:

NWE_CYCLE = NWE_SETUP + NWE_PULSE + NWE_HOLD

= NCS_WR_SETUP + NCS_WR_PULSE + NCS_WR_HOLD

All NWE and NCS (write) timings are defined separately for each chip select as an integer number of Master Clock cycles. To ensure that the NWE and NCS timings are coherent, the user must define the total write cycle instead of the hold timing. This implicitly defines the NWE hold time and NCS (write) hold times as:

NWE_HOLD = NWE_CYCLE - NWE_SETUP - NWE_PULSE

NCS_WR_HOLD = NWE_CYCLE - NCS_WR_SETUP - NCS_WR_PULSE

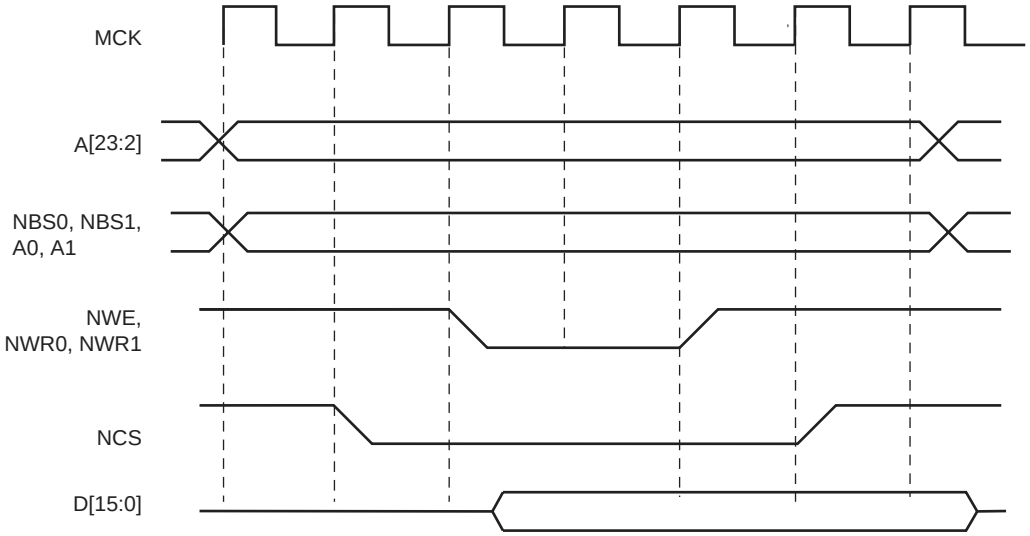
24.10.4 Write Mode

The WRITE_MODE parameter in the SMC_MODE register of the corresponding chip select indicates which signal controls the write operation.

24.10.4.1 Write is Controlled by NWE (WRITE_MODE = 1)

Figure 24-11 shows the waveforms of a write operation with WRITE_MODE set to 1. The data is put on the bus during the pulse and hold steps of the NWE signal. The internal data buffers are turned out after the NWE_SETUP time, and until the end of the write cycle, regardless of the programmed waveform on NCS.

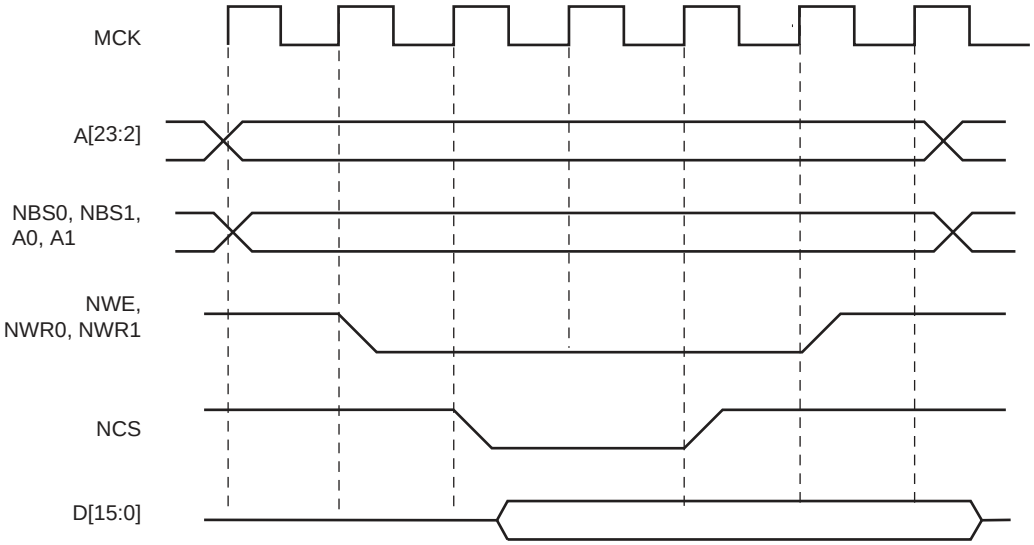
Figure 24-11. WRITE_MODE = 1. The write operation is controlled by NWE



24.10.4.2 Write is Controlled by NCS (WRITE_MODE = 0)

Figure 24-12 shows the waveforms of a write operation with WRITE_MODE set to 0. The data is put on the bus during the pulse and hold steps of the NCS signal. The internal data buffers are turned out after the NCS_WR_SETUP time, and until the end of the write cycle, regardless of the programmed waveform on NWE.

Figure 24-12. WRITE_MODE = 0. The write operation is controlled by NCS



24.10.5 Coding Timing Parameters

All timing parameters are defined for one chip select and are grouped together in one SMC_REGISTER according to their type.

- The SMC_SETUP register groups the definition of all setup parameters: NRD_SETUP, NCS_RD_SETUP, NWE_SETUP, NCS_WR_SETUP
- The SMC_PULSE register groups the definition of all pulse parameters: NRD_PULSE, NCS_RD_PULSE, NWE_PULSE, NCS_WR_PULSE
- The SMC_CYCLE register groups the definition of all cycle parameters: NRD_CYCLE, NWE_CYCLE

Table 24-6 shows how the timing parameters are coded and their permitted range.

Table 24-6. Coding and Range of Timing Parameters

Coded Value	Number of Bits	Effective Value	Permitted Range	
			Coded Value	Effective Value
setup [5:0]	6	128 x setup[5] + setup[4:0]	0 ≤ setup ≤ 31	128..(128+31)
pulse [6:0]	7	256 x pulse[6] + pulse[5:0]	0 ≤ pulse ≤63	256..(256+63)
cycle [8:0]	9	256 x cycle[8:7] + cycle[6:0]	0 ≤ cycle ≤ 127	256.. (256+127) 512.. (512+127) 768..(768+127)

24.10.6 Reset Values of Timing Parameters

Table 24-7 gives the default value of timing parameters at reset.

Table 24-7. Reset Values of Timing Parameters

Register	Reset Value	Description
SMC_SETUP	0x01010101	All setup timings are set to 1
SMC_PULSE	0x01010101	All pulse timings are set to 1
SMC_CYCLE	0x00030003	The read and write operation last 3 Master Clock cycles and provide one hold cycle
WRITE_MODE	1	Write is controlled with NWE
READ_MODE	1	Read is controlled with NRD

24.10.7 Usage Restriction

The SMC does not check the validity of the user-programmed parameters. If the sum of SETUP and PULSE parameters is larger than the corresponding CYCLE parameter, this leads to unpredictable behavior of the SMC.

24.10.7.1 For Read Operations

Null but positive setup and hold of address and NRD and/or NCS can not be guaranteed at the memory interface because of the propagation delay of theses signals through external logic and pads. If positive setup and hold values must be verified, then it is strictly recommended to program non-null values so as to cover possible skews between address, NCS and NRD signals.

24.10.7.2 For Write Operations

If a null hold value is programmed on NWE, the SMC can guarantee a positive hold of address, byte select lines, and NCS signal after the rising edge of NWE. This is true for WRITE_MODE = 1 only. See “Early Read Wait State” on page 356.

For read and write operations: a null value for pulse parameters is forbidden and may lead to unpredictable behavior.

In read and write cycles, the setup and hold time parameters are defined in reference to the address bus. For external devices that require setup and hold time between NCS and NRD signals (read), or between NCS and NWE signals (write), these setup and hold times must be converted into setup and hold times in reference to the address bus.

24.11 Scrambling/Unscrambling Function

The external data bus D[15:0] can be scrambled in order to prevent intellectual property data located in off-chip memories from being easily recovered by analyzing data at the package pin level of either microcontroller or memory device.

The scrambling and unscrambling are performed on-the-fly without additional wait states.

The scrambling method depends on two user-configurable key registers, SMC_KEY1 and SMC_KEY2. These key registers are only accessible in write mode.

The key must be securely stored in a reliable non-volatile memory in order to recover data from the off-chip memory. Any data scrambled with a given key cannot be recovered if the key is lost.

The scrambling/unscrambling function can be enabled or disabled by programming the SMC_OCMS register.

One bit is dedicated to enable/disable NAND Flash scrambling and one bit is dedicated enable/disable scrambling the off chip SRAM. When at least one external SRAM is scrambled, the SMSC field must be set in the SMC_OCMS register.

When multiple chip selects (external SRAM) are handled, it is possible to configure the scrambling function per chip select using the OCMS field in the SMC_TIMINGS registers.

To scramble the NAND Flash contents, the SRSE field must be set in the SMC_OCMS register.

When NAND Flash memory content is scrambled, the on-chip SRAM page buffer associated for the transfer is also scrambled.

24.12 Automatic Wait States

Under certain circumstances, the SMC automatically inserts idle cycles between accesses to avoid bus contention or operation conflict.

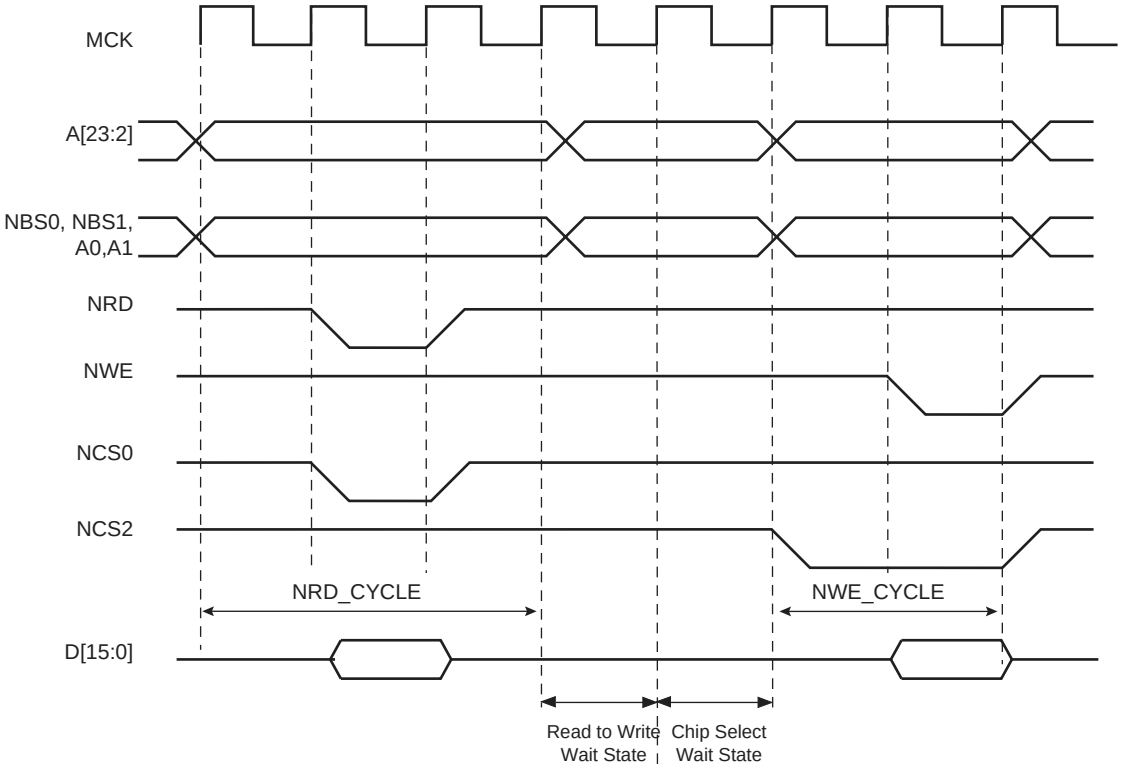
24.12.1 Chip Select Wait States

The SMC always inserts an idle cycle between 2 transfers on separate chip selects. This idle cycle ensures that there is no bus contention between the de-activation of one device and the activation of the next one.

During chip select wait state, all control lines are turned inactive: NBS0 to NBS1, NWR0 to NWR1, NCS[0..3], and NRD lines. They are all set to 1.

Figure 24-13 illustrates a chip select wait state between access on Chip Select 0 and Chip Select 2.

Figure 24-13. Chip Select Wait State between a Read Access on NCS0 and a Write Access on NCS2



24.12.2 Early Read Wait State

In some cases, the SMC inserts a wait state cycle between a write access and a read access to allow time for the write cycle to end before the subsequent read cycle begins. This wait state is not generated in addition to a chip select wait state. The early read cycle thus only occurs between a write and read access to the same memory device (same chip select).

An early read wait state is automatically inserted if at least one of the following conditions is valid:

- if the write controlling signal has no hold time and the read controlling signal has no setup time (Figure 24-14).
- in NCS write controlled mode (WRITE_MODE = 0), if there is no hold timing on the NCS signal and the NCS_RD_SETUP parameter is set to 0, regardless of the read mode (Figure 24-15). The write operation must end with a NCS rising edge. Without an Early Read Wait State, the write operation could not complete properly.
- in NWE controlled mode (WRITE_MODE = 1) and if there is no hold timing (NWE_HOLD = 0), the feedback of the write control signal is used to control address, data, chip select and byte select lines. If the external write control signal is not inactivated as expected due to load capacitances, an Early Read Wait State is inserted and address, data and control signals are maintained one more cycle. See Figure 24-16.

Figure 24-14. Early Read Wait State: Write with No Hold Followed by Read with No Setup

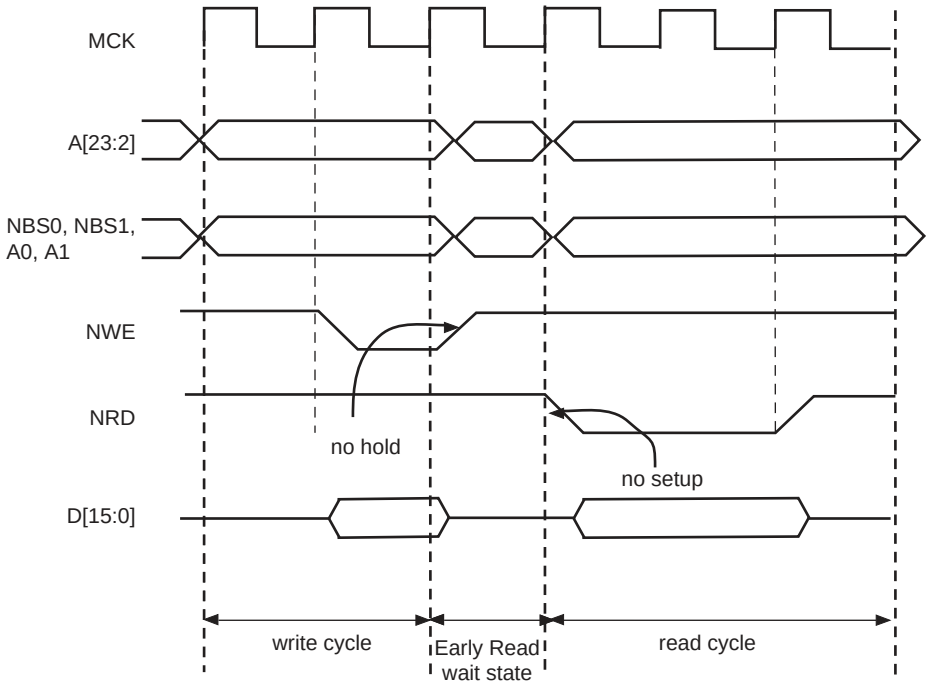


Figure 24-15. Early Read Wait State: NCS Controlled Write with No Hold Followed by a Read with No NCS Setup

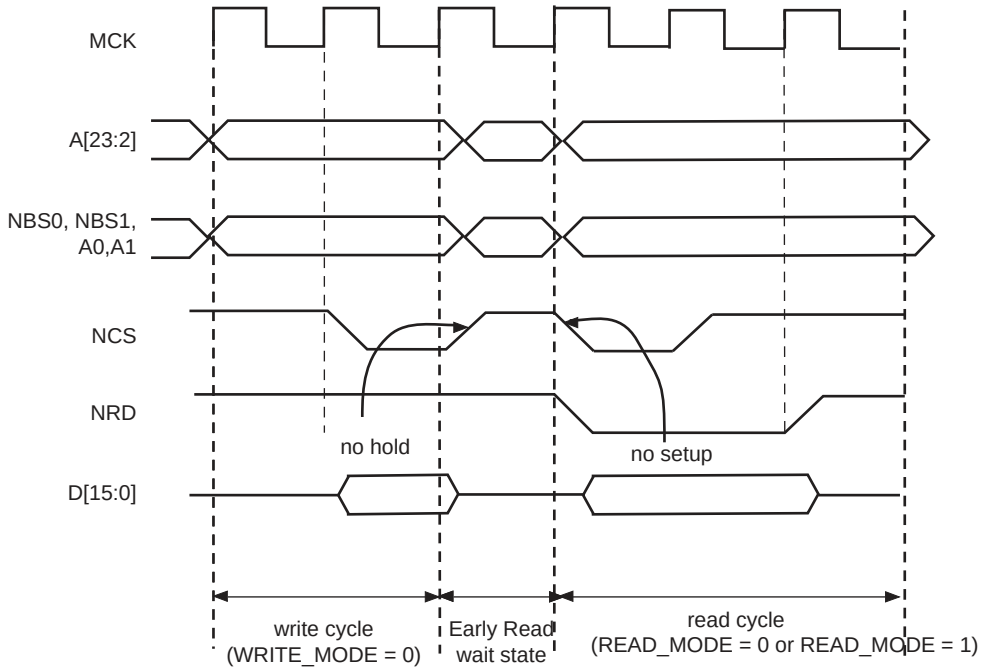
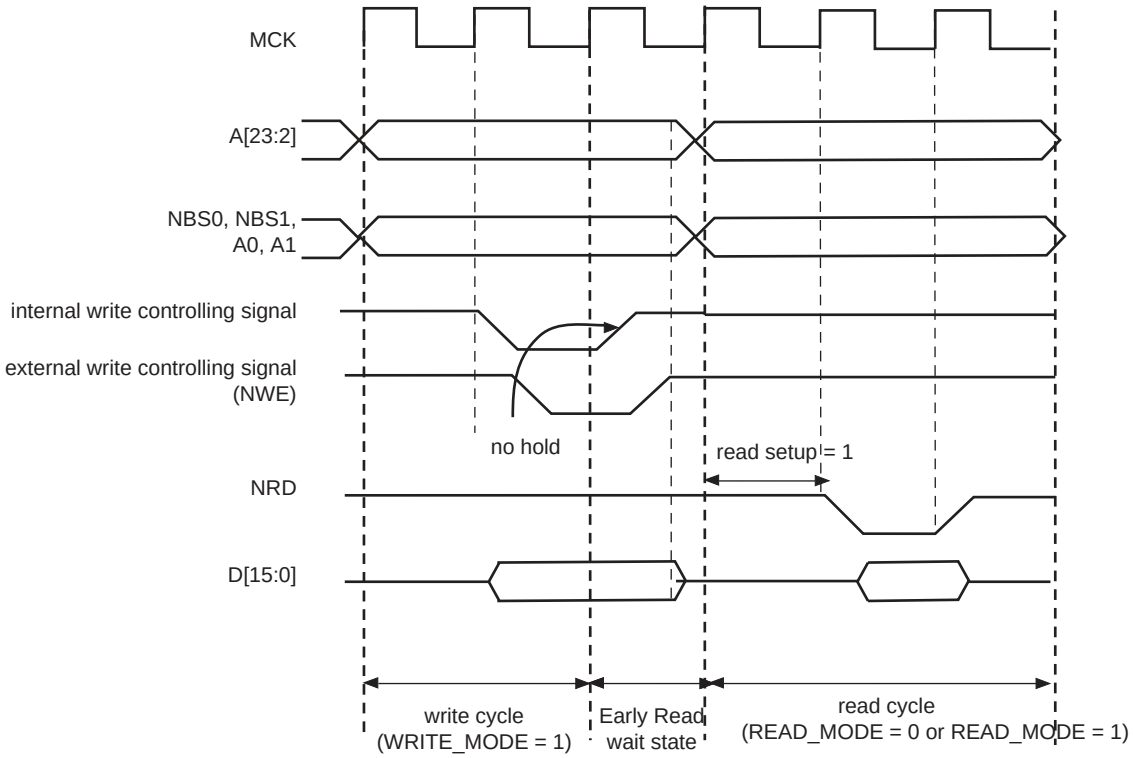


Figure 24-16. Early Read Wait State: NWE-controlled Write with No Hold Followed by a Read with one Set-up Cycle



24.12.3 Reload User Configuration Wait State

The user may change any of the configuration parameters by writing the SMC user interface.

When detecting that a new user configuration has been written in the user interface, the SMC inserts a wait state before starting the next access. The so called “Reload User Configuration Wait State” is used by the SMC to load the new set of parameters to apply to next accesses.

The Reload Configuration Wait State is not applied in addition to the Chip Select Wait State. If accesses before and after re-programming the user interface are made to different devices (Chip Selects), then one single Chip Select Wait State is applied.

On the other hand, if accesses before and after writing the user interface are made to the same device, a Reload Configuration Wait State is inserted, even if the change does not concern the current Chip Select.

24.12.3.1 User Procedure

To insert a Reload Configuration Wait State, the SMC detects a write access to any SMC_MODE register of the user interface. If only the timing registers are modified (SMC_SETUP, SMC_PULSE, SMC_CYCLE registers) in the user interface, the user must validate the modification by writing the SMC_MODE register, even if no change was made on the mode parameters.

24.12.3.2 Slow Clock Mode Transition

A Reload Configuration Wait State is also inserted when the Slow Clock Mode is entered or exited, after the end of the current transfer (see “Slow Clock Mode” on page 370).

24.12.4 Read to Write Wait State

Due to an internal mechanism, a wait cycle is always inserted between consecutive read and write SMC accesses.

This wait cycle is referred to as a read to write wait state in this document.

This wait cycle is applied in addition to chip select and reload user configuration wait states when they are to be inserted. See Figure 24-13 on page 355.

24.13 Data Float Wait States

Some memory devices are slow to release the external bus. For such devices, it is necessary to add wait states (data float wait states) after a read access:

- before starting a read access to a different external memory,
- before starting a write access to the same device or to a different external one.

The Data Float Output Time (t_{DF}) for each external memory device is programmed in the TDF_CYCLES field of the SMC_MODE register for the corresponding chip select. The value of TDF_CYCLES indicates the number of data float wait cycles (between 0 and 15) before the external device releases the bus, and represents the time allowed for the data output to go to high impedance after the memory is disabled.

Data float wait states do not delay internal memory accesses. Hence, a single access to an external memory with long t_{DF} will not slow down the execution of a program from internal memory.

The data float wait states management depends on the READ_MODE and the TDF_MODE fields of the SMC_MODE register for the corresponding chip select.

24.13.1 READ_MODE

Setting READ_MODE to 1 indicates to the SMC that the NRD signal is responsible for turning off the tri-state buffers of the external memory device. The Data Float Period then begins after the rising edge of the NRD signal and lasts TDF_CYCLES MCK cycles.

When the read operation is controlled by the NCS signal (READ_MODE = 0), the TDF field gives the number of MCK cycles during which the data bus remains busy after the rising edge of NCS.

Figure 24-17 illustrates the Data Float Period in NRD-controlled mode (READ_MODE =1), assuming a data float period of 2 cycles (TDF_CYCLES = 2). Figure 24-18 shows the read operation when controlled by NCS (READ_MODE = 0) and the TDF_CYCLES parameter equals 3.

Figure 24-17. TDF Period in NRD Controlled Read Access (TDF = 2)

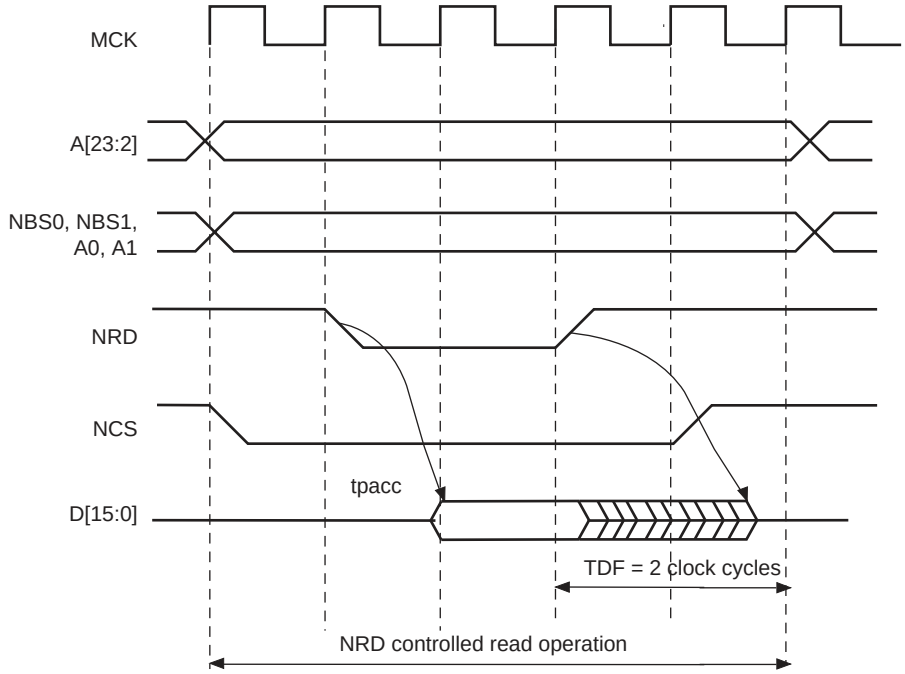
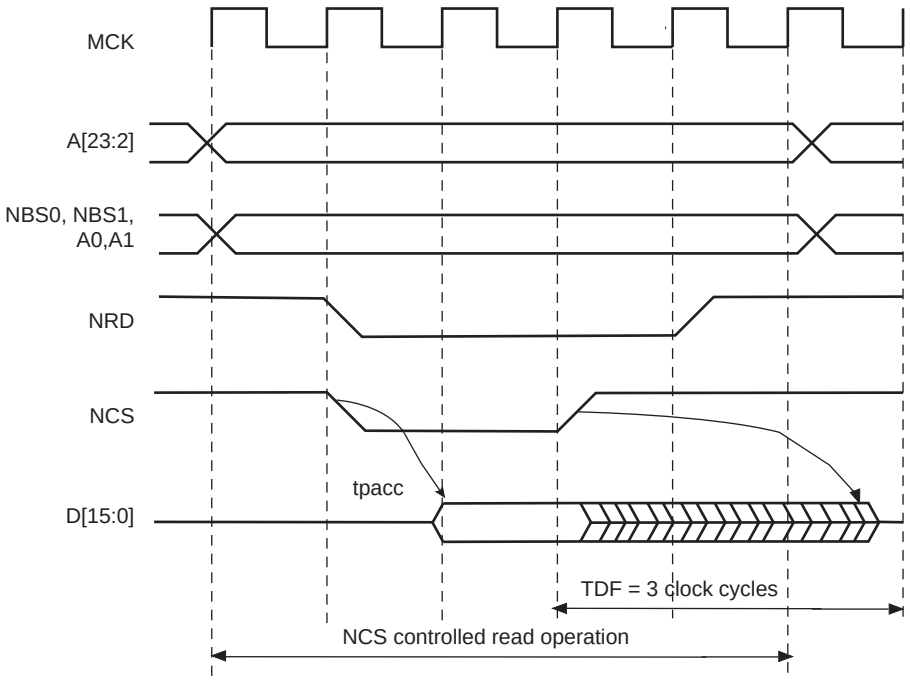


Figure 24-18. TDF Period in NCS Controlled Read Operation (TDF = 3)



24.13.2 TDF Optimization Enabled (TDF_MODE = 1)

When the TDF_MODE of the SMC_MODE register is set to 1 (TDF optimization is enabled), the SMC takes advantage of the setup period of the next access to optimize the number of wait states cycle to insert.

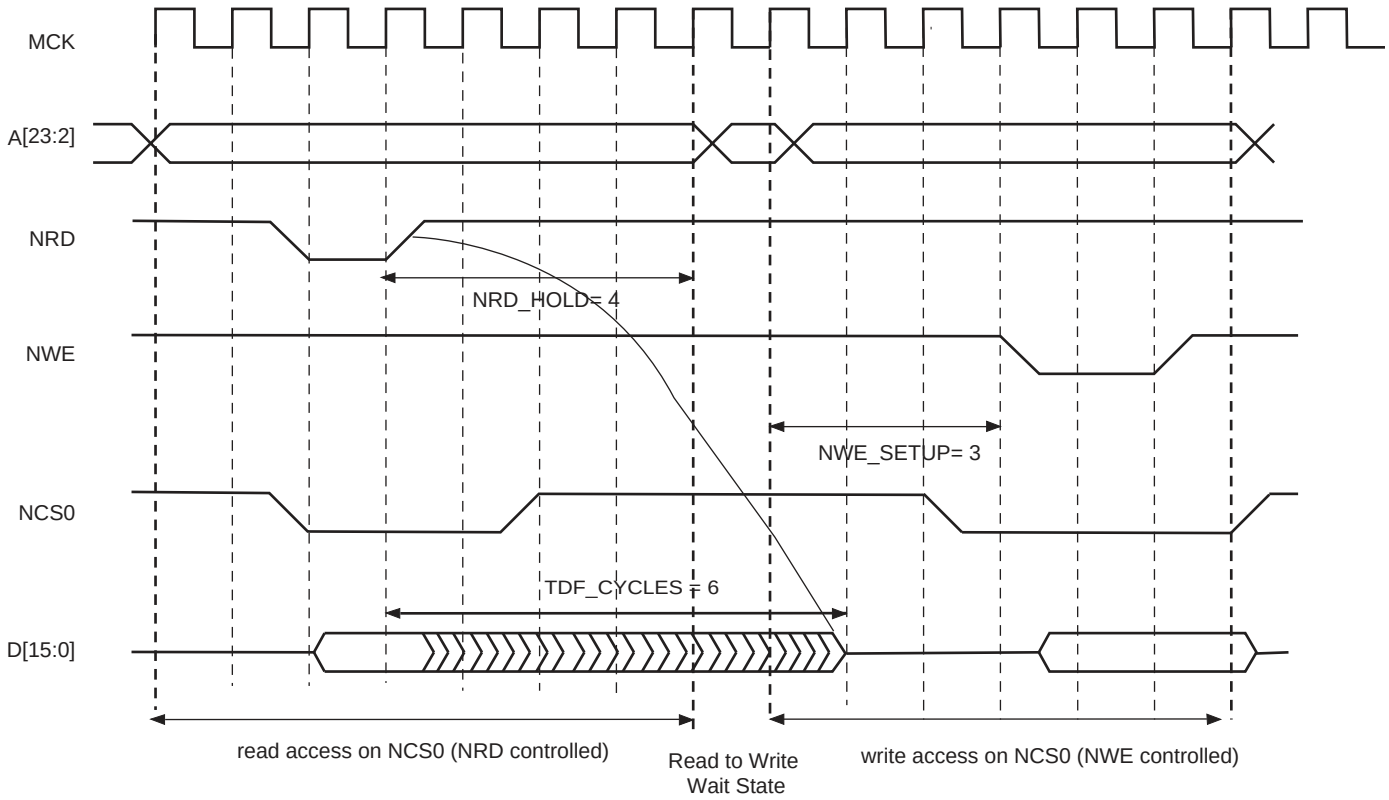
Figure 24-19 shows a read access controlled by NRD, followed by a write access controlled by NWE, on Chip Select 0. Chip Select 0 has been programmed with:

NRD_HOLD = 4; READ_MODE = 1 (NRD controlled)

NWE_SETUP = 3; WRITE_MODE = 1 (NWE controlled)

TDF_CYCLES = 6; TDF_MODE = 1 (optimization enabled).

Figure 24-19. TDF Optimization: No TDF wait states are inserted if the TDF period is over when the next access begins



24.13.3 TDF Optimization Disabled (TDF_MODE = 0)

When optimization is disabled, tdf wait states are inserted at the end of the read transfer, so that the data float period ends when the second access begins. If the hold period of the read1 controlling signal overlaps the data float period, no additional tdf wait states will be inserted.

Figure 24-20, Figure 24-21 and Figure 24-22 illustrate the cases:

- read access followed by a read access on another chip select,
- read access followed by a write access on another chip select,
- read access followed by a write access on the same chip select,

with no TDF optimization.

Figure 24-20. TDF Optimization Disabled (TDF Mode = 0). TDF wait states between 2 read accesses on different chip selects

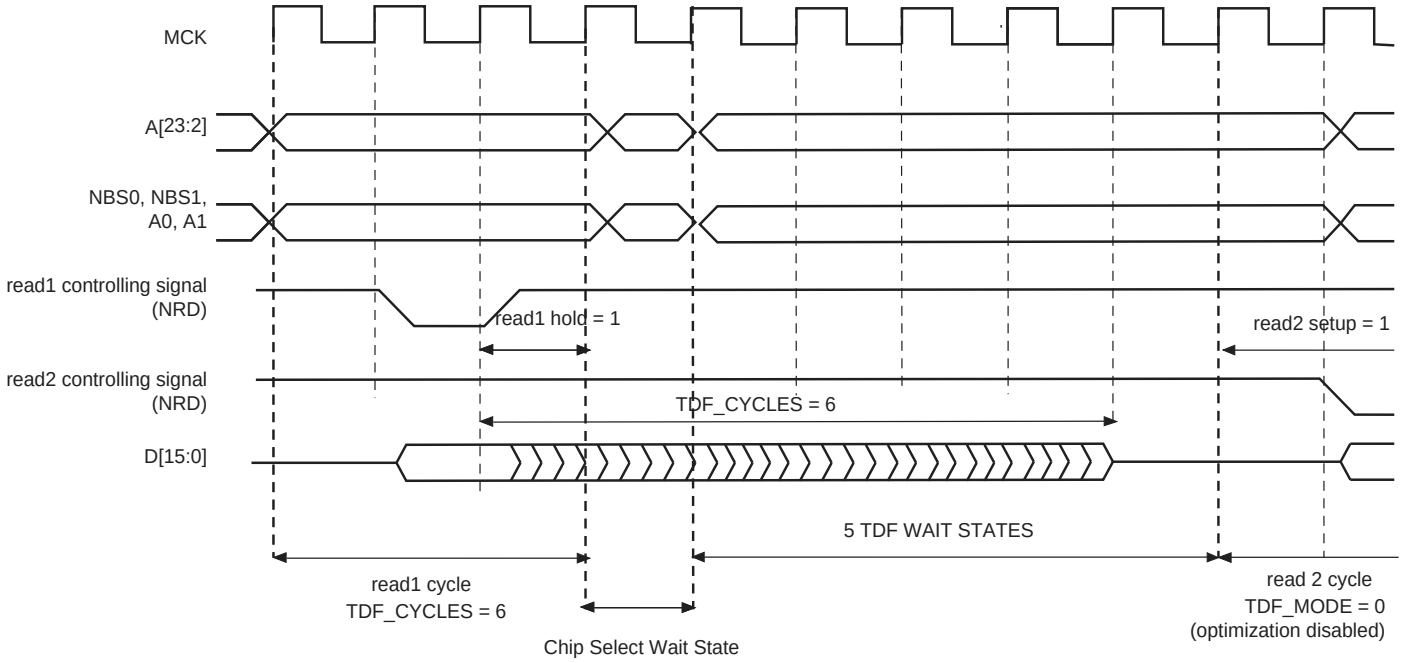


Figure 24-21. TDF Mode = 0: TDF wait states between a read and a write access on different chip selects

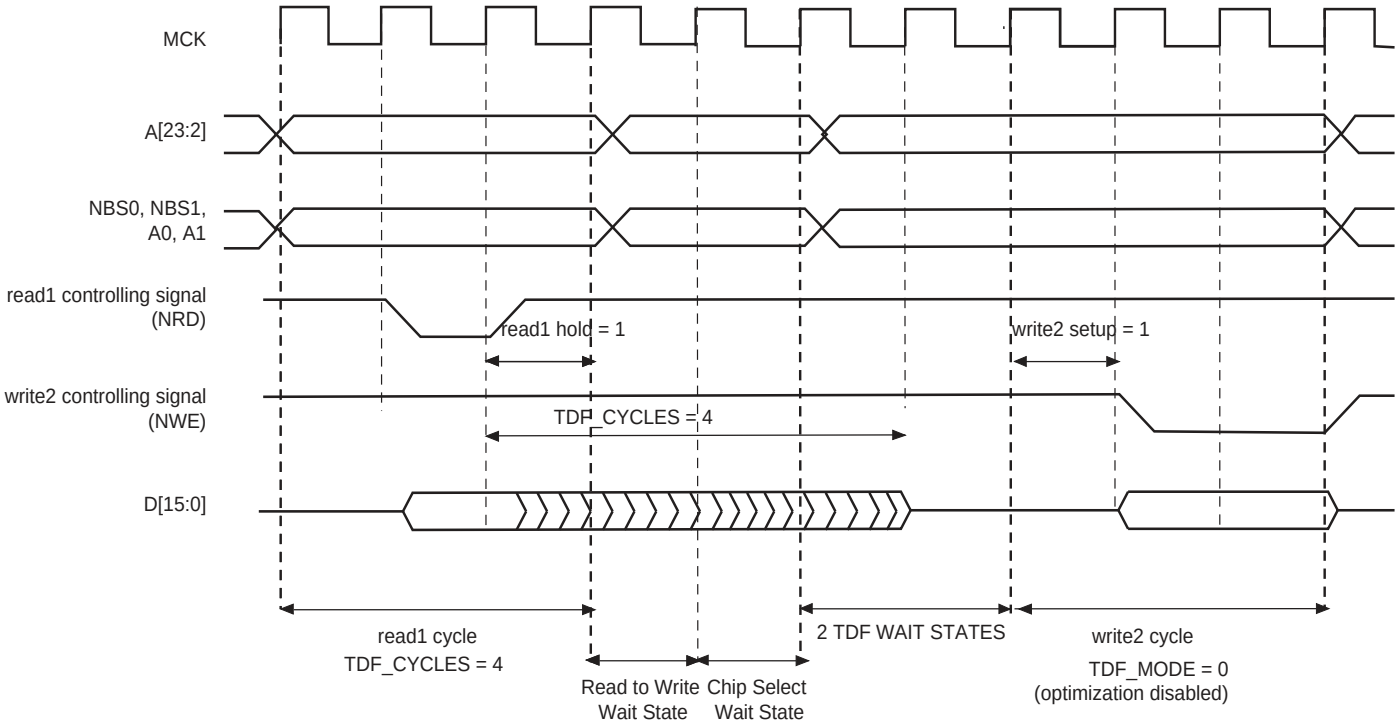
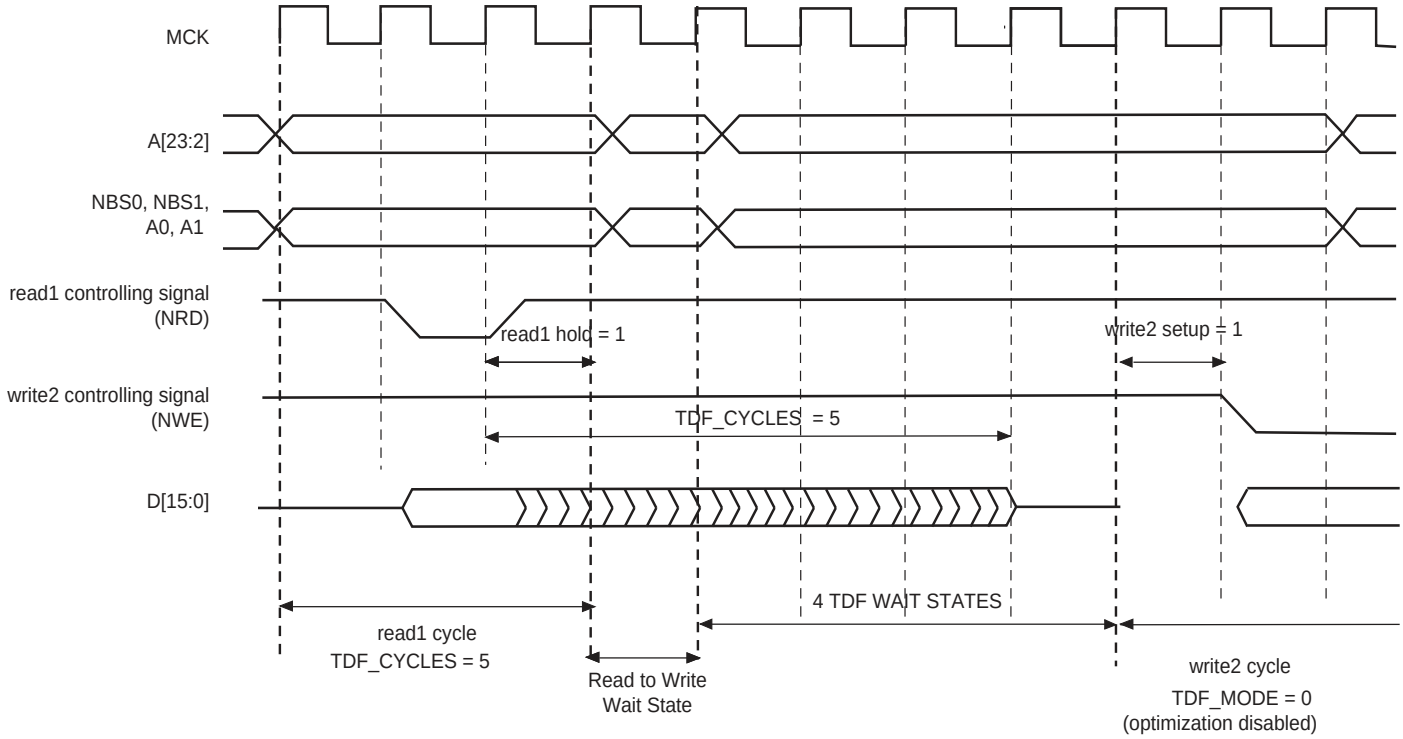


Figure 24-22. TDF Mode = 0: TDF wait states between read and write accesses on the same chip select



24.14 External Wait

Any access can be extended by an external device using the NWAIT input signal of the SMC. The EXNW_MODE field of the SMC_MODE register on the corresponding chip select must be set to either to “10” (frozen mode) or “11” (ready mode). When the EXNW_MODE is set to “00” (disabled), the NWAIT signal is simply ignored on the corresponding chip select. The NWAIT signal delays the read or write operation in regards to the read or write controlling signal, depending on the read and write modes of the corresponding chip select.

24.14.1 Restriction

When one of the EXNW_MODE is enabled, it is mandatory to program at least one hold cycle for the read/write controlling signal. For that reason, the NWAIT signal cannot be used in Slow Clock Mode (“Slow Clock Mode” on page 370).

The NWAIT signal is assumed to be a response of the external device to the read/write request of the SMC. Then NWAIT is examined by the SMC only in the pulse state of the read or write controlling signal. The assertion of the NWAIT signal outside the expected period has no impact on SMC behavior.

24.14.2 Frozen Mode

When the external device asserts the NWAIT signal (active low), and after internal synchronization of this signal, the SMC state is frozen, i.e., SMC internal counters are frozen, and all control signals remain unchanged. When the resynchronized NWAIT signal is deasserted, the SMC completes the access, resuming the access from the point where it was stopped. See Figure 24-23. This mode must be selected when the external device uses the NWAIT signal to delay the access and to freeze the SMC.

The assertion of the NWAIT signal outside the expected period is ignored as illustrated in Figure 24-24.

Figure 24-23. Write Access with NWAIT Assertion in Frozen Mode (EXNW_MODE = 10)

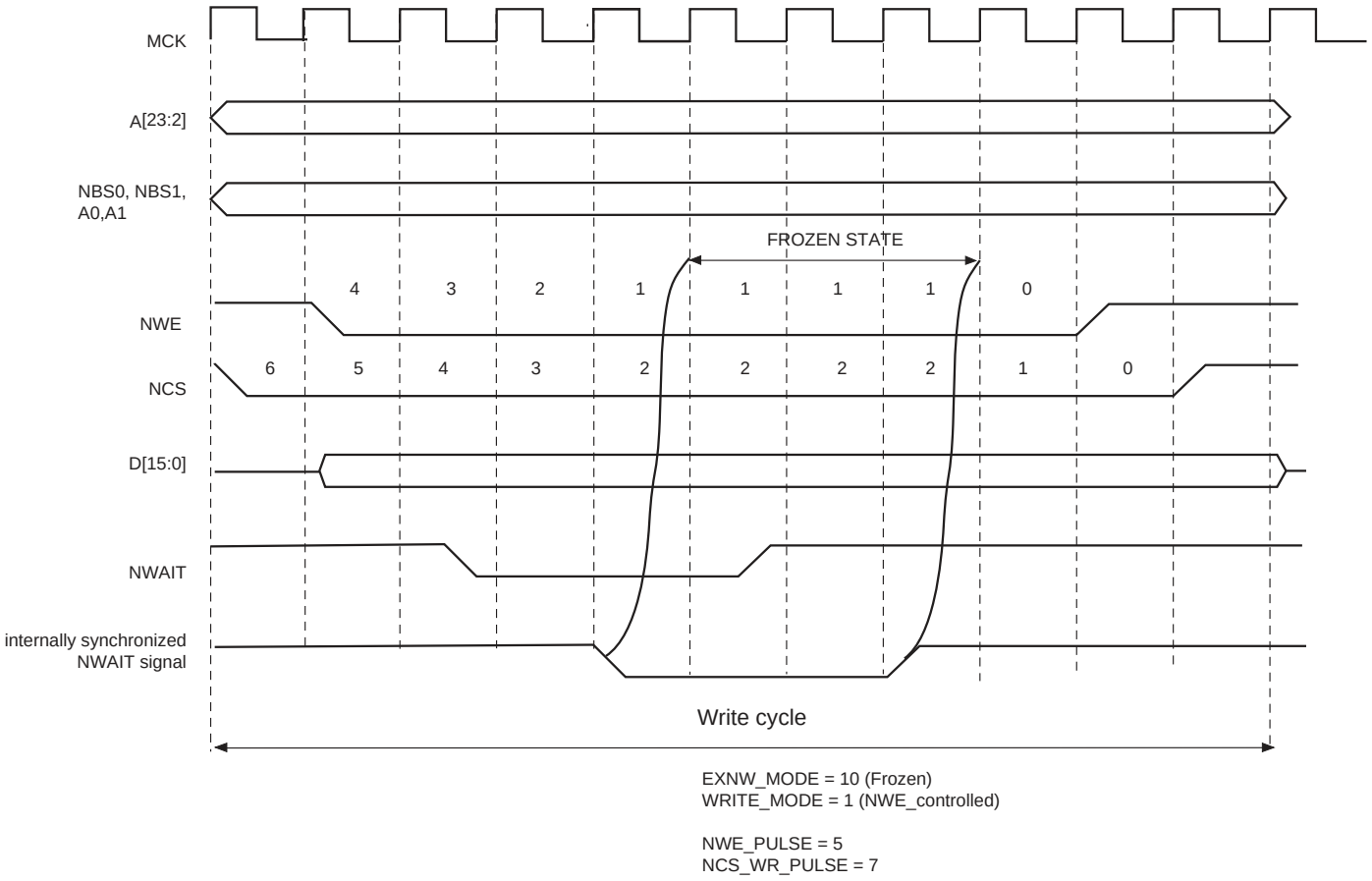
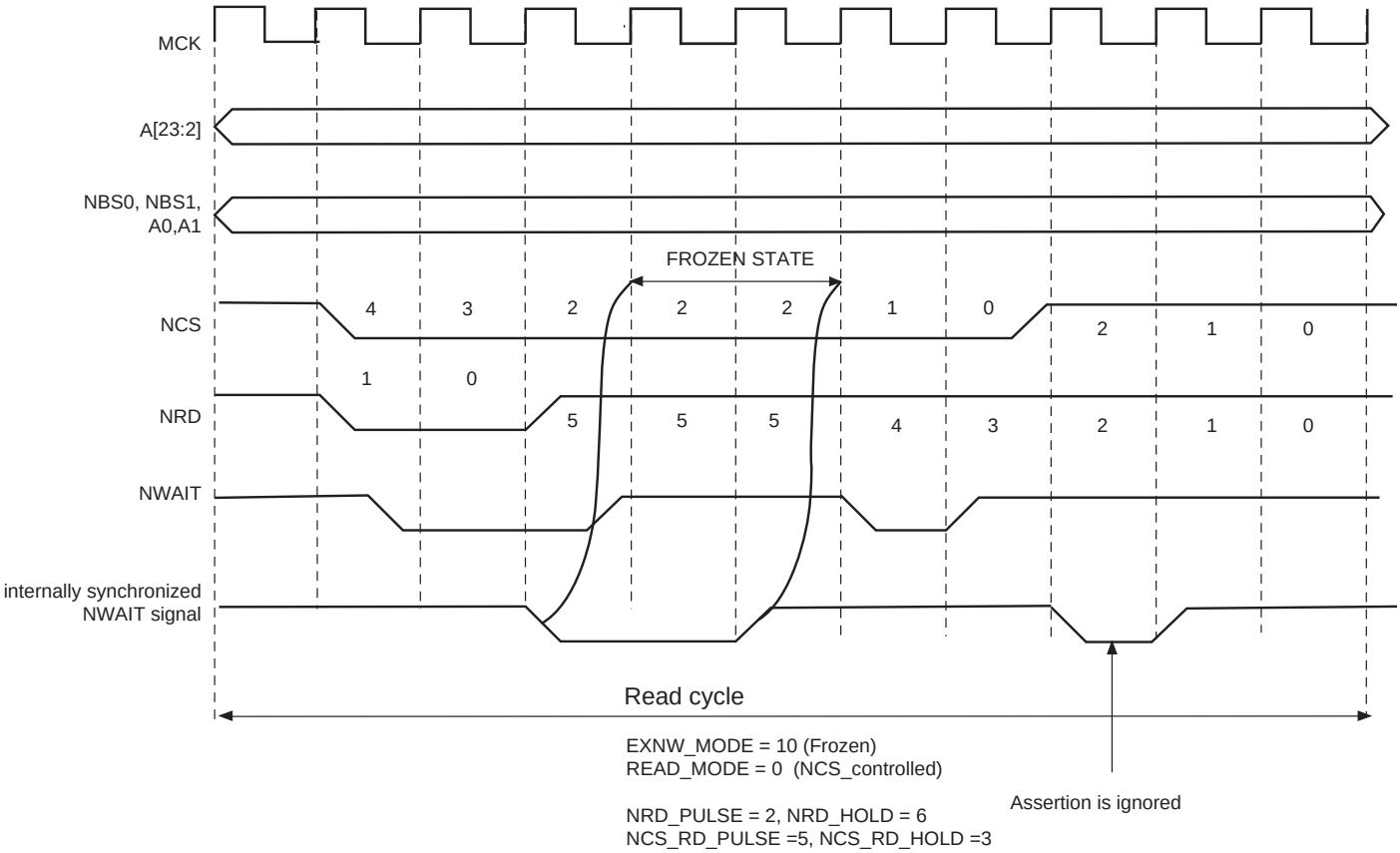


Figure 24-24. Read Access with NWAIT Assertion in Frozen Mode (EXNW_MODE = 10)



24.14.3 Ready Mode

In Ready mode (EXNW_MODE = 11), the SMC behaves differently. Normally, the SMC begins the access by down counting the setup and pulse counters of the read/write controlling signal. In the last cycle of the pulse phase, the resynchronized NWAIT signal is examined.

If asserted, the SMC suspends the access as shown in Figure 24-25 and Figure 24-26. After deassertion, the access is completed: the hold step of the access is performed.

This mode must be selected when the external device uses deassertion of the NWAIT signal to indicate its ability to complete the read or write operation.

If the NWAIT signal is deasserted before the end of the pulse, or asserted after the end of the pulse of the controlling read/write signal, it has no impact on the access length as shown in Figure 24-26.

Figure 24-25. NWAIT Assertion in Write Access: Ready Mode (EXNW_MODE = 11)

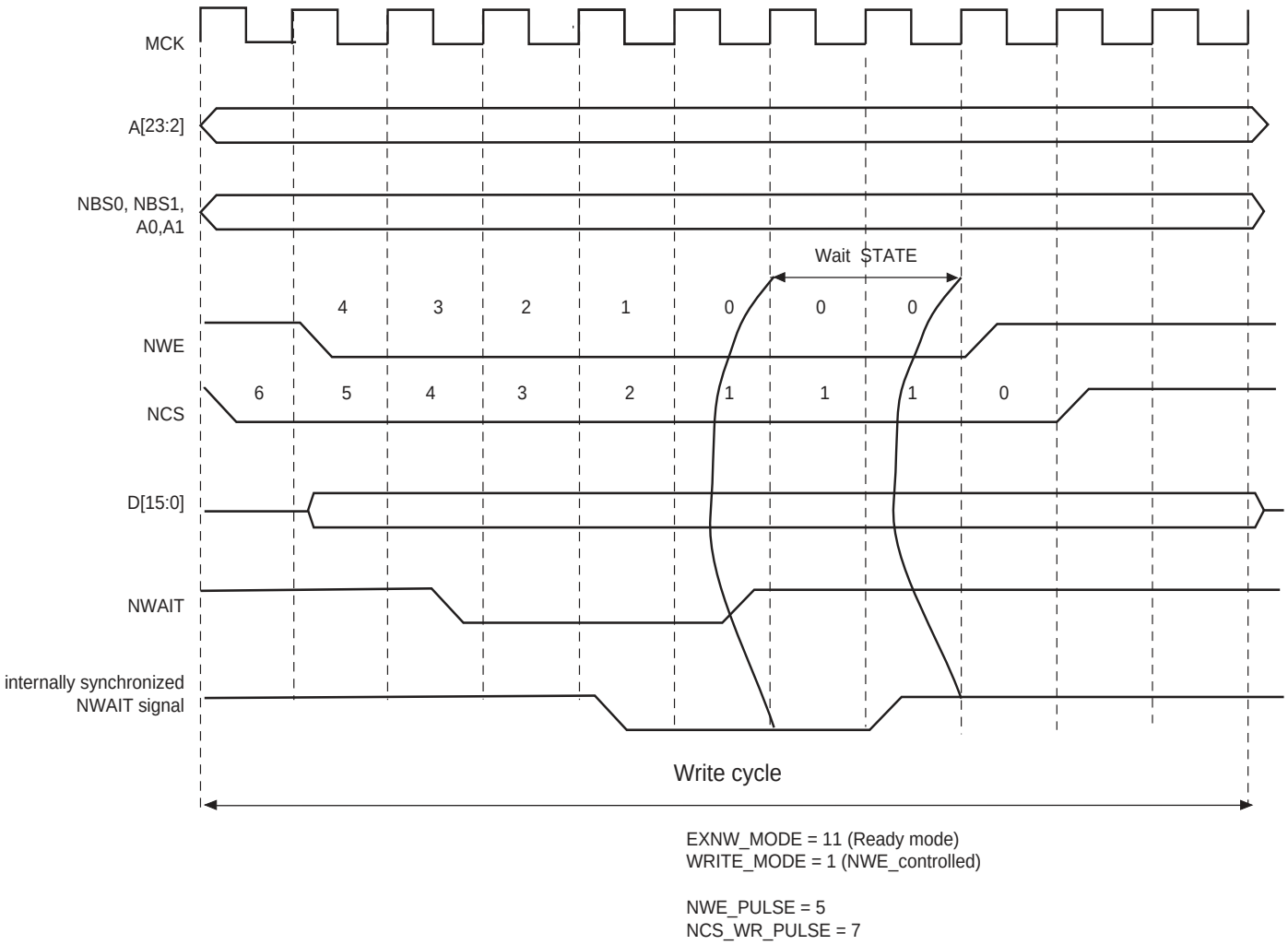
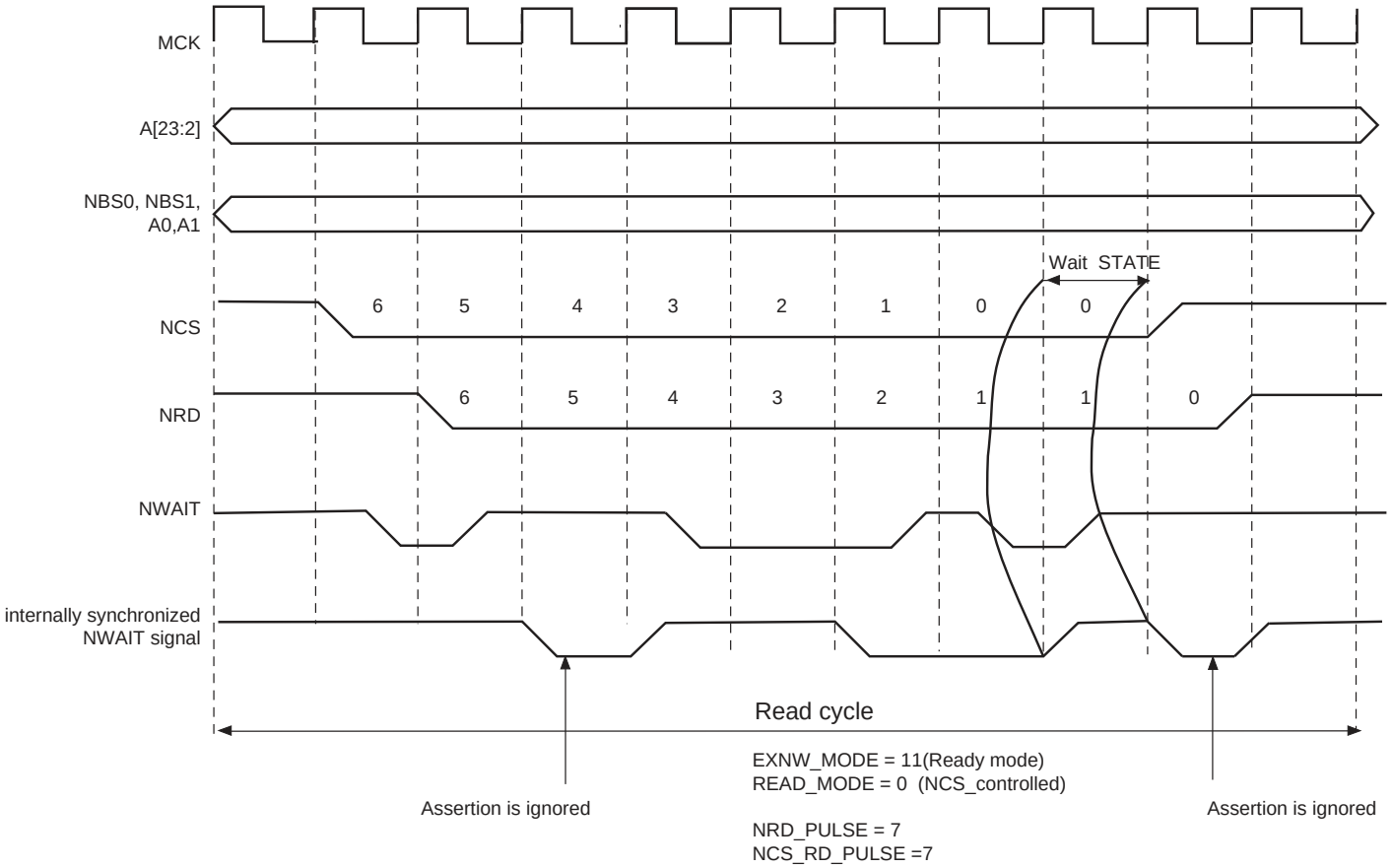


Figure 24-26. NWAIT Assertion in Read Access: Ready Mode (EXNW_MODE = 11)



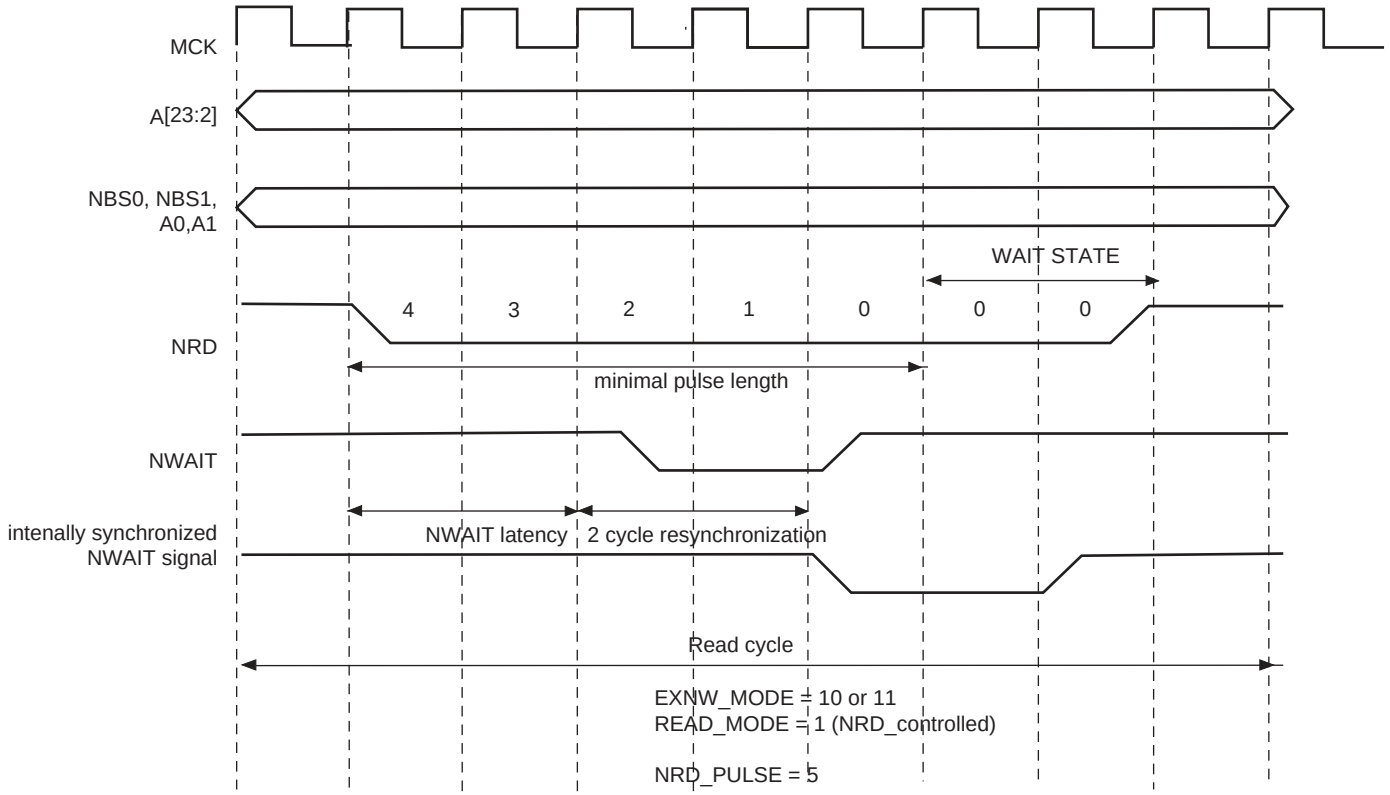
24.14.4 NWAIT Latency and Read/Write Timings

There may be a latency between the assertion of the read/write controlling signal and the assertion of the NWAIT signal by the device. The programmed pulse length of the read/write controlling signal must be at least equal to this latency plus the 2 cycles of resynchronization + 1 cycle. Otherwise, the SMC may enter the hold state of the access without detecting the NWAIT signal assertion. This is true in frozen mode as well as in ready mode. This is illustrated on Figure 24-27.

When EXNW_MODE is enabled (ready or frozen), the user must program a pulse length of the read and write controlling signal of at least:

minimal pulse length = NWAIT latency + 2 resynchronization cycles + 1 cycle

Figure 24-27. NWAIT Latency



24.15 Slow Clock Mode

The SMC is able to automatically apply a set of “slow clock mode” read/write waveforms when an internal signal driven by the Power Management Controller is asserted because MCK has been turned to a very slow clock rate (typically 32 kHz clock rate). In this mode, the user-programmed waveforms are ignored and the slow clock mode waveforms are applied. This mode is provided so as to avoid reprogramming the User Interface with appropriate waveforms at very slow clock rate. When activated, the slow mode is active on all chip selects.

24.15.1 Slow Clock Mode Waveforms

Figure 24-28 illustrates the read and write operations in slow clock mode. They are valid on all chip selects. Table 24-8 indicates the value of read and write parameters in slow clock mode.

Figure 24-28. Read/Write Cycles in Slow Clock Mode

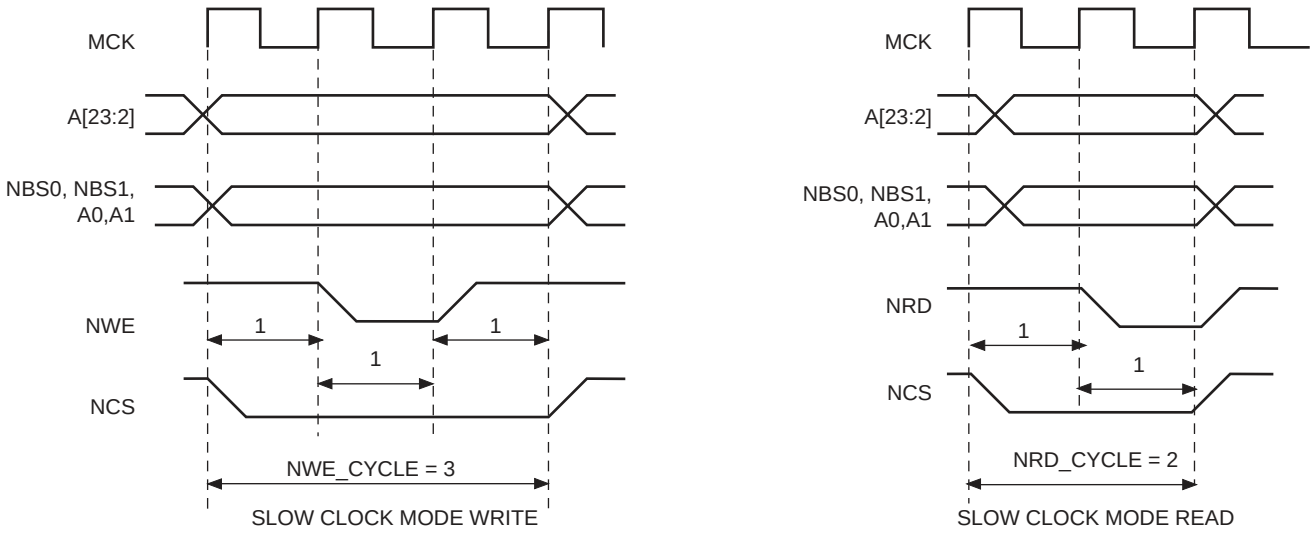


Table 24-8. Read and Write Timing Parameters in Slow Clock Mode

Read Parameters	Duration (cycles)	Write Parameters	Duration (cycles)
NRD_SETUP	1	NWE_SETUP	1
NRD_PULSE	1	NWE_PULSE	1
NCS_RD_SETUP	0	NCS_WR_SETUP	0
NCS_RD_PULSE	2	NCS_WR_PULSE	3
NRD_CYCLE	2	NWE_CYCLE	3

24.15.2 Switching from (to) Slow Clock Mode to (from) Normal Mode

When switching from slow clock mode to normal mode, the current slow clock mode transfer is completed at high clock rate, with the set of slow clock mode parameters. See Figure 24-29. The external device may not be fast enough to support such timings.

Figure 24-30 illustrates the recommended procedure to properly switch from one mode to the other.

Figure 24-29. Clock Rate Transition Occurs while the SMC is Performing a Write Operation

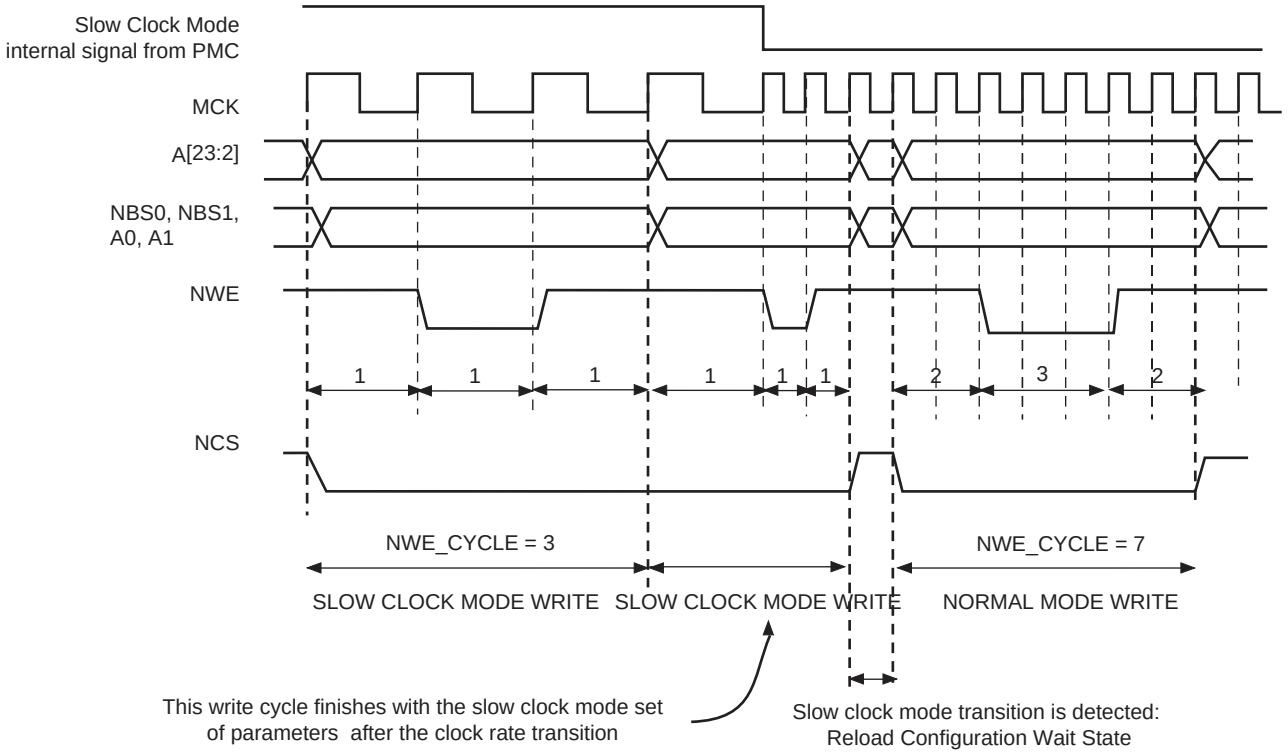
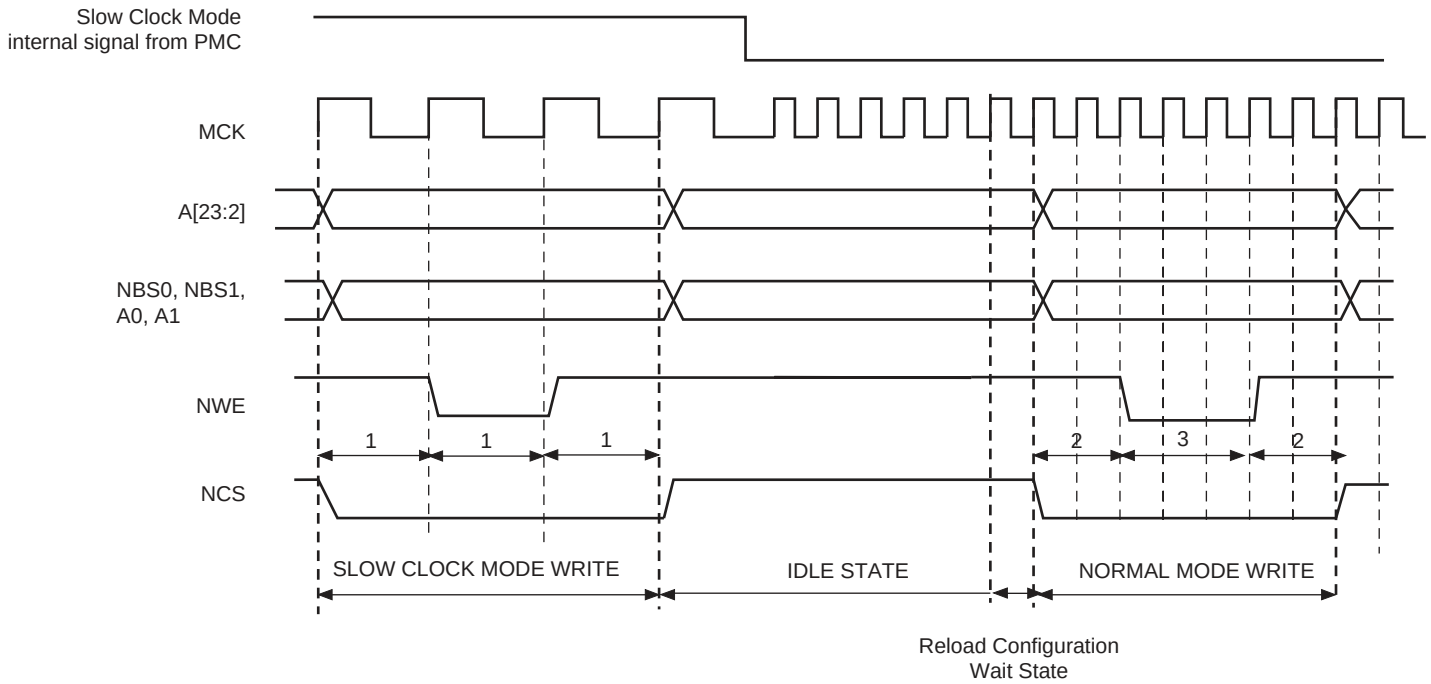


Figure 24-30. Recommended Procedure to Switch from Slow Clock Mode to Normal Mode or from Normal Mode to Slow Clock Mode



24.16 NAND Flash Controller Operations

24.16.1 NFC Overview

The NFC can handle automatic transfers, sending the commands and address to the NAND Flash and transferring the contents of the page (for read and write) to the NFC SRAM. It minimizes the CPU overhead.

24.16.2 NFC Control Registers

NAND Flash Read and NAND Flash Program operations can be performed through the NFC Command Registers. In order to minimize CPU intervention and latency, commands are posted in a command buffer. This buffer provides zero wait state latency. The detailed description of the command encoding scheme is explained below.

The NFC handles automatic transfer between the external NAND Flash and the chip via the NFC SRAM. It is done via NFC Command Registers.

The NFC Command Registers are very efficient to use. When writing to these registers:

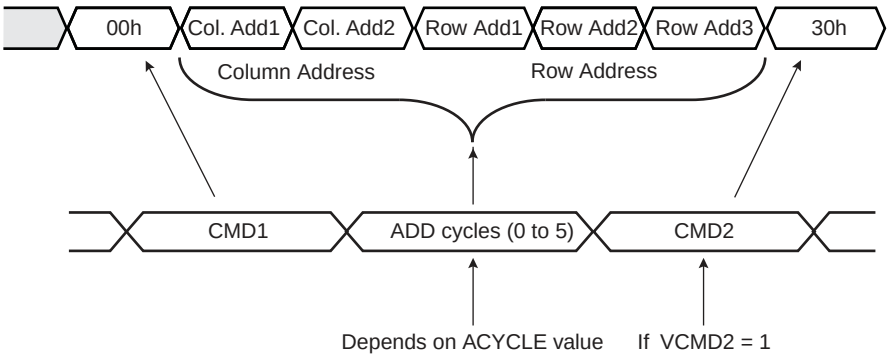
- the address of the register (NFCADDR_CMD) contains the command used,
- the data of the register (NFCDATA_ADDT) contains the address to be sent to the NAND Flash.

So, in one single access the command is sent and immediately executed by the NFC. Even two commands can be programmed within a single access (CMD1, CMD2) depending on the VCMD2 value.

The NFC can send up to 5 Address cycles.

Figure 24-31 below shows a typical NAND Flash Page Read Command of a NAND Flash Memory and correspondence with NFC Address Command Register.

Figure 24-31. NFC/NAND Flash Access Example



For more details refer to “NFC Address Command” on page 374.

The NFC Command Registers can be found at address 0x68000000 - 0x6FFFFFFF. (See Table 24-4, “External Memory Mapping”.)

Reading the NFC command register (to any address) will give the status of the NFC. Especially useful to know if the NFC is busy, for example.

24.16.2.1 Building NFC Address Command Example

The base address is made of address 0x60000000 + NFCCMD bit set = 0x68000000.

Page read operation example:

```
// Build the Address Command (NFCADDR_CMD)
AddressCommand = (0x60000000  |
                  NFCCMD=1 | // NFC Command Enable
                  NFCWR=0   |// NFC Read Data from NAND Flash
                  NFCEN=1    |    // NFC Enable.
                  CSID=1        |        // Chip Select ID = 1
                 ACYCLE= 5 |     // Number of address cycle.
                 VCMD2=1    |               // CMD2 is sent after Address Cycles
                 CMD2=0x30  |               // CMD2 = 30h
                 CMD1=0x0)    // CMD1 = Read Command = 00h

  // Set the Address for Cycle 0
  SMC_ADDR = Col. Add1

  // Write command with the Address Command built above
*AddressCommand = (Col. Add2   |// ADDR_CYCLE1
           Row Add1  | // ADDR_CYCLE2
           Row Add2  |// ADDR_CYCLE3
           Row Add3  )// ADDR_CYCLE4
```

24.16.2.2 NFC Address Command

- **Name:** NFCADDR_CMD
- **Access:** Read-write
- **Reset:** 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	NFCCMD	NFCWR	NFCEN	CSID
23	22	21	20	19	18	17	16
CSID		ACYCLE			VCMD2	CMD2	
15	14	13	12	11	10	9	8
CMD2						CMD1	
7	6	5	4	3	2	1	0
CMD1						–	–

- **CMD1: Command Register Value for Cycle 1**

If NFCCMD is set, when a read or write access occurs, the NFC sends this command.

- **CMD2: Command Register Value for Cycle 2**

If NFCCMD and VCMD2 field are set to one, the NFC sends this command after CMD1.

- **VCMD2: Valid Cycle 2 Command**

When set to true, the CMD2 field is issued after the address cycle.

- **ACYCLE: Number of Address required for the current command**

When ACYCLE field is different from zero, ACYCLE Address cycles are performed after Command Cycle 1. The maximum number of cycles is 5.

- **CSID: Chip Select Identifier**

Chip select used

- **NFCEN: NFC Enable**

When set to true, the NFC will automatically read or write data after the command.

- **NFCWR: NFC Write Enable**

0: The NFC reads data from the NAND Flash.

1: The NFC writes data into the NAND Flash.

- **NFCCMD: NFC Command Enable**

If set to true, CMD indicates that the NFC shall execute the command encoded in the NFCADDR_CMD.

24.16.2.3 NFC Data Address

- **Name:** NFCDATA_ADDT
- **Access:** Write
- **Reset:** 0x00000000

31	30	29	28	27	26	25	24
ADDR_CYCLE4							
23	22	21	20	19	18	17	16
ADDR_CYCLE3							
15	14	13	12	11	10	9	8
ADDR_CYCLE2							
7	6	5	4	3	2	1	0
ADDR_CYCLE1							

- **ADDR_CYCLE1: NAND Flash Array Address Cycle 1**

When less than 5 address cycles are used, ADDR_CYCLE1 is the first byte written to NAND Flash

When 5 address cycles are used, ADDR_CYCLE1 is the second byte written to NAND Flash

- **ADDR_CYCLE2: NAND Flash Array Address Cycle 2**

When less than 5 address cycles are used, ADDR_CYCLE2 is the second byte written to NAND Flash

When 5 address cycles are used, ADDR_CYCLE2 is the third byte written to NAND Flash

- **ADDR_CYCLE3: NAND Flash Array Address Cycle 3**

When less than 5 address cycles are used, ADDR_CYCLE3 is the third byte written to NAND Flash

When 5 address cycles are used, ADDR_CYCLE3 is the fourth byte written to NAND Flash

- **ADDR_CYCLE4: NAND Flash Array Address Cycle 4**

When less than 5 address cycles are used, ADDR_CYCLE4 is the fourth byte written to NAND Flash

When 5 address cycles are used, ADDR_CYCLE4 is the fifth byte written to NAND Flash

Note: If 5 address cycles are used, the first address cycle is ADDR_CYCLE0. Refer to SMC_ADDR register.

24.16.2.4 NFC DATA Status

- **Name:** NFCDATA_Status
- **Access:** Read
- **Reset:** 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	NFCBUSY	NFCWR	NFCEN	CSID

23	22	21	20	19	18	17	16
CSID		ACYCLE			VCMD2	CMD2	

15	14	13	12	11	10	9	8
CMD2						CMD1	

7	6	5	4	3	2	1	0
CMD1						–	–

- **CMD1: Command Register Value for Cycle 1**

When a Read or Write Access occurs, the Physical Memory Interface drives the IO bus with CMD1 field during the Command Latch cycle 1.

- **CMD2: Command Register Value for Cycle 2**

When VCMD2 field is set to true, the Physical Memory Interface drives the IO bus with CMD2 field during the Command Latch cycle 2.

- **VCMD2: Valid Cycle 2 Command**

When set to true, the CMD2 field is issued after addressing cycle.

- **ACYCLE: Number of Address required for the current command**

When ACYCLE field is different from zero, ACYCLE Address cycles are performed after Command Cycle 1.

- **CSID: Chip Select Identifier**

Chip select used

- **NFCEN: NFC Enable**

When set to true, The NFC is enabled.

- **NFCWR: NFC Write Enable**

0: The NFC is in read mode.

1: The NFC is in write mode.

- **NFCBUSY: NFC Busy Status Flag**

If set to true, it indicates that the NFC is busy.

24.16.3 NFC Initialization

Prior to any Command and Data Transfer, the SMC User Interface must be configured to meet the device timing requirements.

- Write enable Configuration

Use NWE_SETUP, NWE_PULSE and NWE_CYCLE to define the write enable waveform according to the device datasheet.

Use TADL field in the SMC_TIMINGS register to configure the timing between the last address latch cycle and the first rising edge of WEN for data input.

Figure 24-32. Write Enable Timing Configuration

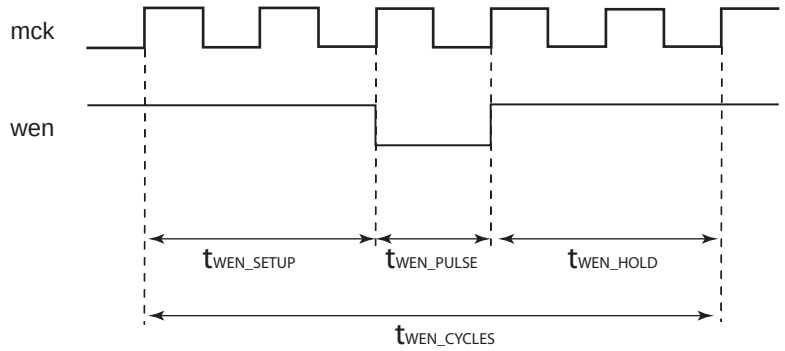
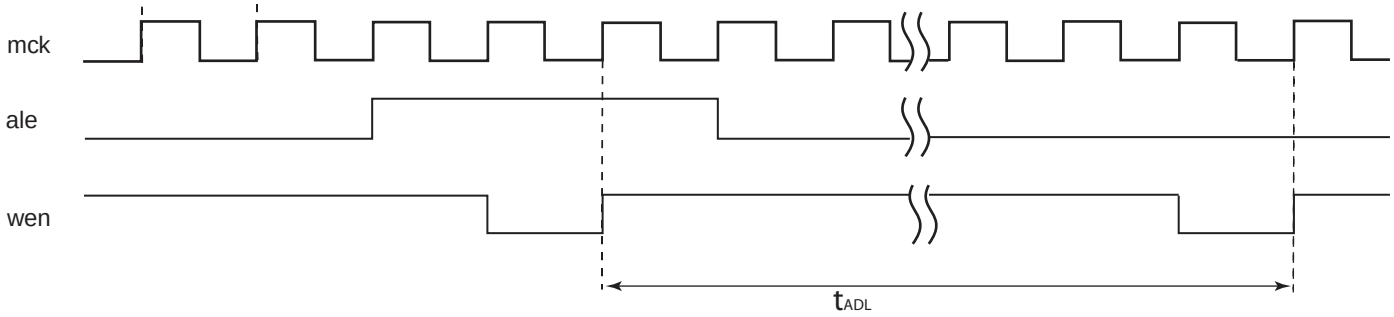


Figure 24-33. Write Enable Timing for NAND Flash Device Data Input Mode.



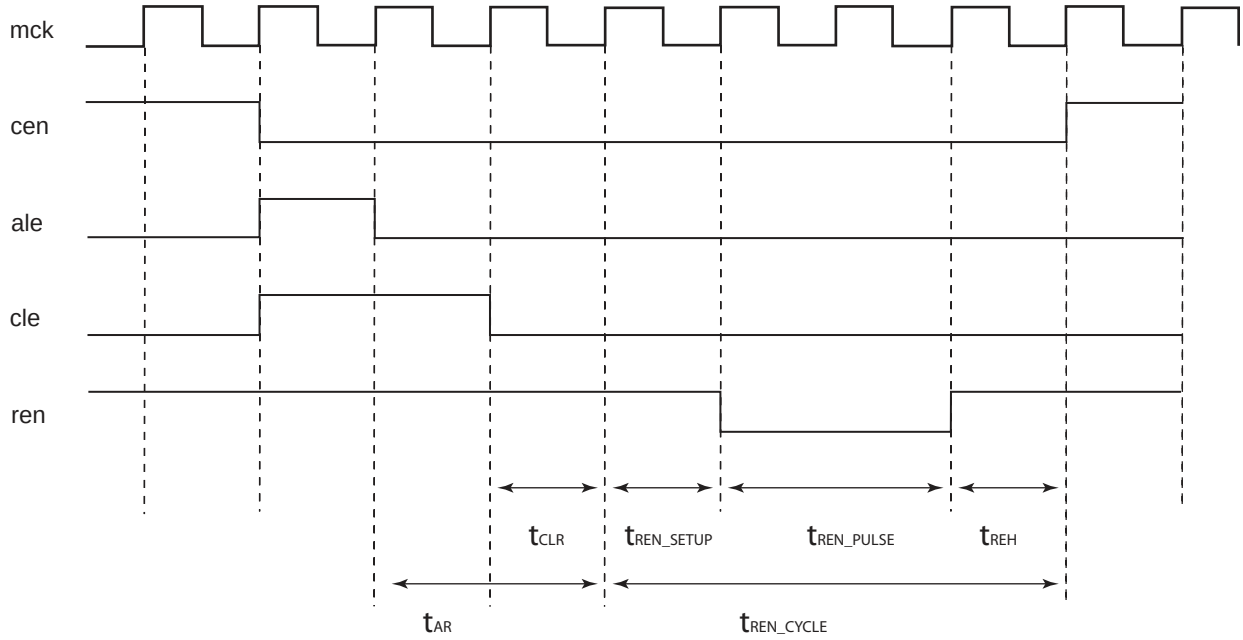
- Read Enable Configuration

Use NRD_SETUP, NRD_PULSE and NRD_CYCLE to define the read enable waveform according to the device datasheet.

Use TAR field in the SMC_TIMINGS register to configure the timings between address latch enable falling edge to read enable falling edge.

Use TCLR field in the SMC_TIMINGS register to configure the timings between the command latch enable falling edge to the read enable falling edge.

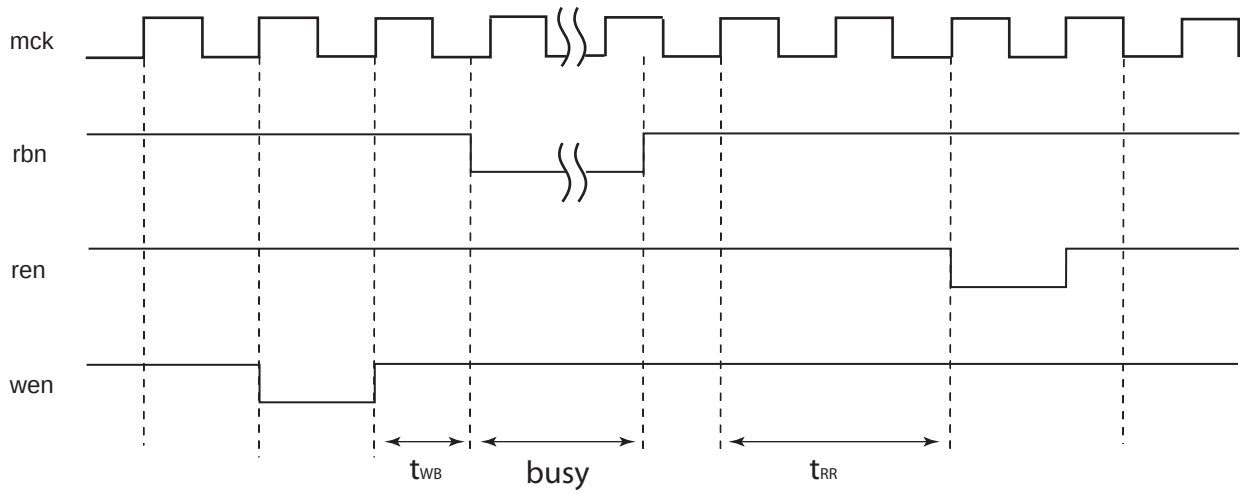
Figure 24-34. Read Enable Timing Configuration Working with NAND Flash Device



- Ready/Busy Signal Timing configuration working with a NAND Flash device

Use TWB field in SMC_TIMINGS register to configure the maximum elapsed time between the rising edge of wen signal and the falling edge of rbn signal. Use TRR field in the SMC_TIMINGS register to program the number of clock cycle between the rising edge of the rbn signal and the falling edge of ren signal.

Figure 24-35. Ready/Busy Timing Configuration

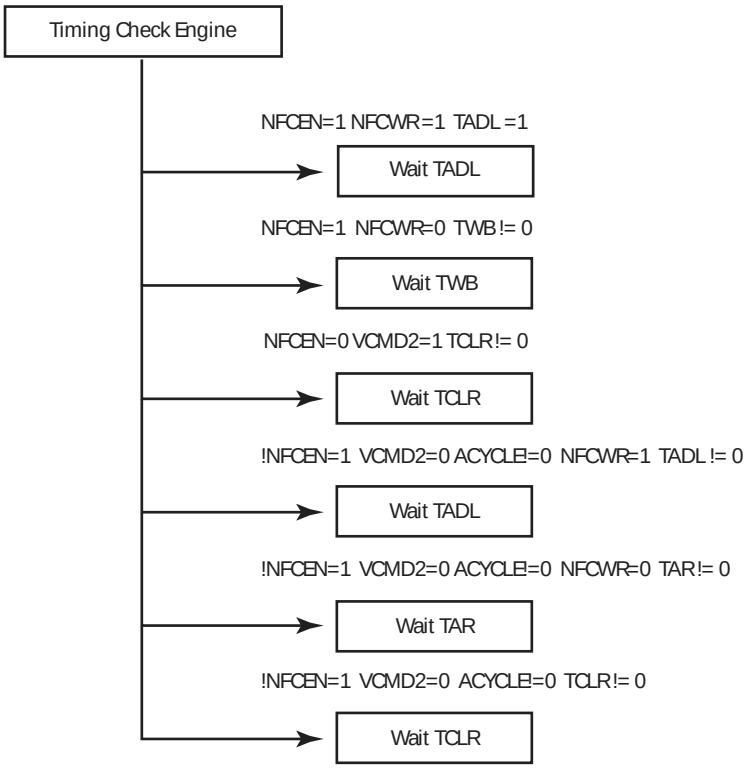


24.16.3.1 NAND Flash Controller Timing Engine

When the NFC Command register is written, the NFC issues a NAND Flash Command and optionally performs a data transfer between the NFC SRAM and the NAND Flash device. The NAND Flash Controller Timing Engine guarantees valid NAND Flash timings, depending on the set of parameters decoded from the address bus. These timings are defined in the SMC_TIMINGS register.

For information on the timing used depending on the command, see Figure 24-36:

Figure 24-36. NAND Flash Controller Timing Engine



See "NFC Address Command" register description and "SMC Timings Register".

24.16.4 NFC SRAM

24.16.4.1 NFC SRAM Mapping

If the NFC is used to read and write Data from and to the NAND Flash, the configuration depends on the page size. See Table 24-9 and Table 24-10 for detailed mapping.

The NFC SRAM size is 4 Kbytes. The NFC can handle NAND Flash with a page size of 4 Kbytes or of a lower size (such as 2 Kbytes for example). In case of a 2-KByte or lower page size, the NFC SRAM can be split into several banks. The SMC_BANK field enables to select the bank used.

Note that a “ping-pong” mode (write or read to a bank while the NFC writes or reads to another bank) is not accessible with the NFC (using 2 different banks).

If the NFC is not used, the NFC SRAM can be used for a general purpose by the application.

Table 24-9. NFC SRAM Mapping with NAND Flash Page Size of 2 Kbytes + 64 bytes

Offset	Use	Access
0x00000000-0x000001FF	Bank 0 Main Area Buffer 0	Read-write
0x00000200-0x000003FF	Bank 0 Main Area Buffer 1	Read-write
0x00000400-0x000005FF	Bank 0 Main Area Buffer 2	Read-write
0x00000600-0x000007FF	Bank 0 Main Area Buffer 3	Read-write
0x00000800-0x0000080F	Bank 0 Spare Area 0	Read-write
0x00000810-0x0000081F	Bank 0 Spare Area 1	Read-write
0x00000820-0x0000082F	Bank 0 Spare Area 2	Read-write
0x00000830-0x0000083F	Bank 0 Spare Area 3	Read-write
0x00000840-0x00000A3F	Bank 1 Main Area Buffer 0	Read-write
0x00000A40-0x00000C3F	Bank 1 Main Area Buffer 1	Read-write
0x00000C40-0x00000E3F	Bank 1 Main Area Buffer 2	Read-write
0x00000E40-0x0000103F	Bank 1 Main Area Buffer 3	Read-write
0x00001040-0x0000104F	Bank 1 Spare Area 0	Read-write
0x00001050-0x0000105F	Bank 1 Spare Area 1	Read-write
0x00001060-0x0000106F	Bank 1 Spare Area 2	Read-write
0x00001070-0x0000107F	Bank 1 Spare Area 3	Read-write
0x00001080-0x00001FFF	Reserved	–

Table 24-10. NFC SRAM Mapping with NAND Flash Page Size of 4 Kbytes + 128 bytes

Offset	Use	Access
0x00000000-0x000001FF	Bank 0 Main Area Buffer 0	Read-write
0x00000200-0x000003FF	Bank 0 Main Area Buffer 1	Read-write
0x00000400-0x000005FF	Bank 0 Main Area Buffer 2	Read-write
0x00000600-0x000007FF	Bank 0 Main Area Buffer 3	Read-write
0x00000800-0x000009FF	Bank 0 Main Area Buffer 4	Read-write
0x00000A00-0x00000BFF	Bank 0 Main Area Buffer 5	Read-write
0x00000C00-0x00000DFF	Bank 0 Main Area Buffer 6	Read-write
0x00000E00-0x00000FFF	Bank 0 Main Area Buffer 7	Read-write
0x00001000-0x0000100F	Bank 0 Spare Area 0	Read-write
0x00001010-0x0000101F	Bank 0 Spare Area 1	Read-write
0x00001020-0x0000102F	Bank 0 Spare Area 2	Read-write

Table 24-10. NFC SRAM Mapping with NAND Flash Page Size of 4 Kbytes + 128 bytes

Offset	Use	Access
0x00001030-0x0000103F	Bank 0 Spare Area 3	Read-write
0x00001040-0x0000104F	Bank 0 Spare Area 4	Read-write
0x00001050-0x0000105F	Bank 0 Spare Area 5	Read-write
0x00001060-0x0000106F	Bank 0 Spare Area 6	Read-write
0x00001070-0x0000107F	Bank 0 Spare Area 7	Read-write
0x00001080-0x00001FFF	Reserved	–

24.16.4.2 NFC SRAM Access Prioritization Algorithm

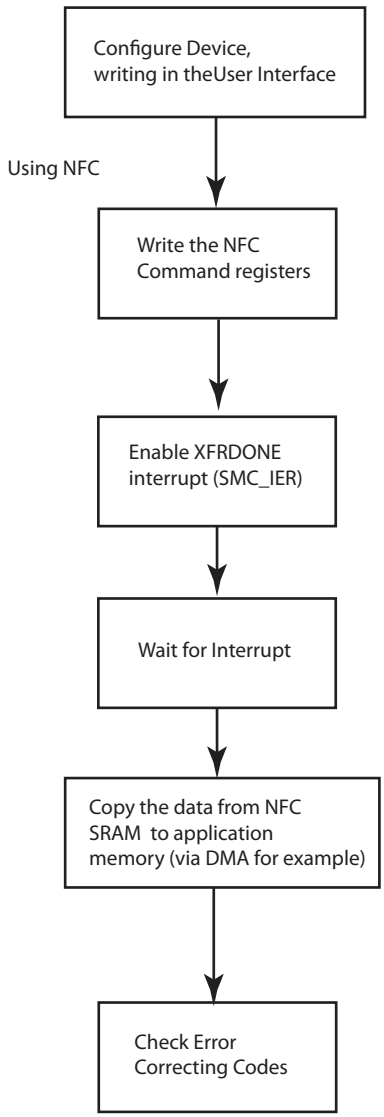
When the NAND Flash Controller (NFC) is reading from or writing to the NFC SRAM, the internal memory is no longer accessible. If an NFC SRAM access occurs when the NFC performs a read or write operation then the access is discarded. The write operation is not performed. The read operation returns undefined data. If this situation is encountered, the status flag AWB located in the NFC status Register is raised and indicates that a shared resource access violation has occurred.

24.16.5 NAND Flash Operations

This section describes the software operations needed to issue commands to the NAND Flash device and perform data transfers using NFC.

24.16.5.1 Page Read

Figure 24-37. Page Read Flow Chart

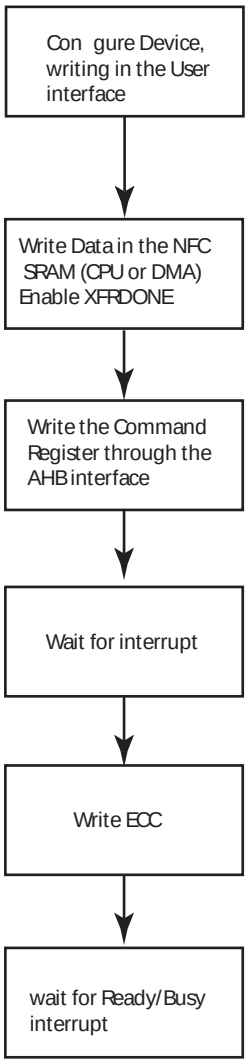


Note that instead of using the interrupt one can poll the NFCBUSY Flag.

For more information on the NFC Control Register, see Section 24.16.2.2 ”NFC Address Command”.

24.16.5.2 Program Page

Figure 24-38. Program Page Flow Chart



Writing the ECC can not be done using the NFC so it needs to be done “manually”.

Note that instead of using the interrupt one can poll the NFCBUSY Flag.

For more information on the NFC Control Register, see Section 24.16.2.2 ”NFC Address Command”.

24.17 SMC Error Correcting Code Functional Description

A page in NAND Flash and SmartMedia memories contains an area for main data and an additional area used for redundancy (ECC). The page is organized in 8-bit or 16-bit words. The page size corresponds to the number of words in the main area plus the number of words in the extra area used for redundancy.

Over time, some memory locations may fail to program or erase properly. In order to ensure that data is stored properly over the life of the NAND Flash device, NAND Flash providers recommend to utilize either 1 ECC per 256 bytes of data, 1 ECC per 512 bytes of data or 1 ECC for all of the page.

The only configurations required for ECC are the NAND Flash or the SmartMedia page size (528/2112/4224) and the type of correction wanted (1 ECC for all the page/1 ECC per 256 bytes of data /1 ECC per 512 bytes of data). Page size is configured setting the PAGESIZE field in the ECC Mode Register (ECC_MR). Type of correction is configured setting the TYPCORRECT field in the ECC Mode Register (ECC_MR).

Note: There is a limitation when using a 16-bit NAND Flash: only 1 ECC for a whole page is possible. There is no limitation when using an 8-bit NAND Flash.

ECC is automatically computed as soon as a read (00h)/write (80h) command to the NAND Flash or the SmartMedia is detected. Read and write access must start at a page boundary.

ECC results are available as soon as the counter reaches the end of the main area. Values in the ECC Parity Registers (ECC_PR0 to ECC_PR15) are then valid and locked until a new start condition occurs (read/write command followed by address cycles).

24.17.1 Write Access

Once the Flash memory page is written, the computed ECC codes are available in the ECC Parity (ECC_PR0 to ECC_PR15) registers. The ECC code values must be written by the software application in the extra area used for redundancy. The number of write accesses in the extra area is a function of the value of the type of correction field. For example, for 1 ECC per 256 bytes of data for a page of 512 bytes, only the values of ECC_PR0 and ECC_PR1 must be written by the software application. Other registers are meaningless.

24.17.2 Read Access

After reading the whole data in the main area, the application must perform read accesses to the extra area where ECC code has been previously stored. Error detection is automatically performed by the ECC controller.

Note: It is mandatory to read consecutively the entire main area and the locations where Parity and NParity values have been previously stored, to let the ECC controller perform error detection.

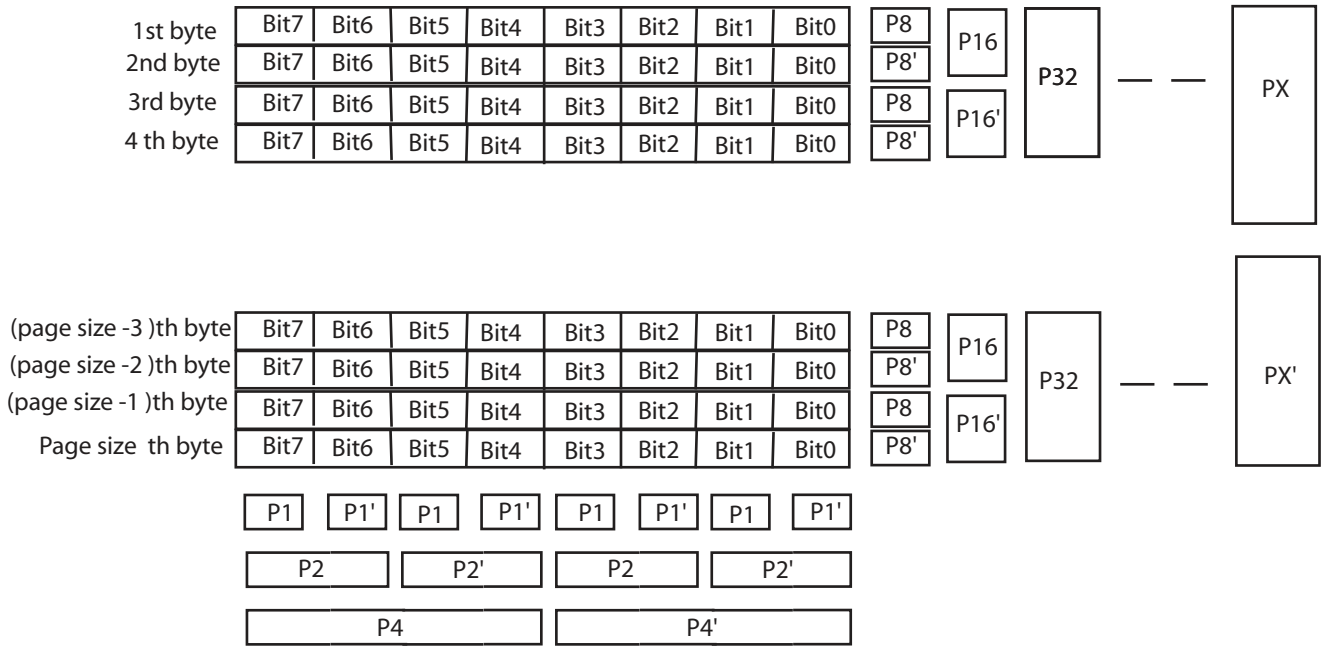
The application can check the ECC Status Registers (ECC_SR1/ECC_SR2) for any detected errors. It is up to the application to correct any detected error. ECC computation can detect four different circumstances:

- No error: XOR between the ECC computation and the ECC code stored at the end of the NAND Flash or SmartMedia page is equal to 0. No error flags in the ECC Status Registers (ECC_SR1/ECC_SR2).
- Recoverable error: Only the RECERR flags in the ECC Status registers (ECC_SR1/ECC_SR2) are set. The corrupted word offset in the read page is defined by the WORDADDR field in the ECC Parity Registers (ECC_PR0 to ECC_PR15). The corrupted bit position in the concerned word is defined in the BITADDR field in the ECC Parity Registers (ECC_PR0 to ECC_PR15).
- ECC error: The ECCERR flag in the ECC Status Registers (ECC_SR1/ECC_SR2) is set. An error has been detected in the ECC code stored in the Flash memory. The position of the corrupted bit can be found by the application performing an XOR between the Parity and the NParity contained in the ECC code stored in the Flash memory.
- Non correctable error: The MULERR flag in the ECC Status Registers (ECC_SR1/ECC_SR2) is set. Several unrecoverable errors have been detected in the Flash memory page.

ECC Status Registers, ECC Parity Registers are cleared when a read/write command is detected or a software reset is performed.

For Single-bit Error Correction and Double-bit Error Detection (SEC-DED) Hsiao code is used. 24-bit ECC is generated in order to perform one bit correction per 256 or 512 bytes for pages of 512/2048/4096 8-bit words. 32-bit ECC is generated in order to perform one bit correction per 512/1024/2048/4096 8- or 16-bit words. They are generated according to the schemes shown in Figure 24-39 and Figure 24-40.

Figure 24-39. Parity Generation for 512/1024/2048/4096 8-bit Words



Page size = 512 Px = 2048
Page size = 1024 Px = 4096
Page size = 2048 Px = 8192
Page size = 4096 Px = 16384

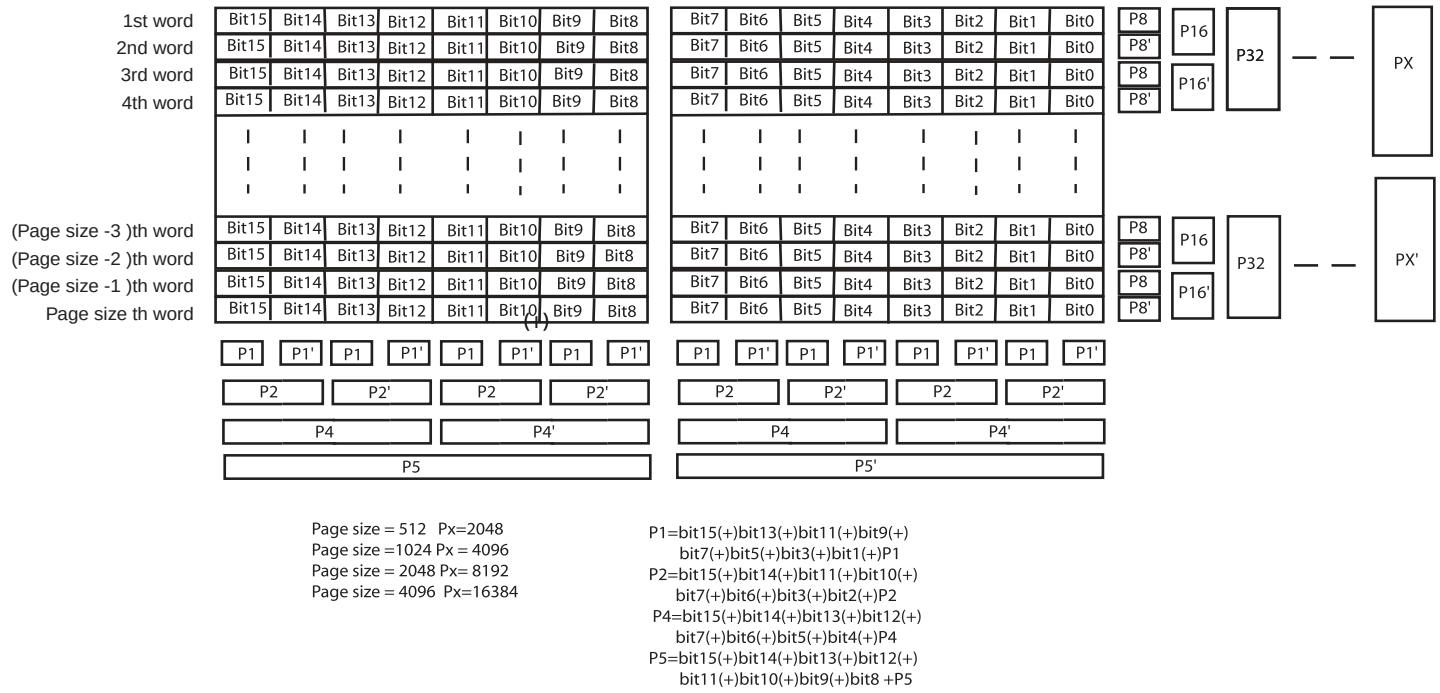
P1=bit7(+)bit5(+)bit3(+)bit1(+)P1
P2=bit7(+)bit6(+)bit3(+)bit2(+)P2
P4=bit7(+)bit6(+)bit5(+)bit4(+)P4
P1'=bit6(+)bit4(+)bit2(+)bit0(+)P1'
P2'=bit5(+)bit4(+)bit1(+)bit0(+)P2'
P4'=bit7(+)bit6(+)bit5(+)bit4(+)P4'

To calculate P8' to PX' and P8 to PX, apply the algorithm that follows.

Page size = 2^n

```
for i =0 to n
begin
 for (j = 0 to page_size_byte)
 begin
  if(j[i] ==1)
   P[2^(i+3)]=bit7(+)bit6(+)bit5(+)bit4(+)bit3(+)
              bit2(+)bit1(+)bit0(+)P[2^(i+3)]
  else
   P[2^(i+3)]'=bit7(+)bit6(+)bit5(+)bit4(+)bit3(+)
               bit2(+)bit1(+)bit0(+)P[2^(i+3)]'
  end
end
```

Figure 24-40. Parity Generation for 512/1024/2048/4096 16-bit Words



Page size = 512 Px=2048
Page size =1024 Px = 4096
Page size = 2048 Px= 8192
Page size = 4096 Px=16384

P1=bit15(+)bit13(+)bit11(+)bit9(+)
bit7(+)bit5(+)bit3(+)bit1(+)P1
P2=bit15(+)bit14(+)bit11(+)bit10(+)
bit7(+)bit6(+)bit3(+)bit2(+)P2
P4=bit15(+)bit14(+)bit13(+)bit12(+)
bit7(+)bit6(+)bit5(+)bit4(+)P4
P5=bit15(+)bit14(+)bit13(+)bit12(+)
bit11(+)bit10(+)bit9(+)bit8 +P5

To calculate P8' to PX' and P8 to PX, apply the algorithm that follows.

Page size = 2^n

```
for i =0 to n
begin
 for (j = 0 to page_size_word)
 begin
  if(j[i] ==1)
   P[2^(i+3)]= bit15(+)bit14(+)bit13(+)bit12(+)
               bit11(+)bit10(+)bit9(+)bit8(+)
               bit7(+)bit6(+)bit5(+)bit4(+)bit3(+)
               bit2(+)bit1(+)bit0(+)P[2^(n+3)]
  else
   P[2^(i+3)]'=bit15(+)bit14(+)bit13(+)bit12(+)
               bit11(+)bit10(+)bit9(+)bit8(+)
               bit7(+)bit6(+)bit5(+)bit4(+)bit3(+)
               bit2(+)bit1(+)bit0(+)P[2^(i+3)]'
  end
end
```

24.18 Power Management Controller (PMC) User Interface

The SMC is programmed using the fields listed in Table 24-11. For each chip, select a set of 4 registers is used to program the parameters of the external device. In Table 24-11, “CS_number” denotes the chip select number. 16 Bytes per chip select are required.

Table 24-11. Register Mapping

Offset	Register	Name	Access	Reset
0x000	SMC NFC Configuration Register	SMC_CFG	Read-write	0x0
0x004	SMC NFC Control Register	SMC_CTRL	Write-only	0x0
0x008	SMC NFC Status Register	SMC_SR	Read-only	0x0
0x00C	SMC NFC Interrupt Enable Register	SMC_IER	Write-only	0x0
0x010	SMC NFC Interrupt Disable Register	SMC_IDR	Write-only	0x0
0x014	SMC NFC Interrupt Mask Register	SMC_IMR	Read-only	0x0
0x018	SMC NFC Address Cycle Zero Register	SMC_ADDR	Read-write	0x0
0x01C	SMC Bank Address Register	SMC_BANK	Read-write	0x0
0x020	SMC ECC Control Register	SMC_ECC_CTRL	Write-only	0x0
0x024	SMC ECC Mode Register	SMC_ECC_MD	Read-write	0x0
0x028	SMC ECC Status 1 Register	SMC_ECC_SR1	Read-only	0x0
0x02C	SMC ECC Parity 0 Register	SMC_ECC_PR0	Read-only	0x0
0x030	SMC ECC parity 1 Register	SMC_ECC_PR1	Read-only	0x0
0x034	SMC ECC status 2 Register	SMC_ECC_SR2	Read-only	0x0
0x038	SMC ECC parity 2 Register	SMC_ECC_PR2	Read-only	0x0
0x03C	SMC ECC parity 3 Register	SMC_ECC_PR3	Read-only	0x0
0x040	SMC ECC parity 4 Register	SMC_ECC_PR4	Read-only	0x0
0x044	SMC ECC parity 5 Register	SMC_ECC_PR5	Read-only	0x0
0x048	SMC ECC parity 6 Register	SMC_ECC_PR6	Read-only	0x0
0x04C	SMC ECC parity 7 Register	SMC_ECC_PR7	Read-only	0x0
0x050	SMC ECC parity 8 Register	SMC_ECC_PR8	Read-only	0x0
0x054	SMC ECC parity 9 Register	SMC_ECC_PR9	Read-only	0x0
0x058	SMC ECC parity 10 Register	SMC_ECC_PR10	Read-only	0x0
0x05C	SMC ECC parity 11 Register	SMC_ECC_PR11	Read-only	0x0
0x060	SMC ECC parity 12 Register	SMC_ECC_PR12	Read-only	0x0
0x064	SMC ECC parity 13 Register	SMC_ECC_PR13	Read-only	0x0
0x068	SMC ECC parity 14 Register	SMC_ECC_PR14	Read-only	0x0
0x06C	SMC ECC parity 15 Register	SMC_ECC_PR15	Read-only	0x0
0x14*CS_number+0x070	SMC Setup Register	SMC_SETUP	Read-write	0x01010101
0x14*CS_number+0x074	SMC Pulse Register	SMC_PULSE	Read-write	0x01010101
0x14*CS_number+0x078	SMC Cycle Register	SMC_CYCLE	Read-write	0x00030003
0x14*CS_number+0x7C	SMC Timings Register	SMC_TIMINGS	Read-write	0x00000000
0x14*CS_number+0x80	SMC Mode Register	SMC_MODE	Read-write	0x10000003

Table 24-11. Register Mapping (Continued)

Offset	Register	Name	Access	Reset
0x110	SMC OCMS Register	SMC_OCMS	Read-write	0x0
0x114	SMC OCMS KEY1 Register	SMC_KEY1	Write-once	0x0
0x118	SMC OCMS KEY2 Register	SMC_KEY2	Write-once	0x0
0x1E4	Write Protection Control Register	SMC_WPCR	Write-only	0x0
0x1E8	Write Protection Status Register	SMC_WPSR	Read-only	0x0
0x1FC	Reserved	–	–	–

24.18.1 SMC NFC Configuration Register

Name: SMC_CFG

Address: 0x400E0000

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	DTOMUL			DTOCYC			

15	14	13	12	11	10	9	8
–	–	RBEDGE	EDGECTRL	–	–	RSPARE	WSPARE

7	6	5	4	3	2	1	0
–	–	–	–	–	–	PAGESIZE	

- **PAGESIZE**

This field defines the page size of the NAND Flash device.

Value	Name	Description
0	PS512_16	Main area 512 Bytes + Spare area 16 Bytes = 528 Bytes
1	PS1024_32	Main area 1024 Bytes + Spare area 32 Bytes = 1056 Bytes
2	PS2048_64	Main area 2048 Bytes + Spare area 64 Bytes = 2112 Bytes
3	PS4096_128	Main area 4096 Bytes + Spare area 128 Bytes = 4224 Bytes

- **WSPARE: Write Spare Area**

0: The NFC skips the spare area in write mode.

1: The NFC writes both main area and spare area in write mode.

- **RSPARE: Read Spare Area**

0: The NFC skips the spare area in read mode.

1: The NFC reads both main area and spare area in read mode.

- **EDGECTRL: Rising/Falling Edge Detection Control**

0: Rising edge is detected.

1: Falling edge is detected.

- **RBEDGE: Ready/Busy Signal Edge Detection**

0: When set to zero, RB_EDGE fields indicate the level of the Ready/Busy lines.

1: When set to one, RB_EDGE fields indicate only transition on Ready/Busy lines.

- **DTOCYC: Data Timeout Cycle Number**

- **DTOMUL: Data Timeout Multiplier**

These fields determine the maximum number of Master Clock cycles that the SMC waits until the detection of a rising edge on Ready/Busy signal.

Data Timeout Multiplier is defined by DTOMUL as shown in the following table:

Value	Name	Description
0	X1	DTOCYC
1	X16	DTOCYC x 16
2	X128	DTOCYC x 128
3	X256	DTOCYC x 256
4	X1024	DTOCYC x 1024
5	X4096	DTOCYC x 4096
6	X65536	DTOCYC x 65536
7	X1048576	DTOCYC x 1048576

If the data timeout set by DTOCYC and DTOMUL has been exceeded, the Data Timeout Error flag (DTOE) in the SMC Status Register (SMC_SR) raises.

24.18.2 SMC NFC Control Register

Name: SMC_CTRL

Address: 0x400E0004

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	NFCDIS	NFCEN

- **NFCEN: NAND Flash Controller Enable**

0: no effect.

1: Enable the NAND Flash controller.

- **NFCDIS: NAND Flash Controller Disable**

0: no effect

1: Disable the NAND Flash controller.

24.18.3 SMC NFC Status Register

Name: SMC_SR

Address: 0x400E0008

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	RB_EDGE0
23	22	21	20	19	18	17	16
NFCASE	AWB	UNDEF	DTOE	–	–	CMDDONE	XFRDONE
15	14	13	12	11	10	9	8
–	NFCSID			NFCWR	–	–	NFCBUSY
7	6	5	4	3	2	1	0
–	–	RB_FALL	RB_RISE	–	–	–	SMCSTS

- **SMCSTS: NAND Flash Controller status (this field cannot be reset)**

0: NAND Flash Controller is disabled.

1: NAND Flash Controller is enabled.

- **RB_RISE: Selected Ready Busy Rising Edge Detected**

When set to one, this flag indicates that a rising edge on Ready/Busy Line has been detected. This flag is reset after a status read operation. The Ready/Busy line selected is the decoding of the set NFCCSID, RBNSEL fields.

- **RB_FALL: Selected Ready Busy Falling Edge Detected**

When set to one, this flag indicates that a falling edge on Ready/Busy Line has been detected. This flag is reset after a status read operation. The Ready/Busy line is selected through the decoding of the set NFCSID, RBNSEL fields.

- **NFCBUSY: NFC Busy (this field cannot be reset)**

When set to one this flag indicates that the Controller is activated and accesses the memory device.

- **NFCWR: NFC Write/Read Operation (this field cannot be reset)**

When a command is issued, this field indicates the current Read or Write Operation. This field can be manually updated with the use of the SMC_CTRL register.

- **NFCSID: NFC Chip Select ID (this field cannot be reset)**

When a command is issued, this field indicates the value of the targeted chip select. This field can be manually updated with the use of the SMC_CTRL register.

- **XFRDONE: NFC Data Transfer Terminated**

When set to one, this flag indicates that the NFC has terminated the Data Transfer. This flag is reset after a status read operation.

- **CMDDONE: Command Done**

When set to one, this flag indicates that the NFC has terminated the Command. This flag is reset after a status read operation.

- **DTOE: Data Timeout Error**

When set to one this flag indicates that the Data timeout set be by DTOMUL and DTOCYC has been exceeded. This flag is reset after a status read operation.

- **UNDEF: Undefined Area Error**

When set to one this flag indicates that the processor performed an access in an undefined memory area. This flag is reset after a status read operation.

- **AWB: Accessing While Busy**

If set to one this flag indicates that an AHB master has performed an access during the busy phase. This flag is reset after a status read operation.

- **NFCASE: NFC Access Size Error**

If set to one, this flag indicates that an illegal access has been detected in the NFC Memory Area. Only Word Access is allowed within the NFC memory area. This flag is reset after a status read operation.

- **RB_EDGEx: Ready/Busy Line x Edge Detected**

If set to one, this flag indicates that an edge has been detected on the Ready/Busy Line x. Depending on the EDGE CTRL field located in the SMC_MODE register, only rising or falling edge is detected. This flag is reset after a status read operation.

24.18.4 SMC NFC Interrupt Enable Register

Name: SMC_IER

Address: 0x400E000C

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	RB_EDGE0
23	22	21	20	19	18	17	16
NFCASE	AWB	UNDEF	DTOE	–	–	CMDDONE	XFRDONE
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	RB_FALL	RB_RISE	–	–	–	–

- **RB_RISE: Ready Busy Rising Edge Detection Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **RB_FALL: Ready Busy Falling Edge Detection Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **XFRDONE: Transfer Done Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **CMDDONE: Command Done Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **DTOE: Data Timeout Error Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **UNDEF: Undefined Area Access Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **AWB: Accessing While Busy Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **NFCASE: NFC Access Size Error Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

- **RB_EDGEx: Ready/Busy Line x Interrupt Enable**

0: No effect.

1: Interrupt source is enabled.

24.18.5 SMC NFC Interrupt Disable Register

Name: SMC_IDR

Address: 0x400E0010

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	RB_EDGE0
23	22	21	20	19	18	17	16
NFCASE	AWB	UNDEF	DTOE	–	–	CMDDONE	XFRDONE
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	RB_FALL	RB_RISE	–	–	–	–

- **RB_RISE: Ready Busy Rising Edge Detection Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **RB_FALL: Ready Busy Falling Edge Detection Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **XFRDONE: Transfer Done Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **CMDDONE: Command Done Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **DTOE: Data Timeout Error Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **UNDEF: Undefined Area Access Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **AWB: Accessing While Busy Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **NFCASE: NFC Access Size Error Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

- **RB_EDGEx: Ready/Busy Line x Interrupt Disable**

0: No effect.

1: Interrupt source is disabled.

24.18.6 SMC NFC Interrupt Mask Register

Name: SMC_IMR

Address: 0x400E0014

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	RB_EDGE0
23	22	21	20	19	18	17	16
NFCASE	AWB	UNDEF	DTOE	–	–	CMDDONE	XFRDONE
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	RB_FALL	RB_RISE	–	–	–	–

- **RB_RISE: Ready Busy Rising Edge Detection Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **RB_FALL: Ready Busy Falling Edge Detection Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **XFRDONE: Transfer Done Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **CMDDONE: Command Done Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **DTOE: Data Timeout Error Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **UNDEF: Undefined Area Access Interrupt Mask5**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **AWB: Accessing While Busy Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **NFCASE: NFC Access Size Error Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

- **RB_EDGEx: Ready/Busy Line x Interrupt Mask**

0: Interrupt source is disabled.

1: Interrupt source is enabled.

24.18.7 SMC NFC Address Cycle Zero Register

Name: SMC_ADDR

Address: 0x400E0018

Access: Read-Write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
ADDR_CYCLE0							

- **ADDR_CYCLE0: NAND Flash Array Address cycle 0**

When 5 address cycles are used, ADDR_CYCLE0 is the first byte written to the NAND Flash (used by the NFC).

24.18.8 SMC NFC Bank Register

Name: SMC_BANK

Address: 0x400E001C

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	–	BANK		

- **BANK: Bank Identifier**

Number of the bank used

24.18.9 SMC ECC Control Register

Name: SMC_ECC_CTRL

Address: 0x400E0020

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	SWRST	RST

- **RST: Reset ECC**

0: No effect.

1: Reset ECC parity registers.

- **SWRST: Software Reset**

0: No effect.

1: Reset all registers.

24.18.10 SMC ECC MODE Register

Name: SMC_ECC_MD

Address: 0x400E0024

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	TYPCORREC		–	–	ECC_PAGESIZE	

- **ECC_PAGESIZE: ECC Page Size**

This field defines the page size of the NAND Flash device.

Value	Name	Description
0	PS512_16	Main area 512 Bytes + Spare area 16 Bytes = 528 Bytes
1	PS1024_32	Main area 1024 Bytes + Spare area 32 Bytes = 1056 Bytes
2	PS2048_64	Main area 2048 Bytes + Spare area 64 Bytes = 2112 Bytes
3	PS4096_128	Main area 4096 Bytes + Spare area 128 Bytes = 4224 Bytes

- **TYPCORREC: Type of Correction**

Value	Name	Description
0	CPAGE	1 bit correction for a page of 512/1024/2048/4096 Bytes (for 8 or 16-bit NAND Flash)
1	C256B	1 bit correction for 256 Bytes of data for a page of 512/2048/4096 bytes (for 8-bit NAND Flash only)
2	C512B	1 bit correction for 512 Bytes of data for a page of 512/2048/4096 bytes (for 8-bit NAND Flash only)

24.18.11 SMC ECC Status Register 1

Name: SMC_ECC_SR1

Address: 0x400E0028

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	ECCERR7	ECCERR7	RECERR7	–	ECCERR6	ECCERR6	RECERR6
23	22	21	20	19	18	17	16
–	ECCERR5	ECCERR5	RECERR5	–	ECCERR4	ECCERR4	RECERR4
15	14	13	12	11	10	9	8
–	MULERR3	ECCERR3	RECERR3	–	MULERR2	ECCERR2	RECERR2
7	6	5	4	3	2	1	0
–	MULERR1	ECCERR1	RECERR1	–	ECCERR0	ECCERR0	RECERR0

- **RECERR0: Recoverable Error**

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR0: ECC Error**

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

If TYPECORRECT = 0, read both ECC Parity 0 and ECC Parity 1 registers, the error occurred at the location which contains a 1 in the least significant 16 bits; else read ECC Parity 0 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR0: Multiple Error**

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR1: Recoverable Error in the page between the 256th and the 511th bytes or the 512nd and the 1023rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR1: ECC Error in the page between the 256th and the 511th bytes or between the 512nd and the 1023rd bytes**

Fixed to 0 if TYPECORREC = 0

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 1 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR1: Multiple Error in the page between the 256th and the 511th bytes or between the 512nd and the 1023rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR2: Recoverable Error in the page between the 512nd and the 767th bytes or between the 1024th and the 1535th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected.

- **ECCERR2: ECC Error in the page between the 512nd and the 767th bytes or between the 1024th and the 1535th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 2 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR2: Multiple Error in the page between the 512nd and the 767th bytes or between the 1024th and the 1535th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR3: Recoverable Error in the page between the 768th and the 1023rd bytes or between the 1536th and the 2047th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR3: ECC Error in the page between the 768th and the 1023rd bytes or between the 1536th and the 2047th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 3 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR3: Multiple Error in the page between the 768th and the 1023rd bytes or between the 1536th and the 2047th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR4: Recoverable Error in the page between the 1024th and the 1279th bytes or between the 2048th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR4: ECC Error in the page between the 1024th and the 1279th bytes or between the 2048th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 4 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR4: Multiple Error in the page between the 1024th and the 1279th bytes or between the 2048th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR5: Recoverable Error in the page between the 1280th and the 1535th bytes or between the 2560th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected

- **ECCERR5: ECC Error in the page between the 1280th and the 1535th bytes or between the 2560th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 5 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR5: Multiple Error in the page between the 1280th and the 1535th bytes or between the 2560th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR6: Recoverable Error in the page between the 1536th and the 1791st bytes or between the 3072nd and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR6: ECC Error in the page between the 1536th and the 1791st bytes or between the 3072nd and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 6 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR6: Multiple Error in the page between the 1536th and the 1791st bytes or between the 3072nd and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR7: Recoverable Error in the page between the 1792nd and the 2047th bytes or between the 3584th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected.

- **ECCERR7: ECC Error in the page between the 1792nd and the 2047th bytes or between the 3584th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 7 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR7: Multiple Error in the page between the 1792nd and the 2047th bytes or between the 3584th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

24.18.12 SMC ECC Status Register 2

Name: SMC_ECC_SR2

Address: 0x400E0034

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	ECCERR15	ECCERR15	RECERR15	–	ECCERR14	ECCERR14	RECERR14
23	22	21	20	19	18	17	16
–	ECCERR13	ECCERR13	RECERR13	–	ECCERR12	ECCERR12	RECERR12
15	14	13	12	11	10	9	8
–	MULERR11	ECCERR11	RECERR11	–	MULERR10	ECCERR10	RECERR10
7	6	5	4	3	2	1	0
–	MULERR9	ECCERR9	RECERR9	–	ECCERR8	ECCERR8	RECERR8

- **RECERR8: Recoverable Error in the page between the 2048th and the 2303rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected

- **ECCERR8: ECC Error in the page between the 2048th and the 2303rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 8 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR8: Multiple Error in the page between the 2048th and the 2303rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR9: Recoverable Error in the page between the 2304th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR9: ECC Error in the page between the 2304th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 9 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR9: Multiple Error in the page between the 2304th and the 2559th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR10: Recoverable Error in the page between the 2560th and the 2815th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected.

- **ECCERR10: ECC Error in the page between the 2560th and the 2815th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 10 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR10: Multiple Error in the page between the 2560th and the 2815th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR11: Recoverable Error in the page between the 2816th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected

- **ECCERR11: ECC Error in the page between the 2816th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 11 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR11: Multiple Error in the page between the 2816th and the 3071st bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR12: Recoverable Error in the page between the 3072nd and the 3327th bytes**

Fixed to 0 if TYPECORREC = 0

0: No Errors Detected

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected

- **ECCERR12: ECC Error in the page between the 3072nd and the 3327th bytes**

Fixed to 0 if TYPECORREC = 0

0: No Errors Detected

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 12 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR12: Multiple Error in the page between the 3072nd and the 3327th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR13: Recoverable Error in the page between the 3328th and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise multiple uncorrected errors were detected.

- **ECCERR13: ECC Error in the page between the 3328th and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 13 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR13: Multiple Error in the page between the 3328th and the 3583rd bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR14: Recoverable Error in the page between the 3584th and the 3839th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected.

- **ECCERR14: ECC Error in the page between the 3584th and the 3839th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 14 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR14: Multiple Error in the page between the 3584th and the 3839th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

- **RECERR15: Recoverable Error in the page between the 3840th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: Errors Detected. If MUL_ERROR is 0, a single correctable error was detected. Otherwise, multiple uncorrected errors were detected.

- **ECCERR15: ECC Error in the page between the 3840th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Errors Detected.

1: A single bit error occurred in the ECC bytes.

Read ECC Parity 15 register, the error occurred at the location which contains a 1 in the least significant 24 bits.

- **MULERR15: Multiple Error in the page between the 3840th and the 4095th bytes**

Fixed to 0 if TYPECORREC = 0.

0: No Multiple Errors Detected.

1: Multiple Errors Detected.

24.18.13 SMC ECC Parity Register 0 for a Page of 512/1024/2048/4096 Bytes

Name: SMC_ECC_PR0

Address: 0x400E002C

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
WORDADDR							
7	6	5	4	3	2	1	0
WORDADDR				BITADDR			

Once the entire main area of a page is written with data, the register content must be stored at any free location of the spare area.

- **BITADDR: Bit Address**

During a page read, this value contains the corrupted bit offset where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.

- **WORDADDR: Word Address**

During a page read, this value contains the word address (8-bit or 16-bit word depending on the memory plane organization).where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.

24.18.14 SMC ECC Parity Register 1 for a Page of 512/1024/2048/4096 Bytes

Name: SMC_ECC_PR1

Address: 0x400E0030

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
NPARITY							
7	6	5	4	3	2	1	0
NPARITY							

- **NPARITY: Parity N**

24.18.15 SMC ECC Parity Registers for 1 ECC per 512 Bytes for a Page of 512/2048/4096 Bytes, 9-bit Word

Name: SMC_ECC_PRx [x=0..7] (W9BIT)

Address: 0x400E0038 [2] .. 0x400E006C [15]

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
NPARITY							
15	14	13	12	11	10	9	8
NPARITY				WORDADDR			
7	6	5	4	3	2	1	0
WORDADDR					BITADDR		

Once the entire main area of a page is written with data, the register content must be stored at any free location of the spare area.

- **BITADDR: Corrupted Bit Address in the Page between (i x 512) and ((i + 1) x 512) - 1) Bytes**

During a page read, this value contains the corrupted bit offset where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.

- **WORDADDR: Corrupted Word Address in the Page between (i x 512) and ((i + 1) x 512) - 1) Bytes**

During a page read, this value contains the word address (9-bit word) where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.

- **NPARITY: Parity N**

24.18.16 SMC ECC Parity Registers for 1 ECC per 256 Bytes for a Page of 512/2048/4096 Bytes, 8-bit Word

Name: SMC_ECC_PRx [x=0..15] (W8BIT)

Address: 0x400E0038 [2] .. 0x400E006C [15]

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
0	NPARITY						
15	14	13	12	11	10	9	8
NPARITY				0	WORDADDR		
7	6	5	4	3	2	1	0
WORDADDR					BITADDR		

Once the entire main area of a page is written with data, the register content must be stored at any free location of the spare area.

- **BITADDR: Corrupted Bit Address in the Page between (i x 256) and ((i + 1) x 512) - 1) Bytes**
- **During a page read, this value contains the corrupted bit offset where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.**
- **WORDADDR: Corrupted Word Address in the Page between (i x 256) and ((i + 1) x 512) - 1) Bytes**

During a page read, this value contains the word address (8-bit word) where an error occurred, if a single error was detected. If multiple errors were detected, this value is meaningless.

- **NPARITY: Parity N**

24.18.17 SMC Setup Register

Name: SMC_SETUPx [x=0..3]

Address: 0x400E0070 [0], 0x400E0084 [1], 0x400E0098 [2], 0x400E00AC [3]

Access: Read-write

Reset: 0x01010101

31	30	29	28	27	26	25	24
–	–	NCS_RD_SETUP					

23	22	21	20	19	18	17	16
–	–	NRD_SETUP					

15	14	13	12	11	10	9	8
–	–	NCS_WR_SETUP					

7	6	5	4	3	2	1	0
–	–	NWE_SETUP					

- **NWE_SETUP: NWE Setup Length**

The NWE signal setup length is defined as:

NWE setup length = (128 * NWE_SETUP[5] + NWE_SETUP[4:0]) clock cycles.

- **NCS_WR_SETUP: NCS Setup Length in Write Access**

In write access, the NCS signal setup length is defined as:

NCS setup length = (128 * NCS_WR_SETUP[5] + NCS_WR_SETUP[4:0]) clock cycles.

- **NRD_SETUP: NRD Setup Length**

The NRD signal setup length is defined as:

NRD setup length = (128 * NRD_SETUP[5] + NRD_SETUP[4:0]) clock cycles.

- **NCS_RD_SETUP: NCS Setup Length in Read Access**

In Read access, the NCS signal setup length is defined as:

NCS setup length = (128 * NCS_RD_SETUP[5] + NCS_RD_SETUP[4:0]) clock cycles.

24.18.18 SMC Pulse Register

Name: SMC_PULSEx [x=0..3]

Address: 0x400E0074 [0], 0x400E0088 [1], 0x400E009C [2], 0x400E00B0 [3]

Access: Read-write

Reset: 0x01010101

31	30	29	28	27	26	25	24
–	–	NCS_RD_PULSE					

23	22	21	20	19	18	17	16
–	–	NRD_PULSE					

15	14	13	12	11	10	9	8
–	–	NCS_WR_PULSE					

7	6	5	4	3	2	1	0
–	–	NWE_PULSE					

- **NWE_PULSE: NWE Pulse Length**

The NWE signal pulse length is defined as:

NWE pulse length = (256 * NWE_PULSE[6]+NWE_PULSE[5:0]) clock cycles.

The NWE pulse must be at least one clock cycle.

- **NCS_WR_PULSE: NCS Pulse Length in WRITE Access**

In Write access, The NCS signal pulse length is defined as:

NCS pulse length = (256 * NCS_WR_PULSE[6] + NCS_WR_PULSE[5:0]) clock cycles.

the NCS pulse must be at least one clock cycle.

- **NRD_PULSE: NRD Pulse Length**

The NRD signal pulse length is defined as:

NRD pulse length = (256 * NRD_PULSE[6] + NRD_PULSE[5:0]) clock cycles.

The NRD pulse width must be as least 1 clock cycle.

- **NCS_RD_PULSE: NCS Pulse Length in READ Access**

In READ mode, The NCS signal pulse length is defined as:

NCS pulse length = (256 * NCS_RD_PULSE[6] + NCS_RD_PULSE[5:0]) clock cycles.

24.18.19 SMC Cycle Register

Name: SMC_CYCLEx [x=0..3]

Address: 0x400E0078 [0], 0x400E008C [1], 0x400E00A0 [2], 0x400E00B4 [3]

Access: Read-write

Reset: 0x00030003

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	NRD_CYCLE

23	22	21	20	19	18	17	16
NRD_CYCLE							

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	NWE_CYCLE

7	6	5	4	3	2	1	0
NWE_CYCLE							

- **NWE_CYCLE: Total Write Cycle Length**

The total write cycle length is the total duration in clock cycles of the write cycle. It is equal to the sum of the setup, pulse and hold steps of the NWE and NCS signals. It is defined as:

Write cycle length = (NWE_CYCLE[8:7] * 256) + NWE_CYCLE[6:0] clock cycles.

- **NRD_CYCLE: Total Read Cycle Length**

The total read cycle length is the total duration in clock cycles of the read cycle. It is equal to the sum of the setup, pulse and hold steps of the NRD and NCS signals. It is defined as:

Read cycle length = (NRD_CYCLE[8:7] * 256) + NRD_CYCLE[6:0] clock cycles.

24.18.20 SMC Timings Register

Name: SMC_TIMINGSx [x=0..3]

Address: 0x400E007C [0], 0x400E0090 [1], 0x400E00A4 [2], 0x400E00B8 [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
NFSEL	RBNSEL			TWB			
23	22	21	20	19	18	17	16
–	–	–	–	TRR			
15	14	13	12	11	10	9	8
–	–	–	OCMS	TAR			
7	6	5	4	3	2	1	0
TADL				TCLR			

- **TCLR: CLE to REN Low Delay**

Command Latch Enable falling edge to Read Enable falling edge timing.

Latch Enable Falling to Read Enable Falling = (TCLR[3] * 64) + TCLR[2:0] clock cycles.

- **TADL: ALE to Data Start**

Last address latch cycle to the first rising edge of WEN for data input.

Last address latch to first rising edge of WEN = (TADL[3] * 64) + TADL[2:0] clock cycles.

- **TAR: ALE to REN Low Delay**

Address Latch Enable falling edge to Read Enable falling edge timing.

Address Latch Enable to Read Enable = (TAR[3] * 64) + TAR[2:0] clock cycles.

- **OCMS: Off Chip Memory Scrambling Enable**

When set to one, the memory scrambling is activated.

- **TRR: Ready to REN Low Delay**

Ready/Busy signal to Read Enable falling edge timing.

Read to REN = (TRR[3] * 64) + TRR[2:0] clock cycles.

- **TWB: WEN High to REN to Busy**

Write Enable rising edge to Ready/Busy falling edge timing.

Write Enable to Read/Busy = (TWB[3] * 64) + TWB[2:0] clock cycles.

- **RBNSEL: Ready/Busy Line Selection**

This field indicates the selected Ready/Busy Line from the RBN bundle.

- **NFSEL: NAND Flash Selection**

If this bit is set to one, the chip select is assigned to NAND Flash write enable and read enable lines drive the Error Correcting Code module.

24.18.21 SMC Mode Register

Name: SMC_MODEx [x=0..3]

Address: 0x400E0080 [0], 0x400E0094 [1], 0x400E00A8 [2], 0x400E00BC [3]

Access: Read-write

Reset: 0x10000003

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	TDF_MODE	TDF_CYCLES			
15	14	13	12	11	10	9	8
–	–	–	DBW	–	–	–	BAT
7	6	5	4	3	2	1	0
–	–	EXNW_MODE		–	–	WRITE_MODE	READ_MODE

- **READ_MODE**

1 (NRD_CTRL): The Read operation is controlled by the NRD signal.

0 (NCS_CTRL): The Read operation is controlled by the NCS signal.

- **WRITE_MODE**

1 (NWE_CTRL): The Write operation is controlled by the NWE signal.

0 (NCS_CTRL): The Write operation is controller by the NCS signal.

- **EXNW_MODE: NWAIT Mode**

The NWAIT signal is used to extend the current read or write signal. It is only taken into account during the pulse phase Read and Write controlling signal. When the use of NWAIT is enabled, at least one cycle hold duration must be programmed for the read and write controlling signal

Value	Name	Description
0	DISABLED	Disabled
1		Reserved
2	FROZEN	Frozen Mode
3	READY	Ready Mode

- Disabled: The NWAIT input signal is ignored on the corresponding Chip Select.
- Frozen Mode: If asserted, the NWAIT signal freezes the current read or write cycle. After deassertion, the read/write cycle is resumed from the point where it was stopped.
- Ready Mode: The NWAIT signal indicates the availability of the external device at the end of the pulse of the controlling read or write signal, to complete the access. If high, the access normally completes. If low, the access is extended until NWAIT returns high.

- **BAT: Byte Access Type**

This field is used only if DBW defines a 16-bit data bus.

1 (BYTE_WRITE): Byte write access type:

– Write operation is controlled using NCS, NWR0, NWR1.

– Read operation is controlled using NCS and NRD.

0 (BYTE_SELECT): Byte select access type:

– Write operation is controlled using NCS, NWE, NBS0, NBS1.

– Read operation is controlled using NCS, NRD, NBS0, NBS1.

- **DBW: Data Bus Width**

Value	Name	Description
0	BIT_8	8-bit bus
1	BIT_16	16-bit bus

- **TDF_CYCLES: Data Float Time**

This field gives the integer number of clock cycles required by the external device to release the data after the rising edge of the read controlling signal. The SMC always provide one full cycle of bus turnaround after the TDF_CYCLES period. The external bus cannot be used by another chip select during TDF_CYCLES + 1 cycles. From 0 up to 15 TDF_CYCLES can be set.

- **TDF_MODE: TDF Optimization**

1: TDF optimization is enabled.

– The number of TDF wait states is optimized using the setup period of the next read/write access.

0: TDF optimization is disabled.

– The number of TDF wait states is inserted before the next access begins.

24.18.22 SMC OCMS Register

Name: SMC_OCMS

Address: 0x400E0110

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	SRSE	SMSE

- **SMSE: Static Memory Controller Scrambling Enable**

0: Disable “Off Chip” Scrambling for SMC access.

1: Enable “Off Chip” Scrambling for SMC access. (If OCMS field is set to 1 in the relevant SMC_TIMINGS register.)

- **SRSE: SRAM Scrambling Enable**

0: Disable SRAM Scrambling for SRAM access.

1: Enable SRAM Scrambling for SRAM access. (If OCMS field is set to 1 in the relevant SMC_TIMINGS register.)

24.18.23 SMC OCMS Key1 Register

Name: SMC_KEY1

Address: 0x400E0114

Access: Write-once

Reset: 0x00000000

31	30	29	28	27	26	25	24
KEY1							

23	22	21	20	19	18	17	16
KEY1							

15	14	13	12	11	10	9	8
KEY1							

7	6	5	4	3	2	1	0
KEY1							

- **KEY1: Off Chip Memory Scrambling (OCMS) Key Part 1**

When Off Chip Memory Scrambling is enabled by setting the SMC_OMCS and SMC_TIMINGS registers in accordance, the data scrambling depends on KEY1 and KEY2 values.

24.18.24 SMC OCMS Key2 Register

Name: SMC_KEY2

Address: 0x400E0118

Access: Write-once

Reset: 0x00000000

31	30	29	28	27	26	25	24
KEY2							

23	22	21	20	19	18	17	16
KEY2							

15	14	13	12	11	10	9	8
KEY2							

7	6	5	4	3	2	1	0
KEY2							

- **KEY2: Off Chip Memory Scrambling (OCMS) Key Part 2**

When Off Chip Memory Scrambling is enabled by setting the SMC_OMCS and SMC_TIMINGS registers in accordance, the data scrambling depends on KEY2 and KEY1 values.

24.18.25 SMC Write Protection Control

Name: SMC_WPCR

Address: 0x400E01E4

Access: Write-only

31	30	29	28	27	26	25	24
WP_KEY							
23	22	21	20	19	18	17	16
WP_KEY							
15	14	13	12	11	10	9	8
WP_KEY							
7	6	5	4	3	2	1	0
							WP_EN

- **WP_EN: Write Protection Enable**

0: Disables the Write Protection if WP_KEY corresponds.

1: Enables the Write Protection if WP_KEY corresponds.

- **WP_KEY: Write Protection KEY password**

Should be written at value **0x534D43** (ASCII code for “SMC”). Writing any other value in this field has no effect.

24.18.26 SMC Write Protection Status

Name: SMC_WPSR

Address: 0x400E01E8

Access: Read-only

31	30	29	28	27	26	25	24
-	-	-	-	-	-	-	-
23	22	21	20	19	18	17	16
WP_VSRC							
15	14	13	12	11	10	9	8
WP_VSRC							
7	6	5	4	3	2	1	0
-	-	-	-	WP_VS			

- **WP_VS: Write Protection Violation Status**

0: No Write Protect Violation has occurred since the last read of the SMC_WPSR register.

1: A Write Protect Violation has occurred since the last read of the SMC_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WP_VSRC.

- **WP_VSRC: Write Protection Violation Source**

WP_VSRC field Indicates the Register offset where the last violation occurred.

25. Peripheral DMA Controller (PDC)

25.1 Description

The Peripheral DMA Controller (PDC) transfers data between on-chip serial peripherals and the on- and/or off-chip memories. The link between the PDC and a serial peripheral is operated by the AHB to APB bridge.

The user interface of each PDC channel is integrated into the user interface of the peripheral it serves. The user interface of mono directional channels (receive only or transmit only), contains two 32-bit memory pointers and two 16-bit counters, one set (pointer, counter) for current transfer and one set (pointer, counter) for next transfer. The bi-directional channel user interface contains four 32-bit memory pointers and four 16-bit counters. Each set (pointer, counter) is used by current transmit, next transmit, current receive and next receive.

Using the PDC removes processor overhead by reducing its intervention during the transfer. This significantly reduces the number of clock cycles required for a data transfer, which improves microcontroller performance.

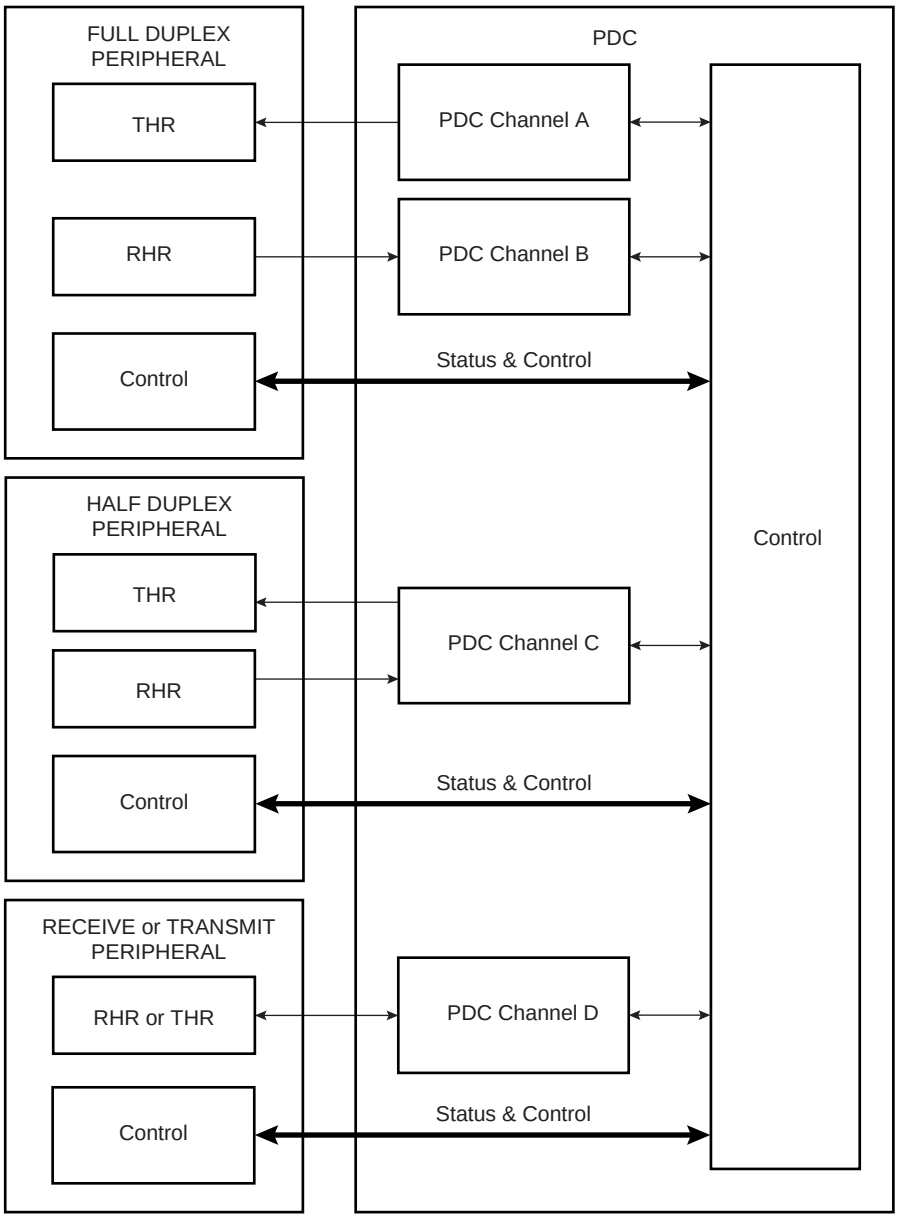
To launch a transfer, the peripheral triggers its associated PDC channels by using transmit and receive signals. When the programmed data is transferred, an end of transfer interrupt is generated by the peripheral itself.

25.2 Embedded Characteristics

- AMBA™ Advanced High-performance Bus (AHB Lite) Compliant Master
- Performs Transfers to/from APB Communication Serial Peripherals
- Supports Half-duplex and Full-duplex Peripherals

25.3 Block Diagram

Figure 25-1. Block Diagram



25.4 Functional Description

25.4.1 Configuration

The PDC channel user interface enables the user to configure and control data transfers for each channel. The user interface of each PDC channel is integrated into the associated peripheral user interface.

The user interface of a serial peripheral, whether it is full or half duplex, contains four 32-bit pointers (RPR, RNPR, TPR, TNPR) and four 16-bit counter registers (RCR, RNCR, TCR, TNCR). However, the transmit and receive parts of each type are programmed differently: the transmit and receive parts of a full duplex peripheral can be programmed at the same time, whereas only one part (transmit or receive) of a half duplex peripheral can be programmed at a time.

32-bit pointers define the access location in memory for current and next transfer, whether it is for read (transmit) or write (receive). 16-bit counters define the size of current and next transfers. It is possible, at any moment, to read the number of transfers left for each channel.

The PDC has dedicated status registers which indicate if the transfer is enabled or disabled for each channel. The status for each channel is located in the associated peripheral status register. Transfers can be enabled and/or disabled by setting TXTEN/TXTDIS and RXTEN/RXTDIS in the peripheral's Transfer Control Register.

At the end of a transfer, the PDC channel sends status flags to its associated peripheral. These flags are visible in the peripheral status register (ENDRX, ENDTX, RXBUFF, and TXBUFE). Refer to Section 25.4.3 and to the associated peripheral user interface.

25.4.2 Memory Pointers

Each full duplex peripheral is connected to the PDC by a receive channel and a transmit channel. Both channels have 32-bit memory pointers that point respectively to a receive area and to a transmit area in on- and/or off-chip memory.

Each half duplex peripheral is connected to the PDC by a bidirectional channel. This channel has two 32-bit memory pointers, one for current transfer and the other for next transfer. These pointers point to transmit or receive data depending on the operating mode of the peripheral.

Depending on the type of transfer (byte, half-word or word), the memory pointer is incremented respectively by 1, 2 or 4 bytes.

If a memory pointer address changes in the middle of a transfer, the PDC channel continues operating using the new address.

25.4.3 Transfer Counters

Each channel has two 16-bit counters, one for current transfer and the other one for next transfer. These counters define the size of data to be transferred by the channel. The current transfer counter is decremented first as the data addressed by current memory pointer starts to be transferred. When the current transfer counter reaches zero, the channel checks its next transfer counter. If the value of next counter is zero, the channel stops transferring data and sets the appropriate flag. But if the next counter value is greater then zero, the values of the next pointer/next counter are copied into the current pointer/current counter and the channel resumes the transfer whereas next pointer/next counter get zero/zero as values. At the end of this transfer the PDC channel sets the appropriate flags in the Peripheral Status Register.

The following list gives an overview of how status register flags behave depending on the counters' values:

- ENDRX flag is set when the PERIPH_RCR register reaches zero.
- RXBUFF flag is set when both PERIPH_RCR and PERIPH_RNCR reach zero.
- ENDTX flag is set when the PERIPH_TCR register reaches zero.
- TXBUFE flag is set when both PERIPH_TCR and PERIPH_TNCR reach zero.

These status flags are described in the Peripheral Status Register.

25.4.4 Data Transfers

The serial peripheral triggers its associated PDC channels' transfers using transmit enable (TXEN) and receive enable (RXEN) flags in the transfer control register integrated in the peripheral's user interface.

When the peripheral receives an external data, it sends a Receive Ready signal to its PDC receive channel which then requests access to the Matrix. When access is granted, the PDC receive channel starts reading the peripheral Receive Holding Register (RHR). The read data are stored in an internal buffer and then written to memory.

When the peripheral is about to send data, it sends a Transmit Ready to its PDC transmit channel which then requests access to the Matrix. When access is granted, the PDC transmit channel reads data from memory and puts them to Transmit Holding Register (THR) of its associated peripheral. The same peripheral sends data according to its mechanism.

25.4.5 PDC Flags and Peripheral Status Register

Each peripheral connected to the PDC sends out receive ready and transmit ready flags and the PDC sends back flags to the peripheral. All these flags are only visible in the Peripheral Status Register.

Depending on the type of peripheral, half or full duplex, the flags belong to either one single channel or two different channels.

25.4.5.1 Receive Transfer End

This flag is set when PERIPH_RCR register reaches zero and the last data has been transferred to memory.

It is reset by writing a non zero value in PERIPH_RCR or PERIPH_RNCR.

25.4.5.2 Transmit Transfer End

This flag is set when PERIPH_TCR register reaches zero and the last data has been written into peripheral THR.

It is reset by writing a non zero value in PERIPH_TCR or PERIPH_TNCR.

25.4.5.3 Receive Buffer Full

This flag is set when PERIPH_RCR register reaches zero with PERIPH_RNCR also set to zero and the last data has been transferred to memory.

It is reset by writing a non zero value in PERIPH_TCR or PERIPH_TNCR.

25.4.5.4 Transmit Buffer Empty

This flag is set when PERIPH_TCR register reaches zero with PERIPH_TNCR also set to zero and the last data has been written into peripheral THR.

It is reset by writing a non zero value in PERIPH_TCR or PERIPH_TNCR.

25.5 Peripheral DMA Controller (PDC) User Interface

Table 25-1. Register Mapping

Offset	Register	Name	Access	Reset
0x100	Receive Pointer Register	PERIPH[(1)]_RPR	Read-write	0
0x104	Receive Counter Register	PERIPH_RCR	Read-write	0
0x108	Transmit Pointer Register	PERIPH_TPR	Read-write	0
0x10C	Transmit Counter Register	PERIPH_TCR	Read-write	0
0x110	Receive Next Pointer Register	PERIPH_RNPR	Read-write	0
0x114	Receive Next Counter Register	PERIPH_RNCR	Read-write	0
0x118	Transmit Next Pointer Register	PERIPH_TNPR	Read-write	0
0x11C	Transmit Next Counter Register	PERIPH_TNCR	Read-write	0
0x120	Transfer Control Register	PERIPH_PTCR	Write-only	0
0x124	Transfer Status Register	PERIPH_PTSR	Read-only	0

Note: 1. PERIPH: Ten registers are mapped in the peripheral memory space at the same offset. These can be defined by the user according to the function and the desired peripheral.)

25.5.1 Receive Pointer Register

Name: PERIPH_RPR

Access: Read-write

31	30	29	28	27	26	25	24
RXPTR							
23	22	21	20	19	18	17	16
RXPTR							
15	14	13	12	11	10	9	8
RXPTR							
7	6	5	4	3	2	1	0
RXPTR							

- **RXPTR: Receive Pointer Register**

RXPTR must be set to receive buffer address.

When a half duplex peripheral is connected to the PDC, RXPTR = TXPTR.

25.5.2 Receive Counter Register

Name: PERIPH_RCR

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
RXCTR							
7	6	5	4	3	2	1	0
RXCTR							

- **RXCTR: Receive Counter Register**

RXCTR must be set to receive buffer size.

When a half duplex peripheral is connected to the PDC, RXCTR = TXCTR.

0 = Stops peripheral data transfer to the receiver

1 - 65535 = Starts peripheral data transfer if corresponding channel is active

25.5.3 Transmit Pointer Register

Name: PERIPH_TPR

Access: Read-write

31	30	29	28	27	26	25	24
TXPTR							
23	22	21	20	19	18	17	16
TXPTR							
15	14	13	12	11	10	9	8
TXPTR							
7	6	5	4	3	2	1	0
TXPTR							

- **TXPTR: Transmit Counter Register**

TXPTR must be set to transmit buffer address.

When a half duplex peripheral is connected to the PDC, RXPTR = TXPTR.

25.5.4 Transmit Counter Register

Name: PERIPH_TCR

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXCTR							
7	6	5	4	3	2	1	0
TXCTR							

- **TXCTR: Transmit Counter Register**

TXCTR must be set to transmit buffer size.

When a half duplex peripheral is connected to the PDC, RXCTR = TXCTR.

0 = Stops peripheral data transfer to the transmitter

1- 65535 = Starts peripheral data transfer if corresponding channel is active

25.5.5 Receive Next Pointer Register

Name: PERIPH_RNPR

Access: Read-write

31	30	29	28	27	26	25	24
RXNPTR							
23	22	21	20	19	18	17	16
RXNPTR							
15	14	13	12	11	10	9	8
RXNPTR							
7	6	5	4	3	2	1	0
RXNPTR							

- **RXNPTR: Receive Next Pointer**

RXNPTR contains next receive buffer address.

When a half duplex peripheral is connected to the PDC, RXNPTR = TXNPTR.

25.5.6 Receive Next Counter Register

Name: PERIPH_RNCR

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
RXNCTR							
7	6	5	4	3	2	1	0
RXNCTR							

- **RXNCTR: Receive Next Counter**

RXNCTR contains next receive buffer size.

When a half duplex peripheral is connected to the PDC, RXNCTR = TXNCTR.

25.5.7 Transmit Next Pointer Register

Name: PERIPH_TNPR

Access: Read-write

31	30	29	28	27	26	25	24
TXNPTR							
23	22	21	20	19	18	17	16
TXNPTR							
15	14	13	12	11	10	9	8
TXNPTR							
7	6	5	4	3	2	1	0
TXNPTR							

- **TXNPTR: Transmit Next Pointer**

TXNPTR contains next transmit buffer address.

When a half duplex peripheral is connected to the PDC, RXNPTR = TXNPTR.

25.5.8 Transmit Next Counter Register

Name: PERIPH_TNCR

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXNCTR							
7	6	5	4	3	2	1	0
TXNCTR							

- **TXNCTR: Transmit Counter Next**

TXNCTR contains next transmit buffer size.

When a half duplex peripheral is connected to the PDC, RXNCTR = TXNCTR.

25.5.9 Transfer Control Register

Name: PERIPH_PTCR

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	TXTDIS	TXTEN
7	6	5	4	3	2	1	0
–	–	–	–	–	–	RXTDIS	RXTEN

- **RXTEN: Receiver Transfer Enable**

0 = No effect.

1 = Enables PDC receiver channel requests if RXTDIS is not set.

When a half duplex peripheral is connected to the PDC, enabling the receiver channel requests automatically disables the transmitter channel requests. It is forbidden to set both TXTEN and RXTEN for a half duplex peripheral.

- **RXTDIS: Receiver Transfer Disable**

0 = No effect.

1 = Disables the PDC receiver channel requests.

When a half duplex peripheral is connected to the PDC, disabling the receiver channel requests also disables the transmitter channel requests.

- **TXTEN: Transmitter Transfer Enable**

0 = No effect.

1 = Enables the PDC transmitter channel requests.

When a half duplex peripheral is connected to the PDC, it enables the transmitter channel requests only if RXTEN is not set. It is forbidden to set both TXTEN and RXTEN for a half duplex peripheral.

- **TXTDIS: Transmitter Transfer Disable**

0 = No effect.

1 = Disables the PDC transmitter channel requests.

When a half duplex peripheral is connected to the PDC, disabling the transmitter channel requests disables the receiver channel requests.

25.5.10 Transfer Status Register

Name: PERIPH_PTSR

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	TXTEN
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	RXTEN

- **RXTEN: Receiver Transfer Enable**

0 = PDC Receiver channel requests are disabled.

1 = PDC Receiver channel requests are enabled.

- **TXTEN: Transmitter Transfer Enable**

0 = PDC Transmitter channel requests are disabled.

1 = PDC Transmitter channel requests are enabled.

26. Clock Generator

26.1 Description

The Clock Generator is made up of:

- A Low Power 32.768 kHz Slow Clock Oscillator with bypass mode
- A Low Power RC Oscillator
- A 3 to 20 MHz Crystal Oscillator (12 MHz needed in case of USB), which can be bypassed
- A factory programmed Fast RC Oscillator, 3 output frequencies can be selected: 4, 8 or 12 MHz. By default 4 MHz is selected.
- A 480 MHz UTMI PLL providing a clock for the USB High Speed Device Controller
- A 96 to 192 MHz programmable PLL (input from 8 to 16 MHz), capable of providing the clock MCK to the processor and to the peripherals.

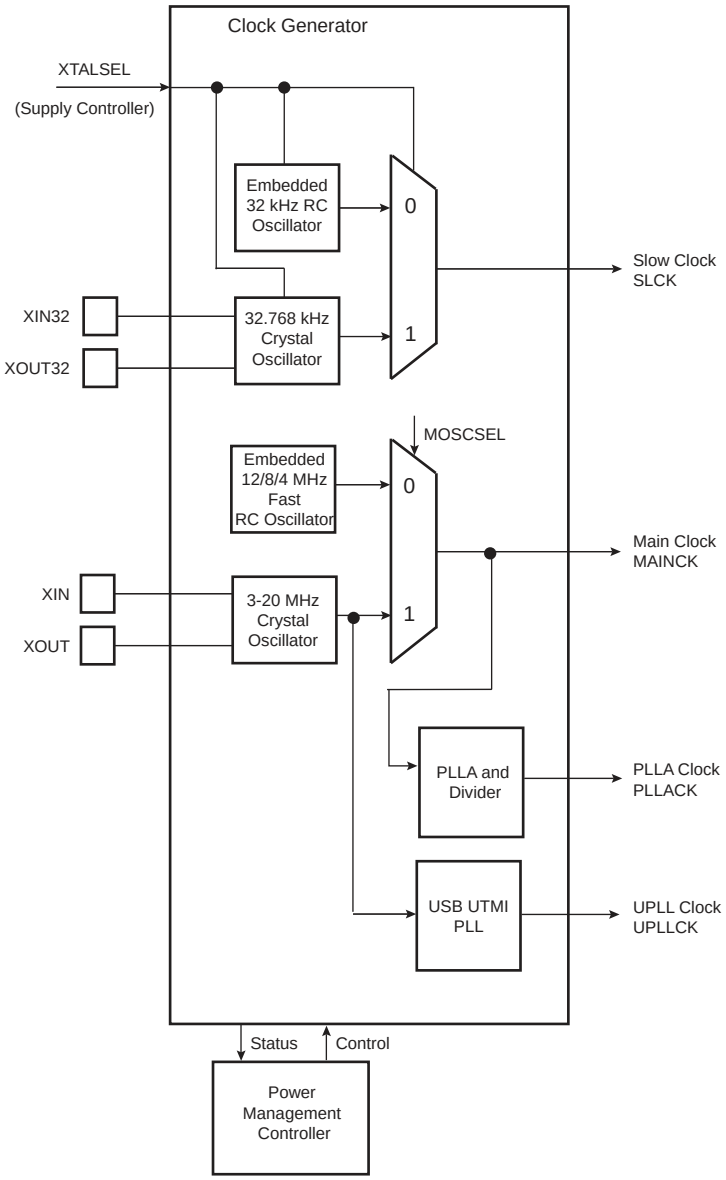
It provides the following clocks:

- SLCK, the Slow Clock, which is the only permanent clock within the system
- MAINCK is the output of the Main Clock Oscillator selection: either Crystal Oscillator or 4/8/12 MHz Fast RC Oscillator
- PLLACK is the output of the Divider and 96 to 192 MHz programmable PLL (PLLA)
- UPLLCK is the output of the 480 MHz UTMI PLL (UPLL)

The Clock Generator User Interface is embedded within the Power Management Controller and is described in Section 27.14 ”Power Management Controller (PMC) User Interface”. However, the Clock Generator registers are named CKGR_.

26.2 Block Diagram

Figure 26-1. Clock Generator Block Diagram



26.3 Slow Clock

The Slow Clock is generated either by the Slow Clock Crystal Oscillator or by the Slow Clock RC Oscillator.

The selection is made by writing the XTALSEL bit in the Supply Controller Control Register (SUPC_CR).

By default, the RC Oscillator is selected.

26.3.1 Slow Clock RC Oscillator

By default, the Slow Clock RC Oscillator is enabled and selected. The user has to take into account the possible drifts of the RC Oscillator. More details are given in Section 42.2 ”DC Characteristics”.

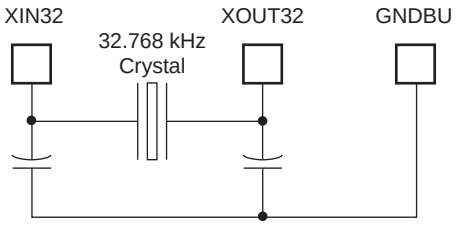
It can be disabled via the XTALSEL bit in the Supply Controller Control Register (SUPC_CR).

26.3.2 Slow Clock Crystal Oscillator

The Clock Generator integrates a 32.768 kHz low-power oscillator.The XIN and XOUT pins must be connected to a 32.768 kHz crystal. Two external capacitors must be wired as shown in Figure 26-2. More details are given in Section 42.2 ”DC Characteristics”.

Note that the user is not obliged to use the Slow Clock Crystal and can use the RC Oscillator instead. In this case, XIN and XOUT can be left unconnected.

Figure 26-2. Typical Slow Clock Crystal Oscillator Connection



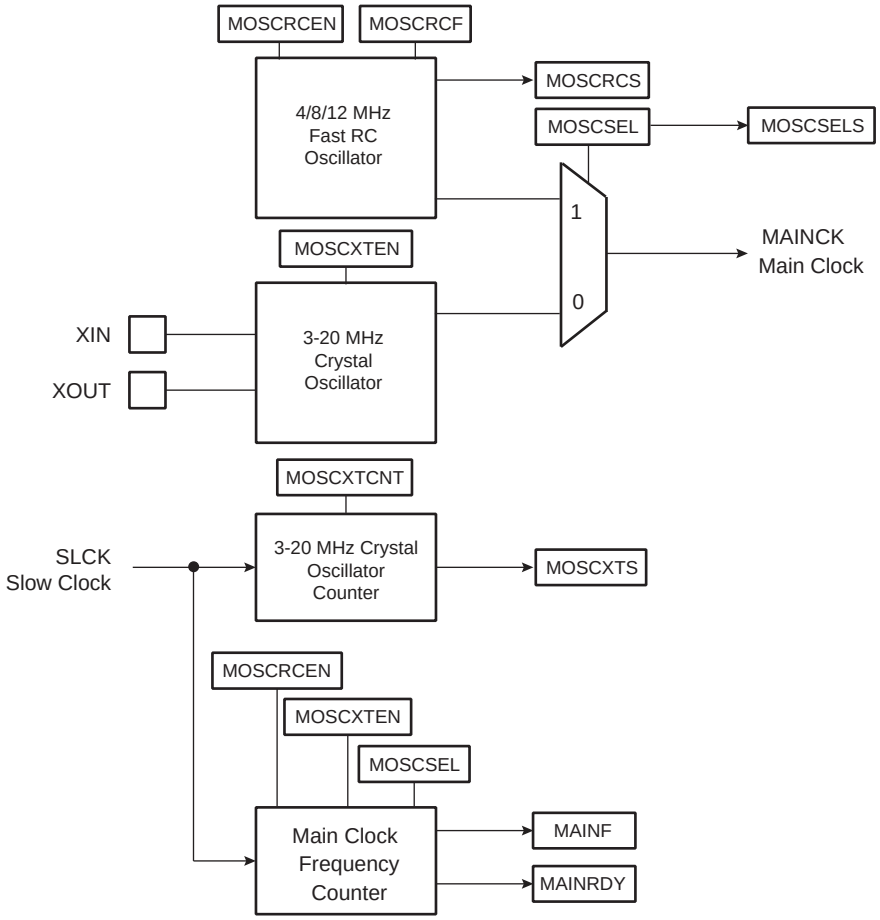
The user can set the Slow Clock Crystal Oscillator in bypass mode instead of connecting a crystal. In this case, the user has to provide the external clock signal on XIN32. The input characteristics of the XIN pin under these conditions are given in Section 42. ”Electrical Characteristics”.

The programmer has to be sure to set the OSCBYPASS bit in the Supply Controller Mode Register (SUPC_MR) and XTALSEL bit in the Supply Controller Control Register (SUPC_CR).

26.4 Main Clock

Figure 26-3 shows the Main Clock block diagram.

Figure 26-3. Main Clock Block Diagram



The Main Clock has two sources:

- 4/8/12 MHz Fast RC Oscillator which starts very quickly and is used at startup
- 3 to 20 MHz Crystal Oscillator, which can be bypassed

26.4.1 4/8/12 MHz Fast RC Oscillator

After reset, the 4/8/12 MHz Fast RC Oscillator is enabled with the 4 MHz frequency selected and it is selected as the source of MAINCK. MAINCK is the default clock selected to start up the system.

The Fast RC Oscillator 8 and 12 MHz frequencies are calibrated in production. Note that is not the case for the 4 MHz frequency.

Please refer to Section 42.2 ”DC Characteristics”.

The software can disable or enable the 4/8/12 MHz Fast RC Oscillator with the MOSCRCEN bit in the Clock Generator Main Oscillator Register (CKGR_MOR).

The user can also select the output frequency of the Fast RC Oscillator: either 4 MHz, 8 MHz or 12 MHz are available. It can be done through MOSCRCF bits in CKGR_MOR. When changing this frequency selection, the MOSCRCS bit in the Power Management Controller Status Register (PMC_SR) is automatically cleared and MAINCK is stopped until the oscillator is stabilized. Once the oscillator is stabilized, MAINCK restarts and MOSCRCS is set.

When disabling the Main Clock by clearing the MOSCRCEN bit in CKGR_MOR, the MOSCRCS bit in the Power Management Controller Status Register (PMC_SR) is automatically cleared, indicating the Main Clock is off.

Setting the MOSCRCS bit in the Power Management Controller Interrupt Enable Register (PMC_IER) can trigger an interrupt to the processor.

26.4.2 3 to 20 MHz Crystal Oscillator

After reset, the 3 to 20 MHz Crystal Oscillator is disabled and it is not selected as the source of MAINCK.

The user can select the 3 to 20 MHz crystal oscillator to be the source of MAINCK, as it provides a more accurate frequency. The software enables or disables the main oscillator so as to reduce power consumption by clearing the MOSCXTEN bit in the Main Oscillator Register (CKGR_MOR).

When disabling the main oscillator by clearing the MOSCXTEN bit in CKGR_MOR, the MOSCXTS bit in PMC_SR is automatically cleared, indicating the Main Clock is off.

When enabling the main oscillator, the user must initiate the main oscillator counter with a value corresponding to the startup time of the oscillator. This startup time depends on the crystal frequency connected to the oscillator.

When the MOSCXTEN bit and the MOSCXTCNT are written in CKGR_MOR to enable the main oscillator, the MOSCXTS bit in the Power Management Controller Status Register (PMC_SR) is cleared and the counter starts counting down on the slow clock divided by 8 from the MOSCXTCNT value. Since the MOSCXTCNT value is coded with 8 bits, the maximum startup time is about 62 ms.

When the counter reaches 0, the MOSCXTS bit is set, indicating that the main clock is valid. Setting the MOSCXTS bit in PMC_IMR can trigger an interrupt to the processor.

26.4.3 Main Clock Oscillator Selection

The user can select either the 4/8/12 MHz Fast RC Oscillator or the 3 to 20 MHz Crystal Oscillator to be the source of Main Clock.

The advantage of the 4/8/12 MHz Fast RC Oscillator is to have fast startup time, this is why it is selected by default (to start up the system) and when entering in Wait Mode.

The advantage of the 3 to 20 MHz Crystal Oscillator is that it is very accurate.

The selection is made by writing the MOSCSEL bit in the Main Oscillator Register (CKGR_MOR). The switch of the Main Clock source is glitch free, so there is no need to run out of SLCK, PLLACK or UPLLCK in order to change the selection. The MOSCSELS bit of the Power Management Controller Status Register (PMC_SR) allows knowing when the switch sequence is done.

Setting the MOSCSELS bit in PMC_IMR can trigger an interrupt to the processor.

26.4.4 Main Clock Frequency Counter

The device features a Main Clock frequency counter that provides the frequency of the Main Clock.

The Main Clock frequency counter is reset and starts incrementing at the Main Clock speed after the next rising edge of the Slow Clock in the following cases:

- when the 4/8/12 MHz Fast RC Oscillator clock is selected as the source of Main Clock and when this oscillator becomes stable (i.e., when the MOSCRCS bit is set)
- when the 3 to 20 MHz Crystal Oscillator is selected as the source of Main Clock and when this oscillator becomes stable (i.e., when the MOSCXTS bit is set)
- when the Main Clock Oscillator selection is modified

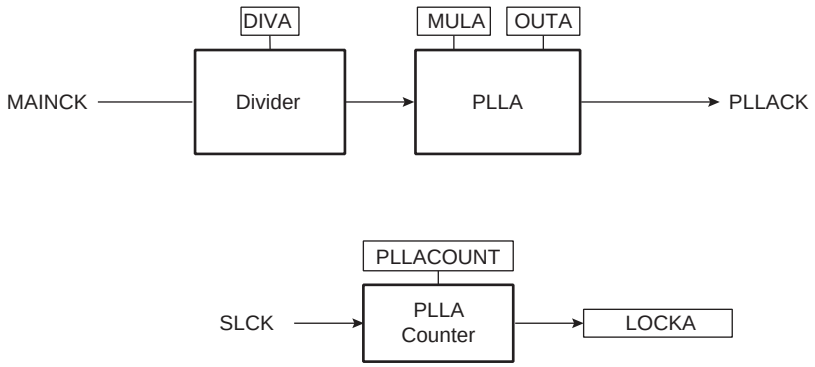
Then, at the 16th falling edge of Slow Clock, the MAINFRDY bit in the Clock Generator Main Clock Frequency Register (CKGR_MCFR) is set and the counter stops counting. Its value can be read in the MAINF field of CKGR_MCFR and gives the number of Main Clock cycles during 16 periods of Slow Clock, so that the frequency of the 4/8/12 MHz Fast RC Oscillator or 3 to 20 MHz Crystal Oscillator can be determined.

26.5 Divider and PLLA Block

The PLLA embeds an input divider to increase the accuracy of the resulting clock signals. However, the user must respect the PLLA minimum input frequency when programming the divider.

Figure 26-4 shows the block diagram of the divider and PLLA block.

Figure 26-4. Divider and PLLA Block Diagram



26.5.1 Divider and Phase Lock Loop Programming

The divider can be set between 1 and 255 in steps of 1. When a divider field (DIV) is set to 0, the output of the corresponding divider and the PLL output is a continuous signal at level 0. On reset, each DIV field is set to 0, thus the corresponding PLL input clock is set to 0.

The PLLA allows multiplication of the divider's outputs. The PLLA clock signal has a frequency that depends on the respective source signal frequency and on the parameters DIVA and MULA. The factor applied to the source signal frequency is (MULA + 1)/DIVA. When MULA is written to 0, the PLLA is disabled and its power consumption is saved. Re-enabling the PLLA can be performed by writing a value higher than 0 in the MULA field.

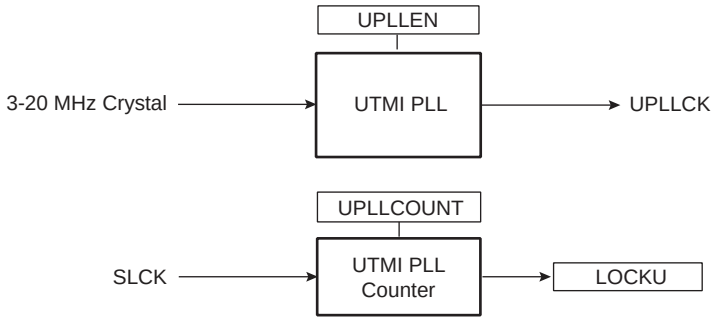
Whenever the PLLA is re-enabled or one of its parameters is changed, the LOCKA bit in PMC_SR is automatically cleared. The values written in the PLLACOUNT field in CKGR_PLLAR are loaded in the PLLA counter. The PLLA counter then decrements at the speed of the Slow Clock until it reaches 0. At this time, the LOCK bit is set in PMC_SR and can trigger an interrupt to the processor. The user has to load the number of Slow Clock cycles required to cover the PLLA transient time into the PLLACOUNT field.

26.6 UTMI Phase Lock Loop Programming

The clock source of the UTMI PLL is the 3–20 MHz Crystal Oscillator. When the 4/8/12 MHz Fast RC Oscillator is selected as the source of MAINCK, the 12 MHz frequency must also be selected because the UTMI PLL multiplier contains a built-in multiplier of x 40 to obtain the USB High Speed 480 MHz.

A 12 MHz crystal is needed to use the USB.

Figure 26-5. UTMI PLL Block Diagram



Whenever the UTMI PLL is enabled by writing UPLLEN in CKGR_UCKR, the LOCKU bit in PMC_SR is automatically cleared. The values written in the PLLCOUNT field in CKGR_UCKR are loaded in the UTMI PLL counter. The UTMI PLL counter then decrements at the speed of the Slow Clock divided by 8 until it reaches 0. At this time, the LOCKU bit is set in PMC_SR and can trigger an interrupt to the processor. The user has to load the number of Slow Clock cycles required to cover the UTMI PLL transient time into the PLLCOUNT field.

27. Power Management Controller (PMC)

27.1 Description

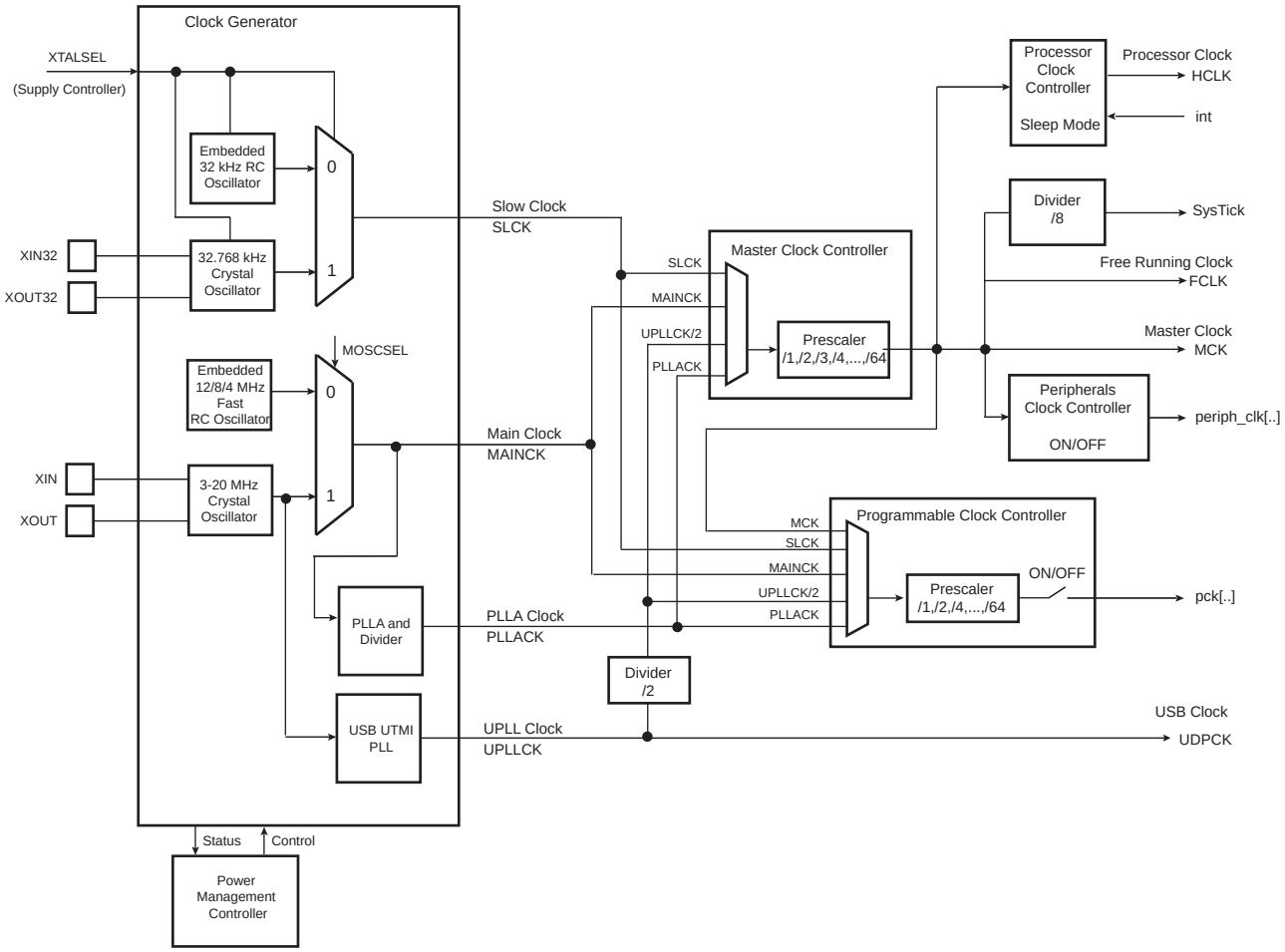
The Power Management Controller (PMC) optimizes power consumption by controlling all system and user peripheral clocks. The PMC enables/disables the clock inputs to many of the peripherals and the Cortex-M3 Processor.

The Power Management Controller provides the following clocks:

- MCK, the Master Clock, programmable from a few hundred Hz to the maximum operating frequency of the device. It is available to the modules running permanently, such as the Enhanced Embedded Flash Controller.
- Processor Clock (HCLK) is automatically switched off when the processor enters Sleep Mode.
- Free running processor Clock (FCLK)
- the Cortex-M3 SysTick external clock
- the USB Device HS Clock (UDPCK)
- Peripheral Clocks, typically MCK, provided to the embedded peripherals (USART, PMC, SPI, TWI, TC, HSMCI, etc.) and independently controllable. In order to reduce the number of clock names in a product, the Peripheral Clocks are named MCK in the product datasheet.
- Programmable Clock Outputs can be selected from the clocks provided by the clock generator and driven on the PCKx pins.

27.2 Block Diagram

Figure 27-1. General Clock Block Diagram



27.3 Master Clock Controller

The Master Clock Controller provides selection and division of the Master Clock (MCK). MCK is the clock provided to all the peripherals and the memory controller.

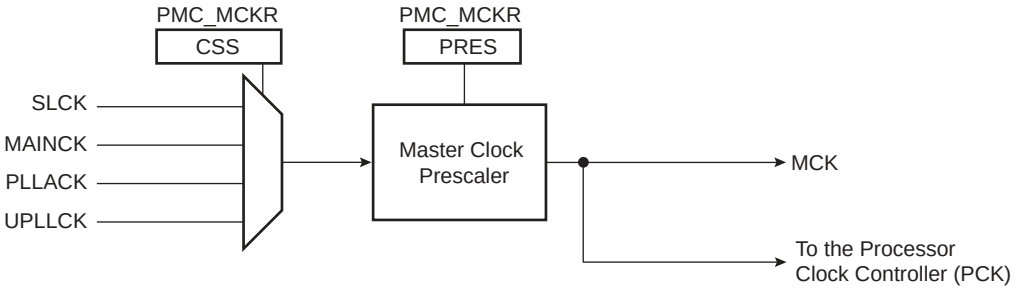
The Master Clock is selected from one of the clocks provided by the Clock Generator. Selecting the Slow Clock provides a Slow Clock signal to the whole device. Selecting the Main Clock saves power consumption of the PLLs.

The Master Clock Controller is made up of a clock selector and a prescaler.

The Master Clock selection is made by writing the CSS field (Clock Source Selection) in PMC_MCKR (Master Clock Register). The prescaler supports the division by a power of 2 of the selected clock between 1 and 64, and the division by 3. The PRES field in PMC_MCKR programs the prescaler.

Each time PMC_MCKR is written to define a new Master Clock, the MCKRDY bit is cleared in PMC_SR. It reads 0 until the Master Clock is established. Then, the MCKRDY bit is set and can trigger an interrupt to the processor. This feature is useful when switching from a high-speed clock to a lower one to inform the software when the change is actually done.

Figure 27-2. Master Clock Controller



27.4 Processor Clock Controller

The PMC features a Processor Clock Controller (HCLK) that implements the Processor Sleep Mode. The Processor Clock can be disabled by executing the WFI (WaitForInterrupt) or the WFE (WaitForEvent) processor instruction while the LPM bit is at 0 in the PMC Fast Startup Mode Register (PMC_FSMR).

The Processor Clock HCLK is enabled after a reset and is automatically re-enabled by any enabled interrupt. The Processor Sleep Mode is achieved by disabling the Processor Clock, which is automatically re-enabled by any enabled fast or normal interrupt, or by the reset of the product.

When Processor Sleep Mode is entered, the current instruction is finished before the clock is stopped, but this does not prevent data transfers from other masters of the system bus.

27.5 SysTick Clock

The SysTick calibration value is fixed to 10500 which allows the generation of a time base of 1 ms with SysTick clock at 10.5 MHz (max HCLK/8).

27.6 Peripheral Clock Controller

The Power Management Controller controls the clocks of each embedded peripheral by the way of the Peripheral Clock Controller. The user can individually enable and disable the Master Clock on the peripherals by writing into the Peripheral Clock Enable (PMC_PCER) and Peripheral Clock Disable (PMC_PCDR) registers. The status of the peripheral clock activity can be read in the Peripheral Clock Status Register (PMC_PCSR).

When a peripheral clock is disabled, the clock is immediately stopped. The peripheral clocks are automatically disabled after a reset.

In order to stop a peripheral, it is recommended that the system software wait until the peripheral has executed its last programmed operation before disabling the clock. This is to avoid data corruption or erroneous behavior of the system.

The bit number within the Peripheral Clock Control registers (PMC_PCER, PMC_PCDR, and PMC_PCSR) is the Peripheral Identifier defined at the product level. Generally, the bit number corresponds to the interrupt source number assigned to the peripheral.

27.7 Free Running Processor Clock

The free running processor clock (FCLK) used for sampling interrupts and clocking debug blocks ensures that interrupts can be sampled, and sleep events can be traced while the processor is sleeping. It is connected to Master Clock (MCK).

27.8 Programmable Clock Output Controller

The PMC controls three signals to be output on external pins, PCKx. Each signal can be independently programmed via the PMC_PCKx registers.

PCKx can be independently selected between the Slow Clock (SLCK), the Main Clock (MAINCK), the PLLA Clock (PLLACK), the UTMI PLL Clock (UPLLCK/2) and the Master Clock (MCK) by writing the CSS field in PMC_PCKx. Each output signal can also be divided by a power of 2 between 1 and 64 by writing the PRES (Prescaler) field in PMC_PCKx.

Each output signal can be enabled and disabled by writing 1 in the corresponding bit, PCKx of PMC_SCER and PMC_SCDR, respectively. The status of the active programmable output clocks are given in the PCKx bits of PMC_SCSR (System Clock Status Register).

Moreover, like the PCK, a status bit in PMC_SR indicates that the Programmable Clock is actually what has been programmed in the Programmable Clock registers.

As the Programmable Clock Controller does not manage with glitch prevention when switching clocks, it is strongly recommended to disable the Programmable Clock before any configuration change and to re-enable it after the change is actually performed.

27.9 Fast Startup

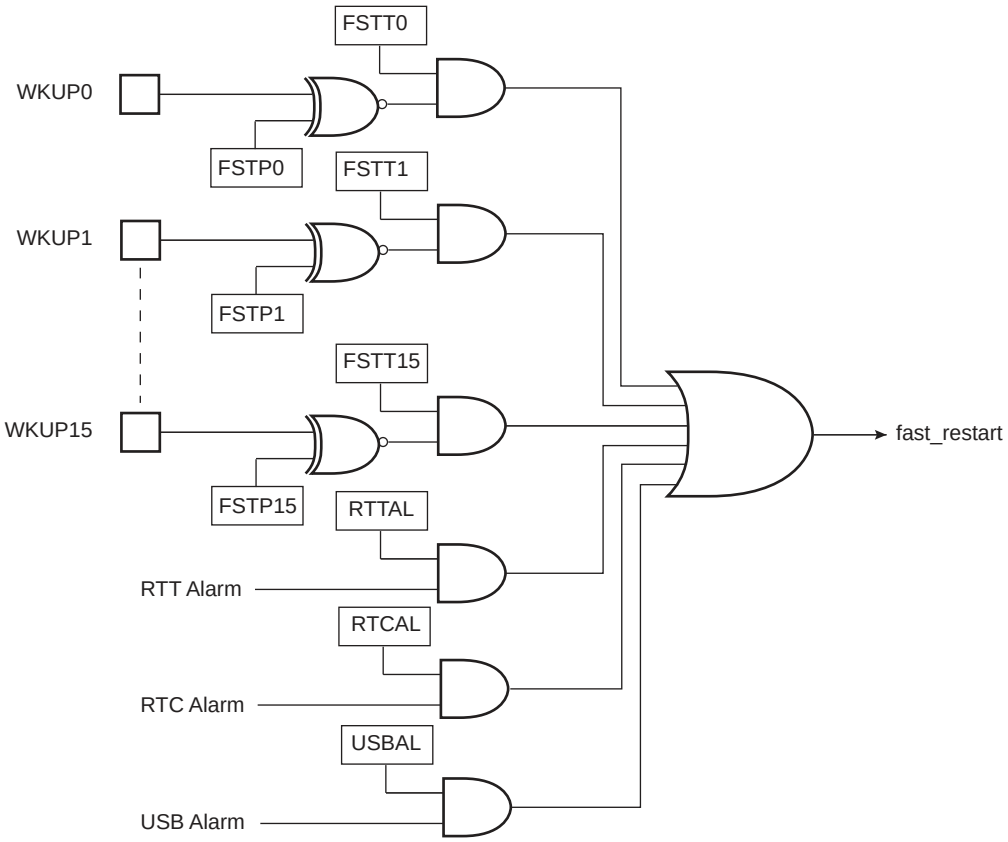
The SAM3U device allows the processor to restart in less than six microseconds while the device is in Wait mode. The system enters Wait mode either by writing the WAITMODE bit at 1 in the PMC Clock Generator Main Oscillator Register (CKGR_MOR), of by executing the WaitForEvent (WFE) instruction of the processor while the LPM bit is at 1 in the PMC Fast Startup Mode Register (PMC_FSMR).

Important: Prior to asserting any WFE instruction to the processor, the internal sources of wakeup provided by RTT, RTC and USB must be cleared and verified too, that none of the enabled external wakeup inputs (WKUP) hold an active polarity.

A Fast Startup is enabled upon the detection of a programmed level on one of the 19 wake-up inputs (WKUP) or upon an active alarm form the RTC, RTT and USB High Speed Device Controller. The polarity of the 16 wake-up inputs is programmable by writing the PMC Fast Startup Polarity Register (PMC_FSPR).

The Fast Restart circuitry, as shown in Figure 27-3, is fully asynchronous and provides a fast startup signal to the Power Management Controller. As soon as the fast startup signal is asserted, this automatically restarts the embedded 4/8/12 MHz Fast RC oscillator.

Figure 27-3. Fast Startup Circuitry



Each wake-up input pin and alarm can be enabled to generate a Fast Startup event by setting the corresponding bit in the Fast Startup Mode Register (PMC_FSMR).

The user interface does not provide any status for Fast Startup, but the user can easily recover this information by reading the PIO Controller and the status registers of the RTC, RTT and USB High Speed Device Controller.

27.10 Clock Failure Detector

The clock failure detector allows to monitor the 3 to 20 MHz Crystal Oscillator and to detect an eventual defect of this oscillator (for example if the crystal is disconnected).

The clock failure detector can be enabled or disabled by means of the CFDEN bit in the PMC Clock Generator Main Oscillator Register (CKGR_MOR). After reset, the detector is disabled. However, if the 3 to 20 MHz Crystal Oscillator is disabled, the clock failure detector is disabled too.

A failure is detected by means of a counter incrementing on the 3 to 20 MHz Crystal oscillator or Ceramic Resonator-based oscillator clock edge and timing logic clocked on the slow clock RC oscillator controlling the counter. The counter is cleared when the slow clock RC oscillator signal is low and enabled when the slow clock RC oscillator is high. Thus the failure detection time is one slow clock RC oscillator clock period. If, during the high level period of slow clock RC oscillator, less than eight fast crystal clock periods have been counted, then a failure is declared.

If a failure of the 3 to 20 MHz Crystal Oscillator clock is detected, the CFDEV flag is set in the PMC Status Register (PMC_SR), and can generate an interrupt if it is not masked. The interrupt remains active until a read operation in the PMC_SR. The user can know the status of the clock failure detector at any time by reading the CFDS bit in the PMC_SR.

If the 3 to 20 MHz Crystal Oscillator clock is selected as the source clock of MAINCK (MOSCSEL = 1), and if the Master Clock Source is PLLACK or UPLLCK (CSS = 2 or 3), then a clock failure detection switches automatically the Master Clock on MAINCK. Then whatever the PMC configuration is, a clock failure detection switches automatically MAINCK on the 4/8/12 MHz Fast RC Oscillator clock. If the Fast RC Oscillator is disabled when a clock failure detection occurs, it is automatically re-enabled by the clock failure detection mechanism.

A clock failure detection activates a fault output that is connected to the Pulse Width Modulator (PWM) Controller. With this connection, the PWM controller is able to force its outputs and to protect the driven device, if a clock failure is detected. This fault output remains active until the defect is detected and until it is not cleared by the bit FOCLR in the PMC Fault Output Clear Register (PMC_FOCR).

It takes two slow clock RC oscillator cycles to detect and switch from the 3 to 20 MHz Crystal or Ceramic Resonator-based oscillator to the 4/8/12 MHz Fast RC Oscillator if the Master Clock source is Main Clock, or three slow clock RC oscillator cycles if the Master Clock source is PLL.

The user can know the status of the fault output at any time by reading the FOS bit in the PMC_SR.

27.11 Programming Sequence

1. Enabling the Main Oscillator:

   The main oscillator is enabled by setting the MOSCXTEN bit in the CKGR_MOR. The user can define a start-up time. This can be achieved by writing a value in the MOSCXTST field in the CKGR_MOR.

   Once this register has been correctly configured, the user must wait for MOSCXTS field in the PMC_SR to be set. This can be done either by polling the status register or by waiting the interrupt line to be raised if the associated interrupt to MOSCXTS has been enabled in the PMC_IER.

   Start Up Time = 8 * MOSCXTST / SLCK = 56 Slow Clock Cycles.

   So, the main oscillator will be enabled (MOSCXTS bit set) after 56 Slow Clock Cycles.

2. Checking the Main Oscillator Frequency (Optional):

   In some situations the user may need an accurate measure of the main clock frequency. This measure can be accomplished via the CKGR_MCFR.

   Once the MAINFRDY field is set in CKGR_MCFR, the user may read the MAINF field in CKGR_MCFR. This provides the number of main clock cycles within sixteen slow clock cycles.

3. Setting PLL and Divider:

   All parameters needed to configure PLLA and the divider are located in the CKGR_PLLAR.

   The DIVA field is used to control the divider itself. It must be set to 1 when PLLA is used. By default, DIVA parameter is set to 0 which means that the divider is turned off.

   The MULA field is the PLLA multiplier factor. This parameter can be programmed between 0 and 2047. If MULA is set to 0, PLLA will be turned off, otherwise the PLLA output frequency is PLLA input frequency multiplied by (MULA + 1).

   The PLLACOUNT field specifies the number of slow clock cycles before LOCKA bit is set in the PMC_SR after CKGR_PLLAR has been written.

   Once the CKGR_PLLA register has been written, the user must wait for the LOCKA bit to be set in the PMC_SR. This can be done either by polling the status register or by waiting the interrupt line to be raised if the associated interrupt to LOCKA has been enabled in the PMC_IER. All parameters in CKGR_PLLAR can be programmed in a single write operation. If at some stage one of the following parameters, MULA, DIVA is modified, LOCKA bit will go low to indicate that PLLA is not ready yet. When PLLA is locked, LOCKA will be set again. The user is constrained to wait for LOCKA bit to be set before using the PLLA output clock.

4. Selection of Master Clock and Processor Clock

   The Master Clock and the Processor Clock are configurable via the PMC_MCKR.

   The CSS field is used to select the Master Clock divider source. By default, the selected clock source is main clock.

   The PRES field is used to control the Master Clock prescaler. The user can choose between different values. Master Clock output is prescaler input divided by PRES parameter. By default, PRES parameter is set to 1 which means that master clock is equal to main clock.

   Once the PMC_MCKR has been written, the user must wait for the MCKRDY bit to be set in the PMC_SR. This can be done either by polling the status register or by waiting for the interrupt line to be raised if the associated interrupt to MCKRDY has been enabled in the PMC_IER.

The PMC_MCKR must not be programmed in a single write operation. The preferred programming sequence for the PMC_MCKR is as follows:

If a new value for CSS field corresponds to PLL Clock,

a. Program PMC_MCKR.PRES field
b. Wait for PMC_SR.MCKRDY bit to be set
c. Program PMC_MCKR.CSS field
d. Wait for PMC_SR.MCKRDY bit to be set

If a new value for CSS field corresponds to Main Clock or Slow Clock,

a. Program PMC_MCKR.CSS field
b. Wait for PMC_SR.MCKRDY bit to be set
c. Program PMC_MCKR.PRES field
d. Wait for PMC_SR.MCKRDY bit to be set

If at some stage one of the following parameters, CSS or PRES, is modified, the MCKRDY bit will go low to indicate that the Master Clock and the Processor Clock are not ready yet. The user must wait for MCKRDY bit to be set again before using the Master and Processor Clocks.

Note: IF PLLx clock was selected as the Master Clock and the user decides to modify it by writing in CKGR_PLLR, the MCKRDY flag will go low while PLL is unlocked. Once PLL is locked again, LOCK goes high and MCKRDY is set. While PLL is unlocked, the Master Clock selection is automatically changed to Slow Clock. For further information, see Section 27.12.2 “Clock Switching Waveforms” on page 460.

Code Example:

```
write_register(PMC_MCKR,0x00000001)
wait (MCKRDY=1)
write_register(PMC_MCKR,0x00000011)
wait (MCKRDY=1)
```

The Master Clock is main clock divided by 16.

The Processor Clock is the Master Clock.

5. Selection of Programmable Clocks

Programmable clocks are controlled via registers; PMC_SCER, PMC_SCDR and PMC_SCSR.

Programmable clocks can be enabled and/or disabled via the PMC_SCER and PMC_SCDR. Three programmable clocks can be enabled or disabled. The PMC_SCSR provides a clear indication as to which programmable clock is enabled. By default all programmable clocks are disabled.

PMC_PCKx registers are used to configure programmable clocks.

The CSS field is used to select the programmable clock divider source. Four clock options are available: main clock, slow clock, PLLACK and UPLLCK. By default, the clock source selected is main clock.

The PRES field is used to control the programmable clock prescaler. It is possible to choose between different values (1, 2, 4, 8, 16, 32, 64). Programmable clock output is prescaler input divided by PRES parameter. By default, the PRES parameter is set to 0 which means that master clock is equal to slow clock.

Once the PMC_PCKx register has been programmed, The corresponding programmable clock must be enabled and the user is constrained to wait for the PCKRDYx bit to be set in the PMC_SR. This can be done either by polling the status register or by waiting the interrupt line to be raised if the associated interrupt to PCKRDYx has been enabled in the PMC_IER. All parameters in PMC_PCKx can be programmed in a single write operation.

If the CSS and PRES parameters are to be modified, the corresponding programmable clock must be disabled first. The parameters can then be modified. Once this has been done, the user must re-enable the programmable clock and wait for the PCKRDYx bit to be set.

Code Example:

```
write_register(PMC_PCK0,0x00000015)
```

Programmable clock 0 is main clock divided by 32.

6. Enabling Peripheral Clocks

Once all of the previous steps have been completed, the peripheral clocks can be enabled and/or disabled via registers PMC_PCER and PMC_PCDR.

15 peripheral clocks can be enabled or disabled. The PMC_PCSR provides a clear view as to which peripheral clock is enabled.

Note: Each enabled peripheral clock corresponds to Master Clock.

Code Examples:

```
write_register(PMC_PCER,0x00000110)
```

Peripheral clocks 4 and 8 are enabled.

```
write_register(PMC_PCDR,0x00000010)
```

Peripheral clock 4 is disabled.

27.12 Clock Switching Details

27.12.1 Master Clock Switching Timings

Table 27-1 and Table 27-2 give the worst case timings required for the Master Clock to switch from one selected clock to another one. This is in the event that the prescaler is de-activated. When the prescaler is activated, an additional time of 64 clock cycles of the new selected clock has to be added.

Table 27-1. Clock Switching Timings (Worst Case)

From / To	Main Clock	SLCK	PLL Clock
Main Clock	–	4 x SLCK + 2.5 x Main Clock	3 x PLL Clock + 4 x SLCK + 1 x Main Clock
SLCK	0.5 x Main Clock + 4.5 x SLCK	–	3 x PLL Clock + 5 x SLCK
PLL Clock	0.5 x Main Clock + 4 x SLCK + PLLCOUNT x SLCK + 2.5 x PLLx Clock	2.5 x PLL Clock + 5 x SLCK + PLLCOUNT x SLCK	2.5 x PLL Clock + 4 x SLCK + PLLCOUNT x SLCK

Notes: 1. PLL designates either the PLLA or the UPLL Clock.
2. PLLCOUNT designates either PLLACOUNT or UPLLCOUNT.

Table 27-2. Clock Switching Timings between Two PLLs (Worst Case)

From / To	PLLA Clock	UPLL Clock
PLLA Clock	2.5 x PLLA Clock + 4 x SLCK + PLLACOUNT x SLCK	3 x PLLA Clock + 4 x SLCK + 1.5 x PLLA Clock
UPLL Clock	3 x UPLL Clock + 4 x SLCK + 1.5 x UPLL Clock	2.5 x UPLL Clock + 4 x SLCK + UPLLCOUNT x SLCK

27.12.2 Clock Switching Waveforms

Figure 27-4. Switch Master Clock from Slow Clock to PLL Clock

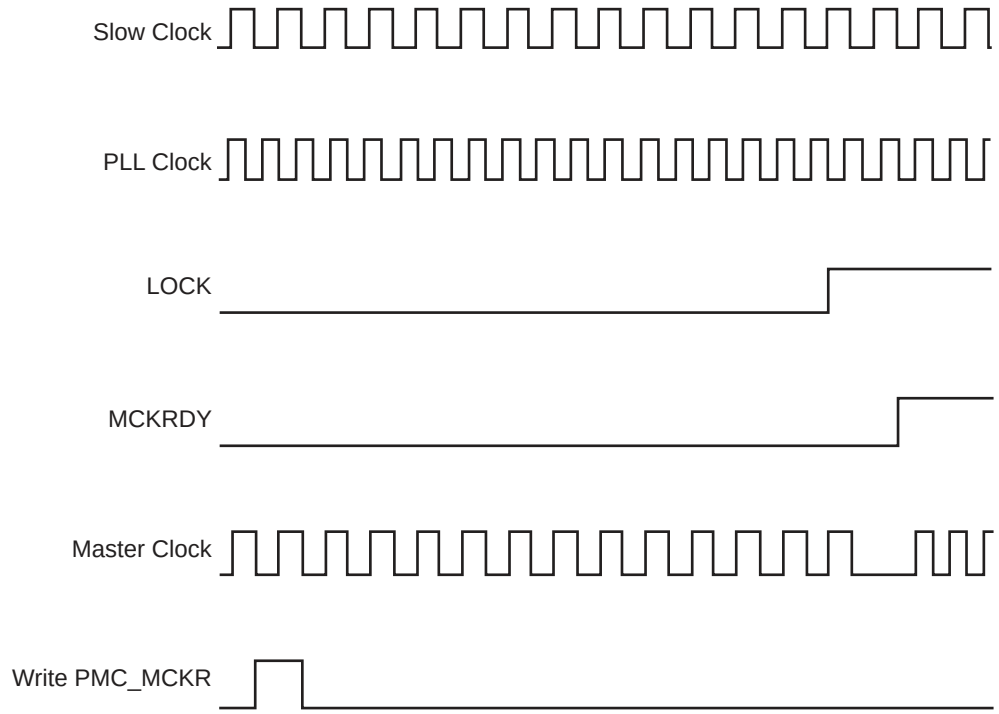


Figure 27-5. Switch Master Clock from Main Clock to Slow Clock

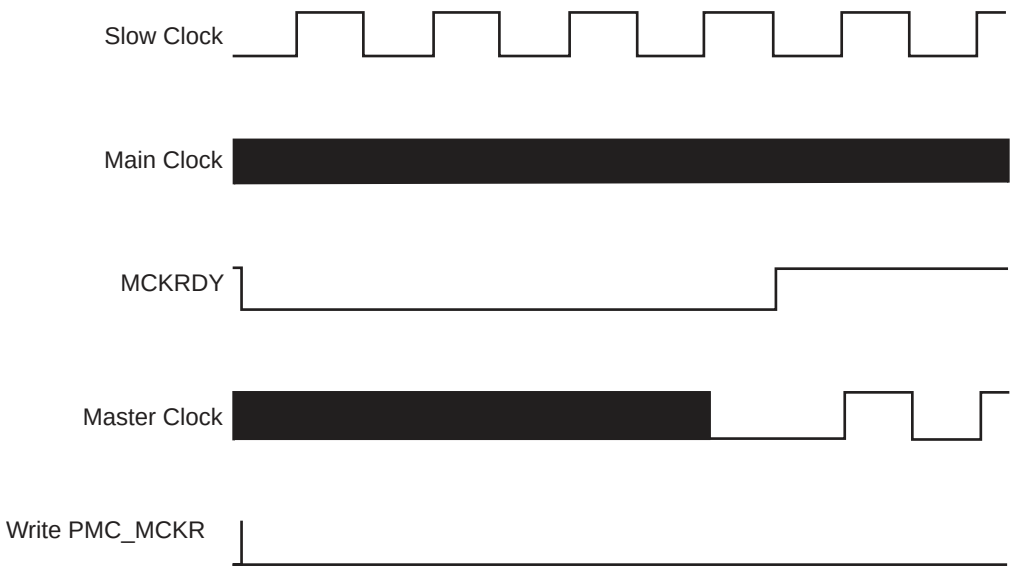


Figure 27-6. Change PLLA Programming

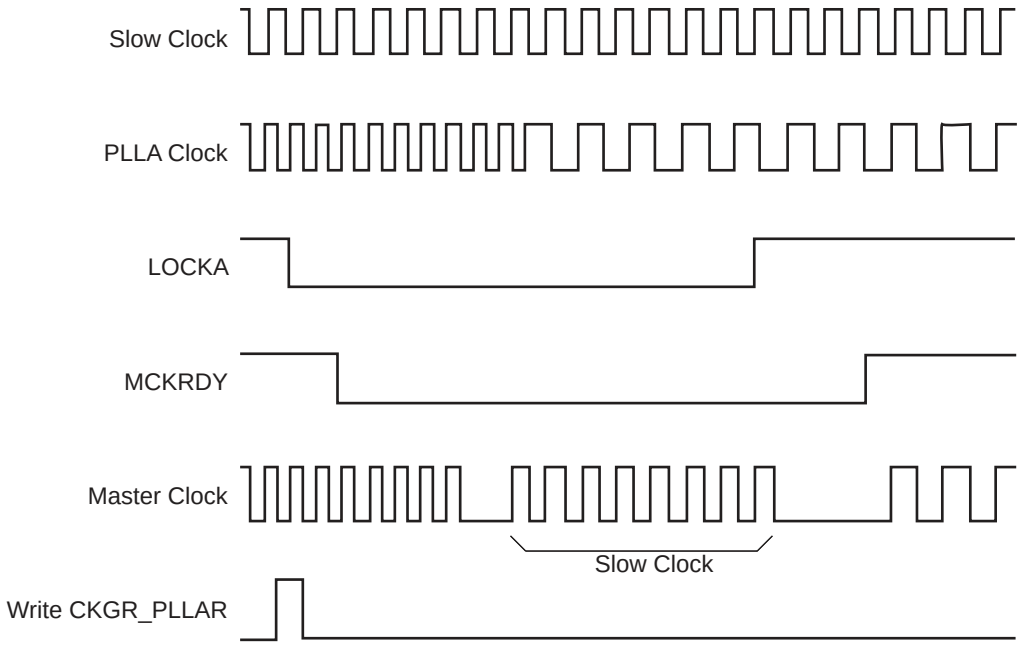
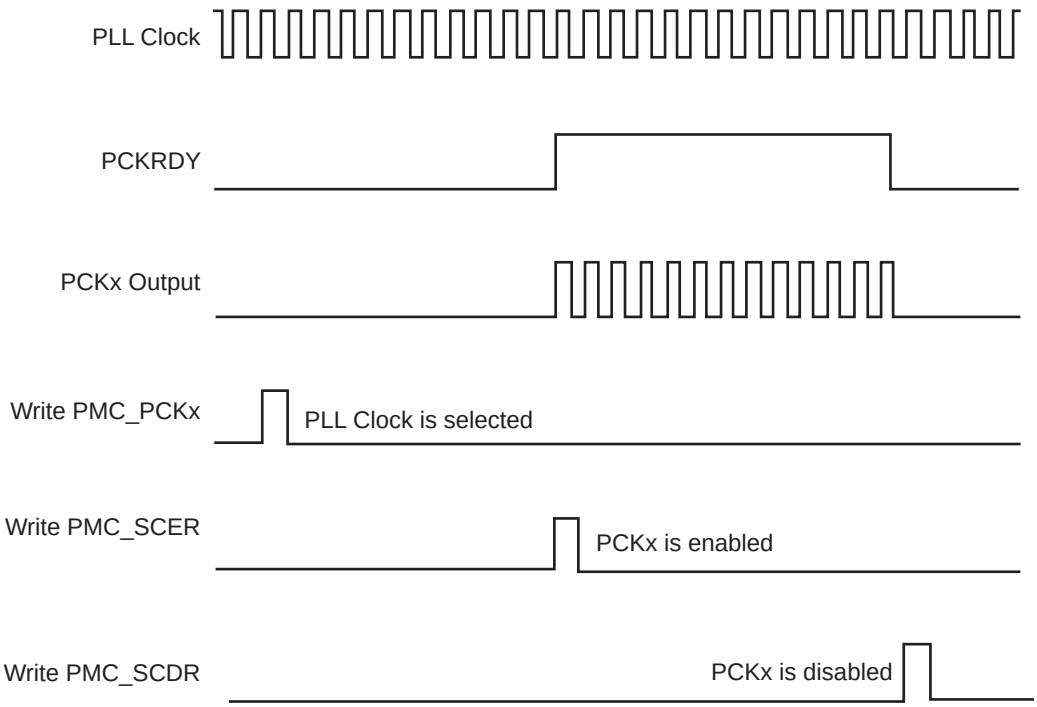


Figure 27-7. Programmable Clock Output Programming



27.13 Register Write Protection

To prevent any single software error from corrupting PMC behavior, certain registers in the address space can be write-protected by setting the WPEN bit in the PMC Write Protection Mode Register (PMC_WPMR).

If a write access to a write-protected register is detected, the WPVS bit in the PMC Write Protection Status Register (PMC_WPSR) is set and the field WPVSRC indicates the register in which the write access has been attempted.

The WPVS bit is automatically cleared after reading the PMC_WPSR.

The following registers can be write-protected:

- “PMC System Clock Enable Register”
- “PMC System Clock Disable Register”
- “PMC Peripheral Clock Enable Register”
- “PMC Peripheral Clock Disable Register”
- “PMC UTMI Clock Configuration Register”
- “PMC Clock Generator Main Oscillator Register”
- “PMC Clock Generator PLLA Register”
- “PMC Programmable Clock Register”
- “PMC Fast Startup Mode Register”
- “PMC Fast Startup Polarity Register”

27.14 Power Management Controller (PMC) User Interface

Table 27-3. Register Mapping

Offset	Register	Name	Access	Reset
0x0000	System Clock Enable Register	PMC_SCER	Write-only	–
0x0004	System Clock Disable Register	PMC_SCDR	Write-only	–
0x0008	System Clock Status Register	PMC _SCSR	Read-only	0x0000_0001
0x000C	Reserved	–	–	–
0x0010	Peripheral Clock Enable Register	PMC _PCER	Write-only	–
0x0014	Peripheral Clock Disable Register	PMC_PCDR	Write-only	–
0x0018	Peripheral Clock Status Register	PMC_PCSR	Read-only	0x0000_0000
0x001C	UTMI Clock Register	CKGR_UCKR	Read/Write	0x1020_0800
0x0020	Main Oscillator Register	CKGR_MOR	Read/Write	0x0000_0001
0x0024	Main Clock Frequency Register	CKGR_MCFR	Read-only	0x0000_0000
0x0028	PLLA Register	CKGR_PLLAR	Read/Write	0x0000_3F00
0x002C	Reserved	–	–	–
0x0030	Master Clock Register	PMC_MCKR	Read/Write	0x0000_0001
0x0034–0x003C	Reserved	–	–	–
0x0040	Programmable Clock 0 Register	PMC_PCK0	Read/Write	0x0000_0000
0x0044	Programmable Clock 1 Register	PMC_PCK1	Read/Write	0x0000_0000
0x0048	Programmable Clock 2 Register	PMC_PCK2	Read/Write	0x0000_0000
0x004C–0x005C	Reserved	–	–	–
0x0060	Interrupt Enable Register	PMC_IER	Write-only	–
0x0064	Interrupt Disable Register	PMC_IDR	Write-only	–
0x0068	Status Register	PMC_SR	Read-only	0x0001_0008
0x006C	Interrupt Mask Register	PMC_IMR	Read-only	0x0000_0000
0x0070	Fast Startup Mode Register	PMC_FSMR	Read/Write	0x0000_0000
0x0074	Fast Startup Polarity Register	PMC_FSPR	Read/Write	0x0000_0000
0x0078	Fault Output Clear Register	PMC_FOCR	Write-only	–
0x007C–0x00FC	Reserved	–	–	–
0xE4	Write Protection Mode Register	PMC_WPMR	Read/Write	0x0000_0000
0xE8	Write Protection Status Register	PMC_WPSR	Read-only	0x0000_0000

27.14.1 PMC System Clock Enable Register

Name: PMC_SCER

Address: 0x400E0400

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	PCK2	PCK1	PCK0
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **PCKx: Programmable Clock x Output Enable**

0: No effect.

1: Enables the corresponding Programmable Clock output.

27.14.2 PMC System Clock Disable Register

Name: PMC_SCDR

Address: 0x400E0404

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	PCK2	PCK1	PCK0
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **PCKx: Programmable Clock x Output Disable**

0: No effect.

1: Disables the corresponding Programmable Clock output.

27.14.3 PMC System Clock Status Register

Name: PMC_SCSR

Address: 0x400E0408

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	PCK2	PCK1	PCK0
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **PCKx: Programmable Clock x Output Status**

0: The corresponding Programmable Clock output is disabled.

1: The corresponding Programmable Clock output is enabled.

27.14.4 PMC Peripheral Clock Enable Register

Name: PMC_PCER

Address: 0x400E0410

Access: Write-only

31	30	29	28	27	26	25	24
PID31	PID30	PID29	PID28	PID27	PID26	PID25	PID24
23	22	21	20	19	18	17	16
PID23	PID22	PID21	PID20	PID19	PID18	PID17	PID16
15	14	13	12	11	10	9	8
PID15	PID14	PID13	PID12	PID11	PID10	PID9	PID8
7	6	5	4	3	2	1	0
PID7	PID6	PID5	PID4	PID3	PID2	-	-

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **PIDx: Peripheral Clock x Enable**

0: No effect.

1: Enables the corresponding peripheral clock.

Note: PID2 to PID31 refer to identifiers as defined in Section 11.1 ”Peripheral Identifiers”.

Note: Programming the control bits of the Peripheral ID that are not implemented has no effect on the behavior of the PMC.

27.14.5 PMC Peripheral Clock Disable Register

Name: PMC_PCDR

Address: 0x400E0414

Access: Write-only

31	30	29	28	27	26	25	24
PID31	PID30	PID29	PID28	PID27	PID26	PID25	PID24
23	22	21	20	19	18	17	16
PID23	PID22	PID21	PID20	PID19	PID18	PID17	PID16
15	14	13	12	11	10	9	8
PID15	PID14	PID13	PID12	PID11	PID10	PID9	PID8
7	6	5	4	3	2	1	0
PID7	PID6	PID5	PID4	PID3	PID2	-	-

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **PIDx: Peripheral Clock x Disable**

0: No effect.

1: Disables the corresponding peripheral clock.

Note: PID2 to PID31 refer to identifiers as defined in Section 11.1 ”Peripheral Identifiers”.

27.14.6 PMC Peripheral Clock Status Register

Name: PMC_PCSR

Address: 0x400E0418

Access: Read-only

31	30	29	28	27	26	25	24
PID31	PID30	PID29	PID28	PID27	PID26	PID25	PID24
23	22	21	20	19	18	17	16
PID23	PID22	PID21	PID20	PID19	PID18	PID17	PID16
15	14	13	12	11	10	9	8
PID15	PID14	PID13	PID12	PID11	PID10	PID9	PID8
7	6	5	4	3	2	1	0
PID7	PID6	PID5	PID4	PID3	PID2	–	–

- **PIDx: Peripheral Clock x Status**

0: The corresponding peripheral clock is disabled.

1: The corresponding peripheral clock is enabled.

Note: PID2 to PID31 refer to identifiers as defined in Section 11.1 "Peripheral Identifiers".

27.14.7 PMC UTMI Clock Configuration Register

Name: CKGR_UCKR

Address: 0x400E041C

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–		–	–	–	–

23	22	21	20	19	18	17	16
UPLLCOUNT				–	–	–	UPLLEN

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **UPLLEN: UTMI PLL Enable**

0: The UTMI PLL is disabled.

1: The UTMI PLL is enabled.

When UPLLEN is set, the LOCKU flag is set once the UTMI PLL startup time is achieved.

- **UPLLCOUNT: UTMI PLL Start-up Time**

Specifies the number of Slow Clock cycles multiplied by 8 for the UTMI PLL start-up time.

27.14.8 PMC Clock Generator Main Oscillator Register

Name: CKGR_MOR

Address: 0x400E0420

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	CFDEN	MOSCSEL

23	22	21	20	19	18	17	16
KEY							

15	14	13	12	11	10	9	8
MOSCXTST							

7	6	5	4	3	2	1	0
–	MOSCRCF			MOSCRCEN	WAITMODE	MOSCXTBY	MOSCXTEN

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **KEY: Password**

Should be written at value 0x37. Writing any other value in this field aborts the write operation.

- **MOSCXTEN: Main Crystal Oscillator Enable**

A crystal must be connected between XIN and XOUT.

0: The Main Crystal Oscillator is disabled.

1: The Main Crystal Oscillator is enabled. MOSCXTBY must be set to 0.

When MOSCXTEN is set, the MOSCXTS flag is set once the Main Crystal Oscillator startup time is achieved.

- **MOSCXTBY: Main Crystal Oscillator Bypass**

0: No effect.

1: The Main Crystal Oscillator is bypassed. MOSCXTEN must be set to 0. An external clock must be connected on XIN.

When MOSCXTBY is set, the MOSCXTS flag in PMC_SR is automatically set.

Clearing MOSCXTEN and MOSCXTBY bits allows resetting the MOSCXTS flag.

- **WAITMODE: Wait Mode Command**

0: No effect.

1: Enters the device in Wait mode.

Note: The bit WAITMODE is write-only

- **MOSCRCEN: Main On-Chip RC Oscillator Enable**

0: The Main On-Chip RC Oscillator is disabled.

1: The Main On-Chip RC Oscillator is enabled.

When MOSCRCEN is set, the MOSCRCS flag is set once the Main On-Chip RC Oscillator startup time is achieved.

- **MOSCRCF: Main On-Chip RC Oscillator Frequency Selection**

At start-up, the Main On-Chip RC Oscillator frequency is 4 MHz.

0: The Fast RC Oscillator Frequency is at 4 MHz (default).

1: The Fast RC Oscillator Frequency is at 8 MHz.

2: The Fast RC Oscillator Frequency is at 12 MHz.

3: Reserved.

- **MOSCXTST: Main Crystal Oscillator Start-up Time**

Specifies the number of Slow Clock cycles multiplied by 8 for the Main Crystal Oscillator start-up time.

- **MOSCSEL: Main Oscillator Selection**

0: The Main On-Chip RC Oscillator is selected.

1: The Main Crystal Oscillator is selected.

- **CFDEN: Clock Failure Detector Enable**

0: The Clock Failure Detector is disabled.

1: The Clock Failure Detector is enabled.

27.14.9 PMC Clock Generator Main Clock Frequency Register

Name: CKGR_MCFR

Address: 0x400E0424

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	MAINFRDY

15	14	13	12	11	10	9	8
MAINF							

7	6	5	4	3	2	1	0
MAINF							

- **MAINF: Main Clock Frequency**

Gives the number of Main Clock cycles within 16 Slow Clock periods.

- **MAINFRDY: Main Clock Ready**

0: MAINF value is not valid or the Main Oscillator is disabled.

1: The Main Oscillator has been enabled previously and MAINF value is available.

27.14.10 PMC Clock Generator PLLA Register

Name: CKGR_PLLAR

Address: 0x400E0428

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	1	–	–	MULA		

23	22	21	20	19	18	17	16
MULA							

15	14	13	12	11	10	9	8
–	–	PLLACOUNT					

7	6	5	4	3	2	1	0
DIVA							

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

Possible limitations on PLLA input frequencies and multiplier factors should be checked before using the PMC.

Warning: Bit 29 must always be set to 1 when programming the CKGR_PLLAR.

- **DIVA: Divider**

Value	Name	Description
0	0	Divider output is 0
1	BYPASS	Divider is bypassed
2–255	–	Divider output is the selected clock divided by DIVA

- **PLLACOUNT: PLLA Counter**

Specifies the number of Slow Clock cycles x8 before the LOCKA bit is set in PMC_SR after CKGR_PLLAR is written.

- **MULA: PLLA Multiplier**

0: The PLLA is deactivated.

1–2047: The PLLA clock frequency is the PLLA input frequency multiplied by MULA + 1.

27.14.11 PMC Master Clock Register

Name: PMC_MCKR

Address: 0x400E0430

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	UPLLDIV	–	–	–	–	–
7	6	5	4	3	2	1	0
–	PRES			–	–	CSS	

- **CSS: Master Clock Source Selection**

Value	Name	Description
0	SLOW_CLK	Slow Clock is selected
1	MAIN_CLK	Main Clock is selected
2	PLLA_CLK	PLLA Clock is selected
3	UPLL_CLK	UPLL/2 Clock is selected

- **PRES: Processor Clock Prescaler**

Value	Name	Description
0	CLK_1	Selected clock
1	CLK_2	Selected clock divided by 2
2	CLK_4	Selected clock divided by 4
3	CLK_8	Selected clock divided by 8
4	CLK_16	Selected clock divided by 16
5	CLK_32	Selected clock divided by 32
6	CLK_64	Selected clock divided by 64
7	CLK_3	Selected clock divided by 3

- **UPLLDIV: UPLL Divider**

0: UPLLDIV = 1 (clock is not divided).

1: UPLLDIV = 2 (clock is divided by 2).

UPLLDIV must be set (clock divided by 2) when UPLL is selected as source of clock for MCK or PCK.

27.14.12 PMC Programmable Clock Register

Name: PMC_PCKx

Address: 0x400E0440

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	PRES			–	CSS		

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **CSS: Master Clock Source Selection**

Value	Name	Description
0	SLOW_CLK	Slow Clock is selected
1	MAIN_CLK	Main Clock is selected
2	PLLA_CLK	PLLA Clock is selected
3	UPLL_CLK	UPLL/2 Clock is selected
4	MCK	Master Clock is selected

- **PRES: Programmable Clock Prescaler**

Value	Name	Description
0	CLK_1	Selected clock
1	CLK_2	Selected clock divided by 2
2	CLK_4	Selected clock divided by 4
3	CLK_8	Selected clock divided by 8
4	CLK_16	Selected clock divided by 16
5	CLK_32	Selected clock divided by 32
6	CLK_64	Selected clock divided by 64

27.14.13 PMC Interrupt Enable Register

Name: PMC_IER

Address: 0x400E0460

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	CFDEV	MOSCRCS	MOSCSELS
15	14	13	12	11	10	9	8
–	–	–	–	–	PCKRDY2	PCKRDY1	PCKRDY0
7	6	5	4	3	2	1	0
–	LOCKU	–	–	MCKRDY	–	LOCKA	MOSCXTS

0: No effect.

1: Enables the corresponding interrupt.

- **MOSCXTS: Main Crystal Oscillator Status Interrupt Enable**
- **LOCKA: PLL A Lock Interrupt Enable**
- **MCKRDY: Master Clock Ready Interrupt Enable**
- **LOCKU: UTMI PLL Lock Interrupt Enable**
- **PCKRDYx: Programmable Clock Ready x Interrupt Enable**
- **MOSCSELS: Main Oscillator Selection Status Interrupt Enable**
- **MOSCRCS: Main On-Chip RC Status Interrupt Enable**
- **CFDEV: Clock Failure Detector Event Interrupt Enable**

27.14.14 PMC Interrupt Disable Register

Name: PMC_IDR

Address: 0x400E0464

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	CFDEV	MOSCRCS	MOSCSELS
15	14	13	12	11	10	9	8
–	–	–	–	–	PCKRDY2	PCKRDY1	PCKRDY0
7	6	5	4	3	2	1	0
–	LOCKU	–	–	MCKRDY	–	LOCKA	MOSCXTS

0: No effect.

1: Disables the corresponding interrupt.

- **MOSCXTS: Main Crystal Oscillator Status Interrupt Disable**
- **LOCKA: PLL A Lock Interrupt Disable**
- **MCKRDY: Master Clock Ready Interrupt Disable**
- **LOCKU: UTMI PLL Lock Interrupt Disable**
- **PCKRDYx: Programmable Clock Ready x Interrupt Disable**
- **MOSCSELS: Main Oscillator Selection Status Interrupt Disable**
- **MOSCRCS: Main On-Chip RC Status Interrupt Disable**
- **CFDEV: Clock Failure Detector Event Interrupt Disable**

27.14.15 PMC Status Register

Name: PMC_SR

Address: 0x400E0468

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	FOS	CFDS	CFDEV	MOSCRCS	MOSCSELS

15	14	13	12	11	10	9	8
–	–	–	–	–	PCKRDY2	PCKRDY1	PCKRDY0

7	6	5	4	3	2	1	0
OSCSELS	LOCKU	–	–	MCKRDY	–	LOCKA	MOSCXTS

- **MOSCXTS: Main XTAL Oscillator Status**

0: Main XTAL oscillator is not stabilized.

1: Main XTAL oscillator is stabilized.

- **LOCKA: PLL A Lock Status**

0: PLL A is not locked

1: PLL A is locked.

- **MCKRDY: Master Clock Status**

0: Master Clock is not ready.

1: Master Clock is ready.

- **LOCKU: UTMI PLL Lock Status**

0: UTMI PLL is not locked.

1: UTMI PLL is locked.

- **OSCSELS: Slow Clock Oscillator Selection**

0: Internal slow clock RC oscillator is selected.

1: External slow clock 32 kHz oscillator is selected.

- **PCKRDYx: Programmable Clock Ready Status**

0: Programmable Clock x is not ready.

1: Programmable Clock x is ready.

- **MOSCSELS: Main Oscillator Selection Status**

0: Selection is in progress.

1: Selection is done.

- **MOSCRCS: Main On-Chip RC Oscillator Status**

0: Main on-chip RC oscillator is not stabilized.

1: Main on-chip RC oscillator is stabilized.

- **CFDEV: Clock Failure Detector Event**

0: No clock failure detection of the main on-chip RC oscillator clock has occurred since the last read of PMC_SR.

1: At least one clock failure detection of the main on-chip RC oscillator clock has occurred since the last read of PMC_SR.

- **CFDS: Clock Failure Detector Status**

0: A clock failure of the main on-chip RC oscillator clock is not detected.

1: A clock failure of the main on-chip RC oscillator clock is detected.

- **FOS: Clock Failure Detector Fault Output Status**

0: The fault output of the clock failure detector is inactive.

1: The fault output of the clock failure detector is active.

27.14.16 PMC Interrupt Mask Register

Name: PMC_IMR

Address: 0x400E046C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	CFDEV	MOSCRCS	MOSCSELS
15	14	13	12	11	10	9	8
–	–	–	–	–	PCKRDY2	PCKRDY1	PCKRDY0
7	6	5	4	3	2	1	0
–	LOCKU	–	–	MCKRDY	–	LOCKA	MOSCXTS

0: The corresponding interrupt is disabled.

1: The corresponding interrupt is enabled.

- **MOSCXTS: Main Crystal Oscillator Status Interrupt Mask**
- **LOCKA: PLL A Lock Interrupt Mask**
- **MCKRDY: Master Clock Ready Interrupt Mask**
- **LOCKU: UTMI PLL Lock Interrupt Mask**
- **PCKRDYx: Programmable Clock Ready x Interrupt Mask**
- **MOSCSELS: Main Oscillator Selection Status Interrupt Mask**
- **MOSCRCS: Main On-Chip RC Status Interrupt Mask**
- **CFDEV: Clock Failure Detector Event Interrupt Mask**

27.14.17 PMC Fast Startup Mode Register

Name: PMC_FSMR

Address: 0x400E0470

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	LPM	–	USBAL	RTCAL	RTTAL
15	14	13	12	11	10	9	8
FSTT15	FSTT14	FSTT13	FSTT12	FSTT11	FSTT10	FSTT9	FSTT8
7	6	5	4	3	2	1	0
FSTT7	FSTT6	FSTT5	FSTT4	FSTT3	FSTT2	FSTT1	FSTT0

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **FSTT0 - FSTT15: Fast Startup Input Enable 0 to 15**

0: The corresponding wake up input has no effect on the Power Management Controller.

1: The corresponding wake up input enables a fast restart signal to the Power Management Controller.

- **RTTAL: RTT Alarm Enable**

0: The RTT alarm has no effect on the Power Management Controller.

1: The RTT alarm enables a fast restart signal to the Power Management Controller.

- **RTCAL: RTC Alarm Enable**

0: The RTC alarm has no effect on the Power Management Controller.

1: The RTC alarm enables a fast restart signal to the Power Management Controller.

- **USBAL: USB Alarm Enable**

0: The USB alarm has no effect on the Power Management Controller.

1: The USB alarm enables a fast restart signal to the Power Management Controller.

- **LPM: Low Power Mode**

0: The WaitForInterrupt (WFI) or WaitForEvent (WFE) instruction of the processor makes the processor enter in Idle Mode.

1: The WaitForEvent (WFE) instruction of the processor makes the system enter in Wait Mode.

27.14.18 PMC Fast Startup Polarity Register

Name: PMC_FSPR

Address: 0x400E0474

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
FSTP15	FSTP14	FSTP13	FSTP12	FSTP11	FSTP10	FSTP9	FSTP8
7	6	5	4	3	2	1	0
FSTP7	FSTP6	FSTP5	FSTP4	FSTP3	FSTP2	FSTP1	FSTP0

This register can only be written if the WPEN bit is cleared in the “PMC Write Protection Mode Register”.

- **FSTPx: Fast Startup Input Polarityx**

Defines the active polarity of the corresponding wake up input. If the corresponding wake up input is enabled and at the FSTP level, it enables a fast restart signal.

27.14.19 PMC Fault Output Clear Register

Name: PMC_FOCR

Address: 0x400E0478

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	FOCLR

- **FOCLR: Fault Output Clear**

Clears the clock failure detector fault output.

27.14.20 PMC Write Protection Mode Register

Name: PMC_WPMR

Address: 0x400E04E4

Access: Read/Write

31	30	29	28	27	26	25	24
WPKEY							

23	22	21	20	19	18	17	16
WPKEY							

15	14	13	12	11	10	9	8
WPKEY							

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WPEN

- **WPEN: Write Protection Enable**

0: Disables the write protection if WPKEY corresponds to 0x504D43 (“PMC” in ASCII).

1: Enables the write protection if WPKEY corresponds to 0x504D43 (“PMC” in ASCII).

See Section 27.13 ”Register Write Protection” for the list of registers that can be write-protected.

- **WPKEY: Write Protection Key**

Value	Name	Description
0x504D43	PASSWD	Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

27.14.21 PMC Write Protection Status Register

Name: PMC_WPSR

Address: 0x400E04E8

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
WPVSRC							

15	14	13	12	11	10	9	8
WPVSRC							

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WPVS

- **WPVS: Write Protection Violation Status**

0: No write protection violation has occurred since the last read of the PMC_WPSR.

1: A write protection violation has occurred since the last read of the PMC_WPSR. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protection Violation Source**

When WPVS = 1, WPVSRC indicates the register address offset at which a write access has been attempted.

28. Chip Identifier (CHIPID)

28.1 Description

Chip Identifier registers permit recognition of the device and its revision. These registers provide the sizes and types of the on-chip memories, as well as the set of embedded peripherals.

Two chip identifier registers are embedded: CHIPID_CIDR (Chip ID Register) and CHIPID_EXID (Extension ID). Both registers contain a hard-wired value that is read-only. The first register contains the following fields:

- EXT - shows the use of the extension identifier register
- NVPTYP and NVPSIZ - identifies the type of embedded non-volatile memory and its size
- ARCH - identifies the set of embedded peripherals
- SRAMSIZ - indicates the size of the embedded SRAM
- EPROC - indicates the embedded ARM processor
- VERSION - gives the revision of the silicon

The second register is device-dependent and reads 0 if the bit EXT is 0.

28.2 Embedded Characteristics

- Chip ID Registers
  - Identification of the Device Revision, Sizes of the Embedded Memories, Set of Peripherals, Embedded Processor

Table 28-1. ATSAM3U Chip IDs Register

Chip Name	CHIPID_CIDR	CHIPID_EXID
AT91SAM3U4C (Rev A)	0x28000961	0x0
AT91SAM3U2C (Rev A)	0x280A0761	0x0
AT91SAM3U1C (Rev A)	0x28090561	0x0
AT91SAM3U4E (Rev A)	0x28100961	0x0
AT91SAM3U2E (Rev A)	0x281A0761	0x0
AT91SAM3U1E (Rev A)	0x28190561	0x0

28.3 Chip Identifier (CHIPID) User Interface

Table 28-2. Register Mapping

Offset	Register	Name	Access	Reset
0x0	Chip ID Register	CHIPID_CIDR	Read-only	–
0x4	Chip ID Extension Register	CHIPID_EXID	Read-only	–

28.3.1 Chip ID Register

Name: CHIPID_CIDR

Address: 0x400E0740

Access: Read-only

31	30	29	28	27	26	25	24
EXT	NVPTYP			ARCH			
23	22	21	20	19	18	17	16
ARCH				SRAMSIZ			
15	14	13	12	11	10	9	8
NVPSIZ2				NVPSIZ			
7	6	5	4	3	2	1	0
EPROC			VERSION				

- **VERSION: Version of the Device**

Current version of the device.

- **EPROC: Embedded Processor**

Value	Name	Description
1	ARM946ES	ARM946ES
2	ARM7TDMI	ARM7TDMI
3	CM3	Cortex-M3
4	ARM920T	ARM920T
5	ARM926EJS	ARM926EJS
6	CA5	Cortex-A5
7	CM4	Cortex-M4

- **NVPSIZ: Nonvolatile Program Memory Size**

Value	Name	Description
0	NONE	None
1	8K	8K bytes
2	16K	16K bytes
3	32K	32K bytes
4		Reserved
5	64K	64K bytes
6		Reserved
7	128K	128K bytes
8		Reserved
9	256K	256K bytes
10	512K	512K bytes
11		Reserved
12	1024K	1024K bytes

Value	Name	Description
13		Reserved
14	2048K	2048K bytes
15		Reserved

- **NVPSIZ2: Second Nonvolatile Program Memory Size**

Value	Name	Description
0	NONE	None
1	8K	8K bytes
2	16K	16K bytes
3	32K	32K bytes
4		Reserved
5	64K	64K bytes
6		Reserved
7	128K	128K bytes
8		Reserved
9	256K	256K bytes
10	512K	512K bytes
11		Reserved
12	1024K	1024K bytes
13		Reserved
14	2048K	2048K bytes
15		Reserved

- **SRAMSIZ: Internal SRAM Size**

Value	Name	Description
0	48K	48K bytes
1	1K	1K bytes
2	2K	2K bytes
3	6K	6K bytes
4	24K	24K bytes
5	4K	4K bytes
6	80K	80K bytes
7	160K	160K bytes
8	8K	8K bytes
9	16K	16K bytes
10	32K	32K bytes
11	64K	64K bytes
12	128K	128K bytes
13	256K	256K bytes

Value	Name	Description
14	96K	96K bytes
15	512K	512K bytes

- **ARCH: Architecture Identifier**

Value	Name	Description
0x19	AT91SAM9xx	AT91SAM9xx Series
0x29	AT91SAM9XExx	AT91SAM9XExx Series
0x34	AT91x34	AT91x34 Series
0x37	CAP7	CAP7 Series
0x39	CAP9	CAP9 Series
0x3B	CAP11	CAP11 Series
0x40	AT91x40	AT91x40 Series
0x42	AT91x42	AT91x42 Series
0x55	AT91x55	AT91x55 Series
0x60	AT91SAM7Axx	AT91SAM7Axx Series
0x61	AT91SAM7AQxx	AT91SAM7AQxx Series
0x63	AT91x63	AT91x63 Series
0x70	AT91SAM7Sxx	AT91SAM7Sxx Series
0x71	AT91SAM7XCxx	AT91SAM7XCxx Series
0x72	AT91SAM7SExx	AT91SAM7SExx Series
0x73	AT91SAM7Lxx	AT91SAM7Lxx Series
0x75	AT91SAM7Xxx	AT91SAM7Xxx Series
0x76	AT91SAM7SLxx	AT91SAM7SLxx Series
0x80	SAM3UxC	SAM3UxC Series (100-pin version)
0x81	SAM3UxE	SAM3UxE Series (144-pin version)
0x83	SAM3AxC	SAM3AxC Series (100-pin version)
0x83	SAM4AxC	SAM4AxC Series (100-pin version)
0x84	SAM3XxC	SAM3XxC Series (100-pin version)
0x84	SAM4XxC	SAM4XxC Series (100-pin version)
0x85	SAM3XxE	SAM3XxE Series (144-pin version)
0x85	SAM4XxE	SAM4XxE Series (144-pin version)
0x86	SAM3XxG	SAM3XxG Series (208/217-pin version)
0x86	SAM4XxG	SAM4XxG Series (208/217-pin version)
0x88	SAM3SxA	SAM3SxASeries (48-pin version)
0x88	SAM4SxA	SAM4SxA Series (48-pin version)
0x89	SAM3SxB	SAM3SxB Series (64-pin version)
0x89	SAM4SxB	SAM4SxB Series (64-pin version)
0x8A	SAM3SxC	SAM3SxC Series (100-pin version)

Value	Name	Description
0x8A	SAM4SxC	SAM4SxC Series (100-pin version)
0x92	AT91x92	AT91x92 Series
0x93	SAM3NxA	SAM3NxA Series (48-pin version)
0x94	SAM3NxB	SAM3NxB Series (64-pin version)
0x95	SAM3NxC	SAM3NxC Series (100-pin version)
0x99	SAM3SDxB	SAM3SDxB Series (64-pin version)
0x9A	SAM3SDxC	SAM3SDxC Series (100-pin version)
0xA5	SAM5A	SAM5A
0xF0	AT75Cxx	AT75Cxx Series

- **NVPTYP: Nonvolatile Program Memory Type**

Value	Name	Description
0	ROM	ROM
1	ROMLESS	ROMless or on-chip Flash
4	SRAM	SRAM emulating ROM
2	FLASH	Embedded Flash Memory
3	ROM_FLASH	ROM and Embedded Flash Memory NVPSIZ is ROM size NVPSIZ2 is Flash size

- **EXT: Extension Flag**

0 = Chip ID has a single register definition without extension

1 = An extended Chip ID exists.

28.3.2 Chip ID Extension Register

Name: CHIPID_EXID

Address: 0x400E0744

Access: Read-only

31	30	29	28	27	26	25	24
EXID							

23	22	21	20	19	18	17	16
EXID							

15	14	13	12	11	10	9	8
EXID							

7	6	5	4	3	2	1	0
EXID							

- **EXID: Chip ID Extension**

Reads 0 if the bit EXT in CHIPID_CIDR is 0.

29. Parallel Input/Output Controller (PIO)

29.1 Description

The Parallel Input/Output Controller (PIO) manages up to 32 fully programmable input/output lines. Each I/O line may be dedicated as a general-purpose I/O or be assigned to a function of an embedded peripheral. This assures effective optimization of the pins of a product.

Each I/O line is associated with a bit number in all of the 32-bit registers of the 32-bit wide User Interface.

Each I/O line of the PIO Controller features:

- An input change interrupt enabling level change detection on any I/O line.
- Additional Interrupt modes enabling rising edge, falling edge, low level or high level detection on any I/O line.
- A glitch filter providing rejection of glitches lower than one-half of system clock cycle.
- A debouncing filter providing rejection of unwanted pulses from key or push button operations.
- Multi-drive capability similar to an open drain I/O line.
- Control of the pull-up of the I/O line.
- Input visibility and output control.

The PIO Controller also features a synchronous output providing up to 32 bits of data output in a single write operation.

29.2 Embedded Characteristics

- Up to 32 Programmable I/O Lines
- Fully Programmable through Set/Clear Registers
- Multiplexing of Two Peripheral Functions per I/O Line
- For each I/O Line (Whether Assigned to a Peripheral or Used as General Purpose I/O)
  - Input Change Interrupt
  - Programmable Glitch Filter
  - Programmable Debouncing Filter
  - Multi-drive Option Enables Driving in Open Drain
  - Programmable Pull Up on Each I/O Line
  - Pin Data Status Register, Supplies Visibility of the Level on the Pin at Any Time
  - Additional Interrupt Modes on a Programmable Event: Rising Edge, Falling Edge, Low Level or High Level
  - Lock of the Configuration by the Connected Peripheral
- Synchronous Output, Provides Set and Clear of Several I/O lines in a Single Write

29.3 Block Diagram

Figure 29-1. Block Diagram

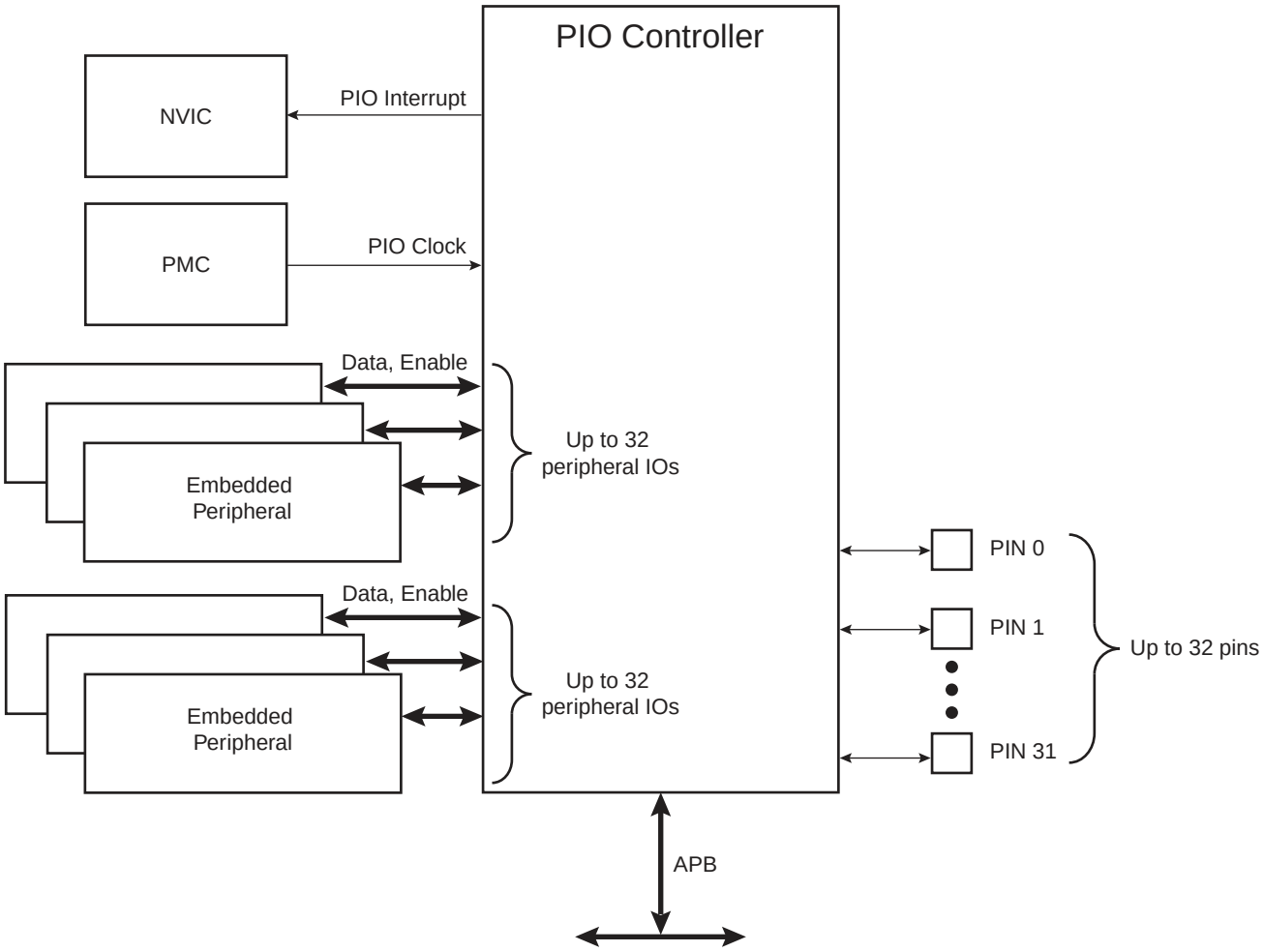
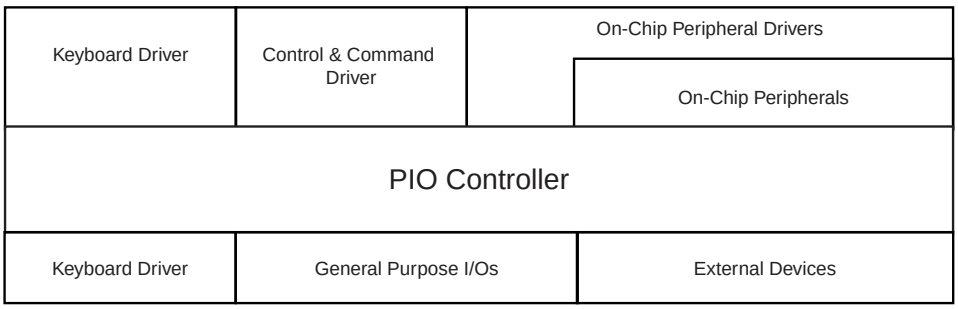


Figure 29-2. Application Block Diagram



29.4 Product Dependencies

29.4.1 Pin Multiplexing

Each pin is configurable, according to product definition as either a general-purpose I/O line only, or as an I/O line multiplexed with one or two peripheral I/Os. As the multiplexing is hardware defined and thus product-dependent, the hardware designer and programmer must carefully determine the configuration of the PIO controllers required by their application. When an I/O line is general-purpose only, i.e. not multiplexed with any peripheral I/O, programming of the PIO Controller regarding the assignment to a peripheral has no effect and only the PIO Controller can control how the pin is driven by the product.

29.4.2 Power Management

The Power Management Controller controls the PIO Controller clock in order to save power. Writing any of the registers of the user interface does not require the PIO Controller clock to be enabled. This means that the configuration of the I/O lines does not require the PIO Controller clock to be enabled.

However, when the clock is disabled, not all of the features of the PIO Controller are available, including glitch filtering. Note that the Input Change Interrupt, Interrupt Modes on a programmable event and the read of the pin level require the clock to be validated.

After a hardware reset, the PIO clock is disabled by default.

The user must configure the Power Management Controller before any access to the input line information.

29.4.3 Interrupt Generation

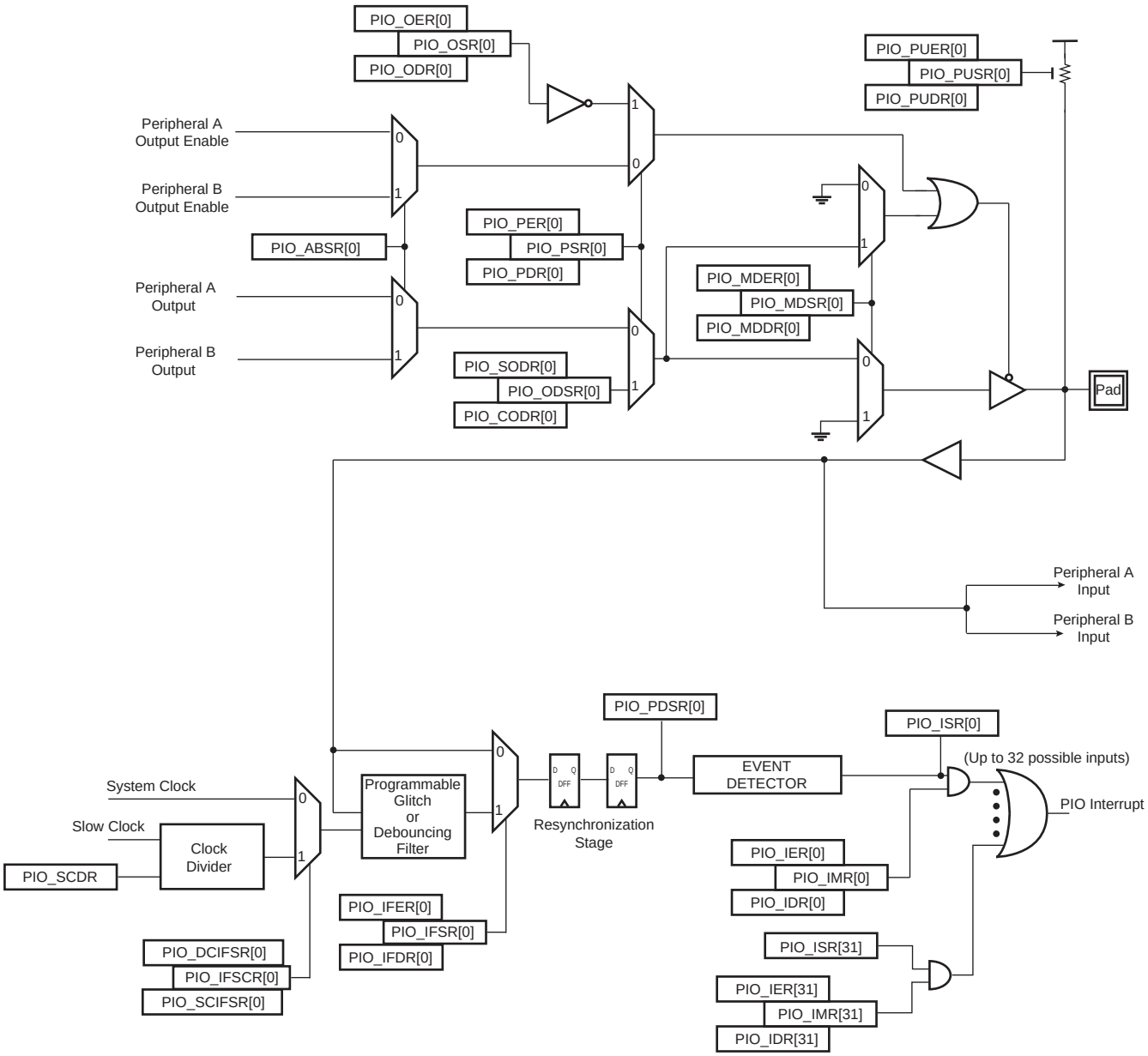
The PIO COntroller is connected on one of the sources of the Nested Vectored Interrupt Controller (NVIC). Using the PIO Controller requires the NVIC to be programmed first.

The PIO Controller interrupt can be generated only if the PIO Controller clock is enabled.

29.5 Functional Description

The PIO Controller features up to 32 fully-programmable I/O lines. Most of the control logic associated to each I/O is represented in Figure 29-3. In this description each signal shown represents but one of up to 32 possible indexes.

Figure 29-3. I/O Line Control Logic



29.5.1 Pull-up Resistor Control

Each I/O line is designed with an embedded pull-up resistor. The pull-up resistor can be enabled or disabled by writing respectively PIO_PUER (Pull-up Enable Register) and PIO_PUDR (Pull-up Disable Resistor). Writing in these registers results in setting or clearing the corresponding bit in PIO_PUSR (Pull-up Status Register). Reading a 1 in PIO_PUSR means the pull-up is disabled and reading a 0 means the pull-up is enabled.

Control of the pull-up resistor is possible regardless of the configuration of the I/O line.

After reset, all of the pull-ups are enabled, i.e. PIO_PUSR resets at the value 0x0.

29.5.2 I/O Line or Peripheral Function Selection

When a pin is multiplexed with one or two peripheral functions, the selection is controlled with the registers PIO_PER (PIO Enable Register) and PIO_PDR (PIO Disable Register). The register PIO_PSR (PIO Status Register) is the result of the set and clear registers and indicates whether the pin is controlled by the corresponding peripheral or by the PIO Controller. A value of 0 indicates that the pin is controlled by the corresponding on-chip peripheral selected in the PIO_ABSR (AB Select Register). A value of 1 indicates the pin is controlled by the PIO controller.

If a pin is used as a general purpose I/O line (not multiplexed with an on-chip peripheral), PIO_PER and PIO_PDR have no effect and PIO_PSR returns 1 for the corresponding bit.

After reset, most generally, the I/O lines are controlled by the PIO controller, i.e. PIO_PSR resets at 1. However, in some events, it is important that PIO lines are controlled by the peripheral (as in the case of memory chip select lines that must be driven inactive after reset or for address lines that must be driven low for booting out of an external memory). Thus, the reset value of PIO_PSR is defined at the product level, depending on the multiplexing of the device.

29.5.3 Peripheral A or B Selection

The PIO Controller provides multiplexing of up to two peripheral functions on a single pin. The selection is performed by writing PIO_ABSR (AB Select Register). For each pin, the corresponding bit at level 0 means peripheral A is selected whereas the corresponding bit at level 1 indicates that peripheral B is selected.

Note that multiplexing of peripheral lines A and B only affects the output line. The peripheral input lines are always connected to the pin input.

After reset, PIO_ABSR is 0, thus indicating that all the PIO lines are configured on peripheral A. However, peripheral A generally does not drive the pin as the PIO Controller resets in I/O line mode.

Writing in PIO_ABSR manages the multiplexing regardless of the configuration of the pin. However, assignment of a pin to a peripheral function requires a write in the peripheral selection register (PIO_ABSR) in addition to a write in PIO_PDR.

29.5.4 Output Control

When the I/0 line is assigned to a peripheral function, i.e. the corresponding bit in PIO_PSR is at 0, the drive of the I/O line is controlled by the peripheral. Peripheral A or B depending on the value in PIO_ABSR (AB Select Register) determines whether the pin is driven or not.

When the I/O line is controlled by the PIO controller, the pin can be configured to be driven. This is done by writing PIO_OER (Output Enable Register) and PIO_ODR (Output Disable Register). The results of these write operations are detected in PIO_OSR (Output Status Register). When a bit in this register is at 0, the corresponding I/O line is used as an input only. When the bit is at 1, the corresponding I/O line is driven by the PIO controller.

The level driven on an I/O line can be determined by writing in PIO_SODR (Set Output Data Register) and PIO_CODR (Clear Output Data Register). These write operations respectively set and clear PIO_ODSR (Output Data Status Register), which represents the data driven on the I/O lines. Writing in PIO_OER and PIO_ODR manages PIO_OSR whether the pin is configured to be controlled by the PIO controller or assigned to a peripheral function. This enables configuration of the I/O line prior to setting it to be managed by the PIO Controller.

Similarly, writing in PIO_SODR and PIO_CODR effects PIO_ODSR. This is important as it defines the first level driven on the I/O line.

29.5.5 Synchronous Data Output

Clearing one (or more) PIO line(s) and setting another one (or more) PIO line(s) synchronously cannot be done by using PIO_SODR and PIO_CODR registers. It requires two successive write operations into two different registers. To overcome this, the PIO Controller offers a direct control of PIO outputs by single write access to PIO_ODSR (Output Data Status Register).Only bits unmasked by PIO_OWSR (Output Write Status Register) are written. The mask bits in PIO_OWSR are set by writing to PIO_OWER (Output Write Enable Register) and cleared by writing to PIO_OWDR (Output Write Disable Register).

After reset, the synchronous data output is disabled on all the I/O lines as PIO_OWSR resets at 0x0.

29.5.6 Multi Drive Control (Open Drain)

Each I/O can be independently programmed in Open Drain by using the Multi Drive feature. This feature permits several drivers to be connected on the I/O line which is driven low only by each device. An external pull-up resistor (or enabling of the internal one) is generally required to guarantee a high level on the line.

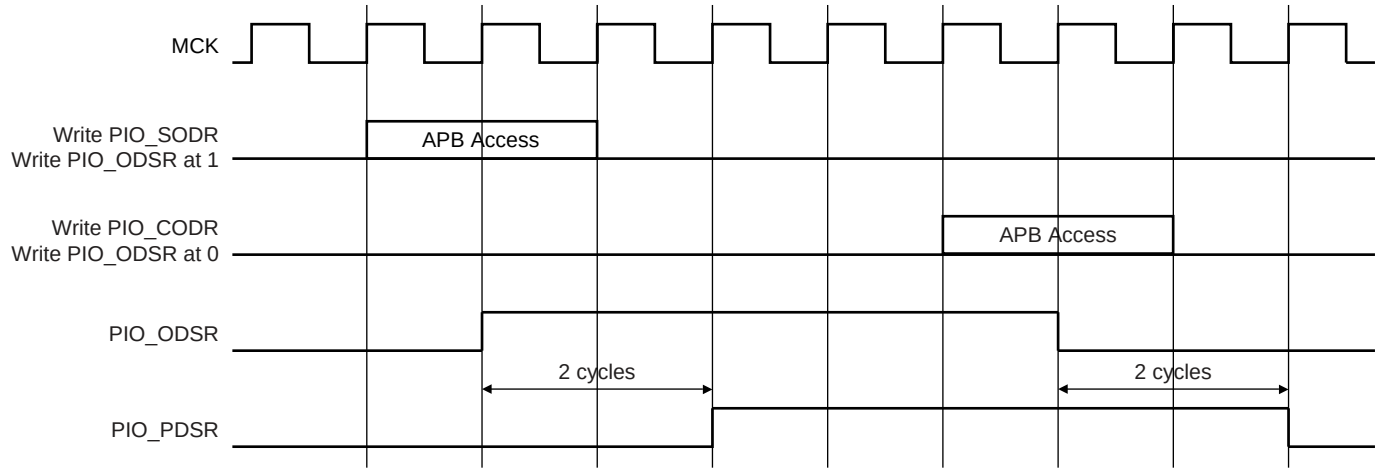
The Multi Drive feature is controlled by PIO_MDER (Multi-driver Enable Register) and PIO_MDDR (Multi-driver Disable Register). The Multi Drive can be selected whether the I/O line is controlled by the PIO controller or assigned to a peripheral function. PIO_MDSR (Multi-driver Status Register) indicates the pins that are configured to support external drivers.

After reset, the Multi Drive feature is disabled on all pins, i.e. PIO_MDSR resets at value 0x0.

29.5.7 Output Line Timings

Figure 29-4 shows how the outputs are driven either by writing PIO_SODR or PIO_CODR, or by directly writing PIO_ODSR. This last case is valid only if the corresponding bit in PIO_OWSR is set. Figure 29-4 also shows when the feedback in PIO_PDSR is available.

Figure 29-4. Output Line Timings



29.5.8 Inputs

The level on each I/O line can be read through PIO_PDSR (Pin Data Status Register). This register indicates the level of the I/O lines regardless of their configuration, whether uniquely as an input or driven by the PIO controller or driven by a peripheral.

Reading the I/O line levels requires the clock of the PIO controller to be enabled, otherwise PIO_PDSR reads the levels present on the I/O line at the time the clock was disabled.

29.5.9 Input Glitch and Debouncing Filters

Optional input glitch and debouncing filters are independently programmable on each I/O line.

The glitch filter can filter a glitch with a duration of less than 1/2 Master Clock (MCK) and the debouncing filter can filter a pulse of less than 1/2 Period of a Programmable Divided Slow Clock.

The selection between glitch filtering or debounce filtering is done by writing in the registers PIO_SCIFSR (System Clock Glitch Input Filter Select Register) and PIO_DIFSR (Debouncing Input Filter Select Register). Writing PIO_SCIFSR and PIO_DIFSR respectively, sets and clears bits in PIO_IFDGSR.

The current selection status can be checked by reading the register PIO_IFDGSR (Glitch or Debouncing Input Filter Selection Status Register).

- If PIO_IFDGSR[i] = 0: The glitch filter can filter a glitch with a duration of less than 1/2 Period of Master Clock.
- If PIO_IFDGSR[i] = 1: The debouncing filter can filter a pulse with a duration of less than 1/2 Period of the Programmable Divided Slow Clock.

For the debouncing filter, the Period of the Divided Slow Clock is performed by writing in the DIV field of the PIO_SCDR (Slow Clock Divider Register)

Tdiv_slclk = ((DIV+1)*2).Tslow_clock

When the glitch or debouncing filter is enabled, a glitch or pulse with a duration of less than 1/2 Selected Clock Cycle (Selected Clock represents MCK or Divided Slow Clock depending on PIO_SCIFSR and PIO_DIFSR programming) is automatically rejected, while a pulse with a duration of 1 Selected Clock (MCK or Divided Slow Clock) cycle or more is accepted. For pulse durations between 1/2 Selected Clock cycle and 1 Selected Clock cycle the pulse may or may not be taken into account, depending on the precise timing of its occurrence. Thus for a pulse to be visible it must exceed 1 Selected Clock cycle, whereas for a glitch to be reliably filtered out, its duration must not exceed 1/2 Selected Clock cycle.

The filters also introduce some latencies, this is illustrated in Figure 29-5 and Figure 29-6.

The glitch filters are controlled by the register set: PIO_IFER (Input Filter Enable Register), PIO_IFDR (Input Filter Disable Register) and PIO_IFSR (Input Filter Status Register). Writing PIO_IFER and PIO_IFDR respectively sets and clears bits in PIO_IFSR. This last register enables the glitch filter on the I/O lines.

When the glitch and/or debouncing filter is enabled, it does not modify the behavior of the inputs on the peripherals. It acts only on the value read in PIO_PDSR and on the input change interrupt detection. The glitch and debouncing filters require that the PIO Controller clock is enabled.

Figure 29-5. Input Glitch Filter Timing

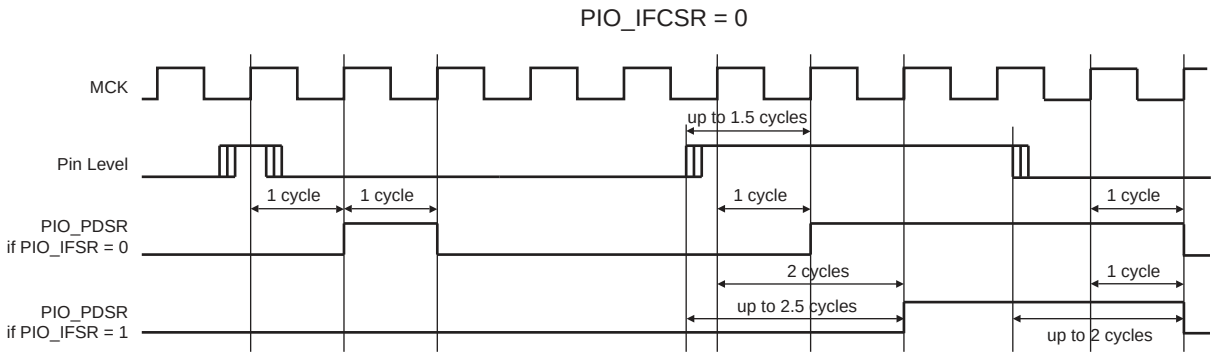
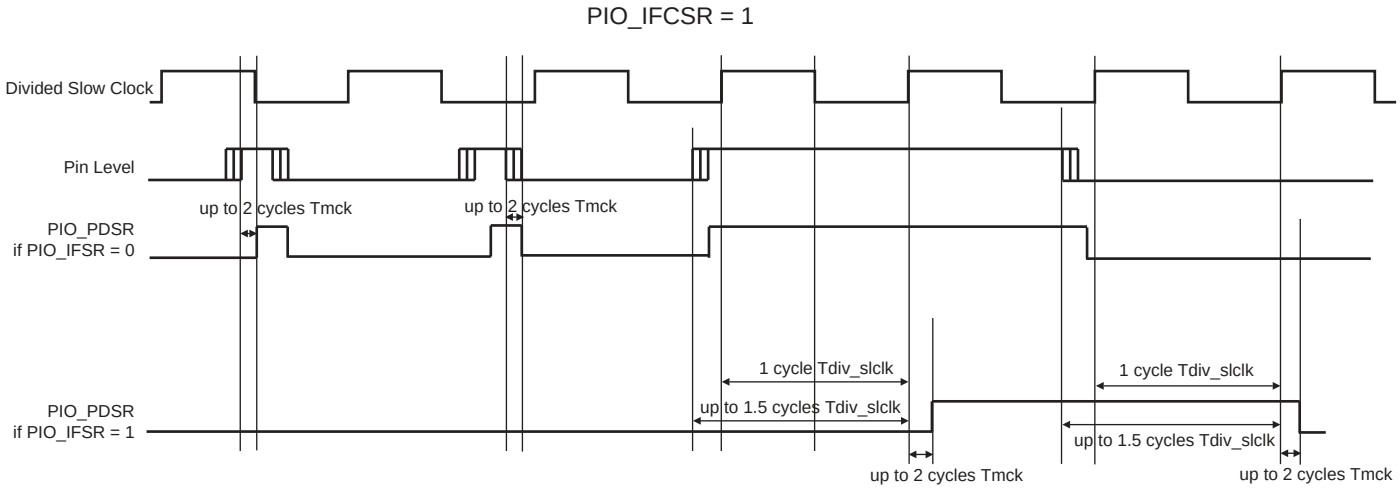


Figure 29-6. Input Debouncing Filter Timing



29.5.10 Input Edge/Level Interrupt

The PIO Controller can be programmed to generate an interrupt when it detects an edge or a level on an I/O line. The Input Edge/Level Interrupt is controlled by writing PIO_IER (Interrupt Enable Register) and PIO_IDR (Interrupt Disable Register), which respectively enable and disable the input change interrupt by setting and clearing the corresponding bit in PIO_IMR (Interrupt Mask Register). As Input change detection is possible only by comparing two successive samplings of the input of the I/O line, the PIO Controller clock must be enabled. The Input Change Interrupt is available, regardless of the configuration of the I/O line, i.e. configured as an input only, controlled by the PIO Controller or assigned to a peripheral function.

By default, the interrupt can be generated at any time an edge is detected on the input.

Some additional Interrupt modes can be enabled/disabled by writing in the PIO_AIMER (Additional Interrupt Modes Enable Register) and PIO_AIMDR (Additional Interrupt Modes Disable Register). The current state of this selection can be read through the PIO_AIMMR (Additional Interrupt Modes Mask Register)

These Additional Modes are:

- Rising Edge Detection
- Falling Edge Detection
- Low Level Detection
- High Level Detection

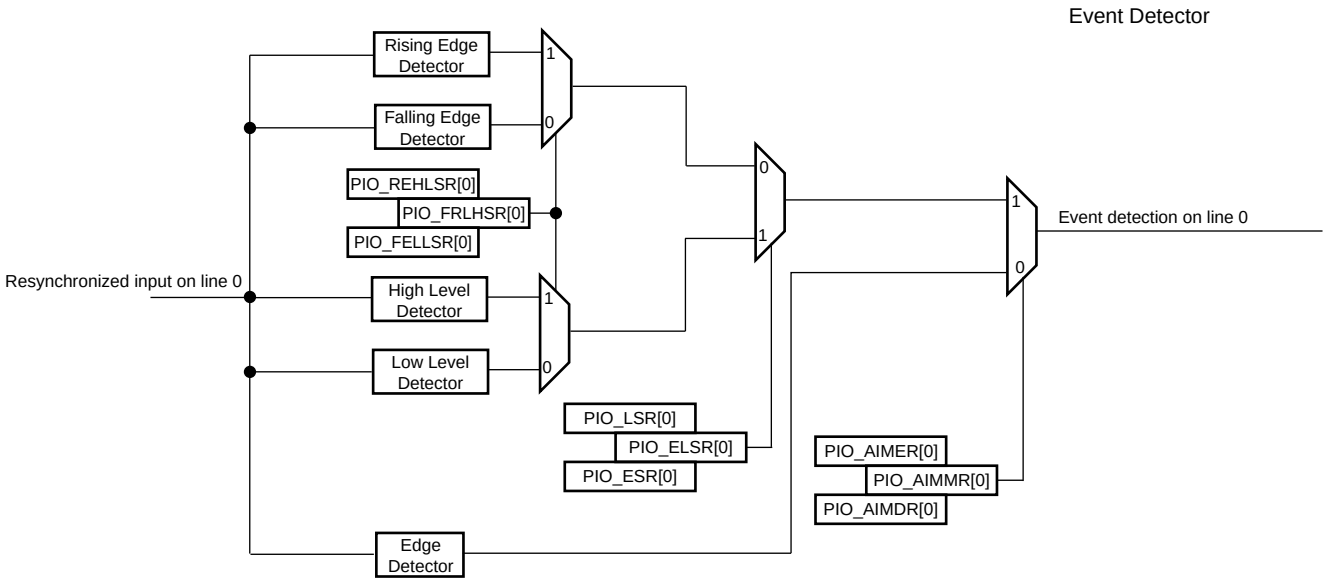
In order to select an Additional Interrupt Mode:

- The type of event detection (Edge or Level) must be selected by writing in the set of registers; PIO_ESR (Edge Select Register) and PIO_LSR (Level Select Register) which enable respectively, the Edge and Level Detection. The current status of this selection is accessible through the PIO_ELSR (Edge/Level Status Register).
- The Polarity of the event detection (Rising/Falling Edge or High/Low Level) must be selected by writing in the set of registers; PIO_FELLSR (Falling Edge /Low Level Select Register) and PIO_REHLSR (Rising Edge/High Level Select Register) which allow to select Falling or Rising Edge (if Edge is selected in the PIO_ELSR) Edge or High or Low Level Detection (if Level is selected in the PIO_ELSR). The current status of this selection is accessible through the PIO_FRLHSR (Fall/Rise - Low/High Status Register).

When an input Edge or Level is detected on an I/O line, the corresponding bit in PIO_ISR (Interrupt Status Register) is set. If the corresponding bit in PIO_IMR is set, the PIO Controller interrupt line is asserted. The interrupt signals of the thirty-two channels are ORed-wired together to generate a single interrupt signal to the Nested Vector Interrupt Controller (NVIC).

When the software reads PIO_ISR, all the interrupts are automatically cleared. This signifies that all the interrupts that are pending when PIO_ISR is read must be handled. When an Interrupt is enabled on a “Level”, the interrupt is generated as long as the interrupt source is not cleared, even if some read accesses in PIO_ISR are performed.

Figure 29-7. Event Detector on Input Lines (Figure represents line 0)



29.5.10.1Example

If generating an interrupt is required on the following:

- Rising edge on PIO line 0
- Falling edge on PIO line 1
- Rising edge on PIO line 2
- Low Level on PIO line 3
- High Level on PIO line 4
- High Level on PIO line 5
- Falling edge on PIO line 6
- Rising edge on PIO line 7
- Any edge on the other lines

The configuration required is described below.

29.5.10.2Interrupt Mode Configuration

All the interrupt sources are enabled by writing 32’hFFFF_FFFF in PIO_IER.

Then the Additional Interrupt Mode is enabled for line 0 to 7 by writing 32’h0000_00FF in PIO_AIMER.

29.5.10.3Edge or Level Detection Configuration

Lines 3, 4 and 5 are configured in Level detection by writing 32’h0000_0038 in PIO_LSR.

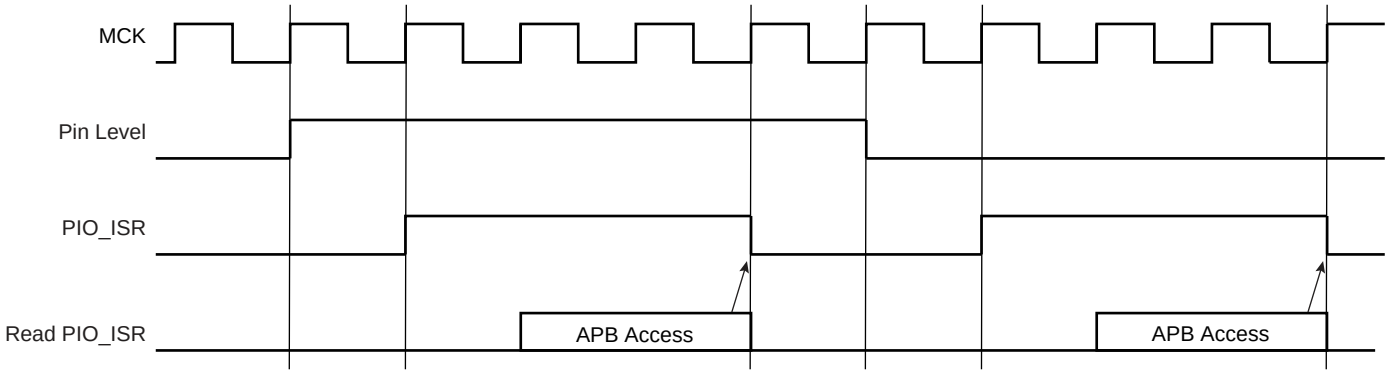
The other lines are configured in Edge detection by default, if they have not been previously configured. Otherwise, lines 0, 1, 2, 6 and 7 must be configured in Edge detection by writing 32’h0000_00C7 in PIO_ESR.

29.5.10.4Falling/Rising Edge or Low/High Level Detection Configuration.

Lines 0, 2, 4, 5 and 7 are configured in Rising Edge or High Level detection by writing 32'h0000_00B5 in PIO_REHLSR.

The other lines are configured in Falling Edge or Low Level detection by default, if they have not been previously configured. Otherwise, lines 1, 3 and 6 must be configured in Falling Edge/Low Level detection by writing 32'h0000_004A in PIO_FELLSR.

Figure 29-8. Input Change Interrupt Timings if there are no Additional Interrupt Modes



29.5.11 I/O Lines Lock

When an I/O line is controlled by a peripheral (particularly the Pulse Width Modulation Controller PWM), it can become locked by the action of this peripheral via an input of the PIO controller. When an I/O line is locked, the write of the corresponding bit in the registers PIO_PER, PIO_PDR, PIO_MDER, PIO_MDDR, PIO_PUDR, PIO_PUER and PIO_ABSR is discarded in order to lock its configuration. The user can know at anytime which I/O line is locked by reading the PIO Lock Status register PIO_LOCKSR. Once an I/O line is locked, the only way to unlock it is to apply an hardware reset to the PIO Controller.

29.6 I/O Lines Programming Example

The programing example as shown in Table 29-1 below is used to obtain the following configuration.

- 4-bit output port on I/O lines 0 to 3, (should be written in a single write operation), open-drain, with pull-up resistor
- Four output signals on I/O lines 4 to 7 (to drive LEDs for example), driven high and low, no pull-up resistor
- Four input signals on I/O lines 8 to 11 (to read push-button states for example), with pull-up resistors, glitch filters and input change interrupts
- Four input signals on I/O line 12 to 15 to read an external device status (polled, thus no input change interrupt), no pull-up resistor, no glitch filter
- I/O lines 16 to 19 assigned to peripheral A functions with pull-up resistor
- I/O lines 20 to 23 assigned to peripheral B functions, no pull-up resistor
- I/O line 24 to 27 assigned to peripheral A with Input Change Interrupt and pull-up resistor

Table 29-1. Programming Example

Register	Value to be Written
PIO_PER	0x0000 FFFF
PIO_PDR	0xFFFF 0000
PIO_OER	0x0000 00FF
PIO_ODR	0xFFFF FF00
PIO_IFER	0x0000 0F00
PIO_IFDR	0xFFFF F0FF
PIO_SODR	0x0000 0000
PIO_CODR	0x0FFF FFFF
PIO_IER	0x0F00 0F00
PIO_IDR	0xF0FF F0FF
PIO_MDER	0x0000 000F
PIO_MDDR	0xFFFF FFF0
PIO_PUDR	0xF0F0 00F0
PIO_PUER	0x0F0F FF0F
PIO_ABSR	0x00F0 0000
PIO_OWER	0x0000 000F
PIO_OWDR	0x0FFF FFF0

29.6.1 Write Protection Registers

To prevent any single software error that may corrupt PIO behavior, certain address spaces can be write-protected by setting the WPEN bit in the "PIO Write Protect Mode Register" (PIO_WPMR).

If a write access to the protected registers is detected, then the WPVS flag in the PIO Write Protect Status Register (PIO_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is reset by writing the PIO Write Protect Mode Register (PIO_WPMR) with the appropriate access key, WPKEY.

The protected registers are:

- "PIO Controller PIO Enable Register" on page 508
- "PIO Controller PIO Disable Register" on page 509
- "PIO Controller Output Enable Register" on page 511
- "PIO Controller Output Disable Register" on page 512
- "PIO Controller Input Filter Enable Register" on page 514
- "PIO Controller Input Filter Disable Register" on page 515
- "PIO Multi-driver Enable Register" on page 525
- "PIO Multi-driver Disable Register" on page 526
- "PIO Pull Up Disable Register" on page 528
- "PIO Pull Up Enable Register" on page 529
- "PIO Peripheral AB Select Register" on page 531
- "PIO Output Write Enable Register" on page 536
- "PIO Output Write Disable Register" on page 537

29.7 Parallel Input/Output Controller (PIO) User Interface

Each I/O line controlled by the PIO Controller is associated with a bit in each of the PIO Controller User Interface registers. Each register is 32 bits wide. If a parallel I/O line is not defined, writing to the corresponding bits has no effect. Undefined bits read zero. If the I/O line is not multiplexed with any peripheral, the I/O line is controlled by the PIO Controller and PIO_PSR returns 1 systematically.

Table 29-2. Register Mapping

Offset	Register	Name	Access	Reset
0x0000	PIO Enable Register	PIO_PER	Write-only	–
0x0004	PIO Disable Register	PIO_PDR	Write-only	–
0x0008	PIO Status Register	PIO_PSR	Read-only	(1)
0x000C	Reserved			
0x0010	Output Enable Register	PIO_OER	Write-only	–
0x0014	Output Disable Register	PIO_ODR	Write-only	–
0x0018	Output Status Register	PIO_OSR	Read-only	0x0000 0000
0x001C	Reserved			
0x0020	Glitch Input Filter Enable Register	PIO_IFER	Write-only	–
0x0024	Glitch Input Filter Disable Register	PIO_IFDR	Write-only	–
0x0028	Glitch Input Filter Status Register	PIO_IFSR	Read-only	0x0000 0000
0x002C	Reserved			
0x0030	Set Output Data Register	PIO_SODR	Write-only	–
0x0034	Clear Output Data Register	PIO_CODR	Write-only	
0x0038	Output Data Status Register	PIO_ODSR	Read-only or(2) Read-write	–
0x003C	Pin Data Status Register	PIO_PDSR	Read-only	(3)
0x0040	Interrupt Enable Register	PIO_IER	Write-only	–
0x0044	Interrupt Disable Register	PIO_IDR	Write-only	–
0x0048	Interrupt Mask Register	PIO_IMR	Read-only	0x00000000
0x004C	Interrupt Status Register(4)	PIO_ISR	Read-only	0x00000000
0x0050	Multi-driver Enable Register	PIO_MDER	Write-only	–
0x0054	Multi-driver Disable Register	PIO_MDDR	Write-only	–
0x0058	Multi-driver Status Register	PIO_MDSR	Read-only	0x00000000
0x005C	Reserved			
0x0060	Pull-up Disable Register	PIO_PUDR	Write-only	–
0x0064	Pull-up Enable Register	PIO_PUER	Write-only	–
0x0068	Pad Pull-up Status Register	PIO_PUSR	Read-only	0x00000000
0x006C	Reserved			

Table 29-2. Register Mapping (Continued)

Offset	Register	Name	Access	Reset
0x0070	Peripheral AB Select Register[5]	PIO_ABSR	Read-Write	0x00000000
0x0074 to 0x007C	Reserved			
0x0080	System Clock Glitch Input Filter Select Register	PIO_SCIFSR	Write-Only	–
0x0084	Debouncing Input Filter Select Register	PIO_DIFSR	Write-Only	–
0x0088	Glitch or Debouncing Input Filter Clock Selection Status Register	PIO_IFDGSR	Read-Only	0x00000000
0x008C	Slow Clock Divider Debouncing Register	PIO_SCDR	Read-Write	0x00000000
0x0090 to 0x009C	Reserved			
0x00A0	Output Write Enable	PIO_OWER	Write-only	–
0x00A4	Output Write Disable	PIO_OWDR	Write-only	–
0x00A8	Output Write Status Register	PIO_OWSR	Read-only	0x00000000
0x00AC	Reserved			
0x00B0	Additional Interrupt Modes Enable Register	PIO_AIMER	Write-Only	–
0x00B4	Additional Interrupt Modes Disables Register	PIO_AIMDR	Write-Only	–
0x00B8	Additional Interrupt Modes Mask Register	PIO_AIMMR	Read-Only	0x00000000
0x00BC	Reserved			
0x00C0	Edge Select Register	PIO_ESR	Write-Only	–
0x00C4	Level Select Register	PIO_LSR	Write-Only	–
0x00C8	Edge/Level Status Register	PIO_ELSR	Read-Only	0x00000000
0x00CC	Reserved			
0x00D0	Falling Edge/Low Level Select Register	PIO_FELLSR	Write-Only	–
0x00D4	Rising Edge/ High Level Select Register	PIO_REHLSR	Write-Only	–
0x00D8	Fall/Rise - Low/High Status Register	PIO_FRLHSR	Read-Only	0x00000000
0x00DC	Reserved			
0x00E0	Lock Status	PIO_LOCKSR	Read-Only	0x00000000
0x00E4	Write Protect Mode Register	PIO_WPMR	Read-write	0x0
0x00E8	Write Protect Status Register	PIO_WPSR	Read-only	0x0
0x00EC to 0x00F8	Reserved			
0x0100 to 0x0144	Reserved			

Notes:
1. Reset value of PIO_PSR depends on the product implementation.
2. PIO_ODSR is Read-only or Read/Write depending on PIO_OWSR I/O lines.
3. Reset value of PIO_PDSR depends on the level of the I/O lines. Reading the I/O line levels requires the clock of the PIO Controller to be enabled, otherwise PIO_PDSR reads the levels present on the I/O line at the time the clock was disabled.
4. PIO_ISR is reset at 0x0. However, the first read of the register may read a different value as input changes may have occurred.
5. Only this set of registers clears the status by writing 1 in the first register and sets the status by writing 1 in the second register.

29.7.1 PIO Controller PIO Enable Register

Name: PIO_PER

Address: 0x400E0C00 (PIOA), 0x400E0E00 (PIOB), 0x400E1000 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: PIO Enable**

0 = No effect.

1 = Enables the PIO to control the corresponding pin (disables peripheral control of the pin).

29.7.2 PIO Controller PIO Disable Register

Name: PIO_PDR

Address: 0x400E0C04 (PIOA), 0x400E0E04 (PIOB), 0x400E1004 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: PIO Disable**

0 = No effect.

1 = Disables the PIO from controlling the corresponding pin (enables peripheral control of the pin).

29.7.3 PIO Controller PIO Status Register

Name: PIO_PSR

Address: 0x400E0C08 (PIOA), 0x400E0E08 (PIOB), 0x400E1008 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: PIO Status**

0 = PIO is inactive on the corresponding I/O line (peripheral is active).

1 = PIO is active on the corresponding I/O line (peripheral is inactive).

29.7.4 PIO Controller Output Enable Register

Name: PIO_OER

Address: 0x400E0C10 (PIOA), 0x400E0E10 (PIOB), 0x400E1010 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Output Enable**

0 = No effect.

1 = Enables the output on the I/O line.

29.7.5 PIO Controller Output Disable Register

Name: PIO_ODR

Address: 0x400E0C14 (PIOA), 0x400E0E14 (PIOB), 0x400E1014 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Output Disable**

0 = No effect.

1 = Disables the output on the I/O line.

29.7.6 PIO Controller Output Status Register

Name: PIO_OSR

Address: 0x400E0C18 (PIOA), 0x400E0E18 (PIOB), 0x400E1018 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Output Status**

0 = The I/O line is a pure input.

1 = The I/O line is enabled in output.

29.7.7 PIO Controller Input Filter Enable Register

Name: PIO_IFER

Address: 0x400E0C20 (PIOA), 0x400E0E20 (PIOB), 0x400E1020 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Input Filter Enable**

0 = No effect.

1 = Enables the input glitch filter on the I/O line.

29.7.8 PIO Controller Input Filter Disable Register

Name: PIO_IFDR

Address: 0x400E0C24 (PIOA), 0x400E0E24 (PIOB), 0x400E1024 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Input Filter Disable**

0 = No effect.

1 = Disables the input glitch filter on the I/O line.

29.7.9 PIO Controller Input Filter Status Register

Name: PIO_IFSR

Address: 0x400E0C28 (PIOA), 0x400E0E28 (PIOB), 0x400E1028 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Input Filer Status**

0 = The input glitch filter is disabled on the I/O line.

1 = The input glitch filter is enabled on the I/O line.

29.7.10 PIO Controller Set Output Data Register

Name: PIO_SODR

Address: 0x400E0C30 (PIOA), 0x400E0E30 (PIOB), 0x400E1030 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Set Output Data**

0 = No effect.

1 = Sets the data to be driven on the I/O line.

29.7.11 PIO Controller Clear Output Data Register

Name: PIO_CODR

Address: 0x400E0C34 (PIOA), 0x400E0E34 (PIOB), 0x400E1034 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Clear Output Data**

0 = No effect.

1 = Clears the data to be driven on the I/O line.

29.7.12 PIO Controller Output Data Status Register

Name: PIO_ODSR

Address: 0x400E0C38 (PIOA), 0x400E0E38 (PIOB), 0x400E1038 (PIOC)

Access: Read-only or Read/Write

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Output Data Status**

0 = The data to be driven on the I/O line is 0.

1 = The data to be driven on the I/O line is 1.

29.7.13 PIO Controller Pin Data Status Register

Name: PIO_PDSR

Address: 0x400E0C3C (PIOA), 0x400E0E3C (PIOB), 0x400E103C (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Output Data Status**

0 = The I/O line is at level 0.

1 = The I/O line is at level 1.

29.7.14 PIO Controller Interrupt Enable Register

Name: PIO_IER

Address: 0x400E0C40 (PIOA), 0x400E0E40 (PIOB), 0x400E1040 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Input Change Interrupt Enable**

0 = No effect.

1 = Enables the Input Change Interrupt on the I/O line.

29.7.15 PIO Controller Interrupt Disable Register

Name: PIO_IDR

Address: 0x400E0C44 (PIOA), 0x400E0E44 (PIOB), 0x400E1044 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Input Change Interrupt Disable**

0 = No effect.

1 = Disables the Input Change Interrupt on the I/O line.

29.7.16 PIO Controller Interrupt Mask Register

Name: PIO_IMR

Address: 0x400E0C48 (PIOA), 0x400E0E48 (PIOB), 0x400E1048 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Input Change Interrupt Mask**

0 = Input Change Interrupt is disabled on the I/O line.

1 = Input Change Interrupt is enabled on the I/O line.

29.7.17 PIO Controller Interrupt Status Register

Name: PIO_ISR

Address: 0x400E0C4C (PIOA), 0x400E0E4C (PIOB), 0x400E104C (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Input Change Interrupt Status**

0 = No Input Change has been detected on the I/O line since PIO_ISR was last read or since reset.

1 = At least one Input Change has been detected on the I/O line since PIO_ISR was last read or since reset.

29.7.18 PIO Multi-driver Enable Register

Name: PIO_MDER

Address: 0x400E0C50 (PIOA), 0x400E0E50 (PIOB), 0x400E1050 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Multi Drive Enable.**

0 = No effect.

1 = Enables Multi Drive on the I/O line.

29.7.19 PIO Multi-driver Disable Register

Name: PIO_MDDR

Address: 0x400E0C54 (PIOA), 0x400E0E54 (PIOB), 0x400E1054 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Multi Drive Disable.**

0 = No effect.

1 = Disables Multi Drive on the I/O line.

29.7.20 PIO Multi-driver Status Register

Name: PIO_MDSR

Address: 0x400E0C58 (PIOA), 0x400E0E58 (PIOB), 0x400E1058 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Multi Drive Status.**

0 = The Multi Drive is disabled on the I/O line. The pin is driven at high and low level.

1 = The Multi Drive is enabled on the I/O line. The pin is driven at low level only.

29.7.21 PIO Pull Up Disable Register

Name: PIO_PUDR

Address: 0x400E0C60 (PIOA), 0x400E0E60 (PIOB), 0x400E1060 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Pull Up Disable.**

0 = No effect.

1 = Disables the pull up resistor on the I/O line.

29.7.22 PIO Pull Up Enable Register

Name: PIO_PUER

Address: 0x400E0C64 (PIOA), 0x400E0E64 (PIOB), 0x400E1064 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Pull Up Enable.**

0 = No effect.

1 = Enables the pull up resistor on the I/O line.

29.7.23 PIO Pull Up Status Register

Name: PIO_PUSR

Address: 0x400E0C68 (PIOA), 0x400E0E68 (PIOB), 0x400E1068 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Pull Up Status.**

0 = Pull Up resistor is enabled on the I/O line.

1 = Pull Up resistor is disabled on the I/O line.

29.7.24 PIO Peripheral AB Select Register

Name: PIO_ABSR

Address: 0x400E0C70 (PIOA), 0x400E0E70 (PIOB), 0x400E1070 (PIOC)

Access: Read-Write

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Peripheral A Select.**

0 = Assigns the I/O line to the Peripheral A function.

1 = Assigns the I/O line to the Peripheral B function.

29.7.25 PIO System Clock Glitch Input Filtering Select Register

Name: PIO_SCIFSR

Address: 0x400E0C80 (PIOA), 0x400E0E80 (PIOB), 0x400E1080 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: System Clock Glitch Filtering Select.**

0 = No Effect.

1 = The Glitch Filter is able to filter glitches with a duration < Tmck/2.

29.7.26 PIO Debouncing Input Filtering Select Register

Name: PIO_DIFSR

Address: 0x400E0C84 (PIOA), 0x400E0E84 (PIOB), 0x400E1084 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Debouncing Filtering Select.**

0 = No Effect.

1 = The Debouncing Filter is able to filter pulses with a duration < Tdiv_slclk/2.

29.7.27 PIO Glitch or Debouncing Input Filter Selection Status Register

Name: PIO_IFDGSR

Address: 0x400E0C88 (PIOA), 0x400E0E88 (PIOB), 0x400E1088 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Glitch or Debouncing Filter Selection Status**

0 = The Glitch Filter is able to filter glitches with a duration < Tmck2.

1 = The Debouncing Filter is able to filter pulses with a duration < Tdiv_slclk/2.

29.7.28 PIO Slow Clock Divider Debouncing Register

Name: PIO_SCDR

Address: 0x400E0C8C (PIOA), 0x400E0E8C (PIOB), 0x400E108C (PIOC)

Access: Read-Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	DIV					
7	6	5	4	3	2	1	0
DIV							

- **DIV: Slow Clock Divider Selection for Debouncing**

Tdiv_slclk = 2*(DIV+1)*Tslow_clock.

29.7.29 PIO Output Write Enable Register

Name: PIO_OWER

Address: 0x400E0CA0 (PIOA), 0x400E0EA0 (PIOB), 0x400E10A0 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Output Write Enable.**

0 = No effect.

1 = Enables writing PIO_ODSR for the I/O line.

29.7.30 PIO Output Write Disable Register

Name: PIO_OWDR

Address: 0x400E0CA4 (PIOA), 0x400E0EA4 (PIOB), 0x400E10A4 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

This register can only be written if the WPEN bit is cleared in “PIO Write Protect Mode Register”.

- **P0-P31: Output Write Disable.**

0 = No effect.

1 = Disables writing PIO_ODSR for the I/O line.

29.7.31 PIO Output Write Status Register

Name: PIO_OWSR

Address: 0x400E0CA8 (PIOA), 0x400E0EA8 (PIOB), 0x400E10A8 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Output Write Status.**

0 = Writing PIO_ODSR does not affect the I/O line.

1 = Writing PIO_ODSR affects the I/O line.

29.7.32 Additional Interrupt Modes Enable Register

Name: PIO_AIMER

Address: 0x400E0CB0 (PIOA), 0x400E0EB0 (PIOB), 0x400E10B0 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Additional Interrupt Modes Enable.**

0 = No effect.

1 = The interrupt source is the event described in PIO_ELSR and PIO_FRLHSR.

29.7.33 Additional Interrupt Modes Disable Register

Name: PIO_AIMDR

Address: 0x400E0CB4 (PIOA), 0x400E0EB4 (PIOB), 0x400E10B4 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Additional Interrupt Modes Disable.**

0 = No effect.

1 = The interrupt mode is set to the default interrupt mode (Both Edge detection).

29.7.34 Additional Interrupt Modes Mask Register

Name: PIO_AIMMR

Address: 0x400E0CB8 (PIOA), 0x400E0EB8 (PIOB), 0x400E10B8 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Peripheral CD Status.**

0 = The interrupt source is a Both Edge detection event

1 = The interrupt source is described by the registers PIO_ELSR and PIO_FRLHSR

29.7.35 Edge Select Register

Name: PIO_ESR

Address: 0x400E0CC0 (PIOA), 0x400E0EC0 (PIOB), 0x400E10C0 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Edge Interrupt Selection.**

0 = No effect.

1 = The interrupt source is an Edge detection event.

29.7.36 Level Select Register

Name: PIO_LSR

Address: 0x400E0CC4 (PIOA), 0x400E0EC4 (PIOB), 0x400E10C4 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Level Interrupt Selection.**

0 = No effect.

1 = The interrupt source is a Level detection event.

29.7.37 Edge/Level Status Register

Name: PIO_ELSR

Address: 0x400E0CC8 (PIOA), 0x400E0EC8 (PIOB), 0x400E10C8 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Edge/Level Interrupt source selection.**

0 = The interrupt source is an Edge detection event.

1 = The interrupt source is a Level detection event.

29.7.38 Falling Edge/Low Level Select Register

Name: PIO_FELLSR

Address: 0x400E0CD0 (PIOA), 0x400E0ED0 (PIOB), 0x400E10D0 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Falling Edge/Low Level Interrupt Selection.**

0 = No effect.

1 = The interrupt source is set to a Falling Edge detection or Low Level detection event, depending on PIO_ELSR.

29.7.39 Rising Edge/High Level Select Register

Name: PIO_REHLSR

Address: 0x400E0CD4 (PIOA), 0x400E0ED4 (PIOB), 0x400E10D4 (PIOC)

Access: Write-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Rising Edge /High Level Interrupt Selection.**

0 = No effect.

1 = The interrupt source is set to a Rising Edge detection or High Level detection event, depending on PIO_ELSR.

29.7.40 Fall/Rise - Low/High Status Register

Name: PIO_FRLHSR

Address: 0x400E0CD8 (PIOA), 0x400E0ED8 (PIOB), 0x400E10D8 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Edge /Level Interrupt Source Selection.**

0 = The interrupt source is a Falling Edge detection (if PIO_ELSR = 0) or Low Level detection event (if PIO_ELSR = 1).

1 = The interrupt source is a Rising Edge detection (if PIO_ELSR = 0) or High Level detection event (if PIO_ELSR = 1).

29.7.41 Lock Status Register

Name: PIO_LOCKSR

Address: 0x400E0CE0 (PIOA), 0x400E0EE0 (PIOB), 0x400E10E0 (PIOC)

Access: Read-only

31	30	29	28	27	26	25	24
P31	P30	P29	P28	P27	P26	P25	P24
23	22	21	20	19	18	17	16
P23	P22	P21	P20	P19	P18	P17	P16
15	14	13	12	11	10	9	8
P15	P14	P13	P12	P11	P10	P9	P8
7	6	5	4	3	2	1	0
P7	P6	P5	P4	P3	P2	P1	P0

- **P0-P31: Lock Status.**

0 = The I/O line is not locked.

1 = The I/O line is locked.

29.7.42 PIO Write Protect Mode Register

Name: PIO_WPMR

Address: 0x400E0CE4 (PIOA), 0x400E0EE4 (PIOB), 0x400E10E4 (PIOC)

Access: Read-write

Reset: See Table 29-2

31	30	29	28	27	26	25	24
WPKEY							
23	22	21	20	19	18	17	16
WPKEY							
15	14	13	12	11	10	9	8
WPKEY							
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPEN

For more information on Write Protection Registers, refer to Section 29.6.1 ”Write Protection Registers”.

- **WPEN: Write Protect Enable**

0 = Disables the Write Protect if WPKEY corresponds to 0x50494F (“PIO” in ASCII).

1 = Enables the Write Protect if WPKEY corresponds to 0x50494F (“PIO” in ASCII).

Protects the registers:

- “PIO Controller PIO Enable Register” on page 508
- “PIO Controller PIO Disable Register” on page 509
- “PIO Controller Output Enable Register” on page 511
- “PIO Controller Output Disable Register” on page 512
- “PIO Controller Input Filter Enable Register” on page 514
- “PIO Controller Input Filter Disable Register” on page 515
- “PIO Multi-driver Enable Register” on page 525
- “PIO Multi-driver Disable Register” on page 526
- “PIO Pull Up Disable Register” on page 528
- “PIO Pull Up Enable Register” on page 529
- “PIO Peripheral AB Select Register” on page 531
- “PIO Output Write Enable Register” on page 536
- “PIO Output Write Disable Register” on page 537

- **WPKEY: Write Protect KEY**

Should be written at value 0x50494F (“PIO” in ASCII). Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

29.7.43 PIO Write Protect Status Register

Name: PIO_WPSR

Address: 0x400E0CE8 (PIOA), 0x400E0EE8 (PIOB), 0x400E10E8 (PIOC)

Access: Read-only

Reset: See Table 29-2

31	30	29	28	27	26	25	24
—	—	—	—	—	—	—	—

23	22	21	20	19	18	17	16
WPVSRC							

15	14	13	12	11	10	9	8
WPVSRC							

7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPVS

- **WPVS: Write Protect Violation Status**

0 = No Write Protect Violation has occurred since the last read of the PIO_WPSR register.

1 = A Write Protect Violation has occurred since the last read of the PIO_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protect Violation Source**

When WPVS is active, this field indicates the write-protected register (through address offset or code) in which a write access has been attempted.

Note: Reading PIO_WPSR automatically clears all fields.

30. Synchronous Serial Controller (SSC)

30.1 Description

The Atmel Synchronous Serial Controller (SSC) provides a synchronous communication link with external devices. It supports many serial synchronous communication protocols generally used in audio and telecom applications such as I2S, Short Frame Sync, Long Frame Sync, etc.

The SSC contains an independent receiver and transmitter and a common clock divider. The receiver and the transmitter each interface with three signals: the TD/RD signal for data, the TK/RK signal for the clock and the TF/RF signal for the Frame Sync. The transfers can be programmed to start automatically or on different events detected on the Frame Sync signal.

The SSC's high-level of programmability and its use of DMA permit a continuous high bit rate data transfer without processor intervention.

Featuring connection to the DMA, the SSC permits interfacing with low processor overhead to the following:

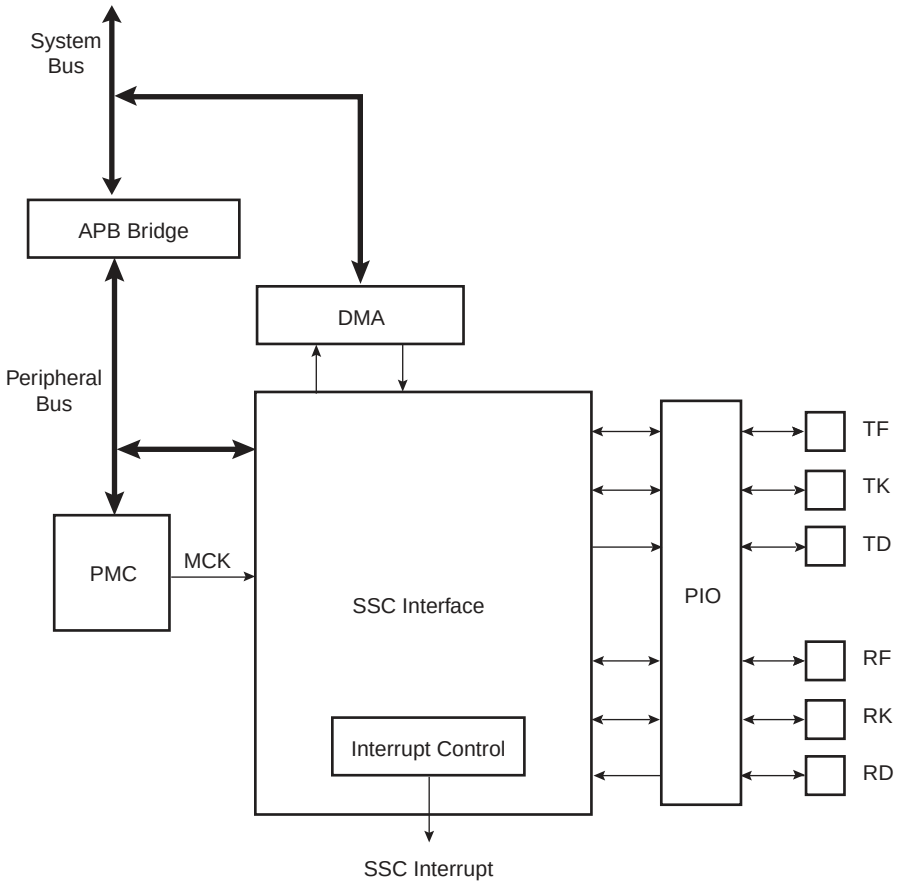
- CODEC's in master or slave mode
- DAC through dedicated serial interface, particularly I2S
- Magnetic card reader

30.2 Embedded Characteristics

- Provides Serial Synchronous Communication Links Used in Audio and Telecom Applications
- Contains an Independent Receiver and Transmitter and a Common Clock Divider
- Interfaced with the DMA Controller (DMAC) to Reduce Processor Overhead
- Offers a Configurable Frame Sync and Data Length
- Receiver and Transmitter Can be Programmed to Start Automatically or on Detection of Different Events on the Frame Sync Signal
- Receiver and Transmitter Include a Data Signal, a Clock Signal and a Frame Synchronization Signal

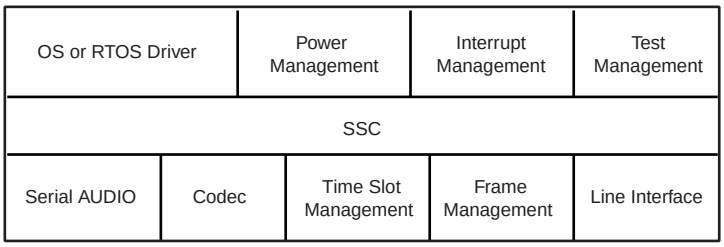
30.3 Block Diagram

Figure 30-1. Block Diagram



30.4 Application Block Diagram

Figure 30-2. Application Block Diagram



30.5 Pin Name List

Table 30-1. I/O Lines Description

Pin Name	Pin Description	Type
RF	Receiver Frame Synchro	Input/Output
RK	Receiver Clock	Input/Output
RD	Receiver Data	Input
TF	Transmitter Frame Synchro	Input/Output
TK	Transmitter Clock	Input/Output
TD	Transmitter Data	Output

30.6 Product Dependencies

30.6.1 I/O Lines

The pins used for interfacing the compliant external devices may be multiplexed with PIO lines.

Before using the SSC receiver, the PIO controller must be configured to dedicate the SSC receiver I/O lines to the SSC peripheral mode.

Before using the SSC transmitter, the PIO controller must be configured to dedicate the SSC transmitter I/O lines to the SSC peripheral mode.

Table 30-2. I/O Lines

Instance	Signal	I/O Line	Peripheral
SSC	RD	PA27	A
SSC	RF	PA31	A
SSC	RK	PA29	A
SSC	TD	PA26	A
SSC	TF	PA30	A
SSC	TK	PA28	A

30.6.2 Power Management

The SSC is not continuously clocked. The SSC interface may be clocked through the Power Management Controller (PMC), therefore the programmer must first configure the PMC to enable the SSC clock.

30.6.3 Interrupt

The SSC interface has an interrupt line connected to the Nested Vector Interrupt Controller (NVIC). Handling interrupts requires programming the NVIC before configuring the SSC.

All SSC interrupts can be enabled/disabled configuring the SSC Interrupt mask register. Each pending and unmasked SSC interrupt will assert the SSC interrupt line. The SSC interrupt service routine can get the interrupt origin by reading the SSC interrupt status register.

Table 30-3. Peripheral IDs

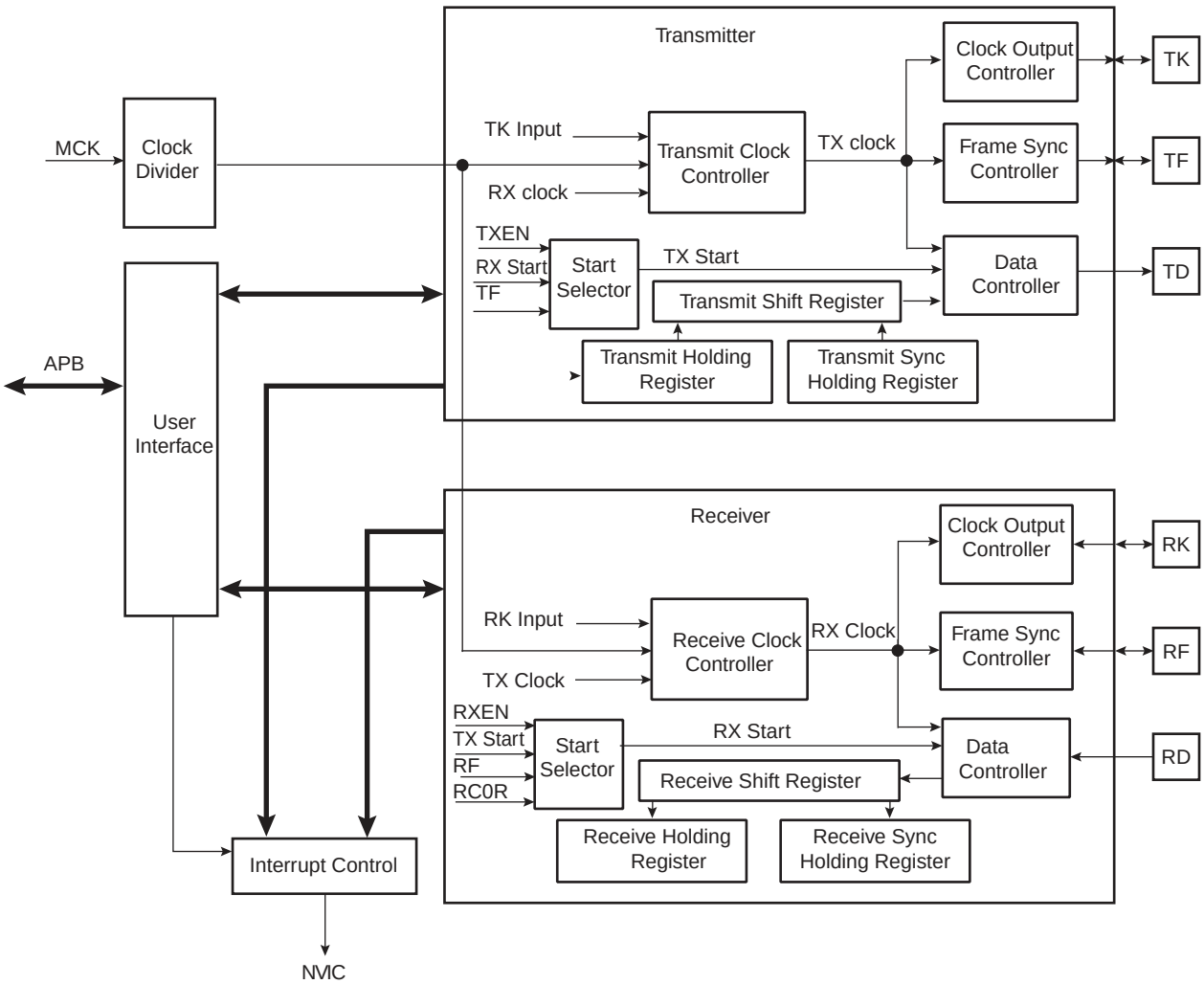
Instance	ID
SSC	21

30.7 Functional Description

This chapter contains the functional description of the following: SSC Functional Block, Clock Management, Data format, Start, Transmitter, Receiver and Frame Sync.

The receiver and transmitter operate separately. However, they can work synchronously by programming the receiver to use the transmit clock and/or to start a data transfer when transmission starts. Alternatively, this can be done by programming the transmitter to use the receive clock and/or to start a data transfer when reception starts. The transmitter and the receiver can be programmed to operate with the clock signals provided on either the TK or RK pins. This allows the SSC to support many slave-mode data transfers. The maximum clock speed allowed on the TK and RK pins is the master clock divided by 2.

Figure 30-3. SSC Functional Block Diagram



30.7.1 Clock Management

The transmitter clock can be generated by:

- an external clock received on the TK I/O pad
- the receiver clock
- the internal clock divider

The receiver clock can be generated by:

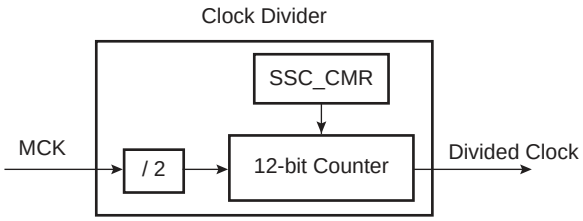
- an external clock received on the RK I/O pad
- the transmitter clock
- the internal clock divider

Furthermore, the transmitter block can generate an external clock on the TK I/O pad, and the receiver block can generate an external clock on the RK I/O pad.

This allows the SSC to support many Master and Slave Mode data transfers.

30.7.1.1 Clock Divider

Figure 30-4. Divided Clock Block Diagram



The Master Clock divider is determined by the 12-bit field DIV counter and comparator (so its maximal value is 4095) in the Clock Mode Register SSC_CMR, allowing a Master Clock division by up to 8190. The Divided Clock is provided to both the Receiver and Transmitter. When this field is programmed to 0, the Clock Divider is not used and remains inactive.

When DIV is set to a value equal to or greater than 1, the Divided Clock has a frequency of Master Clock divided by 2 times DIV. Each level of the Divided Clock has a duration of the Master Clock multiplied by DIV. This ensures a 50% duty cycle for the Divided Clock regardless of whether the DIV value is even or odd.

Figure 30-5. Divided Clock Generation

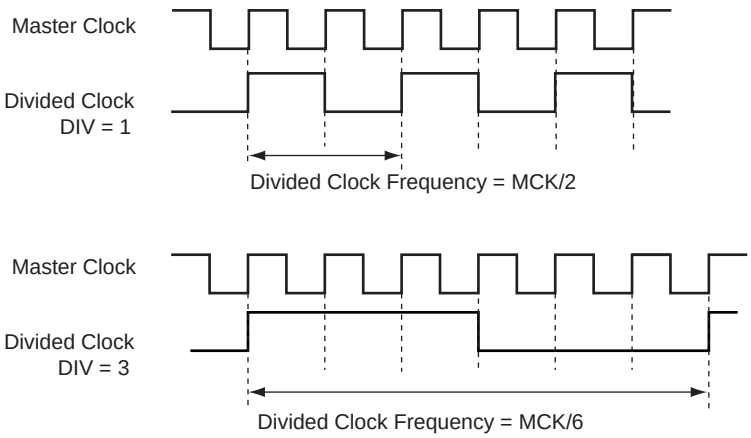


Table 30-4.

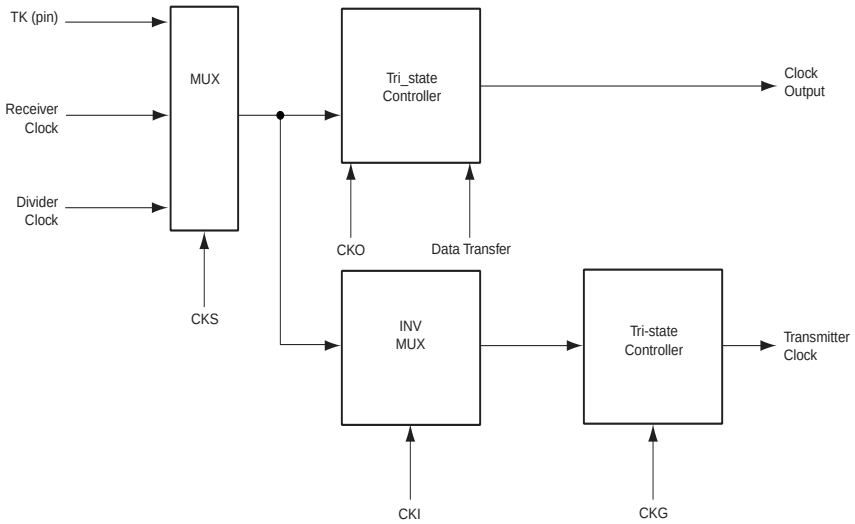
Maximum	Minimum
MCK / 2	MCK / 8190

30.7.1.2 Transmitter Clock Management

The transmitter clock is generated from the receiver clock or the divider clock or an external clock scanned on the TK I/O pad. The transmitter clock is selected by the CKS field in SSC_TCMR (Transmit Clock Mode Register). Transmit Clock can be inverted independently by the CKI bits in SSC_TCMR.

The transmitter can also drive the TK I/O pad continuously or be limited to the actual data transfer. The clock output is configured by the SSC_TCMR register. The Transmit Clock Inversion (CKI) bits have no effect on the clock outputs. Programming the TCMR register to select TK pin (CKS field) and at the same time Continuous Transmit Clock (CKO field) might lead to unpredictable results.

Figure 30-6. Transmitter Clock Management

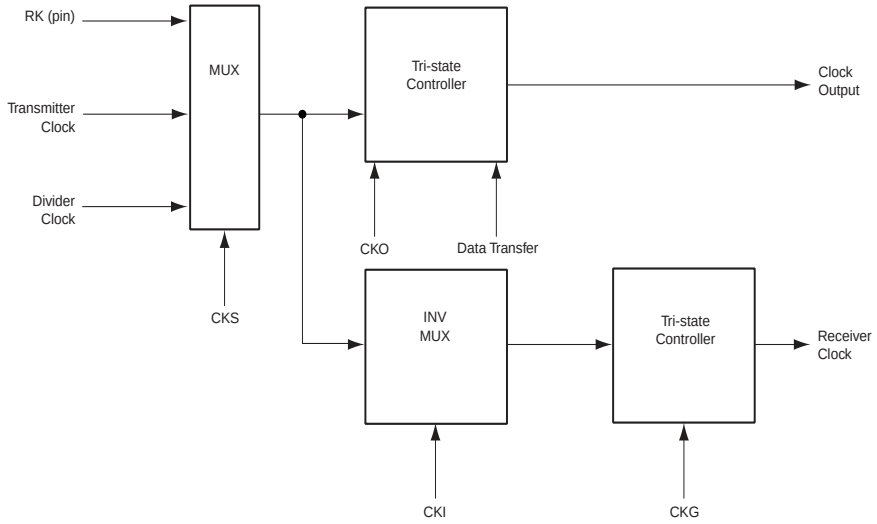


30.7.1.3 Receiver Clock Management

The receiver clock is generated from the transmitter clock or the divider clock or an external clock scanned on the RK I/O pad. The Receive Clock is selected by the CKS field in SSC_RCMR (Receive Clock Mode Register). Receive Clocks can be inverted independently by the CKI bits in SSC_RCMR.

The receiver can also drive the RK I/O pad continuously or be limited to the actual data transfer. The clock output is configured by the SSC_RCMR register. The Receive Clock Inversion (CKI) bits have no effect on the clock outputs. Programming the RCMR register to select RK pin (CKS field) and at the same time Continuous Receive Clock (CKO field) can lead to unpredictable results.

Figure 30-7. Receiver Clock Management



30.7.1.4 Serial Clock Ratio Considerations

The Transmitter and the Receiver can be programmed to operate with the clock signals provided on either the TK or RK pins. This allows the SSC to support many slave-mode data transfers. In this case, the maximum clock speed allowed on the RK pin is:

- Master Clock divided by 2 if Receiver Frame Synchro is input
- Master Clock divided by 3 if Receiver Frame Synchro is output

In addition, the maximum clock speed allowed on the TK pin is:

- Master Clock divided by 6 if Transmit Frame Synchro is input
- Master Clock divided by 2 if Transmit Frame Synchro is output

30.7.2 Transmitter Operations

A transmitted frame is triggered by a start event and can be followed by synchronization data before data transmission.

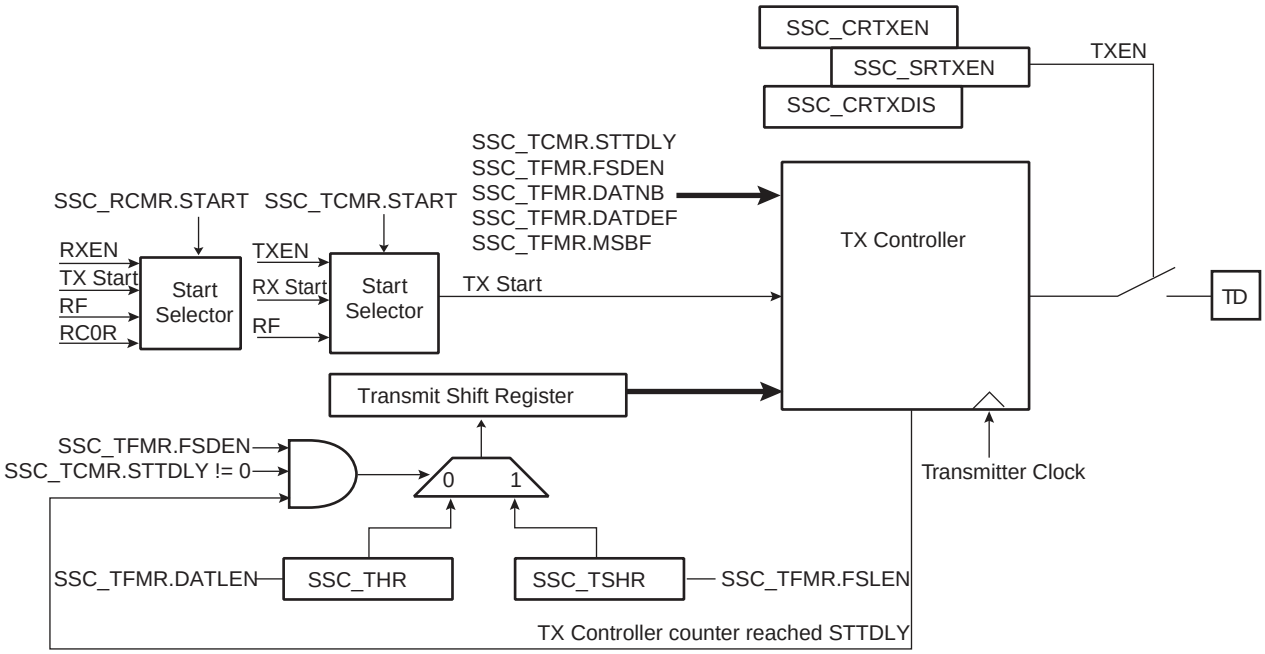
The start event is configured by setting the Transmit Clock Mode Register (SSC_TCMR). See “Start” on page 560.

The frame synchronization is configured setting the Transmit Frame Mode Register (SSC_TFMR). See “Frame Sync” on page 561.

To transmit data, the transmitter uses a shift register clocked by the transmitter clock signal and the start mode selected in the SSC_TCMR. Data is written by the application to the SSC_THR register then transferred to the shift register according to the data format selected.

When both the SSC_THR and the transmit shift register are empty, the status flag TXEMPTY is set in SSC_SR. When the Transmit Holding register is transferred in the Transmit shift register, the status flag TXRDY is set in SSC_SR and additional data can be loaded in the holding register.

Figure 30-8. Transmitter Block Diagram



30.7.3 Receiver Operations

A received frame is triggered by a start event and can be followed by synchronization data before data transmission.

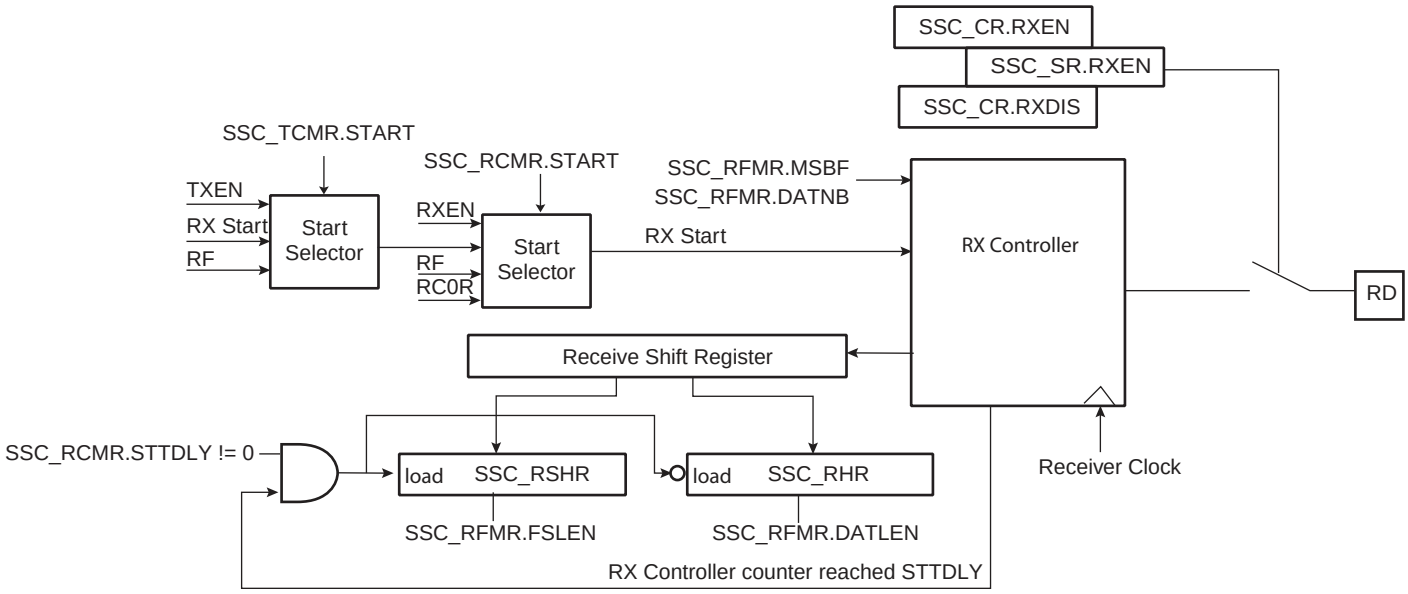
The start event is configured setting the Receive Clock Mode Register (SSC_RCMR). See “Start” on page 560.

The frame synchronization is configured setting the Receive Frame Mode Register (SSC_RFMR). See “Frame Sync” on page 561.

The receiver uses a shift register clocked by the receiver clock signal and the start mode selected in the SSC_RCMR. The data is transferred from the shift register depending on the data format selected.

When the receiver shift register is full, the SSC transfers this data in the holding register, the status flag RXRDY is set in SSC_SR and the data can be read in the receiver holding register. If another transfer occurs before read of the RHR register, the status flag OVERUN is set in SSC_SR and the receiver shift register is transferred in the RHR register.

Figure 30-9. Receiver Block Diagram



30.7.4 Start

The transmitter and receiver can both be programmed to start their operations when an event occurs, respectively in the Transmit Start Selection (START) field of SSC_TCMR and in the Receive Start Selection (START) field of SSC_RCMR.

Under the following conditions the start event is independently programmable:

- Continuous. In this case, the transmission starts as soon as a word is written in SSC_THR and the reception starts as soon as the Receiver is enabled.
- Synchronously with the transmitter/receiver
- On detection of a falling/rising edge on TF/RF
- On detection of a low level/high level on TF/RF
- On detection of a level change or an edge on TF/RF

A start can be programmed in the same manner on either side of the Transmit/Receive Clock Register (RCMR/TCMR). Thus, the start could be on TF (Transmit) or RF (Receive).

Moreover, the Receiver can start when data is detected in the bit stream with the Compare Functions.

Detection on TF/RF input/output is done by the field FSOS of the Transmit/Receive Frame Mode Register (TFMR/RFMR).

Figure 30-10. Transmit Start Mode

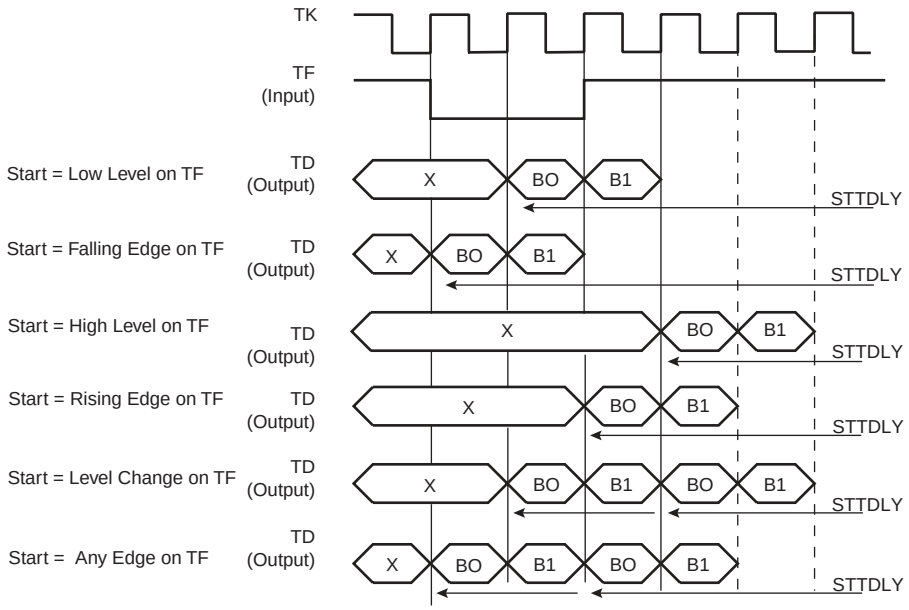
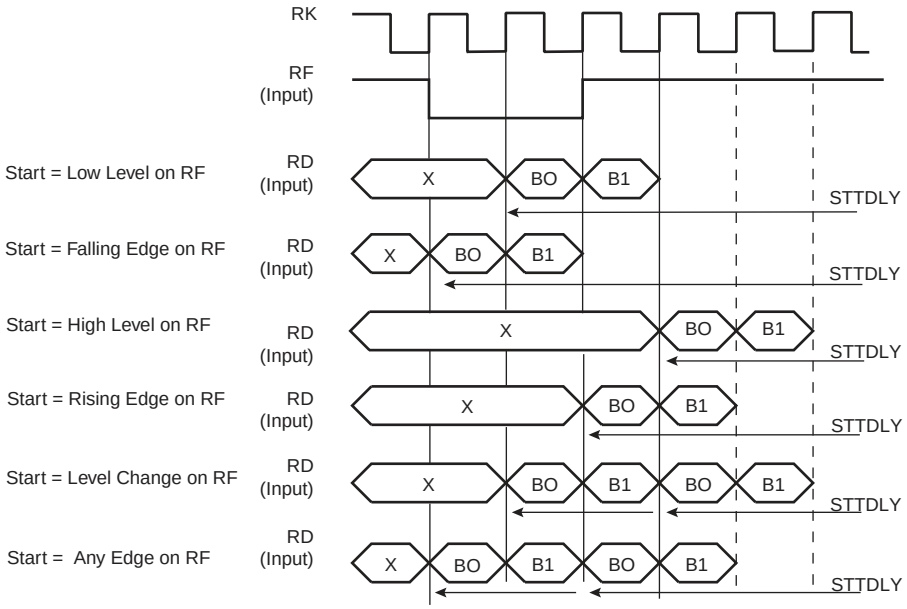


Figure 30-11. Receive Pulse/Edge Start Modes



30.7.5 Frame Sync

The Transmitter and Receiver Frame Sync pins, TF and RF, can be programmed to generate different kinds of frame synchronization signals. The Frame Sync Output Selection (FSOS) field in the Receive Frame Mode Register (SSC_RFMR) and in the Transmit Frame Mode Register (SSC_TFMR) are used to select the required waveform.

- Programmable low or high levels during data transfer are supported.
- Programmable high levels before the start of data transfers or toggling are also supported.

If a pulse waveform is selected, the Frame Sync Length (FSLEN) field in SSC_RFMR and SSC_TFMR programs the length of the pulse, from 1 bit time up to 256 bit time.

The periodicity of the Receive and Transmit Frame Sync pulse output can be programmed through the Period Divider Selection (PERIOD) field in SSC_RCMR and SSC_TCMR.

30.7.5.1 Frame Sync Data

Frame Sync Data transmits or receives a specific tag during the Frame Sync signal.

During the Frame Sync signal, the Receiver can sample the RD line and store the data in the Receive Sync Holding Register and the transmitter can transfer Transmit Sync Holding Register in the Shifter Register. The data length to be sampled/shifted out during the Frame Sync signal is programmed by the FSLEN field in SSC_RFMR/SSC_TFMR and has a maximum value of 16.

Concerning the Receive Frame Sync Data operation, if the Frame Sync Length is equal to or lower than the delay between the start event and the actual data reception, the data sampling operation is performed in the Receive Sync Holding Register through the Receive Shift Register.

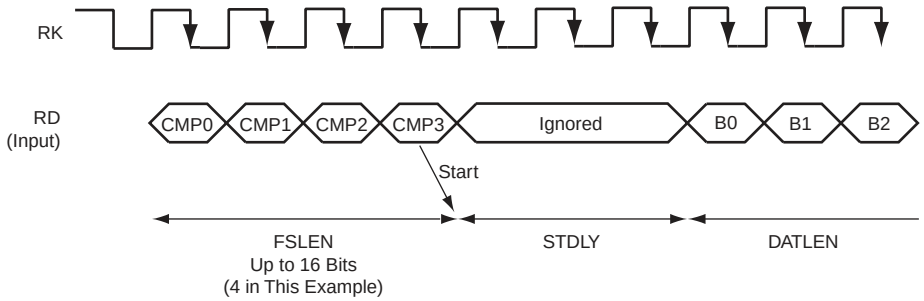
The Transmit Frame Sync Operation is performed by the transmitter only if the bit Frame Sync Data Enable (FSDEN) in SSC_TFMR is set. If the Frame Sync length is equal to or lower than the delay between the start event and the actual data transmission, the normal transmission has priority and the data contained in the Transmit Sync Holding Register is transferred in the Transmit Register, then shifted out.

30.7.5.2 Frame Sync Edge Detection

The Frame Sync Edge detection is programmed by the FSEDGE field in SSC_RFMR/SSC_TFMR. This sets the corresponding flags RXSYN/TXSYN in the SSC Status Register (SSC_SR) on frame synchro edge detection (signals RF/TF).

30.7.6 Receive Compare Modes

Figure 30-12. Receive Compare Modes



30.7.6.1 Compare Functions

Length of the comparison patterns (Compare 0, Compare 1) and thus the number of bits they are compared to is defined by FSLEN, but with a maximum value of 16 bits. Comparison is always done by comparing the last bits received with the comparison pattern. Compare 0 can be one start event of the Receiver. In this case, the receiver compares at each new sample the last bits received at the Compare 0 pattern contained in the Compare 0 Register (SSC_RC0R). When this start event is selected, the user can program the Receiver to start a new data transfer either by writing a new Compare 0, or by receiving continuously until Compare 1 occurs. This selection is done with the bit (STOP) in SSC_RCMR.

30.7.7 Data Format

The data framing format of both the transmitter and the receiver are programmable through the Transmitter Frame Mode Register (SSC_TFMR) and the Receiver Frame Mode Register (SSC_RFMR). In either case, the user can independently select:

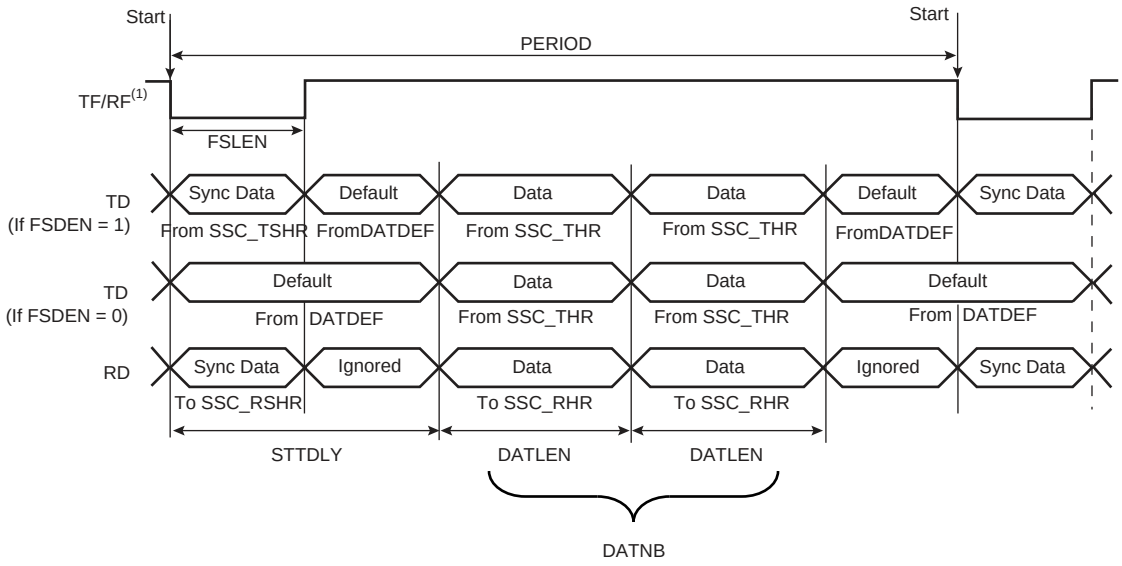
- the event that starts the data transfer (START)
- the delay in number of bit periods between the start event and the first data bit (STTDLY)
- the length of the data (DATLEN)
- the number of data to be transferred for each start event (DATNB).
- the length of synchronization transferred for each start event (FSLEN)
- the bit sense: most or lowest significant bit first (MSBF)

Additionally, the transmitter can be used to transfer synchronization and select the level driven on the TD pin while not in data transfer operation. This is done respectively by the Frame Sync Data Enable (FSDEN) and by the Data Default Value (DATDEF) bits in SSC_TFMR.

Table 30-5. Data Frame Registers

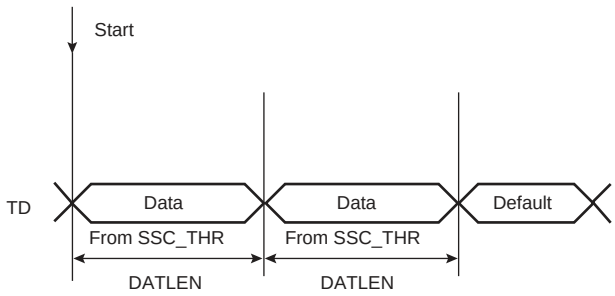
Transmitter	Receiver	Field	Length	Comment
SSC_TFMR	SSC_RFMR	DATLEN	Up to 32	Size of word
SSC_TFMR	SSC_RFMR	DATNB	Up to 16	Number of words transmitted in frame
SSC_TFMR	SSC_RFMR	MSBF		Most significant bit first
SSC_TFMR	SSC_RFMR	FSLEN	Up to 16	Size of Synchro data register
SSC_TFMR		DATDEF	0 or 1	Data default value ended
SSC_TFMR		FSDEN		Enable send SSC_TSHR
SSC_TCMR	SSC_RCMR	PERIOD	Up to 512	Frame size
SSC_TCMR	SSC_RCMR	STTDLY	Up to 255	Size of transmit start delay

Figure 30-13. Transmit and Receive Frame Format in Edge/Pulse Start Modes



Note: 1. Example of input on falling edge of TF/RF.

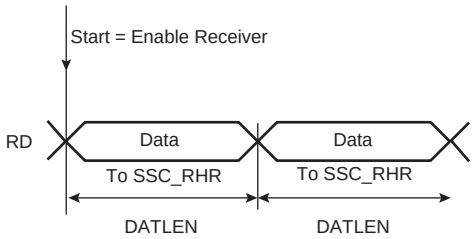
Figure 30-14. Transmit Frame Format in Continuous Mode



Start: 1. TXEMPTY set to 1
2. Write into the SSC_THR

Note: 1. STTDLY is set to 0. In this example, SSC_THR is loaded twice. FSDEN value has no effect on the transmission. SyncData cannot be output in continuous mode.

Figure 30-15. Receive Frame Format in Continuous Mode



Note: 1. STTDLY is set to 0.

30.7.8 Loop Mode

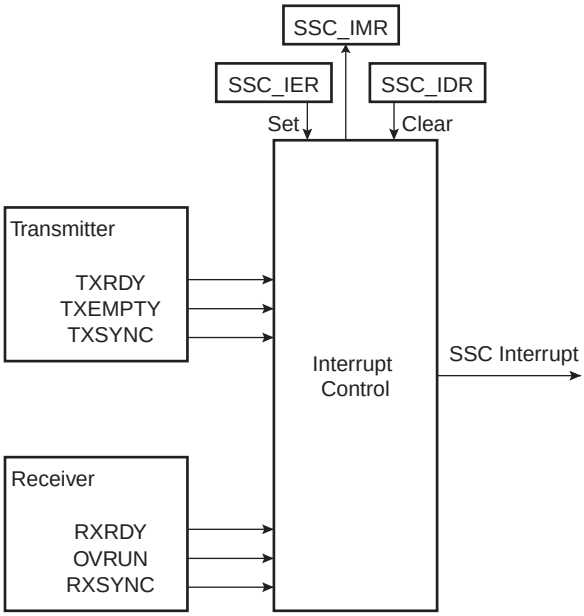
The receiver can be programmed to receive transmissions from the transmitter. This is done by setting the Loop Mode (LOOP) bit in SSC_RFMR. In this case, RD is connected to TD, RF is connected to TF and RK is connected to TK.

30.7.9 Interrupt

Most bits in SSC_SR have a corresponding bit in interrupt management registers.

The SSC can be programmed to generate an interrupt when it detects an event. The interrupt is controlled by writing SSC_IER (Interrupt Enable Register) and SSC_IDR (Interrupt Disable Register) These registers enable and disable, respectively, the corresponding interrupt by setting and clearing the corresponding bit in SSC_IMR (Interrupt Mask Register), which controls the generation of interrupts by asserting the SSC interrupt line connected to the NVIC.

Figure 30-16. Interrupt Block Diagram



30.8 SSC Application Examples

The SSC can support several serial communication modes used in audio or high speed serial links. Some standard applications are shown in the following figures. All serial link applications supported by the SSC are not listed here.

Figure 30-17. Audio Application Block Diagram

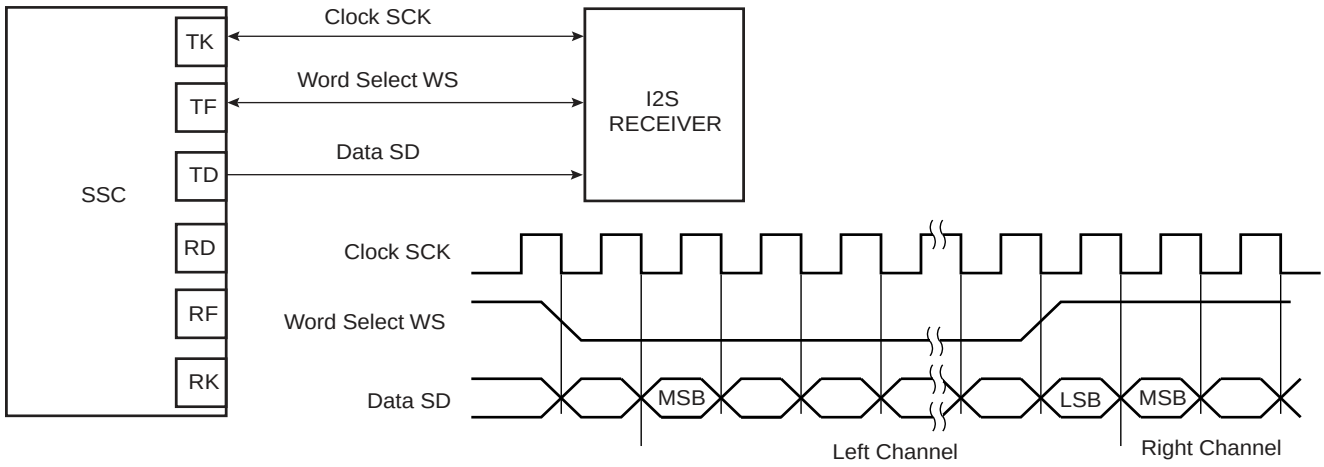


Figure 30-18. Codec Application Block Diagram

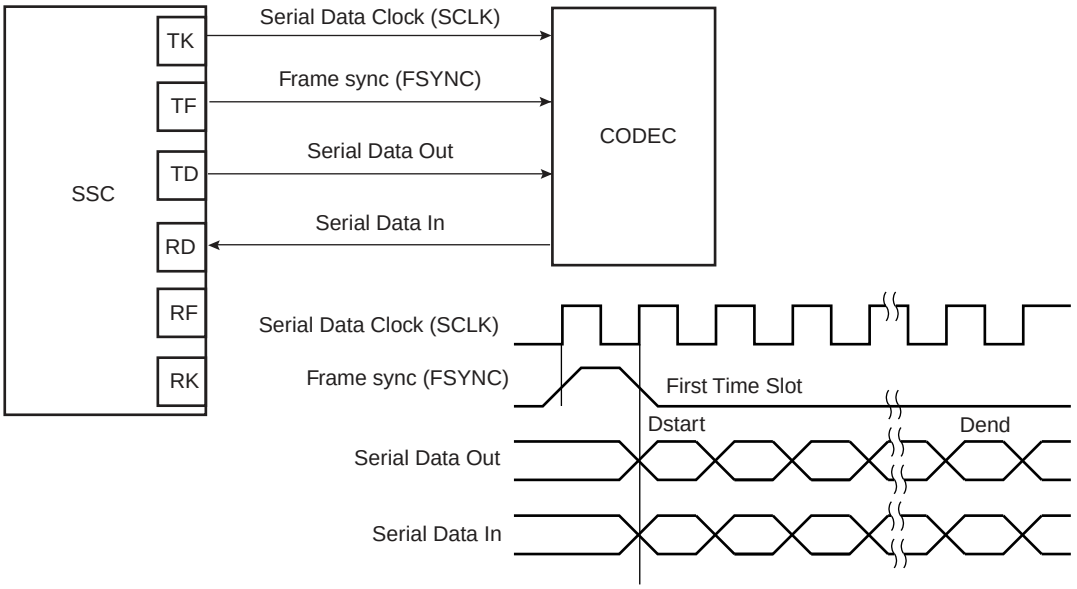
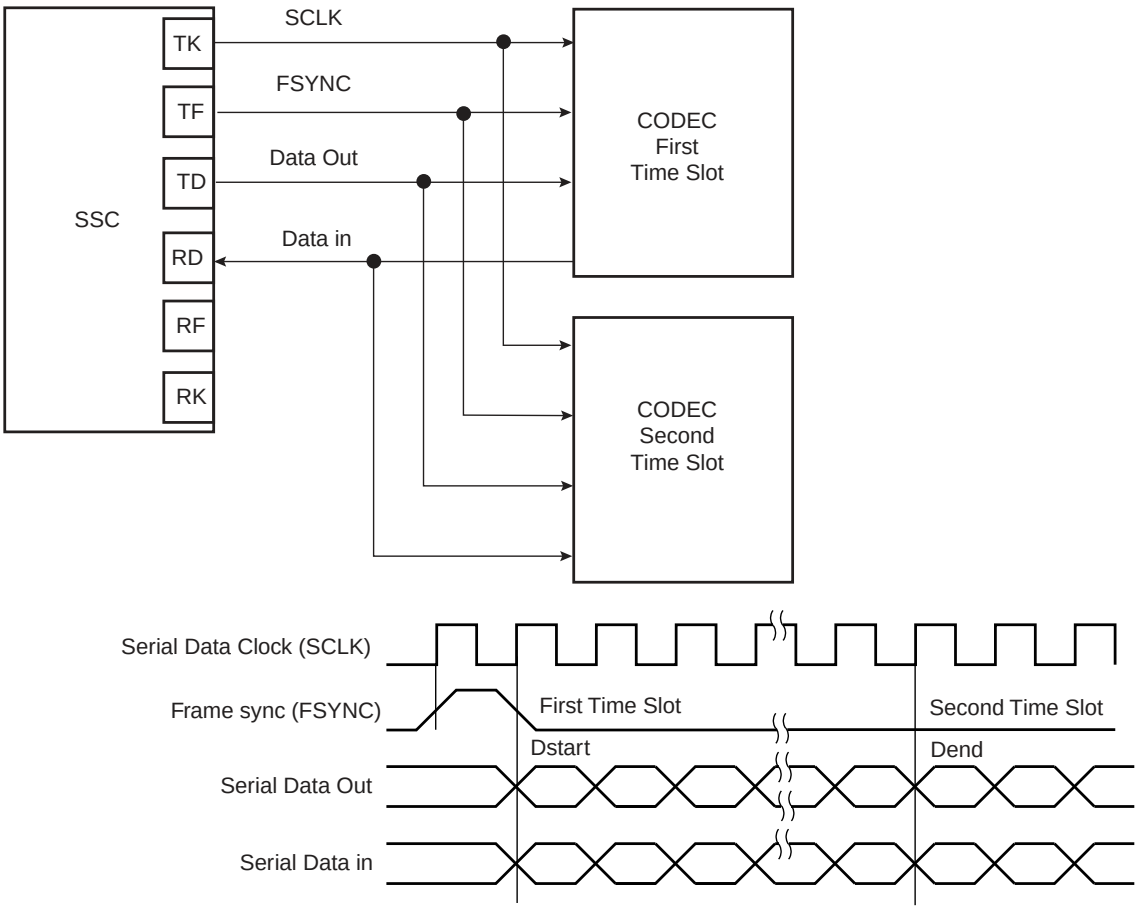


Figure 30-19. Time Slot Application Block Diagram



30.8.1 Write Protection Registers

To prevent any single software error that may corrupt SSC behavior, certain address spaces can be write-protected by setting the WPEN bit in the "SSC Write Protect Mode Register" (SSC_WPMR).

If a write access to the protected registers is detected, then the WPVS flag in the SSC Write Protect Status Register (US_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is reset by writing the SSC Write Protect Mode Register (SSC_WPMR) with the appropriate access key, WPKEY.

The protected registers are:

- "SSC Clock Mode Register" on page 570
- "SSC Receive Clock Mode Register" on page 571
- "SSC Receive Frame Mode Register" on page 573
- "SSC Transmit Clock Mode Register" on page 575
- "SSC Transmit Frame Mode Register" on page 577
- "SSC Receive Compare 0 Register" on page 583
- "SSC Receive Compare 1 Register" on page 584

30.9 Synchronous Serial Controller (SSC) User Interface

Table 30-6. Register Mapping

Offset	Register	Name	Access	Reset
0x0	Control Register	SSC_CR	Write-only	–
0x4	Clock Mode Register	SSC_CMR	Read-write	0x0
0x8	Reserved	–	–	–
0xC	Reserved	–	–	–
0x10	Receive Clock Mode Register	SSC_RCMR	Read-write	0x0
0x14	Receive Frame Mode Register	SSC_RFMR	Read-write	0x0
0x18	Transmit Clock Mode Register	SSC_TCMR	Read-write	0x0
0x1C	Transmit Frame Mode Register	SSC_TFMR	Read-write	0x0
0x20	Receive Holding Register	SSC_RHR	Read-only	0x0
0x24	Transmit Holding Register	SSC_THR	Write-only	–
0x28	Reserved	–	–	–
0x2C	Reserved	–	–	–
0x30	Receive Sync. Holding Register	SSC_RSHR	Read-only	0x0
0x34	Transmit Sync. Holding Register	SSC_TSHR	Read-write	0x0
0x38	Receive Compare 0 Register	SSC_RC0R	Read-write	0x0
0x3C	Receive Compare 1 Register	SSC_RC1R	Read-write	0x0
0x40	Status Register	SSC_SR	Read-only	0x000000CC
0x44	Interrupt Enable Register	SSC_IER	Write-only	–
0x48	Interrupt Disable Register	SSC_IDR	Write-only	–
0x4C	Interrupt Mask Register	SSC_IMR	Read-only	0x0
0xE4	Write Protect Mode Register	SSC_WPMR	Read-write	0x0
0xE8	Write Protect Status Register	SSC_WPSR	Read-only	0x0
0x50-0xFC	Reserved	–	–	–
0x100- 0x124	Reserved	–	–	–

30.9.1 SSC Control Register

Name: SSC_CR

Address: 0x40004000

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
SWRST	–	–	–	–	–	TXDIS	TXEN
7	6	5	4	3	2	1	0
–	–	–	–	–	–	RXDIS	RXEN

- **RXEN: Receive Enable**

0 = No effect.

1 = Enables Receive if RXDIS is not set.

- **RXDIS: Receive Disable**

0 = No effect.

1 = Disables Receive. If a character is currently being received, disables at end of current character reception.

- **TXEN: Transmit Enable**

0 = No effect.

1 = Enables Transmit if TXDIS is not set.

- **TXDIS: Transmit Disable**

0 = No effect.

1 = Disables Transmit. If a character is currently being transmitted, disables at end of current character transmission.

- **SWRST: Software Reset**

0 = No effect.

1 = Performs a software reset. Has priority on any other bit in SSC_CR.

30.9.2 SSC Clock Mode Register

Name: SSC_CMR

Address: 0x40004004

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	DIV			

7	6	5	4	3	2	1	0
DIV							

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **DIV: Clock Divider**

0 = The Clock Divider is not active.

Any Other Value: The Divided Clock equals the Master Clock divided by 2 times DIV. The maximum bit rate is MCK/2. The minimum bit rate is MCK/2 x 4095 = MCK/8190.

30.9.3 SSC Receive Clock Mode Register

Name: SSC_RCMR

Address: 0x40004010

Access: Read-write

31	30	29	28	27	26	25	24
PERIOD							

23	22	21	20	19	18	17	16
STTDLY							

15	14	13	12	11	10	9	8
–	–	–	STOP	START			

7	6	5	4	3	2	1	0
CKG		CKI	CKO			CKS	

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **CKS: Receive Clock Selection**

Value	Name	Description
0	MCK	Divided Clock
1	TK	TK Clock signal
2	RK	RK pin
3		Reserved

- **CKO: Receive Clock Output Mode Selection**

Value	Name	Description	RK Pin
0	NONE	None	Input-only
1	CONTINUOUS	Continuous Receive Clock	Output
2	TRANSFER	Receive Clock only during data transfers	Output
3-7		Reserved	

- **CKI: Receive Clock Inversion**

0 = The data inputs (Data and Frame Sync signals) are sampled on Receive Clock falling edge. The Frame Sync signal output is shifted out on Receive Clock rising edge.

1 = The data inputs (Data and Frame Sync signals) are sampled on Receive Clock rising edge. The Frame Sync signal output is shifted out on Receive Clock falling edge.

CKI affects only the Receive Clock and not the output clock signal.

- **CKG: Receive Clock Gating Selection**

Value	Name	Description	RK Pin
0	NONE	None	Input-only
1	CONTINUOUS	Continuous Receive Clock	Output
2	TRANSFER	Receive Clock only during data transfers	Output
3-7		Reserved	

- **START: Receive Start Selection**

Value	Name	Description
0	CONTINUOUS	Continuous, as soon as the receiver is enabled, and immediately after the end of transfer of the previous data.
1	TRANSMIT	Transmit start
2	RF_LOW	Detection of a low level on RF signal
3	RF_HIGH	Detection of a high level on RF signal
4	RF_FALLING	Detection of a falling edge on RF signal
5	RF_RISING	Detection of a rising edge on RF signal
6	RF_LEVEL	Detection of any level change on RF signal
7	RF_EDGE	Detection of any edge on RF signal
8	CMP_0	Compare 0

- **STOP: Receive Stop Selection**

0 = After completion of a data transfer when starting with a Compare 0, the receiver stops the data transfer and waits for a new compare 0.

1 = After starting a receive with a Compare 0, the receiver operates in a continuous mode until a Compare 1 is detected.

- **STTDLY: Receive Start Delay**

If STTDLY is not 0, a delay of STTDLY clock cycles is inserted between the start event and the actual start of reception. When the Receiver is programmed to start synchronously with the Transmitter, the delay is also applied.

Note: It is very important that STTDLY be set carefully. If STTDLY must be set, it should be done in relation to TAG (Receive Sync Data) reception.

- **PERIOD: Receive Period Divider Selection**

This field selects the divider to apply to the selected Receive Clock in order to generate a new Frame Sync Signal. If 0, no PERIOD signal is generated. If not 0, a PERIOD signal is generated each 2 x (PERIOD+1) Receive Clock.

30.9.4 SSC Receive Frame Mode Register

Name: SSC_RFMR

Address: 0x40004014

Access: Read-write

31	30	29	28	27	26	25	24
FSLEN_EXT	FSLEN_EXT	FSLEN_EXT	FSLEN_EXT	–	–	–	FSEDGE
23	22	21	20	19	18	17	16
–	FSOS			FSLEN			
15	14	13	12	11	10	9	8
–	–	–	–	DATNB			
7	6	5	4	3	2	1	0
MSBF	–	LOOP	DATLEN				

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **DATLEN: Data Length**

0 = Forbidden value (1-bit data length not supported).
Any other value: The bit stream contains DATLEN + 1 data bits.

- **LOOP: Loop Mode**

0 = Normal operating mode.

1 = RD is driven by TD, RF is driven by TF and TK drives RK.

- **MSBF: Most Significant Bit First**

0 = The lowest significant bit of the data register is sampled first in the bit stream.

1 = The most significant bit of the data register is sampled first in the bit stream.

- **DATNB: Data Number per Frame**

This field defines the number of data words to be received after each transfer start, which is equal to (DATNB + 1).

- **FSLEN: Receive Frame Sync Length**

This field defines the number of bits sampled and stored in the Receive Sync Data Register. When this mode is selected by the START field in the Receive Clock Mode Register, it also determines the length of the sampled data to be compared to the Compare 0 or Compare 1 register.

This field is used with FSLEN_EXT to determine the pulse length of the Receive Frame Sync signal.

Pulse length is equal to FSLEN + (FSLEN_EXT * 16) + 1 Receive Clock periods.

- **FSOS: Receive Frame Sync Output Selection**

Value	Name	Description	RF Pin
0	NONE	None	Input-only
1	NEGATIVE	Negative Pulse	Output
2	POSITIVE	Positive Pulse	Output
3	LOW	Driven Low during data transfer	Output
4	HIGH	Driven High during data transfer	Output
5	TOGGLING	Toggling at each start of data transfer	Output
6-7		Reserved	Undefined

- **FSEDGE: Frame Sync Edge Detection**

Determines which edge on Frame Sync will generate the interrupt RXSYN in the SSC Status Register.

Value	Name	Description
0	POSITIVE	Positive Edge Detection
1	NEGATIVE	Negative Edge Detection

- **FSLEN_EXT: FSLEN Field Extension**

Extends FSLEN field. For details, refer to FSLEN bit description on page 573.

30.9.5 SSC Transmit Clock Mode Register

Name: SSC_TCMR

Address: 0x40004018

Access: Read-write

31	30	29	28	27	26	25	24
PERIOD							
23	22	21	20	19	18	17	16
STTDLY							
15	14	13	12	11	10	9	8
–	–	–	–	START			
7	6	5	4	3	2	1	0
CKG		CKI	CKO			CKS	

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **CKS: Transmit Clock Selection**

Value	Name	Description
0	MCK	Divided Clock
1	TK	TK Clock signal
2	RK	RK pin
3		Reserved

- **CKO: Transmit Clock Output Mode Selection**

Value	Name	Description	TK Pin
0	NONE	None	Input-only
1	CONTINUOUS	Continuous Receive Clock	Output
2	TRANSFER	Transmit Clock only during data transfers	Output
3-7		Reserved	

- **CKI: Transmit Clock Inversion**

0 = The data outputs (Data and Frame Sync signals) are shifted out on Transmit Clock falling edge. The Frame sync signal input is sampled on Transmit clock rising edge.

1 = The data outputs (Data and Frame Sync signals) are shifted out on Transmit Clock rising edge. The Frame sync signal input is sampled on Transmit clock falling edge.

CKI affects only the Transmit Clock and not the output clock signal.

- **CKG: Transmit Clock Gating Selection**

Value	Name	Description
0	NONE	None
1	CONTINUOUS	Transmit Clock enabled only if TF Low
2	TRANSFER	Transmit Clock enabled only if TF High

- **START: Transmit Start Selection**

Value	Name	Description
0	CONTINUOUS	Continuous, as soon as a word is written in the SSC_THR Register (if Transmit is enabled), and immediately after the end of transfer of the previous data.
1	RECEIVE	Receive start
2	RF_LOW	Detection of a low level on TF signal
3	RF_HIGH	Detection of a high level on TF signal
4	RF_FALLING	Detection of a falling edge on TF signal
5	RF_RISING	Detection of a rising edge on TF signal
6	RF_LEVEL	Detection of any level change on TF signal
7	RF_EDGE	Detection of any edge on TF signal
8	CMP_0	Compare 0

- **STTDLY: Transmit Start Delay**

If STTDLY is not 0, a delay of STTDLY clock cycles is inserted between the start event and the actual start of transmission of data. When the Transmitter is programmed to start synchronously with the Receiver, the delay is also applied.

Note: STTDLY must be set carefully. If STTDLY is too short in respect to TAG (Transmit Sync Data) emission, data is emitted instead of the end of TAG.

- **PERIOD: Transmit Period Divider Selection**

This field selects the divider to apply to the selected Transmit Clock to generate a new Frame Sync Signal. If 0, no period signal is generated. If not 0, a period signal is generated at each 2 x (PERIOD+1) Transmit Clock.

30.9.6 SSC Transmit Frame Mode Register

Name: SSC_TFMR

Address: 0x4000401C

Access: Read-write

31	30	29	28	27	26	25	24
FSLEN_EXT	FSLEN_EXT	FSLEN_EXT	FSLEN_EXT	–	–	–	FSEDGE
23	22	21	20	19	18	17	16
FSDEN	FSOS			FSLEN			
15	14	13	12	11	10	9	8
–	–	–	–	DATNB			
7	6	5	4	3	2	1	0
MSBF	–	DATDEF	DATLEN				

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **DATLEN: Data Length**

0 = Forbidden value (1-bit data length not supported).

Any other value: The bit stream contains DATLEN + 1 data bits.

- **DATDEF: Data Default Value**

This bit defines the level driven on the TD pin while out of transmission. Note that if the pin is defined as multi-drive by the PIO Controller, the pin is enabled only if the SCC TD output is 1.

- **MSBF: Most Significant Bit First**

0 = The lowest significant bit of the data register is shifted out first in the bit stream.

1 = The most significant bit of the data register is shifted out first in the bit stream.

- **DATNB: Data Number per frame**

This field defines the number of data words to be transferred after each transfer start, which is equal to (DATNB +1).

- **FSLEN: Transmit Frame Sync Length**

This field defines the length of the Transmit Frame Sync signal and the number of bits shifted out from the Transmit Sync Data Register if FSDEN is 1.

This field is used with FSLEN_EXT to determine the pulse length of the Transmit Frame Sync signal.

Pulse length is equal to FSLEN + (FSLEN_EXT * 16) + 1 Transmit Clock period.

- **FSOS: Transmit Frame Sync Output Selection**

Value	Name	Description	RF Pin
0	NONE	None	Input-only
1	NEGATIVE	Negative Pulse	Output
2	POSITIVE	Positive Pulse	Output
3	LOW	Driven Low during data transfer	Output
4	HIGH	Driven High during data transfer	Output
5	TOGGLING	Toggling at each start of data transfer	Output
6-7		Reserved	Undefined

- **FSDEN: Frame Sync Data Enable**

0 = The TD line is driven with the default value during the Transmit Frame Sync signal.

1 = SSC_TSHR value is shifted out during the transmission of the Transmit Frame Sync signal.

- **FSEDGE: Frame Sync Edge Detection**

Determines which edge on frame sync will generate the interrupt TXSYN (Status Register).

Value	Name	Description
0	POSITIVE	Positive Edge Detection
1	NEGATIVE	Negative Edge Detection

- **FSLEN_EXT: FSLEN Field Extension**

Extends FSLEN field. For details, refer to FSLEN bit description on page 577.

30.9.7 SSC Receive Holding Register

Name: SSC_RHR

Address: 0x40004020

Access: Read-only

31	30	29	28	27	26	25	24
RDAT							

23	22	21	20	19	18	17	16
RDAT							

15	14	13	12	11	10	9	8
RDAT							

7	6	5	4	3	2	1	0
RDAT							

- **RDAT: Receive Data**

Right aligned regardless of the number of data bits defined by DATLEN in SSC_RFMR.

30.9.8 SSC Transmit Holding Register

Name: SSC_THR

Address: 0x40004024

Access: Write-only

31	30	29	28	27	26	25	24
TDAT							

23	22	21	20	19	18	17	16
TDAT							

15	14	13	12	11	10	9	8
TDAT							

7	6	5	4	3	2	1	0
TDAT							

- **TDAT: Transmit Data**

Right aligned regardless of the number of data bits defined by DATLEN in SSC_TFMR.

30.9.9 SSC Receive Synchronization Holding Register

Name: SSC_RSHR

Address: 0x40004030

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
RSDAT							

7	6	5	4	3	2	1	0
RSDAT							

- **RSDAT: Receive Synchronization Data**

30.9.10 SSC Transmit Synchronization Holding Register

Name: SSC_TSHR

Address: 0x40004034

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
TSDAT							

7	6	5	4	3	2	1	0
TSDAT							

- **TSDAT: Transmit Synchronization Data**

30.9.11 SSC Receive Compare 0 Register

Name: SSC_RC0R

Address: 0x40004038

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
CP0							
7	6	5	4	3	2	1	0
CP0							

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **CP0: Receive Compare Data 0**

30.9.12 SSC Receive Compare 1 Register

Name: SSC_RC1R

Address: 0x4000403C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
CP1							
7	6	5	4	3	2	1	0
CP1							

This register can only be written if the WPEN bit is cleared in “SSC Write Protect Mode Register” .

- **CP1: Receive Compare Data 1**

30.9.13 SSC Status Register

Name: SSC_SR

Address: 0x40004040

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	RXEN	TXEN
15	14	13	12	11	10	9	8
–	–	–	–	RXSYN	TXSYN	CP1	CP0
7	6	5	4	3	2	1	0
–	–	OVRUN	RXRDY	–	–	TXEMPTY	TXRDY

- **TXRDY: Transmit Ready**

0 = Data has been loaded in SSC_THR and is waiting to be loaded in the Transmit Shift Register (TSR).

1 = SSC_THR is empty.

- **TXEMPTY: Transmit Empty**

0 = Data remains in SSC_THR or is currently transmitted from TSR.

1 = Last data written in SSC_THR has been loaded in TSR and last data loaded in TSR has been transmitted.

- **RXRDY: Receive Ready**

0 = SSC_RHR is empty.

1 = Data has been received and loaded in SSC_RHR.

- **OVRUN: Receive Overrun**

0 = No data has been loaded in SSC_RHR while previous data has not been read since the last read of the Status Register.

1 = Data has been loaded in SSC_RHR while previous data has not yet been read since the last read of the Status Register.

- **CP0: Compare 0**

0 = A compare 0 has not occurred since the last read of the Status Register.

1 = A compare 0 has occurred since the last read of the Status Register.

- **CP1: Compare 1**

0 = A compare 1 has not occurred since the last read of the Status Register.

1 = A compare 1 has occurred since the last read of the Status Register.

- **TXSYN: Transmit Sync**

0 = A Tx Sync has not occurred since the last read of the Status Register.

1 = A Tx Sync has occurred since the last read of the Status Register.

- **RXSYN: Receive Sync**

0 = An Rx Sync has not occurred since the last read of the Status Register.

1 = An Rx Sync has occurred since the last read of the Status Register.

- **TXEN: Transmit Enable**

0 = Transmit is disabled.

1 = Transmit is enabled.

- **RXEN: Receive Enable**

0 = Receive is disabled.

1 = Receive is enabled.

30.9.14 SSC Interrupt Enable Register

Name: SSC_IER

Address: 0x40004044

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	RXSYN	TXSYN	CP1	CP0
7	6	5	4	3	2	1	0
–	–	OVRUN	RXRDY	–	–	TXEMPTY	TXRDY

- **TXRDY: Transmit Ready Interrupt Enable**

0 = 0 = No effect.

1 = Enables the Transmit Ready Interrupt.

- **TXEMPTY: Transmit Empty Interrupt Enable**

0 = No effect.

1 = Enables the Transmit Empty Interrupt.

- **RXRDY: Receive Ready Interrupt Enable**

0 = No effect.

1 = Enables the Receive Ready Interrupt.

- **OVRUN: Receive Overrun Interrupt Enable**

0 = No effect.

1 = Enables the Receive Overrun Interrupt.

- **CP0: Compare 0 Interrupt Enable**

0 = No effect.

1 = Enables the Compare 0 Interrupt.

- **CP1: Compare 1 Interrupt Enable**

0 = No effect.

1 = Enables the Compare 1 Interrupt.

- **TXSYN: Tx Sync Interrupt Enable**

0 = No effect.

1 = Enables the Tx Sync Interrupt.

- **RXSYN: Rx Sync Interrupt Enable**

0 = No effect.

1 = Enables the Rx Sync Interrupt.

30.9.15 SSC Interrupt Disable Register

Name: SSC_IDR

Address: 0x40004048

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	RXSYN	TXSYN	CP1	CP0
7	6	5	4	3	2	1	0
–	–	OVRUN	RXRDY	–	–	TXEMPTY	TXRDY

- **TXRDY: Transmit Ready Interrupt Disable**

0 = No effect.

1 = Disables the Transmit Ready Interrupt.

- **TXEMPTY: Transmit Empty Interrupt Disable**

0 = No effect.

1 = Disables the Transmit Empty Interrupt.

- **RXRDY: Receive Ready Interrupt Disable**

0 = No effect.

1 = Disables the Receive Ready Interrupt.

- **OVRUN: Receive Overrun Interrupt Disable**

0 = No effect.

1 = Disables the Receive Overrun Interrupt.

- **CP0: Compare 0 Interrupt Disable**

0 = No effect.

1 = Disables the Compare 0 Interrupt.

- **CP1: Compare 1 Interrupt Disable**

0 = No effect.

1 = Disables the Compare 1 Interrupt.

- **TXSYN: Tx Sync Interrupt Enable**

0 = No effect.

1 = Disables the Tx Sync Interrupt.

- **RXSYN: Rx Sync Interrupt Enable**

0 = No effect.

1 = Disables the Rx Sync Interrupt.

30.9.16 SSC Interrupt Mask Register

Name: SSC_IMR

Address: 0x4000404C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	RXSYN	TXSYN	CP1	CP0
7	6	5	4	3	2	1	0
–	–	OVRUN	RXRDY	–	–	TXEMPTY	TXRDY

- **TXRDY: Transmit Ready Interrupt Mask**

0 = The Transmit Ready Interrupt is disabled.

1 = The Transmit Ready Interrupt is enabled.

- **TXEMPTY: Transmit Empty Interrupt Mask**

0 = The Transmit Empty Interrupt is disabled.

1 = The Transmit Empty Interrupt is enabled.

- **RXRDY: Receive Ready Interrupt Mask**

0 = The Receive Ready Interrupt is disabled.

1 = The Receive Ready Interrupt is enabled.

- **OVRUN: Receive Overrun Interrupt Mask**

0 = The Receive Overrun Interrupt is disabled.

1 = The Receive Overrun Interrupt is enabled.

- **CP0: Compare 0 Interrupt Mask**

0 = The Compare 0 Interrupt is disabled.

1 = The Compare 0 Interrupt is enabled.

- **CP1: Compare 1 Interrupt Mask**

0 = The Compare 1 Interrupt is disabled.

1 = The Compare 1 Interrupt is enabled.

- **TXSYN: Tx Sync Interrupt Mask**

0 = The Tx Sync Interrupt is disabled.

1 = The Tx Sync Interrupt is enabled.

- **RXSYN: Rx Sync Interrupt Mask**

0 = The Rx Sync Interrupt is disabled.

1 = The Rx Sync Interrupt is enabled.

30.9.17 SSC Write Protect Mode Register

Name: SSC_WPMR

Address: 0x400040E4

Access: Read-write

Reset: See Table 30-6

31	30	29	28	27	26	25	24
WPKEY							
23	22	21	20	19	18	17	16
WPKEY							
15	14	13	12	11	10	9	8
WPKEY							
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPEN

- **WPEN: Write Protect Enable**

0 = Disables the Write Protect if WPKEY corresponds to 0x535343 (“SSC” in ASCII).

1 = Enables the Write Protect if WPKEY corresponds to 0x535343 (“SSC” in ASCII).

Protects the registers:

- “SSC Clock Mode Register” on page 570
- “SSC Receive Clock Mode Register” on page 571
- “SSC Receive Frame Mode Register” on page 573
- “SSC Transmit Clock Mode Register” on page 575
- “SSC Transmit Frame Mode Register” on page 577
- “SSC Receive Compare 0 Register” on page 583
- “SSC Receive Compare 1 Register” on page 584

- **WPKEY: Write Protect KEY**

Should be written at value 0x535343 (“SSC” in ASCII). Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

30.9.18 SSC Write Protect Status Register

Name: SSC_WPSR

Address: 0x400040E8

Access: Read-only

Reset: See Table 30-6

31	30	29	28	27	26	25	24
—	—	—	—	—	—	—	—
23	22	21	20	19	18	17	16
WPVSRC							
15	14	13	12	11	10	9	8
WPVSRC							
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPVS

- **WPVS: Write Protect Violation Status**

0 = No Write Protect Violation has occurred since the last read of the SSC_WPSR register.

1 = A Write Protect Violation has occurred since the last read of the SSC_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protect Violation Source**

When WPVS is active, this field indicates the write-protected register (through address offset or code) in which a write access has been attempted.

Note: Reading SSC_WPSR automatically clears all fields.

31. Serial Peripheral Interface (SPI)

31.1 Description

The Serial Peripheral Interface (SPI) circuit is a synchronous serial data link that provides communication with external devices in Master or Slave Mode. It also enables communication between processors if an external processor is connected to the system.

The Serial Peripheral Interface is essentially a shift register that serially transmits data bits to other SPIs. During a data transfer, one SPI system acts as the “master”' which controls the data flow, while the other devices act as “slaves'' which have data shifted into and out by the master. Different CPUs can take turn being masters (Multiple Master Protocol opposite to Single Master Protocol where one CPU is always the master while all of the others are always slaves) and one master may simultaneously shift data into multiple slaves. However, only one slave may drive its output to write data back to the master at any given time.

A slave device is selected when the master asserts its NSS signal. If multiple slave devices exist, the master generates a separate slave select signal for each slave (NPCS).

The SPI system consists of two data lines and two control lines:

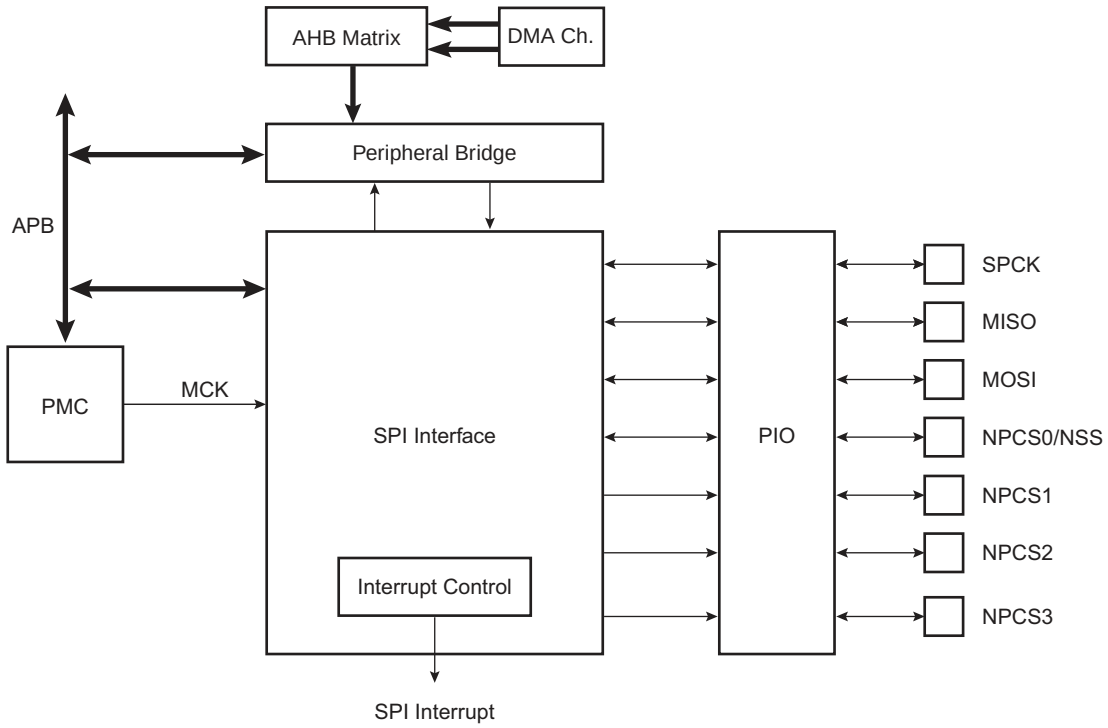
- Master Out Slave In (MOSI): This data line supplies the output data from the master shifted into the input(s) of the slave(s).
- Master In Slave Out (MISO): This data line supplies the output data from a slave to the input of the master. There may be no more than one slave transmitting data during any particular transfer.
- Serial Clock (SPCK): This control line is driven by the master and regulates the flow of the data bits. The master may transmit data at a variety of baud rates; the SPCK line cycles once for each bit that is transmitted.
- Slave Select (NSS): This control line allows slaves to be turned on and off by hardware.

31.2 Embedded Characteristics

- Supports Communication with Serial External Devices
  - Four Chip Selects with External Decoder Support Allow Communication with Up to 15 Peripherals
  - Serial Memories, such as DataFlash and 3-wire EEPROMs
  - Serial Peripherals, such as ADCs, DACs, LCD Controllers, CAN Controllers and Sensors
  - External Co-processors
- Master or Slave Serial Peripheral Bus Interface
  - 8- to 16-bit Programmable Data Length Per Chip Select
  - Programmable Phase and Polarity Per Chip Select
  - Programmable Transfer Delay Between Consecutive Transfers and Delay Before SPI Clock per Chip Select
  - Programmable Delay Between Chip Selects
  - Selectable Mode Fault Detection
- Connection to DMA Channel Capabilities Optimizes Data Transfers
  - One channel for the Receiver, One Channel for the Transmitter

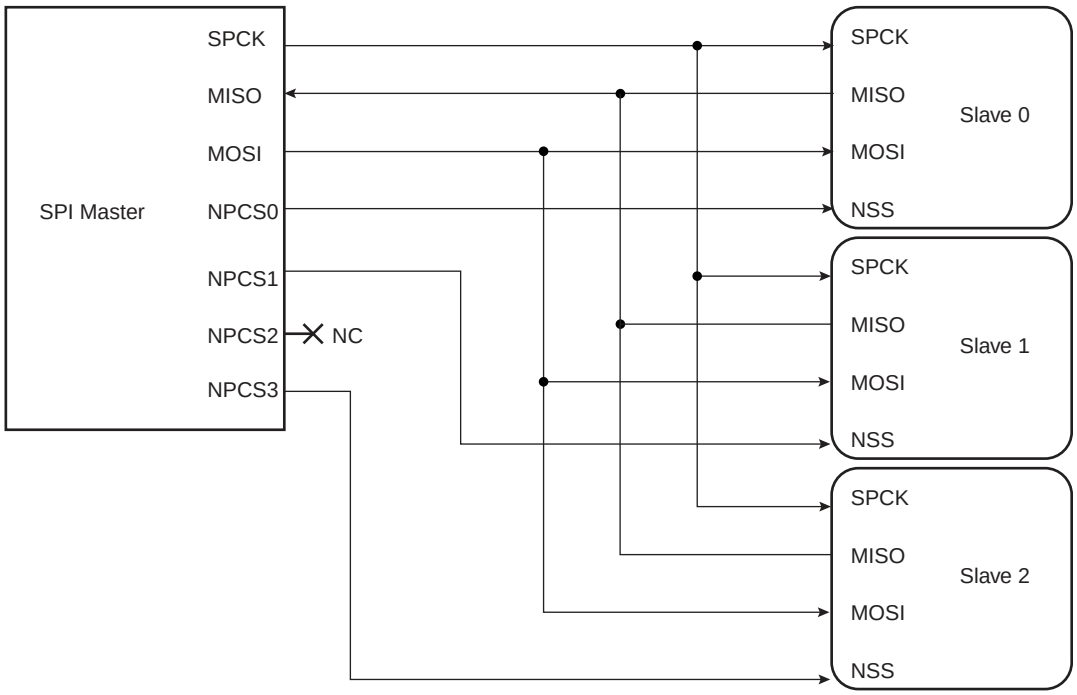
31.3 Block Diagram

Figure 31-1. Block Diagram



31.4 Application Block Diagram

Figure 31-2. Application Block Diagram: Single Master/Multiple Slave Implementation



31.5 Signal Description

Table 31-1. Signal Description

Pin Name	Pin Description	Type	
		Master	Slave
MISO	Master In Slave Out	Input	Output
MOSI	Master Out Slave In	Output	Input
SPCK	Serial Clock	Output	Input
NPCS1-NPCS3	Peripheral Chip Selects	Output	Unused
NPCS0/NSS	Peripheral Chip Select/Slave Select	Output	Input

31.6 Product Dependencies

31.6.1 I/O Lines

The pins used for interfacing the compliant external devices may be multiplexed with PIO lines. The programmer must first program the PIO controllers to assign the SPI pins to their peripheral functions.

Table 31-2. I/O Lines

Instance	Signal	I/O Line	Peripheral
SPI	MISO	PA13	A
SPI	MOSI	PA14	A
SPI	NPCS0	PA16	A
SPI	NPCS1	PA0	B
SPI	NPCS1	PC3	B
SPI	NPCS1	PC19	B
SPI	NPCS2	PA1	B
SPI	NPCS2	PC4	B
SPI	NPCS2	PC14	B
SPI	NPCS3	PA19	B
SPI	NPCS3	PC5	B
SPI	SPCK	PA15	A

31.6.2 Power Management

The SPI may be clocked through the Power Management Controller (PMC), thus the programmer must first configure the PMC to enable the SPI clock.

31.6.3 Interrupt

The SPI interface has an interrupt line connected to the Interrupt Controller. Handling the SPI interrupt requires programming the interrupt controller before configuring the SPI.

Table 31-3. Peripheral IDs

Instance	ID
SPI	20

31.7 Functional Description

31.7.1 Modes of Operation

The SPI operates in Master Mode or in Slave Mode.

Operation in Master Mode is programmed by writing at 1 the MSTR bit in the Mode Register. The pins NPCS0 to NPCS3 are all configured as outputs, the SPCK pin is driven, the MISO line is wired on the receiver input and the MOSI line driven as an output by the transmitter.

If the MSTR bit is written at 0, the SPI operates in Slave Mode. The MISO line is driven by the transmitter output, the MOSI line is wired on the receiver input, the SPCK pin is driven by the transmitter to synchronize the receiver. The NPCS0 pin becomes an input, and is used as a Slave Select signal (NSS). The pins NPCS1 to NPCS3 are not driven and can be used for other purposes.

The data transfers are identically programmable for both modes of operations. The baud rate generator is activated only in Master Mode.

31.7.2 Data Transfer

Four combinations of polarity and phase are available for data transfers. The clock polarity is programmed with the CPOL bit in the Chip Select Register. The clock phase is programmed with the NCPHA bit. These two parameters determine the edges of the clock signal on which data is driven and sampled. Each of the two parameters has two possible states, resulting in four possible combinations that are incompatible with one another. Thus, a master/slave pair must use the same parameter pair values to communicate. If multiple slaves are used and fixed in different configurations, the master must reconfigure itself each time it needs to communicate with a different slave.

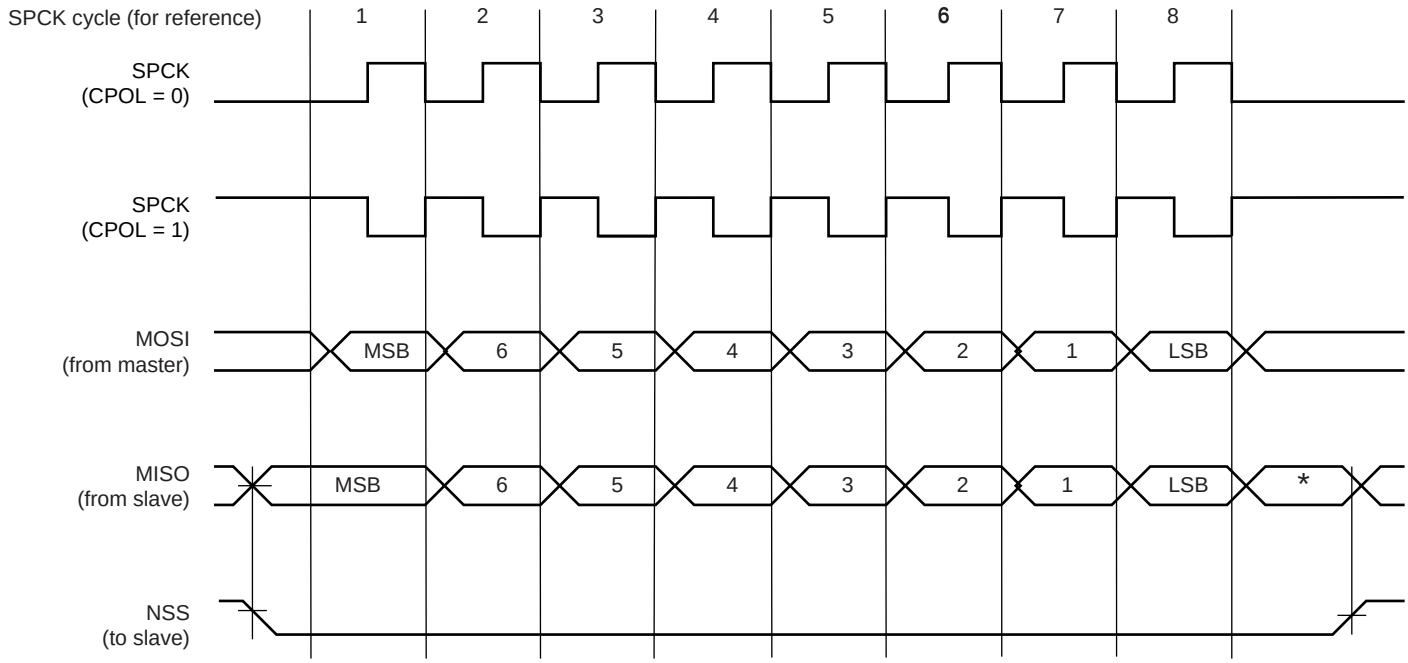
Table 31-4 shows the four modes and corresponding parameter settings.

Table 31-4. SPI Bus Protocol Mode

SPI Mode	CPOL	NCPHA	Shift SPCK Edge	Capture SPCK Edge	SPCK Inactive Level
0	0	1	Falling	Rising	Low
1	0	0	Rising	Falling	Low
2	1	1	Rising	Falling	High
3	1	0	Falling	Rising	High

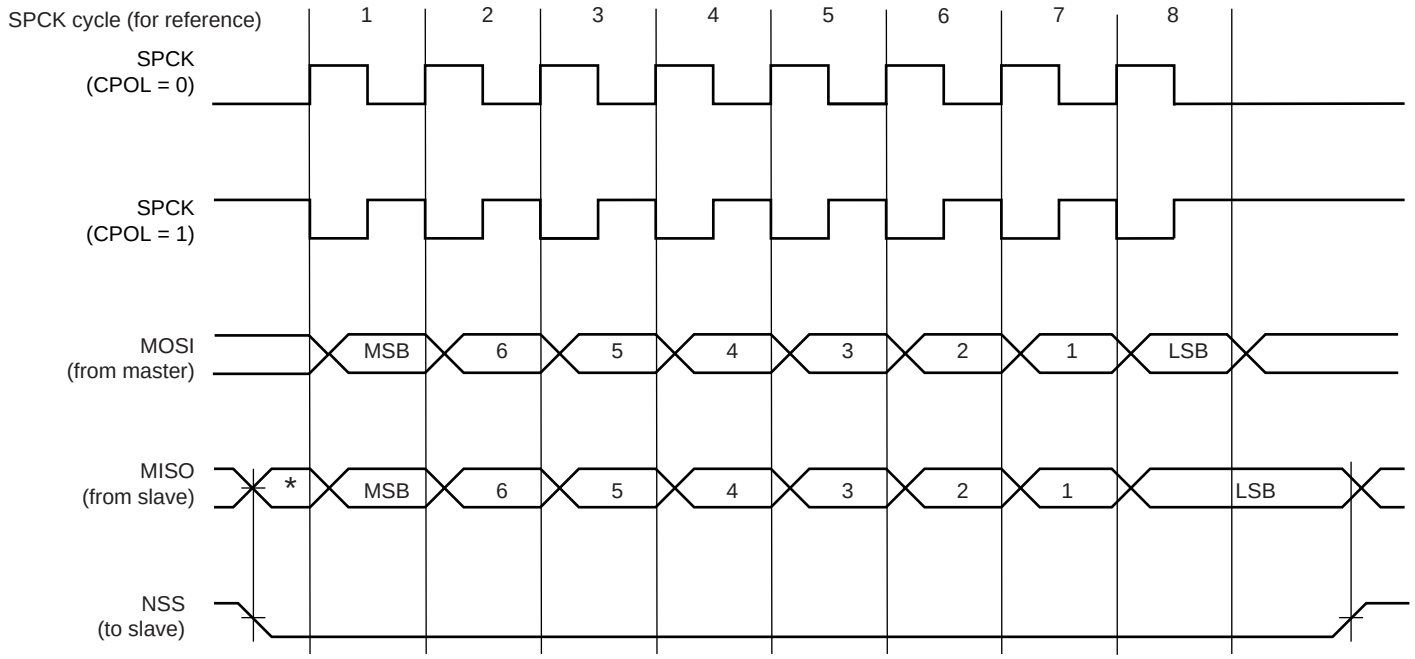
Figure 31-3 and Figure 31-4 show examples of data transfers.

Figure 31-3. SPI Transfer Format (NCPHA = 1, 8 bits per transfer)



* Not defined, but normally MSB of previous character received.

Figure 31-4. SPI Transfer Format (NCPHA = 0, 8 bits per transfer)



* Not defined but normally LSB of previous character transmitted.

31.7.3 Master Mode Operations

When configured in Master Mode, the SPI operates on the clock generated by the internal programmable baud rate generator. It fully controls the data transfers to and from the slave(s) connected to the SPI bus. The SPI drives the chip select line to the slave and the serial clock signal (SPCK).

The SPI features two holding registers, the Transmit Data Register and the Receive Data Register, and a single Shift Register. The holding registers maintain the data flow at a constant rate.

After enabling the SPI, a data transfer begins when the processor writes to the SPI_TDR (Transmit Data Register). The written data is immediately transferred in the Shift Register and transfer on the SPI bus starts. While the data in the Shift Register is shifted on the MOSI line, the MISO line is sampled and shifted in the Shift Register. Receiving data cannot occur without transmitting data. If receiving mode is not needed, for example when communicating with a slave receiver only (such as an LCD), the receive status flags in the status register can be discarded.

Before writing the TDR, the PCS field in the SPI_MR register must be set in order to select a slave.

After enabling the SPI, a data transfer begins when the processor writes to the SPI_TDR (Transmit Data Register). The written data is immediately transferred in the Shift Register and transfer on the SPI bus starts. While the data in the Shift Register is shifted on the MOSI line, the MISO line is sampled and shifted in the Shift Register. Transmission cannot occur without reception.

Before writing the TDR, the PCS field must be set in order to select a slave.

If new data is written in SPI_TDR during the transfer, it stays in it until the current transfer is completed. Then, the received data is transferred from the Shift Register to SPI_RDR, the data in SPI_TDR is loaded in the Shift Register and a new transfer starts.

The transfer of a data written in SPI_TDR in the Shift Register is indicated by the TDRE bit (Transmit Data Register Empty) in the Status Register (SPI_SR). When new data is written in SPI_TDR, this bit is cleared. The TDRE bit is used to trigger the Transmit DMA channel.

The end of transfer is indicated by the TXEMPTY flag in the SPI_SR register. If a transfer delay (DLYBCT) is greater than 0 for the last transfer, TXEMPTY is set after the completion of said delay. The master clock (MCK) can be switched off at this time.

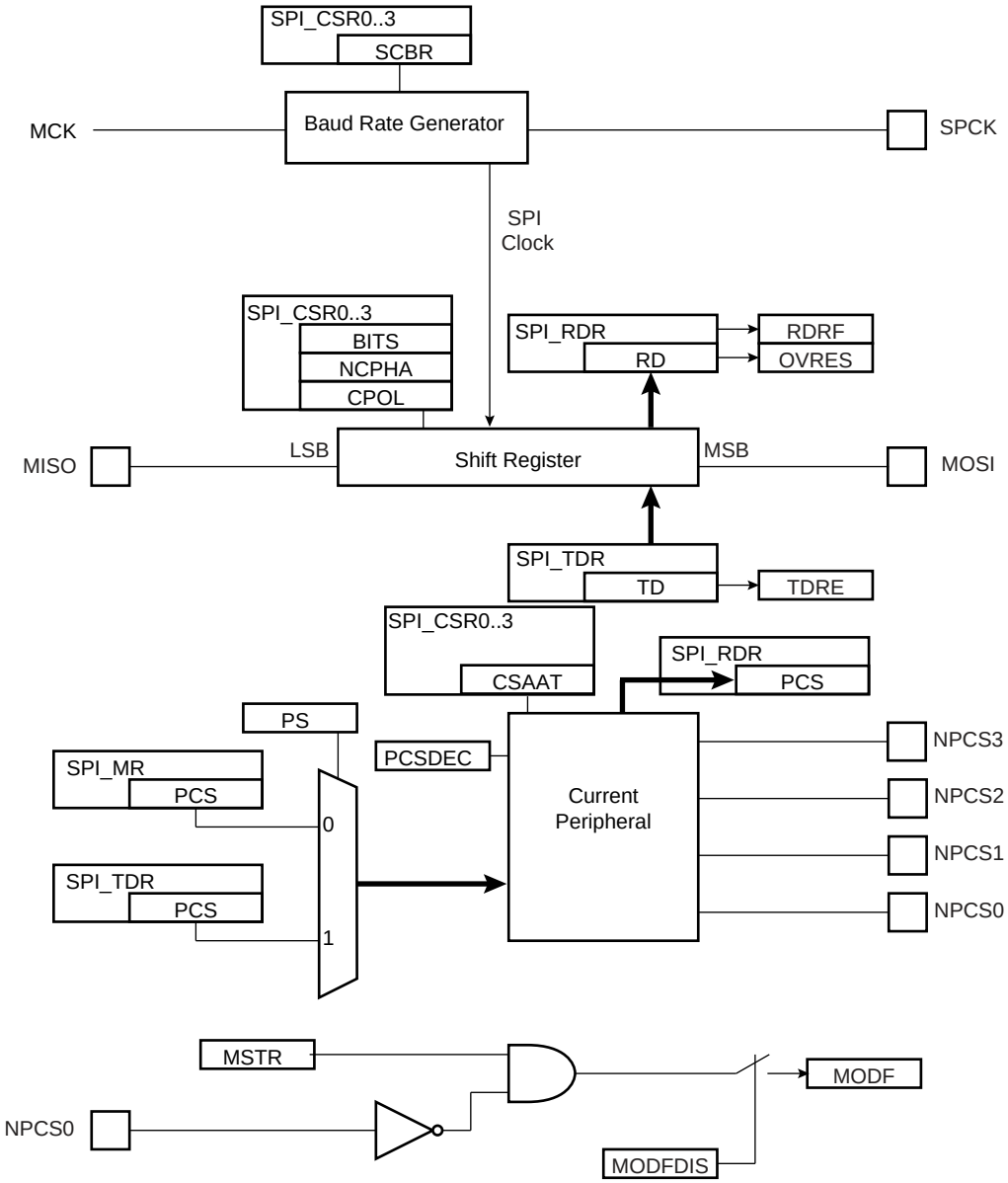
The transfer of received data from the Shift Register in SPI_RDR is indicated by the RDRF bit (Receive Data Register Full) in the Status Register (SPI_SR). When the received data is read, the RDRF bit is cleared.

If the SPI_RDR (Receive Data Register) has not been read before new data is received, the Overrun Error bit (OVRES) in SPI_SR is set. As long as this flag is set, data is loaded in SPI_RDR. The user has to read the status register to clear the OVRES bit.

Figure 31-5, shows a block diagram of the SPI when operating in Master Mode. Figure 31-6 on page 602 shows a flow chart describing how transfers are handled.

31.7.3.1 Master Mode Block Diagram

Figure 31-5. Master Mode Block Diagram



31.7.3.2 Master Mode Flow Diagram

Figure 31-6. Master Mode Flow Diagram

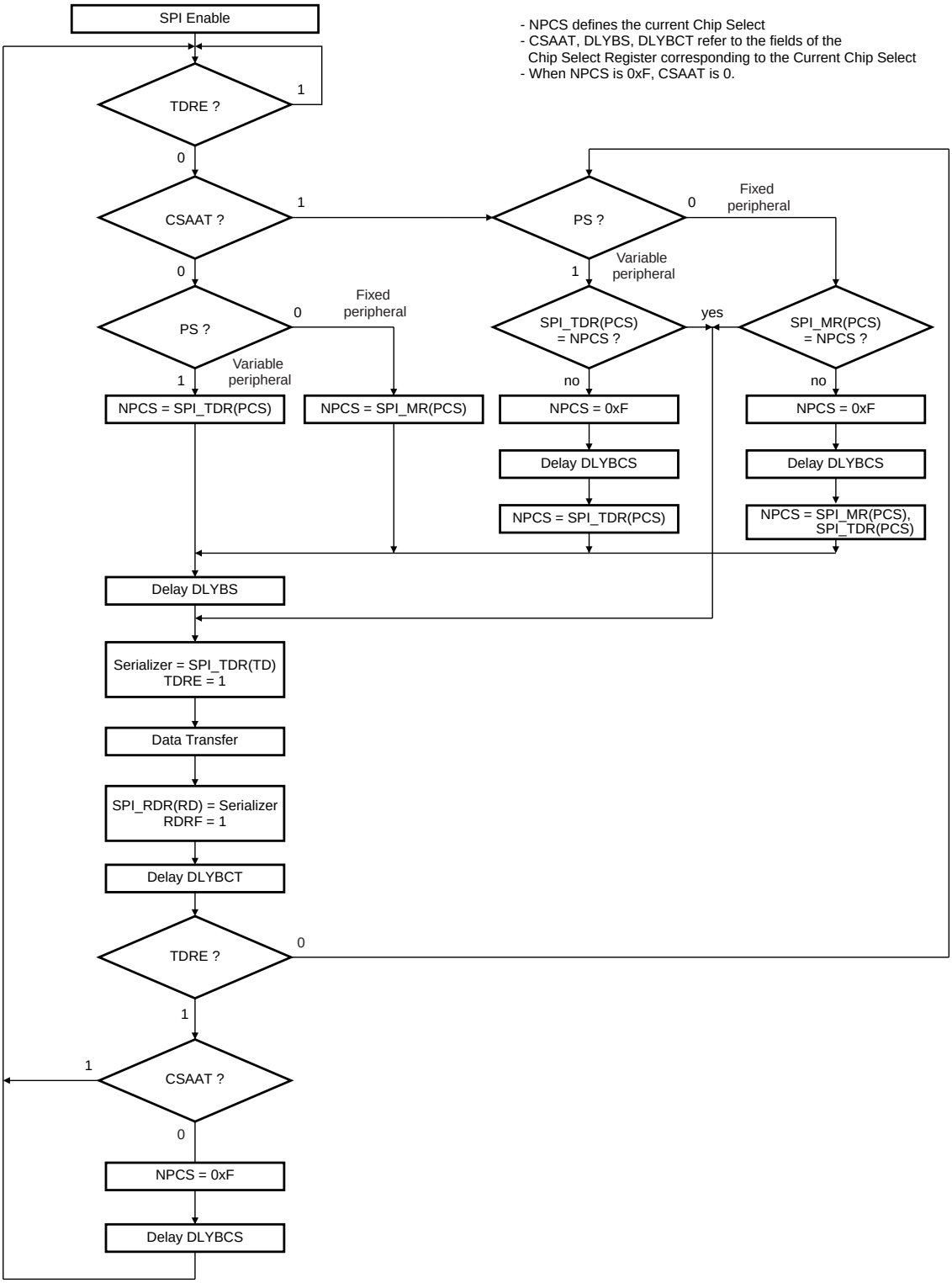
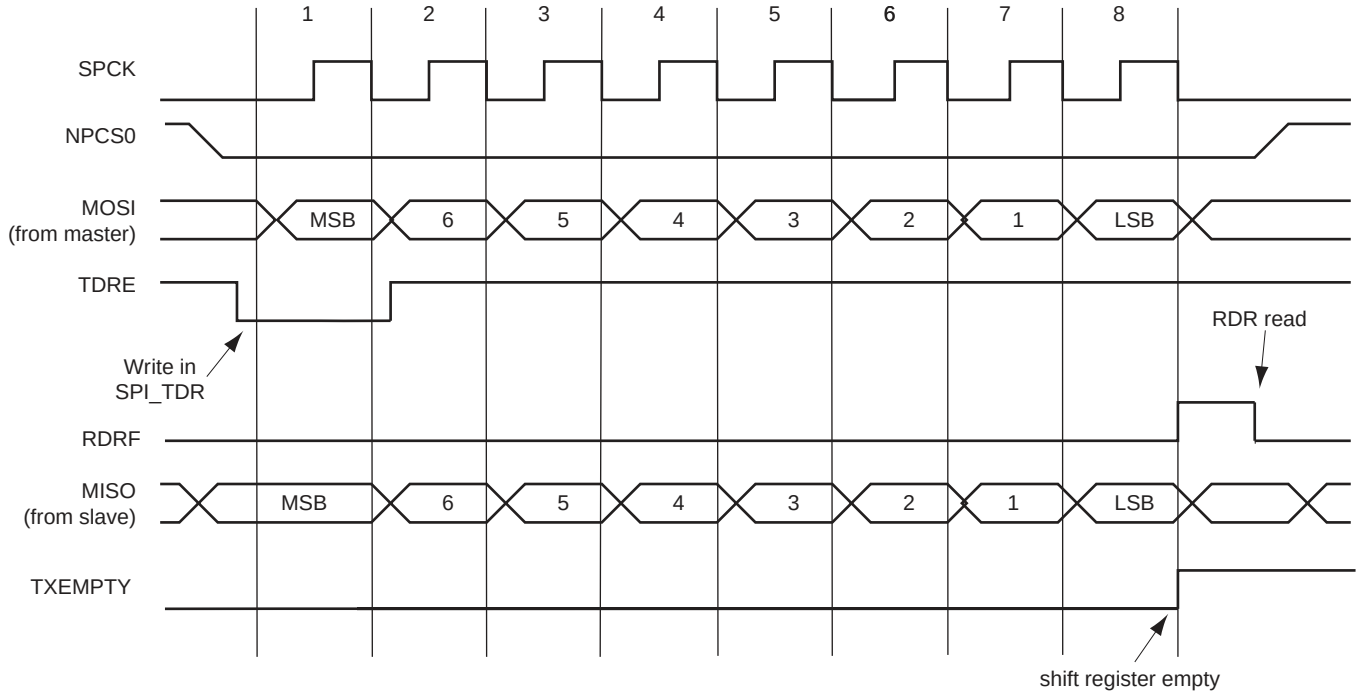


Figure 31-7 shows Transmit Data Register Empty (TDRE), Receive Data Register (RDRF) and Transmission Register Empty (TXEMPTY) status flags behavior within the SPI_SR (Status Register) during an 8-bit data transfer in fixed mode and no Peripheral Data Controller involved.

Figure 31-7. Status Register Flags Behavior



31.7.3.3 Clock Generation

The SPI Baud rate clock is generated by dividing the Master Clock (MCK), by a value between 1 and 255.

This allows a maximum operating baud rate at up to Master Clock and a minimum operating baud rate of MCK divided by 255.

Programming the SCBR field at 0 is forbidden. Triggering a transfer while SCBR is at 0 can lead to unpredictable results.

At reset, SCBR is 0 and the user has to program it at a valid value before performing the first transfer.

The divisor can be defined independently for each chip select, as it has to be programmed in the SCBR field of the Chip Select Registers. This allows the SPI to automatically adapt the baud rate for each interfaced peripheral without reprogramming.

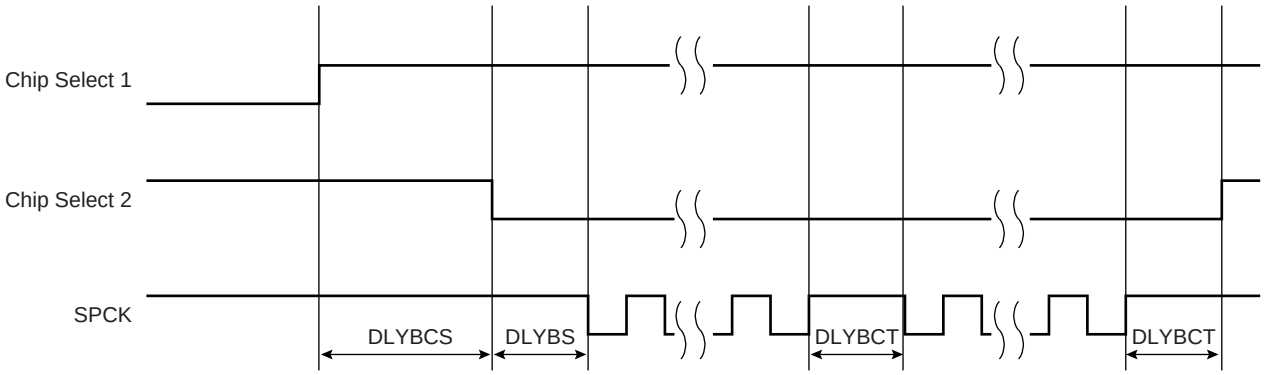
31.7.3.4 Transfer Delays

Figure 31-8 shows a chip select transfer change and consecutive transfers on the same chip select. Three delays can be programmed to modify the transfer waveforms:

- The delay between chip selects, programmable only once for all the chip selects by writing the DLYBCS field in the Mode Register. Allows insertion of a delay between release of one chip select and before assertion of a new one.
- The delay before SPCK, independently programmable for each chip select by writing the field DLYBS. Allows the start of SPCK to be delayed after the chip select has been asserted.
- The delay between consecutive transfers, independently programmable for each chip select by writing the DLYBCT field. Allows insertion of a delay between two transfers occurring on the same chip select

These delays allow the SPI to be adapted to the interfaced peripherals and their speed and bus release time.

Figure 31-8. Programmable Delays



31.7.3.5 Peripheral Selection

The serial peripherals are selected through the assertion of the NPCS0 to NPCS3 signals. By default, all the NPCS signals are high before and after each transfer.

- Fixed Peripheral Select: SPI exchanges data with only one peripheral

Fixed Peripheral Select is activated by writing the PS bit to zero in SPI_MR (Mode Register). In this case, the current peripheral is defined by the PCS field in SPI_MR and the PCS field in the SPI_TDR has no effect.

- Variable Peripheral Select: Data can be exchanged with more than one peripheral without having to reprogram the NPCS field in the SPI_MR register.

Variable Peripheral Select is activated by setting PS bit to one. The PCS field in SPI_TDR is used to select the current peripheral. This means that the peripheral selection can be defined for each new data. The value to write in the SPI_TDR register as the following format.

[xxxxxxx(7-bit) + LASTXFER(1-bit)(1)+ xxxx(4-bit) + PCS (4-bit) + DATA (8 to 16-bit)] with PCS equals to the chip select to assert as defined in Section 31.8.4 (SPI Transmit Data Register) and LASTXFER bit at 0 or 1 depending on CSAAT bit.

Note: 1. Optional.

CSAAT, LASTXFER and CSNAAT bits are discussed in Section 31.7.3.9 ”Peripheral Deselection with DMAC” .

If LASTXFER is used, the command must be issued before writing the last character. Instead of LASTXFER, the user can use the SPIDIS command. After the end of the DMA transfer, wait for the TXEMPTY flag, then write SPIDIS into the SPI_CR register (this will not change the configuration register values); the NPCS will be deactivated after the last character transfer. Then, another DMA transfer can be started if the SPIEN was previously written in the SPI_CR register.

31.7.3.6 SPI Direct Access Memory Controller (DMAC)

In both fixed and variable mode the Direct Memory Access Controller (DMAC) can be used to reduce processor overhead.

The Fixed Peripheral Selection allows buffer transfers with a single peripheral. Using the DMAC is an optimal means, as the size of the data transfer between the memory and the SPI is either 8 bits or 16 bits. However, changing the peripheral selection requires the Mode Register to be reprogrammed.

The Variable Peripheral Selection allows buffer transfers with multiple peripherals without reprogramming the Mode Register. Data written in SPI_TDR is 32 bits wide and defines the real data to be transmitted and the peripheral it is destined to. Using the DMAC in this mode requires 32-bit wide buffers, with the data in the LSBs and the PCS and LASTXFER fields in the MSBs, however the SPI still controls the number of bits (8 to16) to be transferred through MISO and MOSI lines with the chip select configuration registers. This is not the optimal means in term of memory size for the buffers, but it provides a very effective means to exchange data with several peripherals without any intervention of the processor.

31.7.3.7 Peripheral Chip Select Decoding

The user can program the SPI to operate with up to 15 peripherals by decoding the four Chip Select lines, NPCS0 to NPCS3 with 1 of up to 16 decoder/demultiplexer. This can be enabled by writing the PCSDEC bit at 1 in the Mode Register (SPI_MR).

When operating without decoding, the SPI makes sure that in any case only one chip select line is activated, i.e., one NPCS line driven low at a time. If two bits are defined low in a PCS field, only the lowest numbered chip select is driven low.

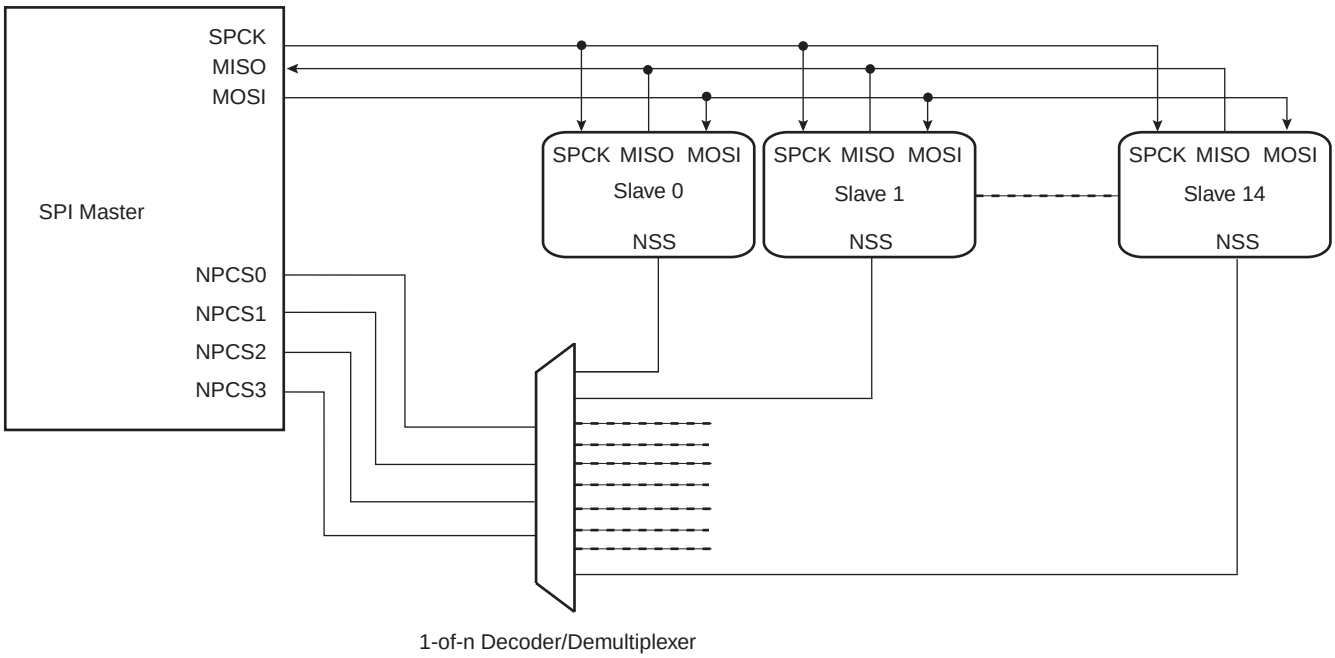
When operating with decoding, the SPI directly outputs the value defined by the PCS field on NPCS lines of either the Mode Register or the Transmit Data Register (depending on PS).

As the SPI sets a default value of 0xF on the chip select lines (i.e. all chip select lines at 1) when not processing any transfer, only 15 peripherals can be decoded.

The SPI has only four Chip Select Registers, not 15. As a result, when decoding is activated, each chip select defines the characteristics of up to four peripherals. As an example, SPI_CRS0 defines the characteristics of the externally decoded peripherals 0 to 3, corresponding to the PCS values 0x0 to 0x3. Thus, the user has to make sure to connect compatible peripherals on the decoded chip select lines 0 to 3, 4 to 7, 8 to 11 and 12 to 14. Figure 31-9 below shows such an implementation.

If the CSAAT bit is used, with or without the DMAC, the Mode Fault detection for NPCS0 line must be disabled. This is not needed for all other chip select lines since Mode Fault Detection is only on NPCS0.

Figure 31-9. Chip Select Decoding Application Block Diagram: Single Master/Multiple Slave Implementation



31.7.3.8 Peripheral Deselection without DMAC

During a transfer of more than one data on a Chip Select without the DMAC, the SPI_TDR is loaded by the processor, the flag TDRE rises as soon as the content of the SPI_TDR is transferred into the internal shift register. When this flag is detected high, the SPI_TDR can be reloaded. If this reload by the processor occurs before the end of the current transfer and if the next transfer is performed on the same chip select as the current transfer, the Chip Select is not de-asserted between the two transfers. But depending on the application software handling the SPI status register flags (by interrupt or polling method) or servicing other interrupts or other tasks, the processor may not reload the SPI_TDR in time to keep the chip select active (low). A null Delay Between Consecutive Transfer (DLYBCT) value in the SPI_CSR register, will give even less time for the processor to reload the SPI_TDR. With some SPI slave peripherals, requiring the chip select line to remain active (low) during a full set of transfers might lead to communication errors.

To facilitate interfacing with such devices, the Chip Select Register [CSR0...CSR3] can be programmed with the CSAAT bit (Chip Select Active After Transfer) at 1. This allows the chip select lines to remain in their current state (low = active) until transfer to another chip select is required. Even if the SPI_TDR is not reloaded the chip select will remain active. To have the chip select line to raise at the end of the transfer the Last transfer Bit (LASTXFER) in the SPI_MR register must be set at 1 before writing the last data to transmit into the SPI_TDR.

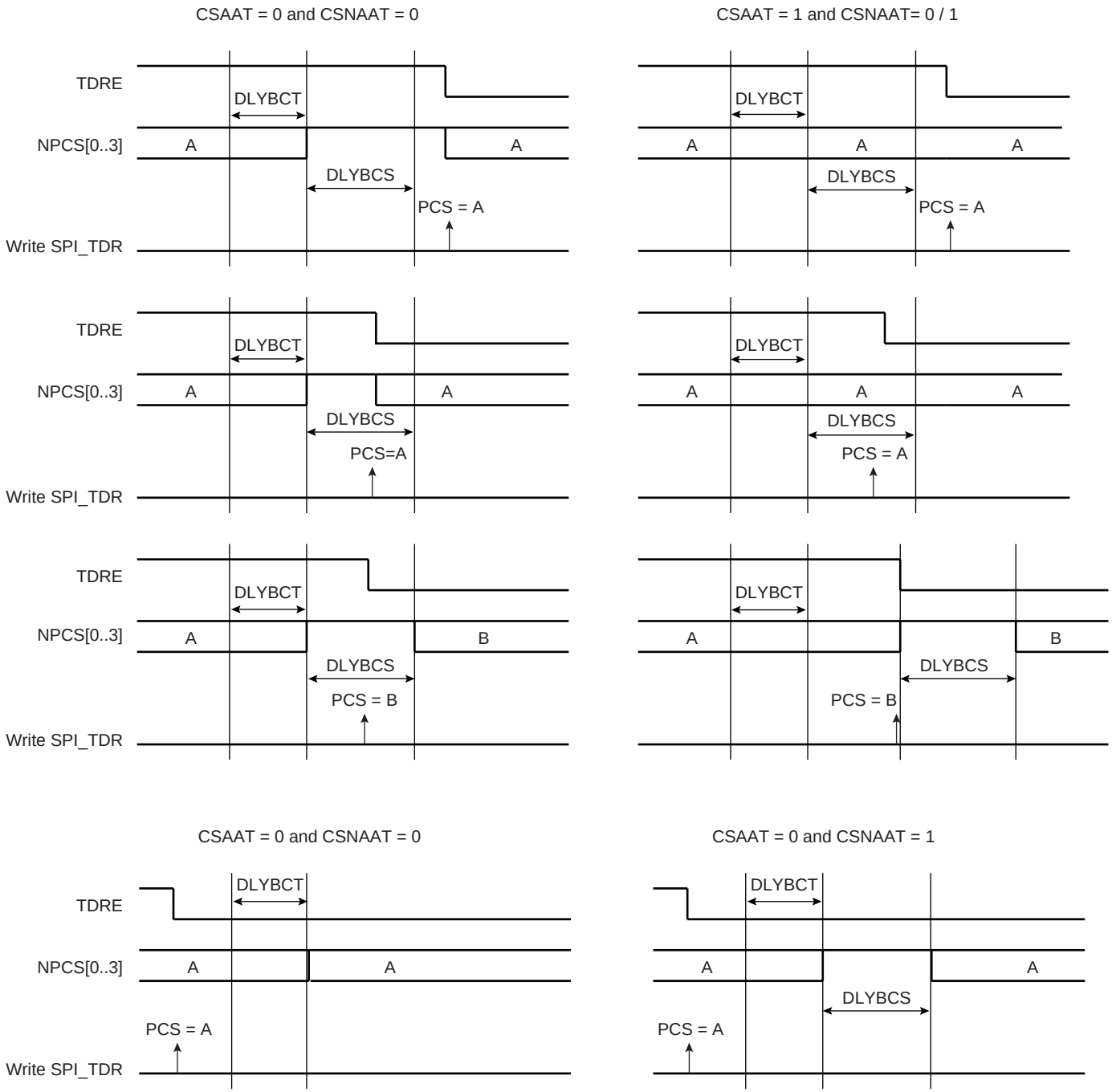
31.7.3.9 Peripheral Deselection with DMAC

When the Direct Memory Access Controller is used, the chip select line will remain low during the whole transfer since the TDRE flag is managed by the DMAC itself. The reloading of the SPI_TDR by the DMAC is done as soon as TDRE flag is set to one. In this case the use of CSAAT bit might not be needed. However, it may happen that when other DMAC channels connected to other peripherals are in use as well, the SPI DMAC might be delayed by another (DMAC with a higher priority on the bus). Having DMAC buffers in slower memories like flash memory or SDRAM compared to fast internal SRAM, may lengthen the reload time of the SPI_TDR by the DMAC as well. This means that the SPI_TDR might not be reloaded in time to keep the chip select line low. In this case the chip select line may toggle between data transfer and according to some SPI Slave devices, the communication might get lost. The use of the CSAAT bit might be needed.

When the CSAAT bit is set at 0, the NPCS does not rise in all cases between two transfers on the same peripheral. During a transfer on a Chip Select, the flag TDRE rises as soon as the content of the SPI_TDR is transferred into the internal shifter. When this flag is detected the SPI_TDR can be reloaded. If this reload occurs before the end of the current transfer and if the next transfer is performed on the same chip select as the current transfer, the Chip Select is not de-asserted between the two transfers. This might lead to difficulties for interfacing with some serial peripherals requiring the chip select to be de-asserted after each transfer. To facilitate interfacing with such devices, the Chip Select Register can be programmed with the CSNAAT bit (Chip Select Not Active After Transfer) at 1. This allows to de-assert systematically the chip select lines during a time DLYBCS. (The value of the CSNAAT bit is taken into account only if the CSAAT bit is set at 0 for the same Chip Select).

Figure 31-10 shows different peripheral deselection cases and the effect of the CSAAT and CSNAAT bits.

Figure 31-10. Peripheral Deselection



31.7.3.10Mode Fault Detection

A mode fault is detected when the SPI is programmed in Master Mode and a low level is driven by an external master on the NPCS0/NSS signal. In this case, multi-master configuration, NPCS0, MOSI, MISO and SPCK pins must be configured in open drain (through the PIO controller). When a mode fault is detected, the MODF bit in the SPI_SR is set until the SPI_SR is read and the SPI is automatically disabled until re-enabled by writing the SPIEN bit in the SPI_CR (Control Register) at 1.

By default, the Mode Fault detection circuitry is enabled. The user can disable Mode Fault detection by setting the MODFDIS bit in the SPI Mode Register (SPI_MR).

31.7.4 SPI Slave Mode

When operating in Slave Mode, the SPI processes data bits on the clock provided on the SPI clock pin (SPCK).

The SPI waits for NSS to go active before receiving the serial clock from an external master. When NSS falls, the clock is validated on the serializer, which processes the number of bits defined by the BITS field of the Chip Select Register 0 (SPI_CSR0). These bits are processed following a phase and a polarity defined respectively by the NCPHA and CPOL bits of the SPI_CSR0. Note that BITS, CPOL and NCPHA of the other Chip Select Registers have no effect when the SPI is programmed in Slave Mode.

The bits are shifted out on the MISO line and sampled on the MOSI line.

(For more information on BITS field, see also, the (Note:) below the register table; Section 31.8.9 “SPI Chip Select Register” on page 621.)

When all the bits are processed, the received data is transferred in the Receive Data Register and the RDRF bit rises. If the SPI_RDR (Receive Data Register) has not been read before new data is received, the Overrun Error bit (OVRES) in SPI_SR is set. As long as this flag is set, data is loaded in SPI_RDR. The user has to read the status register to clear the OVRES bit.

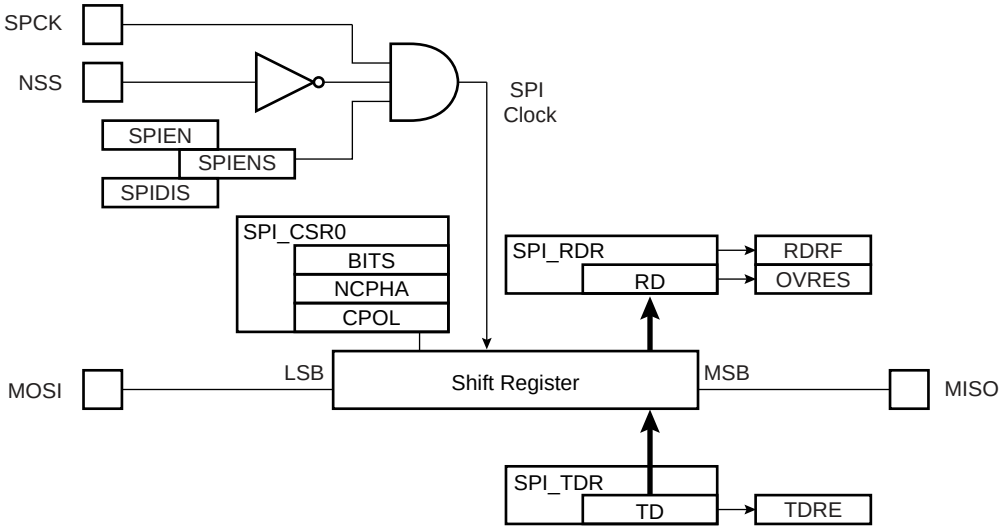
When a transfer starts, the data shifted out is the data present in the Shift Register. If no data has been written in the Transmit Data Register (SPI_TDR), the last data received is transferred. If no data has been received since the last reset, all bits are transmitted low, as the Shift Register resets at 0.

When a first data is written in SPI_TDR, it is transferred immediately in the Shift Register and the TDRE bit rises. If new data is written, it remains in SPI_TDR until a transfer occurs, i.e. NSS falls and there is a valid clock on the SPCK pin. When the transfer occurs, the last data written in SPI_TDR is transferred in the Shift Register and the TDRE bit rises. This enables frequent updates of critical variables with single transfers.

Then, a new data is loaded in the Shift Register from the Transmit Data Register. In case no character is ready to be transmitted, i.e. no character has been written in SPI_TDR since the last load from SPI_TDR to the Shift Register, the Shift Register is not modified and the last received character is retransmitted. In this case the Underrun Error Status Flag (UNDES) is set in the SPI_SR.

Figure 31-11 shows a block diagram of the SPI when operating in Slave Mode.

Figure 31-11. Slave Mode Functional Bloc Diagram



31.7.5 Write Protected Registers

To prevent any single software error that may corrupt SPI behavior, the registers listed below can be write-protected by setting the WPEN bit in the SPI Write Protection Mode Register (SPI_WPMR).

If a write access in a write-protected register is detected, then the WPVS flag in the SPI Write Protection Status Register (SPI_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is automatically reset after reading the SPI Write Protection Status Register (SPI_WPSR).

List of the write-protected registers:

Section 31.8.2 ”SPI Mode Register”

Section 31.8.9 ”SPI Chip Select Register”

31.8 Serial Peripheral Interface (SPI) User Interface

Table 31-5. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	SPI_CR	Write-only	---
0x04	Mode Register	SPI_MR	Read-write	0x0
0x08	Receive Data Register	SPI_RDR	Read-only	0x0
0x0C	Transmit Data Register	SPI_TDR	Write-only	---
0x10	Status Register	SPI_SR	Read-only	0x000000F0
0x14	Interrupt Enable Register	SPI_IER	Write-only	---
0x18	Interrupt Disable Register	SPI_IDR	Write-only	---
0x1C	Interrupt Mask Register	SPI_IMR	Read-only	0x0
0x20 - 0x2C	Reserved			
0x30	Chip Select Register 0	SPI_CSR0	Read-write	0x0
0x34	Chip Select Register 1	SPI_CSR1	Read-write	0x0
0x38	Chip Select Register 2	SPI_CSR2	Read-write	0x0
0x3C	Chip Select Register 3	SPI_CSR3	Read-write	0x0
0x4C - 0xE0	Reserved	–	–	–
0xE4	Write Protection Control Register	SPI_WPMR	Read-write	0x0
0xE8	Write Protection Status Register	SPI_WPSR	Read-only	0x0
0x00E8 - 0x00F8	Reserved	–	–	–
0x00FC	Reserved	–	–	–

31.8.1 SPI Control Register

Name: SPI_CR

Address: 0x40008000

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	LASTXFER
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
SWRST	–	–	–	–	–	SPIDIS	SPIEN

- **SPIEN: SPI Enable**

0 = No effect.

1 = Enables the SPI to transfer and receive data.

- **SPIDIS: SPI Disable**

0 = No effect.

1 = Disables the SPI.

As soon as SPIDIS is set, SPI finishes its transfer.

All pins are set in input mode and no data is received or transmitted.

If a transfer is in progress, the transfer is finished before the SPI is disabled.

If both SPIEN and SPIDIS are equal to one when the control register is written, the SPI is disabled.

- **SWRST: SPI Software Reset**

0 = No effect.

1 = Reset the SPI. A software-triggered hardware reset of the SPI interface is performed.

The SPI is in slave mode after software reset.

DMAC channels are not affected by software reset.

- **LASTXFER: Last Transfer**

0 = No effect.

1 = The current NPCS will be deasserted after the character written in TD has been transferred. When CSAAT is set, this allows to close the communication with the current serial peripheral by raising the corresponding NPCS line as soon as TD transfer has completed.

Refer to Section 31.7.3.5 ”Peripheral Selection” for more details.

31.8.2 SPI Mode Register

Name: SPI_MR

Address: 0x40008004

Access: Read-write

31	30	29	28	27	26	25	24
DLYBCS							
23	22	21	20	19	18	17	16
–	–	–	–	PCS			
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
LLB	–	WDRBT	MODFDIS	–	PCSDEC	PS	MSTR

This register can only be written if the WPEN bit is cleared in "SPI Write Protection Mode Register".

- **MSTR: Master/Slave Mode**

0 = SPI is in Slave mode.

1 = SPI is in Master mode.

- **PS: Peripheral Select**

0 = Fixed Peripheral Select.

1 = Variable Peripheral Select.

- **PCSDEC: Chip Select Decode**

0 = The chip selects are directly connected to a peripheral device.

1 = The four chip select lines are connected to a 4- to 16-bit decoder.

When PCSDEC equals one, up to 15 Chip Select signals can be generated with the four lines using an external 4- to 16-bit decoder. The Chip Select Registers define the characteristics of the 15 chip selects according to the following rules:

SPI_CSR0 defines peripheral chip select signals 0 to 3.

SPI_CSR1 defines peripheral chip select signals 4 to 7.

SPI_CSR2 defines peripheral chip select signals 8 to 11.

SPI_CSR3 defines peripheral chip select signals 12 to 14.

- **MODFDIS: Mode Fault Detection**

0 = Mode fault detection is enabled.

1 = Mode fault detection is disabled.

- **WDRBT: Wait Data Read Before Transfer**

0 = No Effect. In master mode, a transfer can be initiated whatever the state of the Receive Data Register is.

1 = In Master Mode, a transfer can start only if the Receive Data Register is empty, i.e. does not contain any unread data. This mode prevents overrun error in reception.

- **LLB: Local Loopback Enable**

0 = Local loopback path disabled.

1 = Local loopback path enabled

LLB controls the local loopback on the data serializer for testing in Master Mode only. (MISO is internally connected on MOSI.)

- **PCS: Peripheral Chip Select**

This field is only used if Fixed Peripheral Select is active (PS = 0).

If PCSDEC = 0:

PCS = xxx0	NPCS[3:0] = 1110
PCS = xx01	NPCS[3:0] = 1101
PCS = x011	NPCS[3:0] = 1011
PCS = 0111	NPCS[3:0] = 0111
PCS = 1111	forbidden (no peripheral is selected)

(x = don’t care)

If PCSDEC = 1:

NPCS[3:0] output signals = PCS.

- **DLYBCS: Delay Between Chip Selects**

This field defines the delay from NPCS inactive to the activation of another NPCS. The DLYBCS time guarantees non-overlapping chip selects and solves bus contentions in case of peripherals having long data float times.

If DLYBCS is less than or equal to six, six MCK periods will be inserted by default.

Otherwise, the following equation determines the delay:

$$\text{Delay Between Chip Selects} = \frac{DLYBCS}{MCK}$$

31.8.3 SPI Receive Data Register

Name: SPI_RDR

Address: 0x40008008

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	PCS			
15	14	13	12	11	10	9	8
RD							
7	6	5	4	3	2	1	0
RD							

- **RD: Receive Data**

Data received by the SPI Interface is stored in this register right-justified. Unused bits read zero.

- **PCS: Peripheral Chip Select**

In Master Mode only, these bits indicate the value on the NPCS pins at the end of a transfer. Otherwise, these bits read zero.

Note: When using variable peripheral select mode (PS = 1 in SPI_MR) it is mandatory to also set the WDRBT field to 1 if the SPI_RDR PCS field is to be processed.

31.8.4 SPI Transmit Data Register

Name: SPI_TDR

Address: 0x4000800C

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	LASTXFER

23	22	21	20	19	18	17	16
–	–	–	–	PCS			

15	14	13	12	11	10	9	8
TD							

7	6	5	4	3	2	1	0
TD							

- **TD: Transmit Data**

Data to be transmitted by the SPI Interface is stored in this register. Information to be transmitted must be written to the transmit data register in a right-justified format.

- **PCS: Peripheral Chip Select**

This field is only used if Variable Peripheral Select is active (PS = 1).

If PCSDEC = 0:

PCS = xxx0	NPCS[3:0] = 1110
PCS = xx01	NPCS[3:0] = 1101
PCS = x011	NPCS[3:0] = 1011
PCS = 0111	NPCS[3:0] = 0111
PCS = 1111	forbidden (no peripheral is selected)

(x = don’t care)

If PCSDEC = 1:

NPCS[3:0] output signals = PCS

- **LASTXFER: Last Transfer**

0 = No effect.

1 = The current NPCS will be deasserted after the character written in TD has been transferred. When CSAAT is set, this allows to close the communication with the current serial peripheral by raising the corresponding NPCS line as soon as TD transfer has completed.

This field is only used if Variable Peripheral Select is active (PS = 1).

31.8.5 SPI Status Register

Name: SPI_SR

Address: 0x40008010

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	SPIENS
15	14	13	12	11	10	9	8
–	–	–	–	–	UNDES	TXEMPTY	NSSR
7	6	5	4	3	2	1	0
–	–	–	–	OVRES	MODF	TDRE	RDRF

- **RDRF: Receive Data Register Full**

0 = No data has been received since the last read of SPI_RDR

1 = Data has been received and the received data has been transferred from the serializer to SPI_RDR since the last read of SPI_RDR.

- **TDRE: Transmit Data Register Empty**

0 = Data has been written to SPI_TDR and not yet transferred to the serializer.

1 = The last data written in the Transmit Data Register has been transferred to the serializer.

TDRE equals zero when the SPI is disabled or at reset. The SPI enable command sets this bit to one.

- **MODF: Mode Fault Error**

0 = No Mode Fault has been detected since the last read of SPI_SR.

1 = A Mode Fault occurred since the last read of the SPI_SR.

- **OVRES: Overrun Error Status**

0 = No overrun has been detected since the last read of SPI_SR.

1 = An overrun has occurred since the last read of SPI_SR.

An overrun occurs when SPI_RDR is loaded at least twice from the serializer since the last read of the SPI_RDR.

- **NSSR: NSS Rising**

0 = No rising edge detected on NSS pin since last read.

1 = A rising edge occurred on NSS pin since last read.

- **TXEMPTY: Transmission Registers Empty**

0 = As soon as data is written in SPI_TDR.

1 = SPI_TDR and internal shifter are empty. If a transfer delay has been defined, TXEMPTY is set after the completion of such delay.

- **UNDES: Underrun Error Status (Slave Mode Only)**

0 = No underrun has been detected since the last read of SPI_SR.

1 = A transfer begins whereas no data has been loaded in the Transmit Data Register.

- **SPIENS: SPI Enable Status**

0 = SPI is disabled.

1 = SPI is enabled.

31.8.6 SPI Interrupt Enable Register

Name: SPI_IER

Address: 0x40008014

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	UNDES	TXEMPTY	NSSR
7	6	5	4	3	2	1	0
–	–	–	–	OVRES	MODF	TDRE	RDRF

0 = No effect.

1 = Enables the corresponding interrupt.

- **RDRF: Receive Data Register Full Interrupt Enable**
- **TDRE: SPI Transmit Data Register Empty Interrupt Enable**
- **MODF: Mode Fault Error Interrupt Enable**
- **OVRES: Overrun Error Interrupt Enable**
- **NSSR: NSS Rising Interrupt Enable**
- **TXEMPTY: Transmission Registers Empty Enable**
- **UNDES: Underrun Error Interrupt Enable**

31.8.7 SPI Interrupt Disable Register

Name: SPI_IDR

Address: 0x40008018

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	UNDES	TXEMPTY	NSSR
7	6	5	4	3	2	1	0
–	–	–	–	OVRES	MODF	TDRE	RDRF

0 = No effect.

1 = Disables the corresponding interrupt.

- **RDRF: Receive Data Register Full Interrupt Disable**
- **TDRE: SPI Transmit Data Register Empty Interrupt Disable**
- **MODF: Mode Fault Error Interrupt Disable**
- **OVRES: Overrun Error Interrupt Disable**
- **NSSR: NSS Rising Interrupt Disable**
- **TXEMPTY: Transmission Registers Empty Disable**
- **UNDES: Underrun Error Interrupt Disable**

31.8.8 SPI Interrupt Mask Register

Name: SPI_IMR

Address: 0x4000801C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	UNDES	TXEMPTY	NSSR
7	6	5	4	3	2	1	0
–	–	–	–	OVRES	MODF	TDRE	RDRF

0 = The corresponding interrupt is not enabled.

1 = The corresponding interrupt is enabled.

- **RDRF: Receive Data Register Full Interrupt Mask**
- **TDRE: SPI Transmit Data Register Empty Interrupt Mask**
- **MODF: Mode Fault Error Interrupt Mask**
- **OVRES: Overrun Error Interrupt Mask**
- **NSSR: NSS Rising Interrupt Mask**
- **TXEMPTY: Transmission Registers Empty Mask**
- **UNDES: Underrun Error Interrupt Mask**

31.8.9 SPI Chip Select Register

Name: SPI_CSRx[x=0..3]

Address: 0x40008030

Access: Read/Write

31	30	29	28	27	26	25	24
DLYBCT							
23	22	21	20	19	18	17	16
DLYBS							
15	14	13	12	11	10	9	8
SCBR							
7	6	5	4	3	2	1	0
BITS				CSAAT	CSNAAT	NCPHA	CPOL

This register can only be written if the WPEN bit is cleared in "SPI Write Protection Mode Register".

Note: SPI_CSRx registers must be written even if the user wants to use the defaults. The BITS field will not be updated with the translated value unless the register is written.

- **CPOL: Clock Polarity**

0 = The inactive state value of SPCK is logic level zero.

1 = The inactive state value of SPCK is logic level one.

CPOL is used to determine the inactive state value of the serial clock (SPCK). It is used with NCPHA to produce the required clock/data relationship between master and slave devices.

- **NCPHA: Clock Phase**

0 = Data is changed on the leading edge of SPCK and captured on the following edge of SPCK.

1 = Data is captured on the leading edge of SPCK and changed on the following edge of SPCK.

NCPHA determines which edge of SPCK causes data to change and which edge causes data to be captured. NCPHA is used with CPOL to produce the required clock/data relationship between master and slave devices.

- **CSNAAT: Chip Select Not Active After Transfer (Ignored if CSAAT = 1)**

0 = The Peripheral Chip Select does not rise between two transfers if the SPI_TDR is reloaded before the end of the first transfer and if the two transfers occur on the same Chip Select.

1 = The Peripheral Chip Select rises systematically after each transfer performed on the same slave. It remains active after the end of transfer for a minimal duration of:

  - $\frac{DLYBCT}{MCK}$ (if DLYBCT field is different from 0)
  - $\frac{DLYBCT + 1}{MCK}$ (if DLYBCT field equals 0)

- **CSAAT: Chip Select Active After Transfer**

0 = The Peripheral Chip Select Line rises as soon as the last transfer is achieved.

1 = The Peripheral Chip Select does not rise after the last transfer is achieved. It remains active until a new transfer is requested on a different chip select.

- **BITS: Bits Per Transfer**

(See the (Note:) below the register table; Section 31.8.9 “SPI Chip Select Register” on page 621.)

The BITS field determines the number of data bits transferred. Reserved values should not be used.

Value	Name	Description
0	8_BIT	8 bits for transfer
1	9_BIT	9 bits for transfer
2	10_BIT	10 bits for transfer
3	11_BIT	11 bits for transfer
4	12_BIT	12 bits for transfer
5	13_BIT	13 bits for transfer
6	14_BIT	14 bits for transfer
7	15_BIT	15 bits for transfer
8	16_BIT	16 bits for transfer
9	–	Reserved
10	–	Reserved
11	–	Reserved
12	–	Reserved
13	–	Reserved
14	–	Reserved
15	–	Reserved

- **SCBR: Serial Clock Baud Rate**

In Master Mode, the SPI Interface uses a modulus counter to derive the SPCK baud rate from the Master Clock MCK. The Baud rate is selected by writing a value from 1 to 255 in the SCBR field. The following equations determine the SPCK baud rate:

$$\text{SPCK Baudrate} = \frac{MCK}{SCBR}$$

Programming the SCBR field at 0 is forbidden. Triggering a transfer while SCBR is at 0 can lead to unpredictable results.

At reset, SCBR is 0 and the user has to program it at a valid value before performing the first transfer.

Note: If one of the SCBR fields inSPI_CSRx is set to 1, the other SCBR fields in SPI_CSRx must be set to 1 as well, if they are required to process transfers. If they are not used to transfer data, they can be set at any value.

- **DLYBS: Delay Before SPCK**

This field defines the delay from NPCS valid to the first valid SPCK transition.

When DLYBS equals zero, the NPCS valid to SPCK transition is 1/2 the SPCK clock period.

Otherwise, the following equations determine the delay:

$$\text{Delay Before SPCK} = \frac{DLYBS}{MCK}$$

- **DLYBCT: Delay Between Consecutive Transfers**

This field defines the delay between two consecutive transfers with the same peripheral without removing the chip select. The delay is always inserted after each transfer and before removing the chip select if needed.

When DLYBCT equals zero, no delay between consecutive transfers is inserted and the clock keeps its duty cycle over the character transfers.

Otherwise, the following equation determines the delay:

$$\text{Delay Between Consecutive Transfers} = \frac{32 \times DLYBCT}{MCK}$$

31.8.10 SPI Write Protection Mode Register

Name: SPI_WPMR

Address: 0x400080E4

Access: Read-write

31	30	29	28	27	26	25	24
WPKEY							
23	22	21	20	19	18	17	16
WPKEY							
15	14	13	12	11	10	9	8
WPKEY							
7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	WPEN

- **WPEN: Write Protection Enable**

0: The Write Protection is Disabled

1: The Write Protection is Enabled

- **WPKEY: Write Protection Key Password**

If a value is written in WPEN, the value is taken into account only if WPKEY is written with “SPI” (SPI written in ASCII Code, ie 0x535049 in hexadecimal).

List of the write-protected registers:

Section 31.8.2 ”SPI Mode Register”

Section 31.8.9 ”SPI Chip Select Register”

31.8.11 SPI Write Protection Status Register

Name: SPI_WPSR

Address: 0x400080E8

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
WPVSRC							
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	WPVS

- **WPVS: Write Protection Violation Status**

0 = No Write Protect Violation has occurred since the last read of the SPI_WPSR register.

1 = A Write Protect Violation has occurred since the last read of the SPI_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protection Violation Source**

This Field indicates the APB Offset of the register concerned by the violation (SPI_MR or SPI_CSRx)

32. Two-wire Interface (TWI)

32.1 Description

The Atmel Two-wire Interface (TWI) interconnects components on a unique two-wire bus, made up of one clock line and one data line with speeds of up to 400 Kbits per second, based on a byte-oriented transfer format. It can be used with any Atmel Two-wire Interface bus Serial EEPROM and I²C compatible device such as Real Time Clock (RTC), Dot Matrix/Graphic LCD Controllers and Temperature Sensor, to name but a few. The TWI is programmable as a master or a slave with sequential or single-byte access. Multiple master capability is supported. 20

Arbitration of the bus is performed internally and puts the TWI in slave mode automatically if the bus arbitration is lost.

A configurable baud rate generator permits the output data rate to be adapted to a wide range of core clock frequencies.

Below, Table 32-1 lists the compatibility level of the Atmel Two-wire Interface in Master Mode and a full I^2C compatible device.

Table 32-1. Atmel TWI compatibility with I^2C Standard

I^2C Standard	Atmel TWI
Standard Mode Speed (100 KHz)	Supported
Fast Mode Speed (400 KHz)	Supported
7 or 10 bits Slave Addressing	Supported
START BYTE(1)	Not Supported
Repeated Start (Sr) Condition	Supported
ACK and NACK Management	Supported
Slope control and input filtering (Fast mode)	Not Supported
Clock stretching	Supported
Multi Master Capability	Supported

Note: 1. START + b000000001 + Ack + Sr

32.2 Embedded Characteristics

- Compatible with Atmel Two-wire Interface Serial Memory and I²C Compatible Devices(1)
- One, Two or Three Bytes for Slave Address
- Sequential Read-write Operations
- Master, Multi-master and Slave Mode Operation
- Bit Rate: Up to 400 Kbits
- General Call Supported in Slave mode
- SMBUS Quick Command Supported in Master Mode
- Connection to Peripheral DMA Controller (PDC) Channel Capabilities Optimizes Data Transfers in Master Mode Only
  - One Channel for the Receiver, One Channel for the Transmitter
  - Next Buffer Support

Note: 1. See Table 32-1 for details on compatibility with I²C Standard.

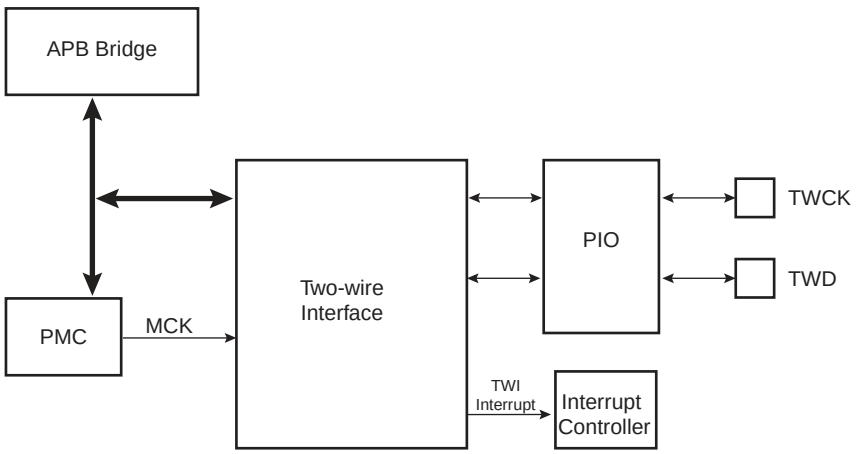
32.3 List of Abbreviations

Table 32-2. Abbreviations

Abbreviation	Description
TWI	Two-wire Interface
A	Acknowledge
NA	Non Acknowledge
P	Stop
S	Start
Sr	Repeated Start
SADR	Slave Address
ADR	Any address except SADR
R	Read
W	Write

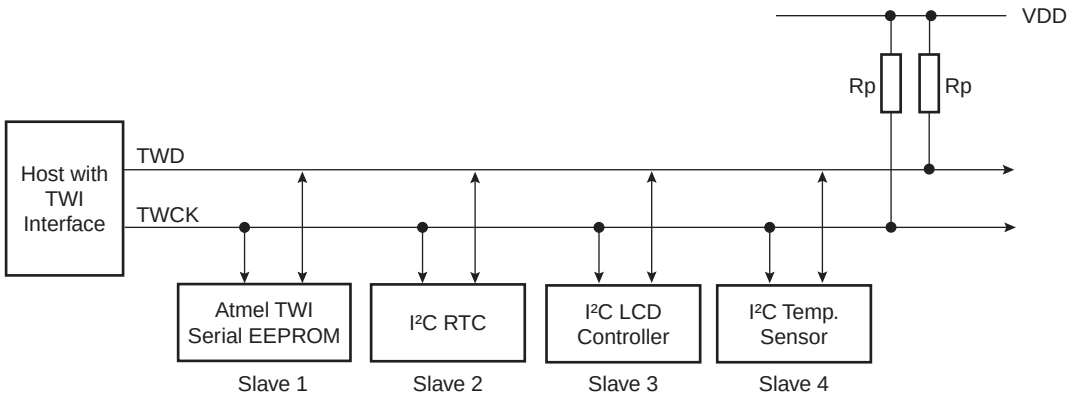
32.4 Block Diagram

Figure 32-1. Block Diagram



32.5 Application Block Diagram

Figure 32-2. Application Block Diagram



Rp: Pull up value as given by the I²C Standard

32.5.1 I/O Lines Description

Table 32-3. I/O Lines Description

Pin Name	Pin Description	Type
TWD	Two-wire Serial Data	Input/Output
TWCK	Two-wire Serial Clock	Input/Output

32.6 Product Dependencies

32.6.1 I/O Lines

Both TWD and TWCK are bidirectional lines, connected to a positive supply voltage via a current source or pull-up resistor (see Figure 32-2 on page 628). When the bus is free, both lines are high. The output stages of devices connected to the bus must have an open-drain or open-collector to perform the wired-AND function.

TWD and TWCK pins may be multiplexed with PIO lines. To enable the TWI, the programmer must perform the following step:

- Program the PIO controller to dedicate TWD and TWCK as peripheral lines.

The user must not program TWD and TWCK as open-drain. It is already done by the hardware.

Table 32-4. I/O Lines

Instance	Signal	I/O Line	Peripheral
TWI0	TWCK0	PA10	A
TWI0	TWD0	PA9	A
TWI1	TWCK1	PA25	A
TWI1	TWD1	PA24	A

32.6.2 Power Management

- Enable the peripheral clock.

The TWI interface may be clocked through the Power Management Controller (PMC), thus the programmer must first configure the PMC to enable the TWI clock.

32.6.3 Interrupt

The TWI interface has an interrupt line connected to the Interrupt Controller. In order to handle interrupts, the Interrupt Controller must be programmed before configuring the TWI.

32.7 Functional Description

32.7.1 Transfer Format

The data put on the TWD line must be 8 bits long. Data is transferred MSB first; each byte must be followed by an acknowledgement. The number of bytes per transfer is unlimited (see Figure 32-4).

Each transfer begins with a START condition and terminates with a STOP condition (see Figure 32-3).

- A high-to-low transition on the TWD line while TWCK is high defines the START condition.
- A low-to-high transition on the TWD line while TWCK is high defines a STOP condition.

Figure 32-3. START and STOP Conditions

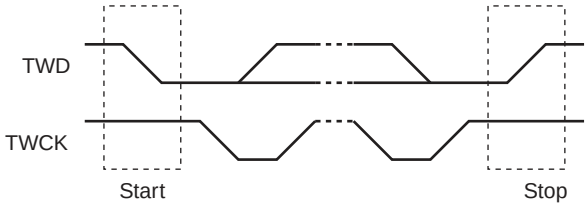
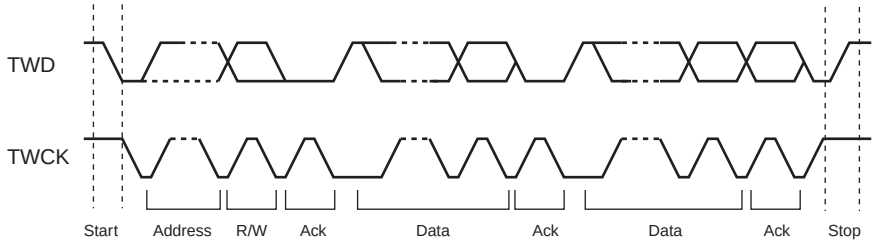


Figure 32-4. Transfer Format



32.7.2 Modes of Operation

The TWI has different modes of operations:

- Master transmitter mode
- Master receiver mode
- Multi-master transmitter mode
- Multi-master receiver mode
- Slave transmitter mode
- Slave receiver mode

These modes are described in the following chapters.

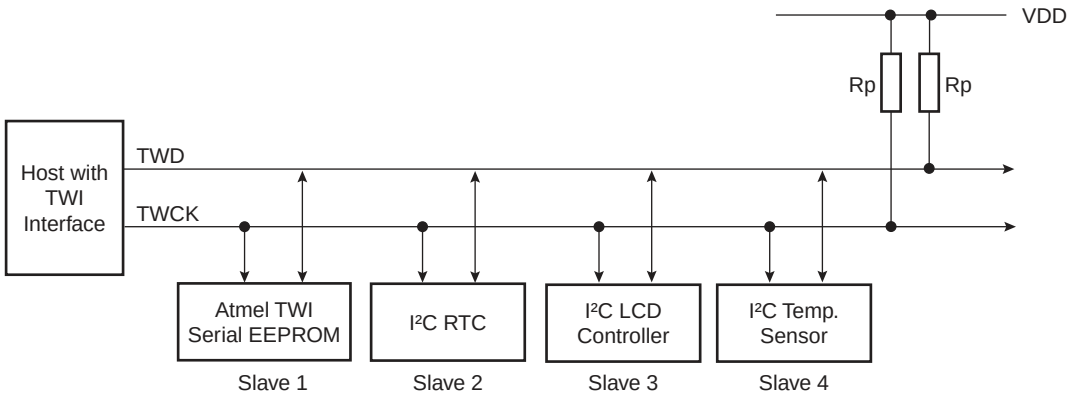
32.8 Master Mode

32.8.1 Definition

The Master is the device that starts a transfer, generates a clock and stops it.

32.8.2 Application Block Diagram

Figure 32-5. Master Mode Typical Application Block Diagram



Rp: Pull up value as given by the I²C Standard

32.8.3 Programming Master Mode

The following registers have to be programmed before entering Master mode:

1. DADR (+ IADRSZ + IADR if a 10 bit device is addressed): The device address is used to access slave devices in read or write mode.
2. CKDIV + CHDIV + CLDIV: Clock Waveform.
3. SVDIS: Disable the slave mode.
4. MSEN: Enable the master mode.

32.8.4 Master Transmitter Mode

After the master initiates a Start condition when writing into the Transmit Holding Register, TWI_THR, it sends a 7-bit slave address, configured in the Master Mode register (DADR in TWI_MMR), to notify the slave device. The bit following the slave address indicates the transfer direction, 0 in this case (MREAD = 0 in TWI_MMR).

The TWI transfers require the slave to acknowledge each received byte. During the acknowledge clock pulse (9th pulse), the master releases the data line (HIGH), enabling the slave to pull it down in order to generate the acknowledge. The master polls the data line during this clock pulse and sets the Not Acknowledge bit (**NACK)** in the status register if the slave does not acknowledge the byte. As with the other status bits, an interrupt can be generated if enabled in the interrupt enable register (TWI_IER). If the slave acknowledges the byte, the data written in the TWI_THR, is then shifted in the internal shifter and transferred. When an acknowledge is detected, the TXRDY bit is set until a new write in the TWI_THR.

TXRDY is used as Transmit Ready for the PDC transmit channel.

While no new data is written in the TWI_THR, the Serial Clock Line is tied low. When new data is written in the TWI_THR, the SCL is released and the data is sent. To generate a STOP event, the STOP command must be performed by writing in the STOP field of TWI_CR.

After a Master Write transfer, the Serial Clock line is stretched (tied low) while no new data is written in the TWI_THR or until a STOP command is performed.

See Figure 32-6, Figure 32-7, and Figure 32-8.

Figure 32-6. Master Write with One Data Byte

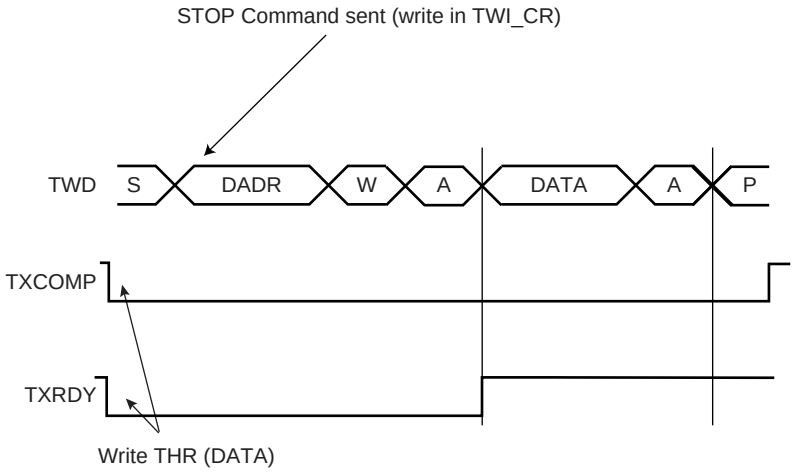


Figure 32-7. Master Write with Multiple Data Bytes

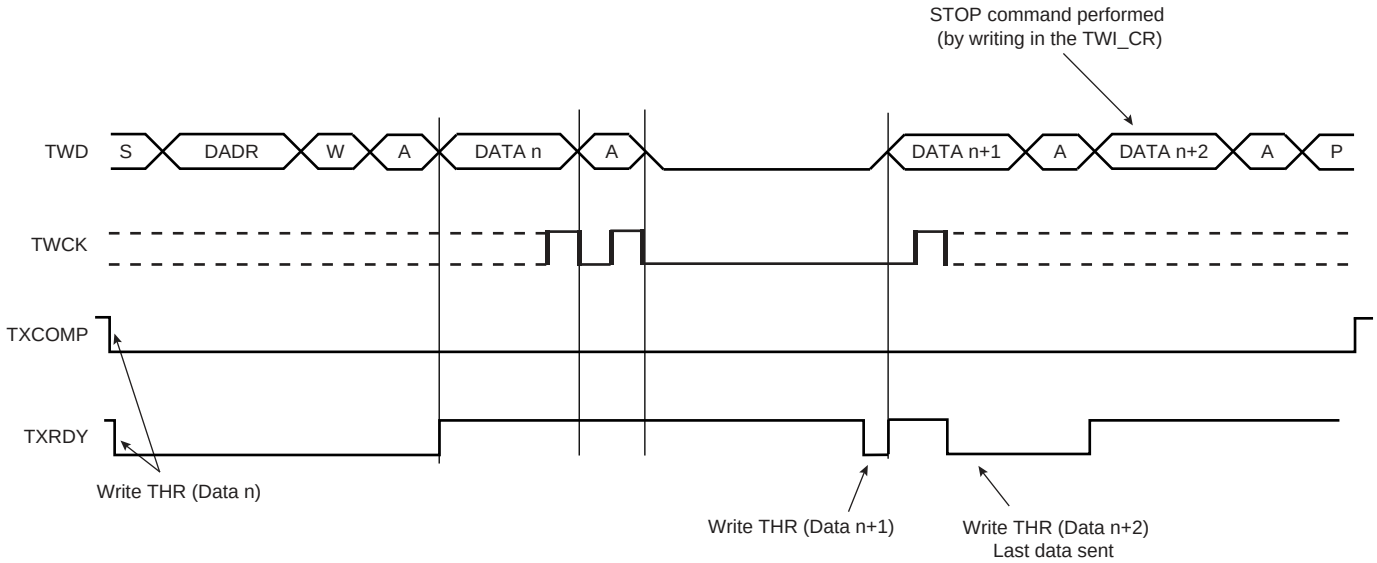
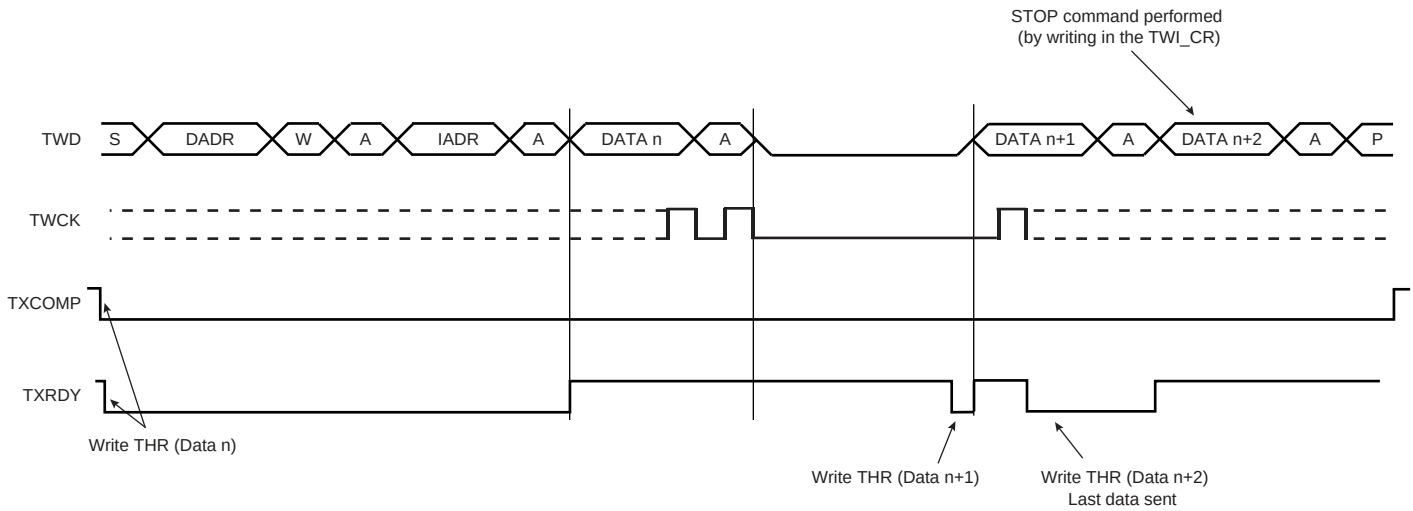


Figure 32-8. Master Write with One Byte Internal Address and Multiple Data Bytes



32.8.5 Master Receiver Mode

The read sequence begins by setting the START bit. After the start condition has been sent, the master sends a 7-bit slave address to notify the slave device. The bit following the slave address indicates the transfer direction, 1 in this case (MREAD = 1 in TWI_MMR). During the acknowledge clock pulse (9th pulse), the master releases the data line (HIGH), enabling the slave to pull it down in order to generate the acknowledge. The master polls the data line during this clock pulse and sets the **NACK** bit in the status register if the slave does not acknowledge the byte.

If an acknowledge is received, the master is then ready to receive data from the slave. After data has been received, the master sends an acknowledge condition to notify the slave that the data has been received except for the last data, after the stop condition. See Figure 32-9. When the RXRDY bit is set in the status register, a character has been received in the receive-holding register (TWI_RHR). The RXRDY bit is reset when reading the TWI_RHR.

When a single data byte read is performed, with or without internal address **(IADR)**, the START and STOP bits must be set at the same time. See Figure 32-9. When a multiple data byte read is performed, with or without internal address **(IADR)**, the STOP bit must be set after the next-to-last data received. See Figure 32-10. For Internal Address usage see Section 32.8.6.

Figure 32-9. Master Read with One Data Byte

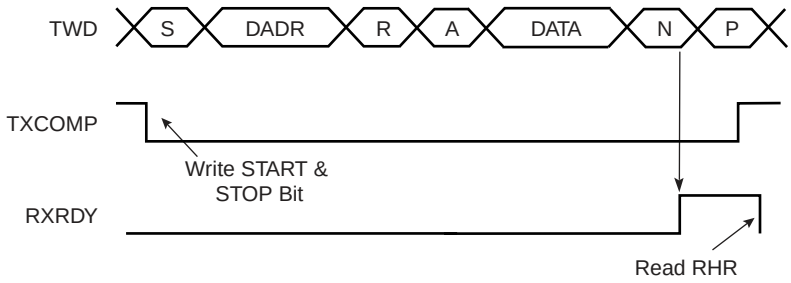
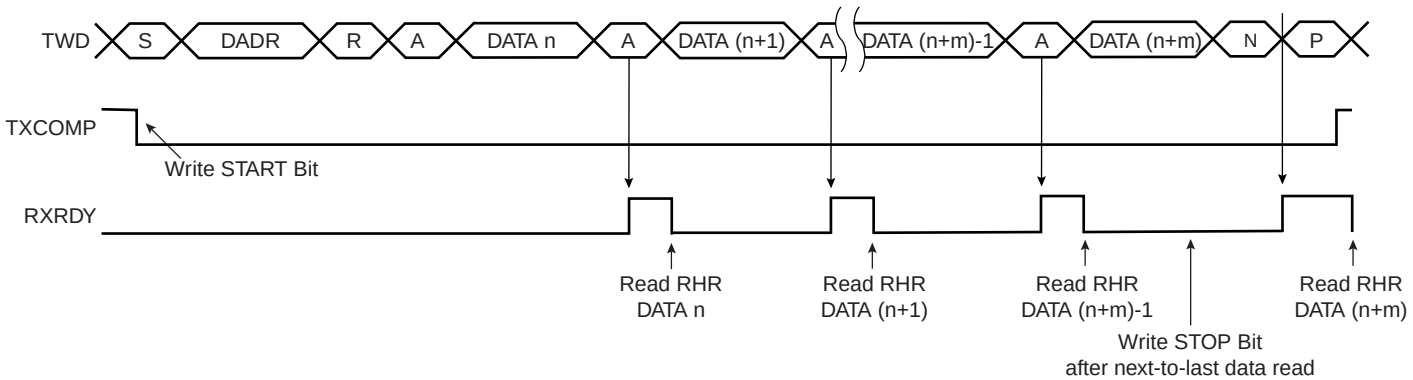


Figure 32-10. Master Read with Multiple Data Bytes



RXRDY is used as Receive Ready for the PDC receive channel.

32.8.6 Internal Address

The TWI interface can perform various transfer formats: Transfers with 7-bit slave address devices and 10-bit slave address devices.

32.8.6.1 7-bit Slave Addressing

When Addressing 7-bit slave devices, the internal address bytes are used to perform random address (read or write) accesses to reach one or more data bytes, within a memory page location in a serial memory, for example. When performing read operations with an internal address, the TWI performs a write operation to set the internal address into the slave device, and then switch to Master Receiver mode. Note that the second start condition (after sending the IADR) is sometimes called “repeated start” (Sr) in I^2C fully-compatible devices. See Figure 32-12. See Figure 32-11 and Figure 32-13 for Master Write operation with internal address.

The three internal address bytes are configurable through the Master Mode register (TWI_MMR).

If the slave device supports only a 7-bit address, i.e. no internal address, **IADRSZ** must be set to 0.

In the figures below the following abbreviations are used:

- S Start
- Sr Repeated Start
- P Stop
- W Write
- R Read
- A Acknowledge
- N Not Acknowledge
- DADR Device Address
- IADR Internal Address

Figure 32-11. Master Write with One, Two or Three Bytes Internal Address and One Data Byte

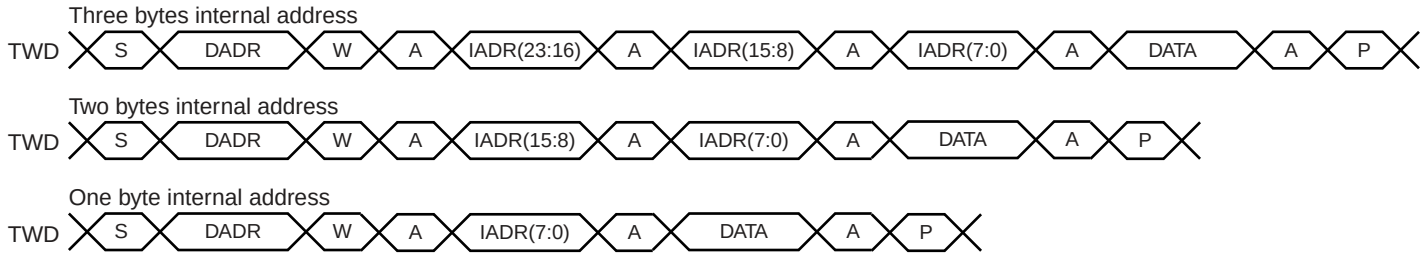
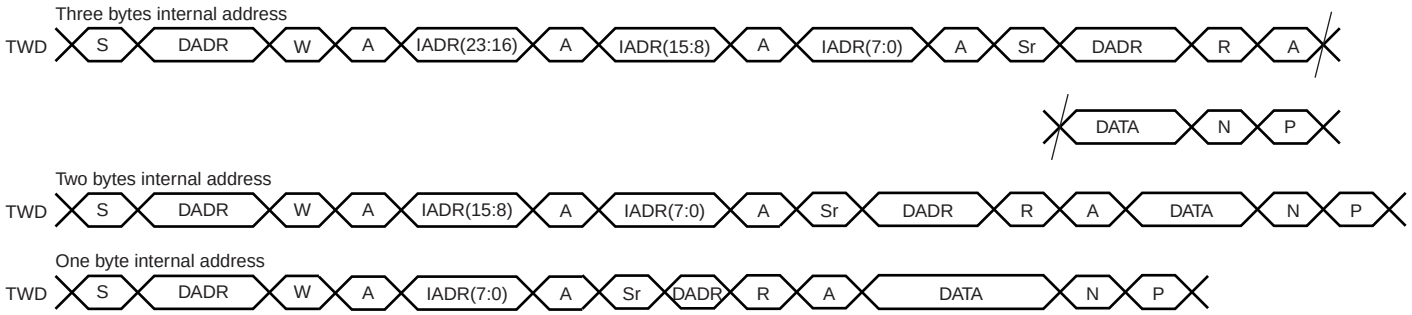


Figure 32-12. Master Read with One, Two or Three Bytes Internal Address and One Data Byte



32.8.6.2 10-bit Slave Addressing

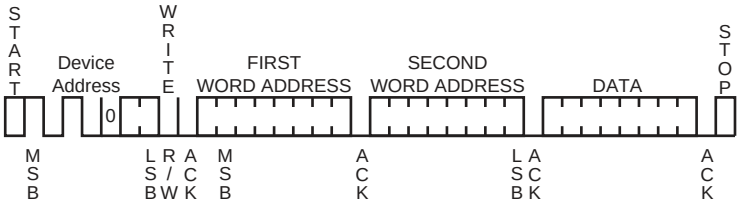
For a slave address higher than 7 bits, the user must configure the address size **(IADRSZ**) and set the other slave address bits in the internal address register (TWI_IADR). The two remaining Internal address bytes, IADR[15:8] and IADR[23:16] can be used the same as in 7-bit Slave Addressing.

Example: Address a 10-bit device (10-bit device address is b1 b2 b3 b4 b5 b6 b7 b8 b9 b10)

1. Program IADRSZ = 1,
2. Program DADR with 1 1 1 1 0 b1 b2 (b1 is the MSB of the 10-bit address, b2, etc.)
3. Program TWI_IADR with b3 b4 b5 b6 b7 b8 b9 b10 (b10 is the LSB of the 10-bit address)

Figure 32-13 below shows a byte write to an Atmel AT24LC512 EEPROM. This demonstrates the use of internal addresses to access the device.

Figure 32-13. Internal Address Usage



32.8.7 Using the Peripheral DMA Controller (PDC)

The use of the PDC significantly reduces the CPU load.

To assure correct implementation, respect the following programming sequences:

32.8.7.1 Data Transmit with the PDC

1. Initialize the transmit PDC (memory pointers, transfer size).
2. Configure the master mode.
3. Start the transfer by setting the PDC TXTEN bit.
4. Wait for the PDC ENDTX Flag either by using the polling method or ENDTX interrupt.
5. Disable the PDC by setting the PDC TXDIS bit.

32.8.7.2 Data Receive with the PDC

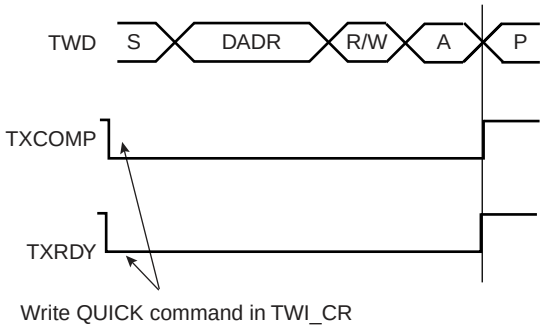
1. Initialize the receive PDC (memory pointers, transfer size - 1).
2. Configure the master mode (DADR, CKDIV, etc.).
3. Start the transfer by setting the PDC RXTEN bit.
4. Wait for the PDC ENDRX Flag either by using polling method or ENDRX interrupt.
5. Disable the PDC by setting the PDC RXDIS bit.

32.8.8 SMBUS Quick Command (Master Mode Only)

The TWI interface can perform a Quick Command:

1. Configure the master mode (DADR, CKDIV, etc.).
2. Write the MREAD bit in the TWI_MMR register at the value of the one-bit command to be sent.
3. Start the transfer by setting the QUICK bit in the TWI_CR.

Figure 32-14. SMBUS Quick Command



32.8.9 Read-write Flowcharts

The following flowcharts shown in Figure 32-16 on page 638, Figure 32-17 on page 639, Figure 32-18 on page 640, Figure 32-19 on page 641 and Figure 32-20 on page 642 give examples for read and write operations. A polling or interrupt method can be used to check the status bits. The interrupt method requires that the interrupt enable register (TWI_IER) be configured first.

Figure 32-15. TWI Write Operation with Single Data Byte without Internal Address

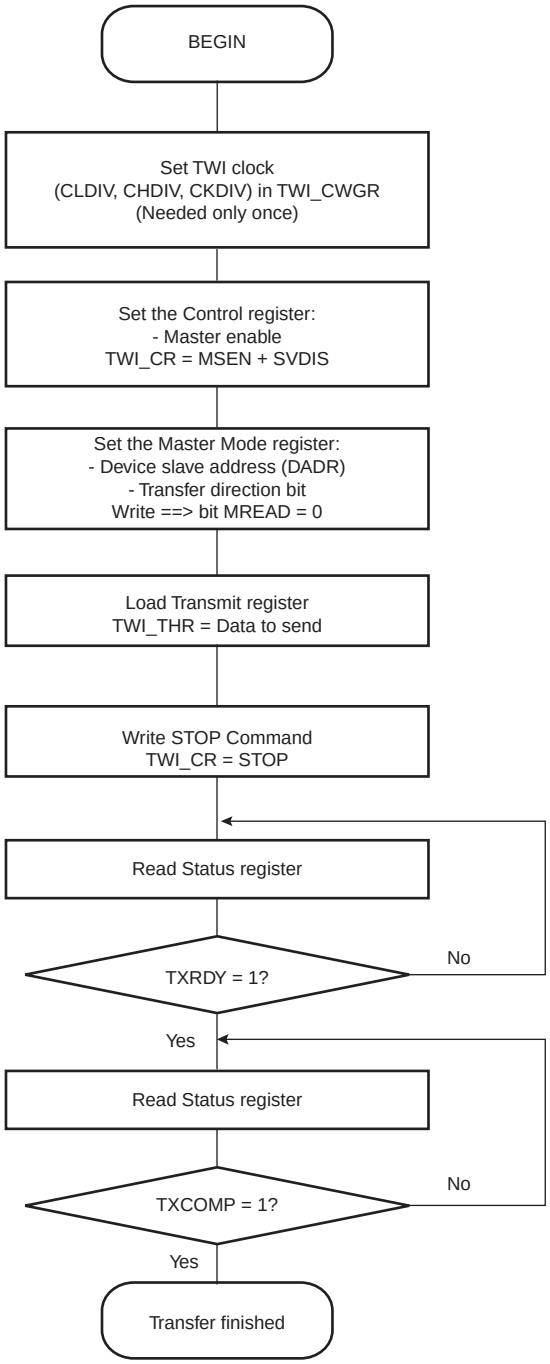


Figure 32-16. TWI Write Operation with Single Data Byte and Internal Address

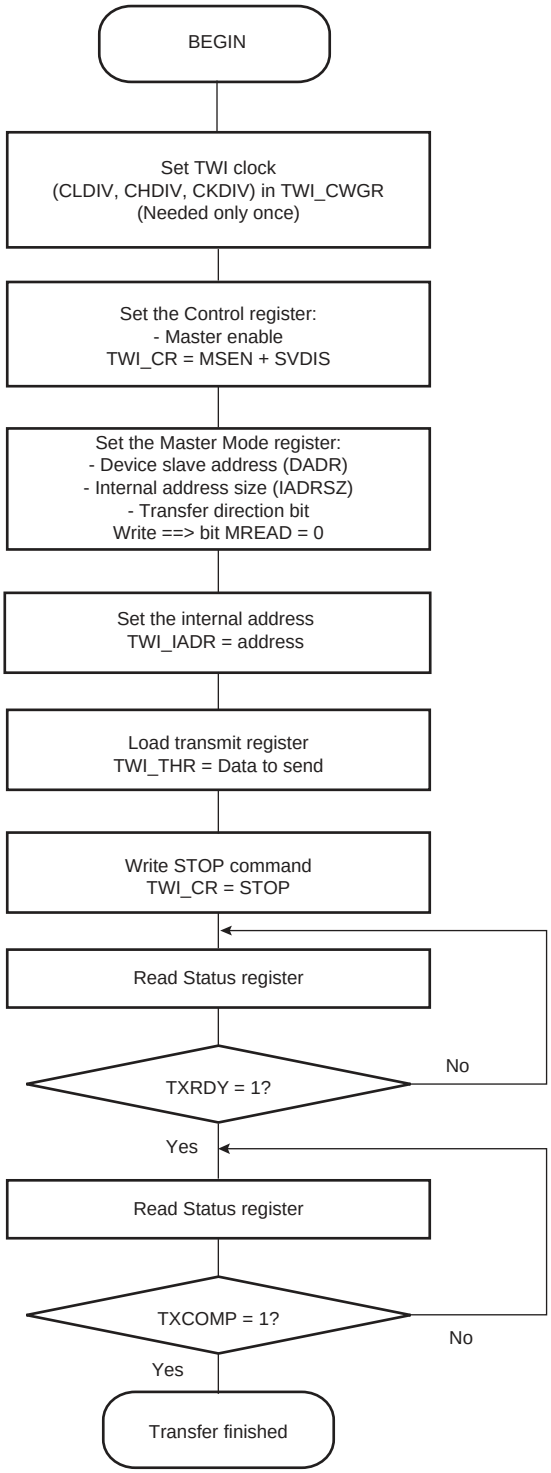


Figure 32-17. TWI Write Operation with Multiple Data Bytes with or without Internal Address

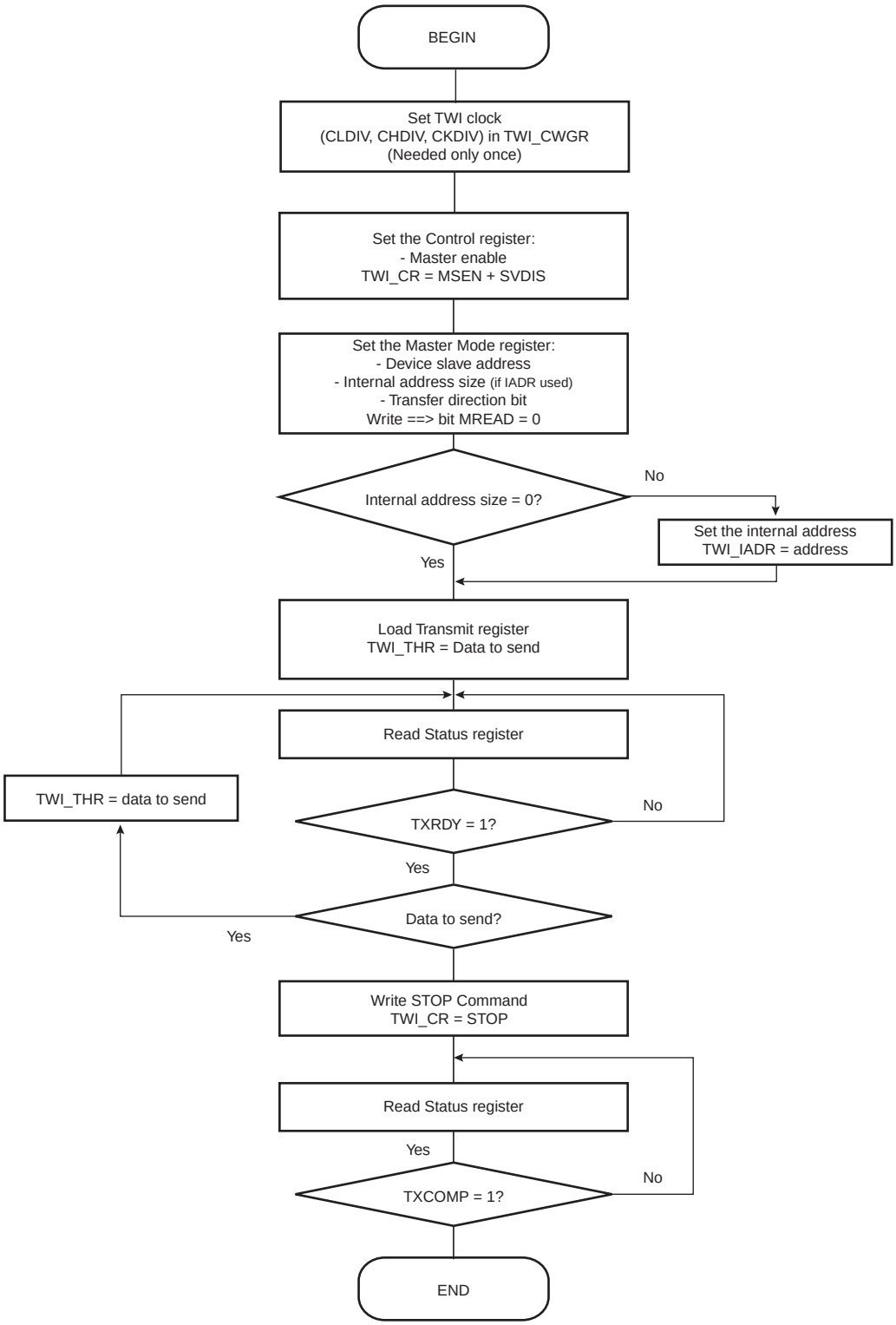


Figure 32-18. TWI Read Operation with Single Data Byte without Internal Address

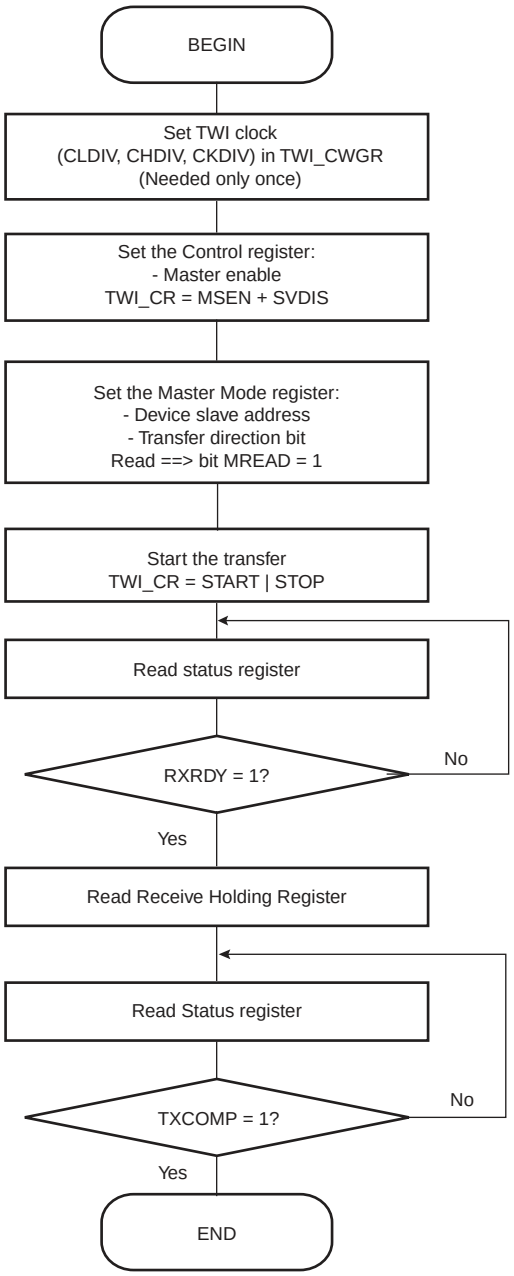


Figure 32-19. TWI Read Operation with Single Data Byte and Internal Address

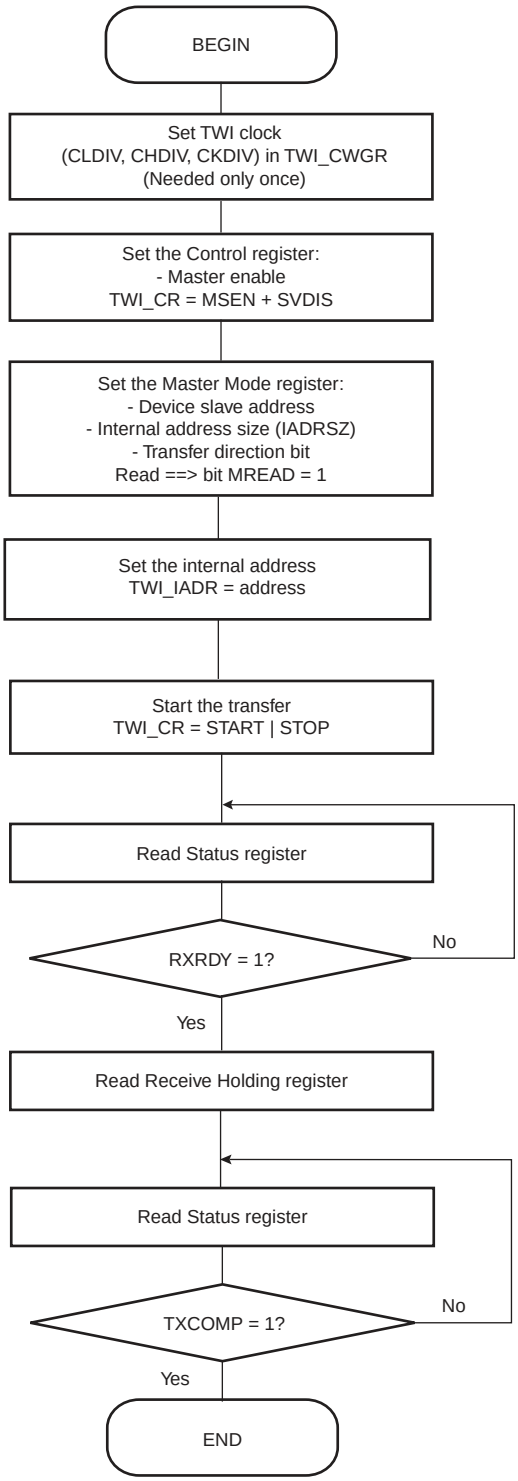
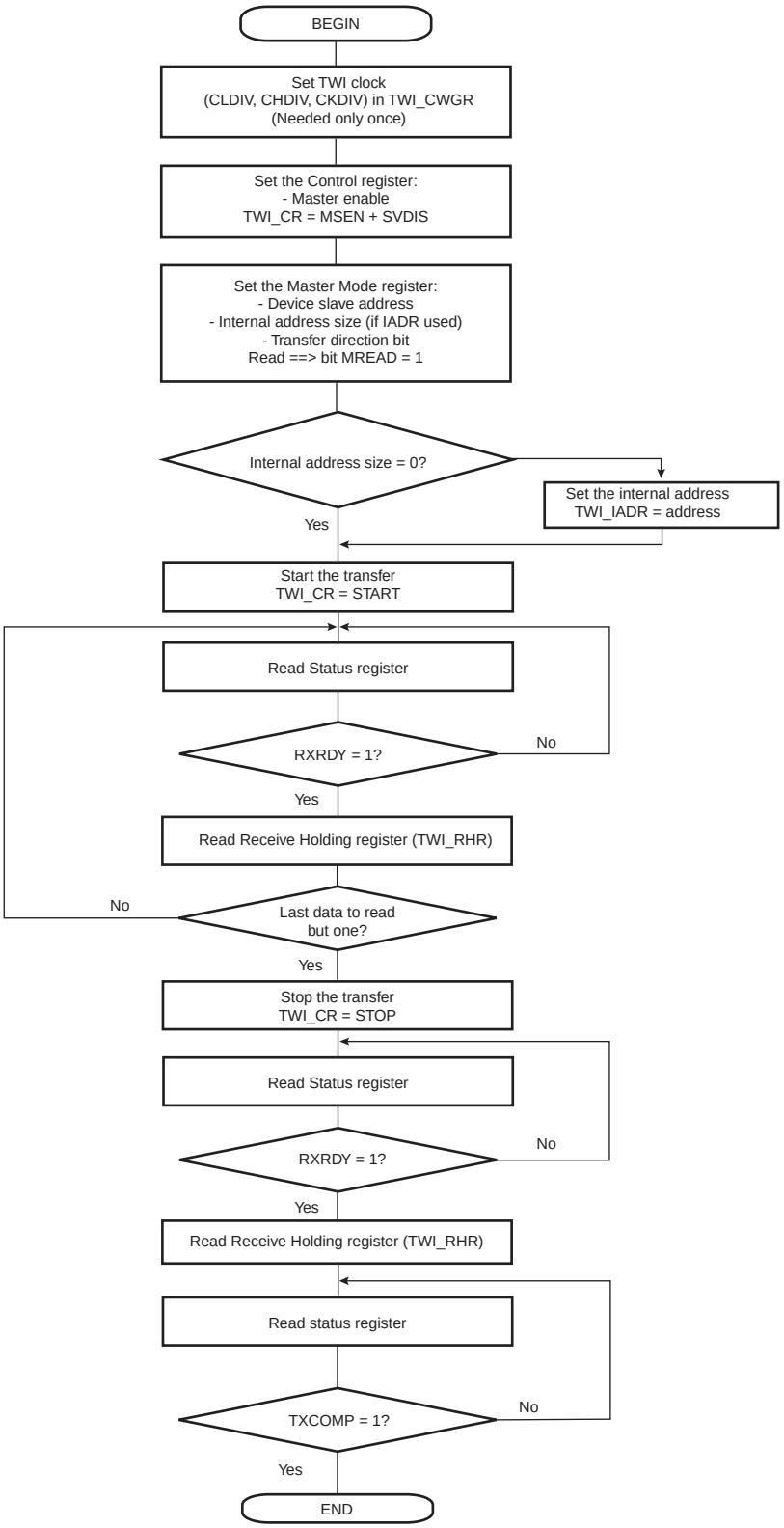


Figure 32-20. TWI Read Operation with Multiple Data Bytes with or without Internal Address



32.9 Multi-master Mode

32.9.1 Definition

More than one master may handle the bus at the same time without data corruption by using arbitration.

Arbitration starts as soon as two or more masters place information on the bus at the same time, and stops (arbitration is lost) for the master that intends to send a logical one while the other master sends a logical zero.

As soon as arbitration is lost by a master, it stops sending data and listens to the bus in order to detect a stop. When the stop is detected, the master who has lost arbitration may put its data on the bus by respecting arbitration.

Arbitration is illustrated in Figure 32-22 on page 644.

32.9.2 Different Multi-master Modes

Two multi-master modes may be distinguished:

1. TWI is considered as a Master only and will never be addressed.
2. TWI may be either a Master or a Slave and may be addressed.

Note: In both Multi-master modes arbitration is supported.

32.9.2.1 TWI as Master Only

In this mode, TWI is considered as a Master only (MSEN is always at one) and must be driven like a Master with the ARBLST (ARBitration Lost) flag in addition.

If arbitration is lost (ARBLST = 1), the programmer must reinitiate the data transfer.

If the user starts a transfer (ex.: DADR + START + W + Write in THR) and if the bus is busy, the TWI automatically waits for a STOP condition on the bus to initiate the transfer (see Figure 32-21 on page 644).

Note: The state of the bus (busy or free) is not indicated in the user interface.

32.9.2.2 TWI as Master or Slave

The automatic reversal from Master to Slave is not supported in case of a lost arbitration.

Then, in the case where TWI may be either a Master or a Slave, the programmer must manage the pseudo Multi-master mode described in the steps below.

1. Program TWI in Slave mode (SADR + MSDIS + SVEN) and perform Slave Access (if TWI is addressed).
2. If TWI has to be set in Master mode, wait until TXCOMP flag is at 1.
3. Program Master mode (DADR + SVDIS + MSEN) and start the transfer (ex: START + Write in THR).
4. As soon as the Master mode is enabled, TWI scans the bus in order to detect if it is busy or free. When the bus is considered as free, TWI initiates the transfer.
5. As soon as the transfer is initiated and until a STOP condition is sent, the arbitration becomes relevant and the user must monitor the ARBLST flag.
6. If the arbitration is lost (ARBLST is set to 1), the user must program the TWI in Slave mode in the case where the Master that won the arbitration wanted to access the TWI.
7. If TWI has to be set in Slave mode, wait until TXCOMP flag is at 1 and then program the Slave mode.

Note: In the case where the arbitration is lost and TWI is addressed, TWI will not acknowledge even if it is programmed in Slave mode as soon as ARBLST is set to 1. Then, the Master must repeat SADR.

Figure 32-21. Programmer Sends Data While the Bus is Busy

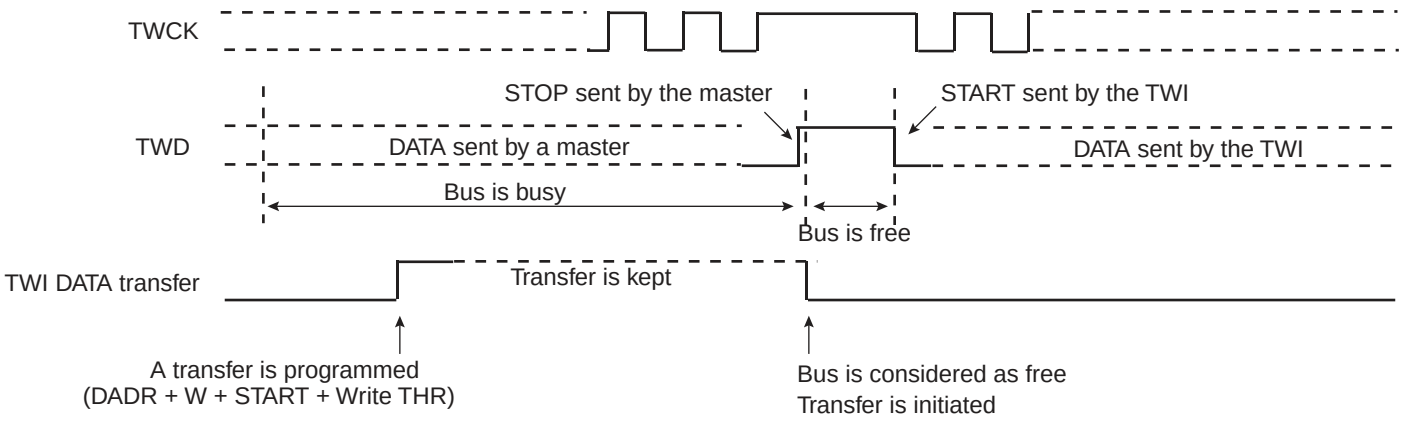
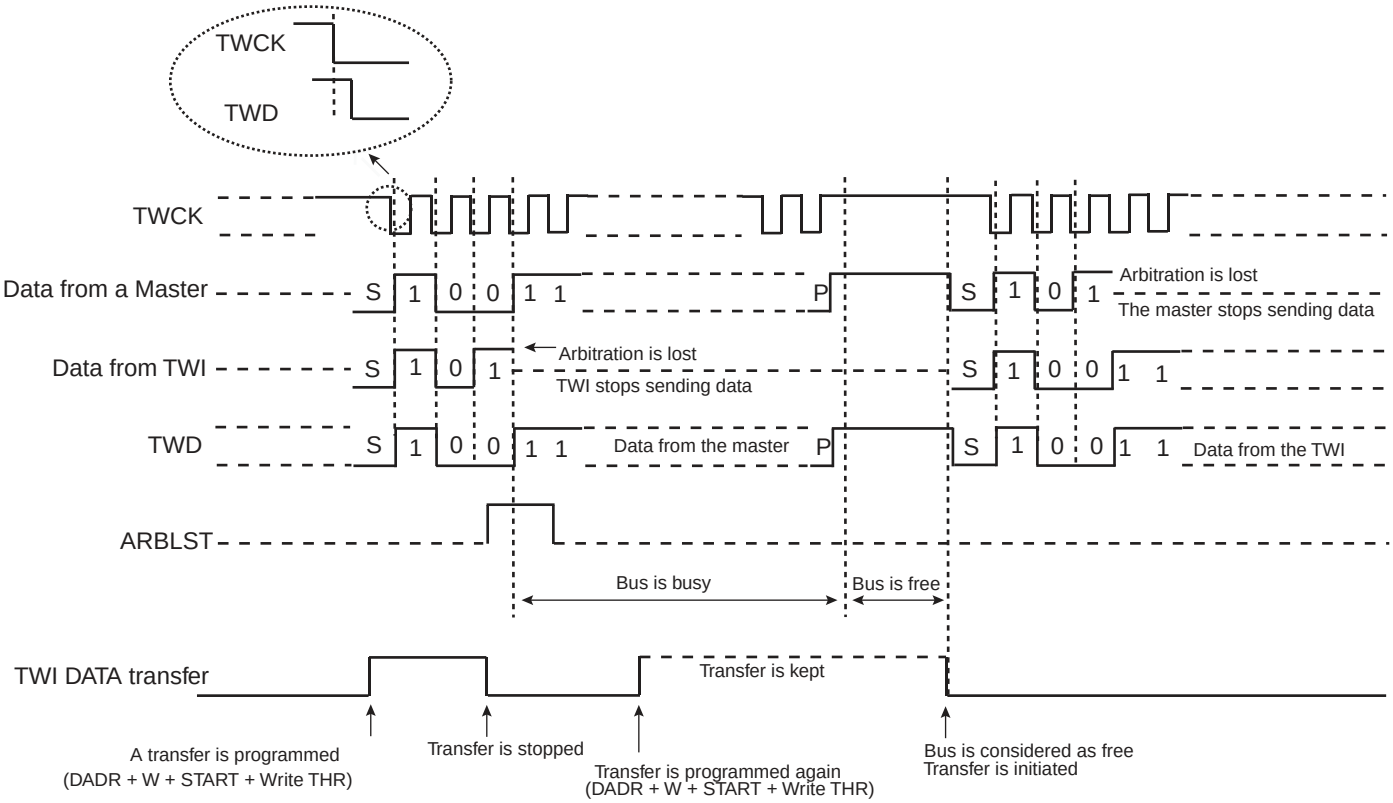
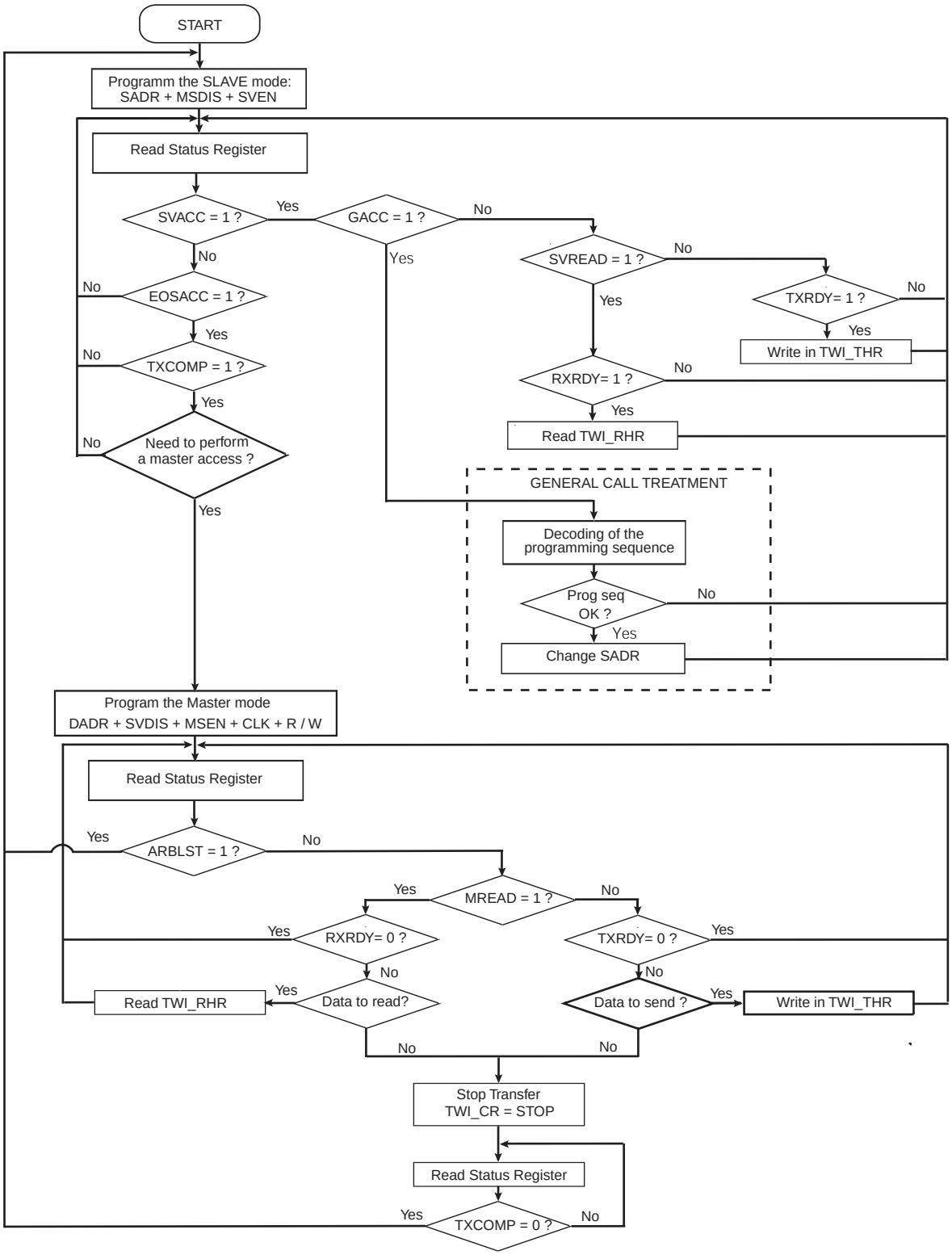


Figure 32-22. Arbitration Cases



The flowchart shown in Figure 32-23 on page 645 gives an example of read and write operations in Multi-master mode.

Figure 32-23. Multi-master Flowchart



32.10 Slave Mode

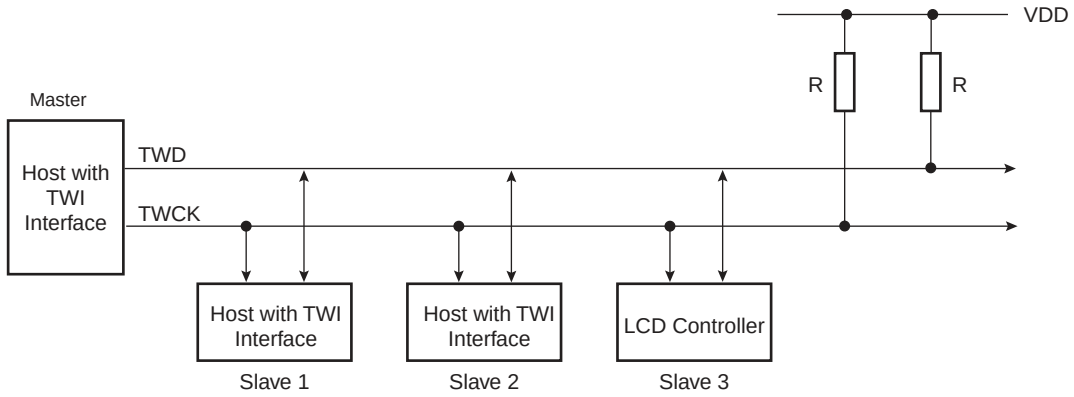
32.10.1 Definition

The Slave Mode is defined as a mode where the device receives the clock and the address from another device called the master.

In this mode, the device never initiates and never completes the transmission (START, REPEATED_START and STOP conditions are always provided by the master).

32.10.2 Application Block Diagram

Figure 32-24. Slave Mode Typical Application Block Diagram



32.10.3 Programming Slave Mode

The following fields must be programmed before entering Slave mode:

1. SADR (TWI_SMR): The slave device address is used in order to be accessed by master devices in read or write mode.
2. MSDIS (TWI_CR): Disable the master mode.
3. SVEN (TWI_CR): Enable the slave mode.

As the device receives the clock, values written in TWI_CWGR are not taken into account.

32.10.4 Receiving Data

After a Start or Repeated Start condition is detected and if the address sent by the Master matches with the Slave address programmed in the SADR (Slave ADdress) field, SVACC (Slave ACCess) flag is set and SVREAD (Slave READ) indicates the direction of the transfer.

SVACC remains high until a STOP condition or a repeated START is detected. When such a condition is detected, EOSACC (End Of Slave ACCess) flag is set.

32.10.4.1 Read Sequence

In the case of a Read sequence (SVREAD is high), TWI transfers data written in the TWI_THR (TWI Transmit Holding Register) until a STOP condition or a REPEATED_START + an address different from SADR is detected. Note that at the end of the read sequence TXCOMP (Transmission Complete) flag is set and SVACC reset.

As soon as data is written in the TWI_THR, TXRDY (Transmit Holding Register Ready) flag is reset, and it is set when the shift register is empty and the sent data acknowledged or not. If the data is not acknowledged, the NACK flag is set.

Note that a STOP or a repeated START always follows a NACK.

See Figure 32-25 on page 647.

32.10.4.2 Write Sequence

In the case of a Write sequence (SVREAD is low), the RXRDY (Receive Holding Register Ready) flag is set as soon as a character has been received in the TWI_RHR (TWI Receive Holding Register). RXRDY is reset when reading the TWI_RHR.

TWI continues receiving data until a STOP condition or a REPEATED_START + an address different from SADR is detected. Note that at the end of the write sequence TXCOMP flag is set and SVACC reset.

See Figure 32-26 on page 648.

32.10.4.3 Clock Synchronization Sequence

In the case where TWI_THR or TWI_RHR is not written/read in time, TWI performs a clock synchronization.

Clock stretching information is given by the SCLWS (Clock Wait state) bit.

See Figure 32-28 on page 649 and Figure 32-29 on page 650.

32.10.4.4 General Call

In the case where a GENERAL CALL is performed, GACC (General Call ACCess) flag is set.

After GACC is set, it is up to the programmer to interpret the meaning of the GENERAL CALL and to decode the new address programming sequence.

See Figure 32-27 on page 648.

32.10.5 Data Transfer

32.10.5.1 Read Operation

The read mode is defined as a data requirement from the master.

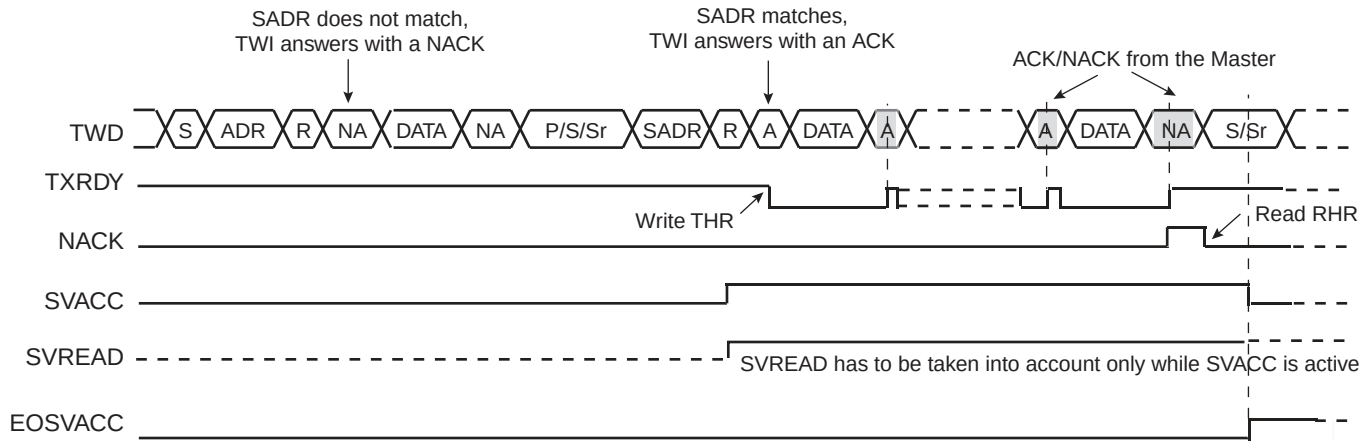
After a START or a REPEATED START condition is detected, the decoding of the address starts. If the slave address (SADR) is decoded, SVACC is set and SVREAD indicates the direction of the transfer.

Until a STOP or REPEATED START condition is detected, TWI continues sending data loaded in the TWI_THR register.

If a STOP condition or a REPEATED START + an address different from SADR is detected, SVACC is reset.

Figure 32-25 on page 647 describes the write operation.

Figure 32-25. Read Access Ordered by a MASTER



Notes:
1. When SVACC is low, the state of SVREAD becomes irrelevant.
2. TXRDY is reset when data has been transmitted from TWI_THR to the shift register and set when this data has been acknowledged or non acknowledged.

32.10.5.2 Write Operation

The write mode is defined as a data transmission from the master.

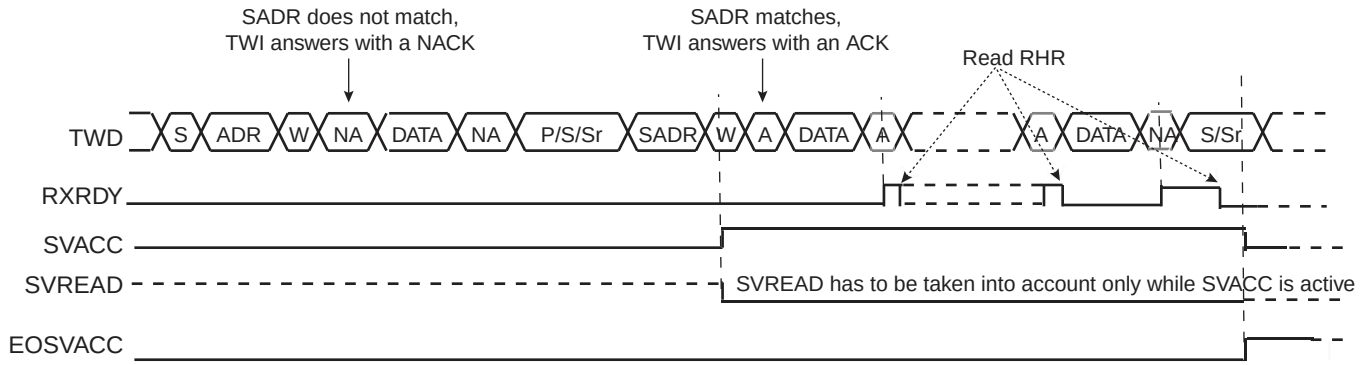
After a START or a REPEATED START, the decoding of the address starts. If the slave address is decoded, SVACC is set and SVREAD indicates the direction of the transfer (SVREAD is low in this case).

Until a STOP or REPEATED START condition is detected, TWI stores the received data in the TWI_RHR register.

If a STOP condition or a REPEATED START + an address different from SADR is detected, SVACC is reset.

Figure 32-26 on page 648 describes the Write operation.

Figure 32-26. Write Access Ordered by a Master



Notes:
1. When SVACC is low, the state of SVREAD becomes irrelevant.
2. RXRDY is set when data has been transmitted from the shift register to the TWI_RHR and reset when this data is read.

32.10.5.3 General Call

The general call is performed in order to change the address of the slave.

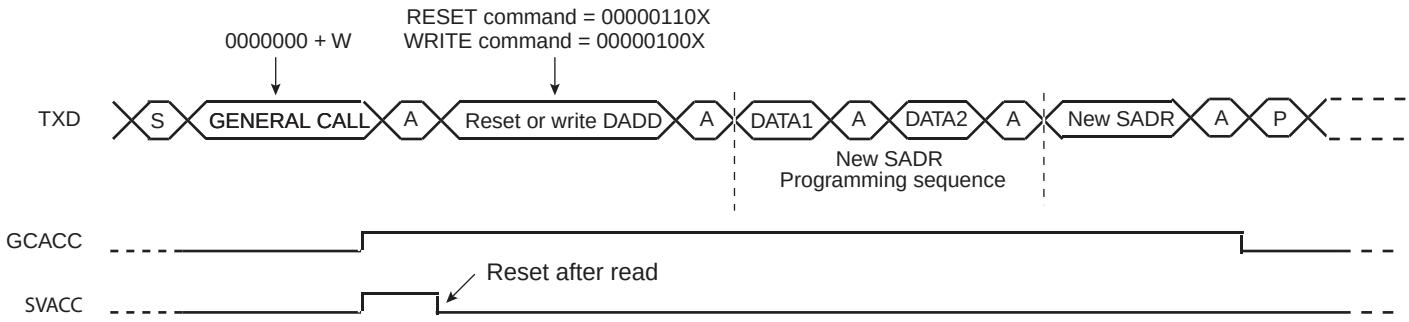
If a GENERAL CALL is detected, GACC is set.

After the detection of General Call, it is up to the programmer to decode the commands which come afterwards.

In case of a WRITE command, the programmer has to decode the programming sequence and program a new SADR if the programming sequence matches.

Figure 32-27 on page 648 describes the General Call access.

Figure 32-27. Master Performs a General Call



Note: This method allows the user to create an own programming sequence by choosing the programming bytes and the number of them. The programming sequence has to be provided to the master.

32.10.5.4 Clock Synchronization

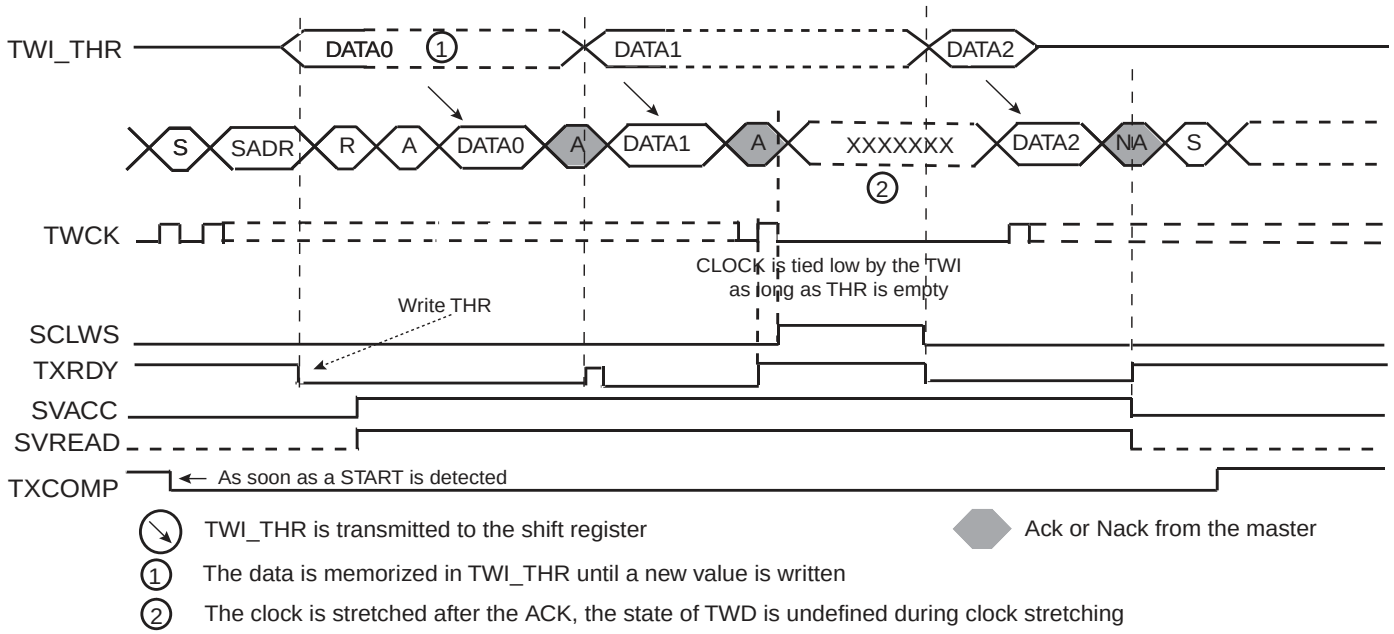
In both read and write modes, it may happen that TWI_THR/TWI_RHR buffer is not filled /emptied before the emission/reception of a new character. In this case, to avoid sending/receiving undesired data, a clock stretching mechanism is implemented.

Clock Synchronization in Read Mode

The clock is tied low if the shift register is empty and if a STOP or REPEATED START condition was not detected. It is tied low until the shift register is loaded.

Figure 32-28 on page 649 describes the clock synchronization in Read mode.

Figure 32-28. Clock Synchronization in Read Mode



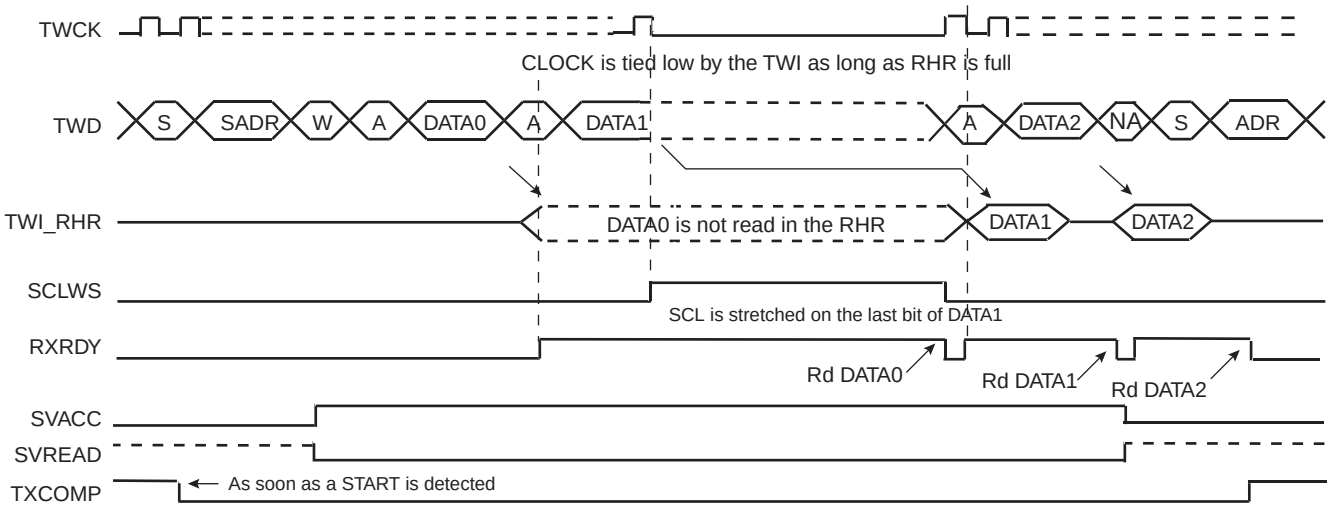
Notes:
1. TXRDY is reset when data has been written in the TWI_THR to the shift register and set when this data has been acknowledged or non acknowledged.
2. At the end of the read sequence, TXCOMP is set after a STOP or after a REPEATED_START + an address different from SADR.
3. SCLWS is automatically set when the clock synchronization mechanism is started.

Clock Synchronization in Write Mode

The clock is tied low if the shift register and the TWI_RHR is full. If a STOP or REPEATED_START condition was not detected, it is tied low until TWI_RHR is read.

Figure 32-29 on page 650 describes the clock synchronization in Read mode.

Figure 32-29. Clock Synchronization in Write Mode



Notes:
1. At the end of the read sequence, TXCOMP is set after a STOP or after a REPEATED_START + an address different from SADR.
2. SCLWS is automatically set when the clock synchronization mechanism is started and automatically reset when the mechanism is finished.

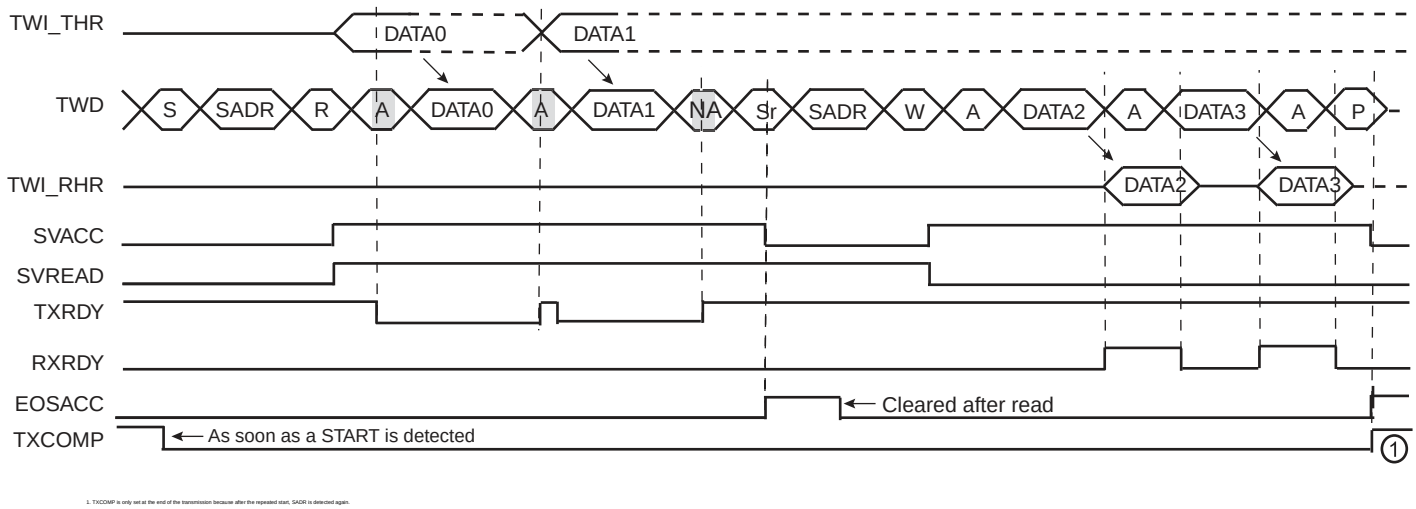
32.10.5.5 Reversal after a Repeated Start

Reversal of Read to Write

The master initiates the communication by a read command and finishes it by a write command.

Figure 32-30 on page 651 describes the repeated start + reversal from Read to Write mode.

Figure 32-30. Repeated Start + Reversal from Read to Write Mode

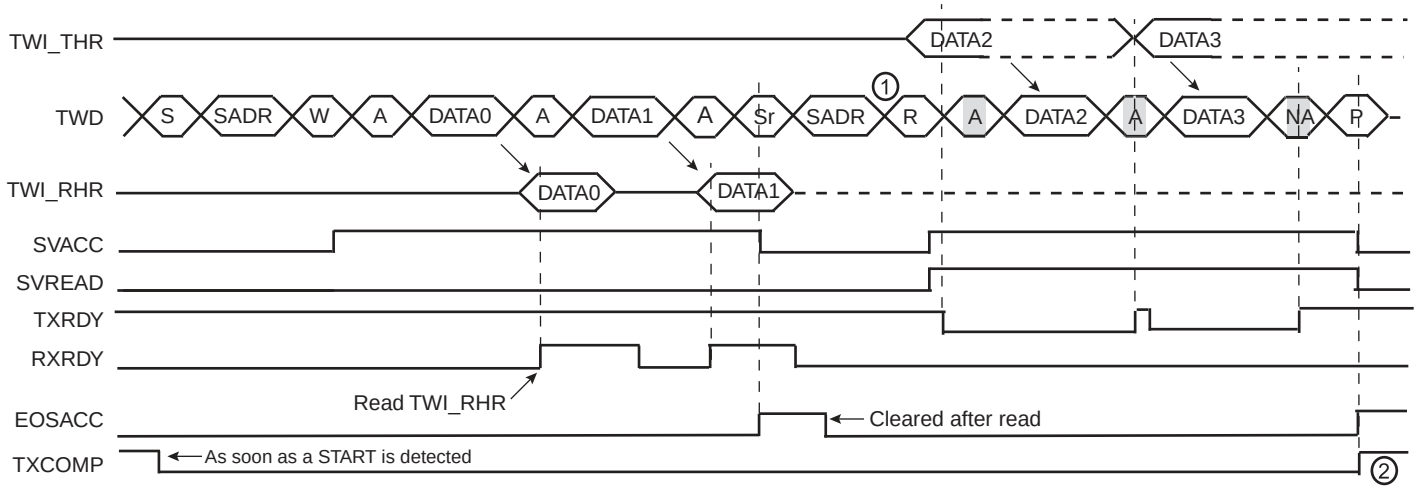


1. TXCOMP is only set at the end of the transmission because after the repeated start, SADR is detected again.

Reversal of Write to Read

The master initiates the communication by a write command and finishes it by a read command. Figure 32-31 on page 651 describes the repeated start + reversal from Write to Read mode.

Figure 32-31. Repeated Start + Reversal from Write to Read Mode

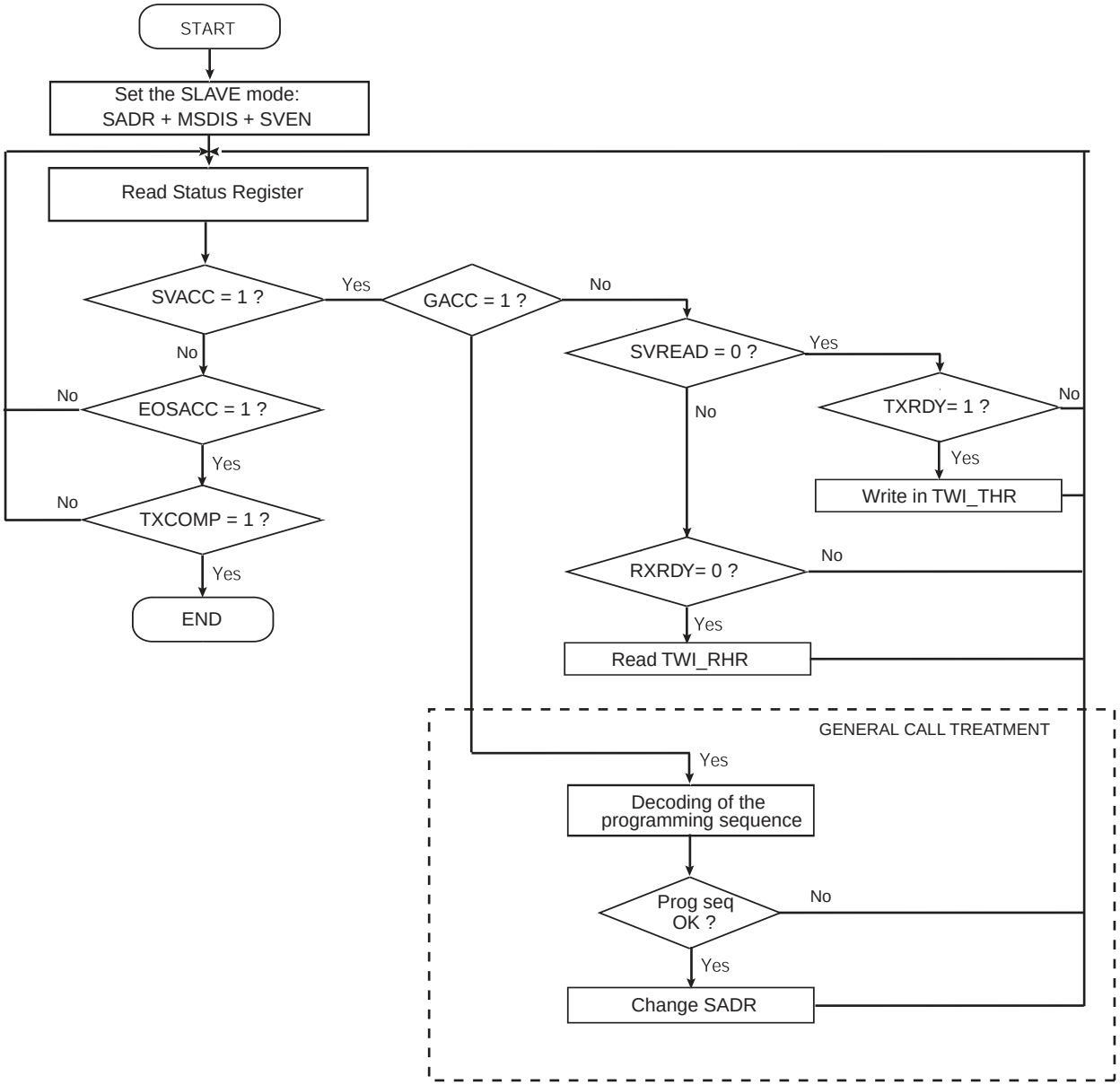


Notes:
1. In this case, if TWI_THR has not been written at the end of the read command, the clock is automatically stretched before the ACK.
2. TXCOMP is only set at the end of the transmission because after the repeated start, SADR is detected again.

32.10.6 Read Write Flowcharts

The flowchart shown in Figure 32-32 on page 652 gives an example of read and write operations in Slave mode. A polling or interrupt method can be used to check the status bits. The interrupt method requires that the interrupt enable register (TWI_IER) be configured first.

Figure 32-32. Read Write Flowchart in Slave Mode



32.11 Two-wire Interface (TWI) User Interface

Table 32-5. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	TWI_CR	Write-only	N / A
0x04	Master Mode Register	TWI_MMR	Read-write	0x00000000
0x08	Slave Mode Register	TWI_SMR	Read-write	0x00000000
0x0C	Internal Address Register	TWI_IADR	Read-write	0x00000000
0x10	Clock Waveform Generator Register	TWI_CWGR	Read-write	0x00000000
0x14 - 0x1C	Reserved	–	–	–
0x20	Status Register	TWI_SR	Read-only	0x0000F009
0x24	Interrupt Enable Register	TWI_IER	Write-only	N / A
0x28	Interrupt Disable Register	TWI_IDR	Write-only	N / A
0x2C	Interrupt Mask Register	TWI_IMR	Read-only	0x00000000
0x30	Receive Holding Register	TWI_RHR	Read-only	0x00000000
0x34	Transmit Holding Register	TWI_THR	Write-only	0x00000000
0xEC - 0xFC(1)	Reserved	–	–	–
0x100 - 0x124	Reserved for the PDC	–	–	–

Note: 1. All unlisted offset values are considered as “reserved”.

32.11.1 TWI Control Register

Name: TWI_CR

Address: 0x40084000 (0), 0x40088000 (1)

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
SWRST	QUICK	SVDIS	SVEN	MSDIS	MSEN	STOP	START

- **START: Send a START Condition**

0 = No effect.

1 = A frame beginning with a START bit is transmitted according to the features defined in the mode register.

This action is necessary when the TWI peripheral wants to read data from a slave. When configured in Master Mode with a write operation, a frame is sent as soon as the user writes a character in the Transmit Holding Register (TWI_THR).

- **STOP: Send a STOP Condition**

0 = No effect.

1 = STOP Condition is sent just after completing the current byte transmission in master read mode.

  – In single data byte master read, the START and STOP must both be set.
  – In multiple data bytes master read, the STOP must be set after the last data received but one.
  – In master read mode, if a NACK bit is received, the STOP is automatically performed.
  – In master data write operation, a STOP condition will be sent after the transmission of the current data is finished.

- **MSEN: TWI Master Mode Enabled**

0 = No effect.

1 = If MSDIS = 0, the master mode is enabled.

Note: Switching from Slave to Master mode is only permitted when TXCOMP = 1.

- **MSDIS: TWI Master Mode Disabled**

0 = No effect.

1 = The master mode is disabled, all pending data is transmitted. The shifter and holding characters (if it contains data) are transmitted in case of write operation. In read operation, the character being transferred must be completely received before disabling.

- **SVEN: TWI Slave Mode Enabled**

0 = No effect.

1 = If SVDIS = 0, the slave mode is enabled.

Note: Switching from Master to Slave mode is only permitted when TXCOMP = 1.

- **SVDIS: TWI Slave Mode Disabled**

0 = No effect.

1 = The slave mode is disabled. The shifter and holding characters (if it contains data) are transmitted in case of read operation. In write operation, the character being transferred must be completely received before disabling.

- **QUICK: SMBUS Quick Command**

0 = No effect.

1 = If Master mode is enabled, a SMBUS Quick Command is sent.

- **SWRST: Software Reset**

0 = No effect.

1 = Equivalent to a system reset.

32.11.2 TWI Master Mode Register

Name: TWI_MMR

Address: 0x40084004 (0), 0x40088004 (1)

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	DADR						

15	14	13	12	11	10	9	8
–	–	–	MREAD	–	–	IADRSZ	

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **IADRSZ: Internal Device Address Size**

Value	Name	Description
0	NONE	No internal device address
1	1_BYTE	One-byte internal device address
2	2_BYTE	Two-byte internal device address
3	3_BYTE	Three-byte internal device address

- **MREAD: Master Read Direction**

0 = Master write direction.

1 = Master read direction.

- **DADR: Device Address**

The device address is used to access slave devices in read or write mode. Those bits are only used in Master mode.

32.11.3 TWI Slave Mode Register

Name: TWI_SMR

Address: 0x40084008 (0), 0x40088008 (1)

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	SADR						
15	14	13	12	11	10	9	8
–	–	–	–	–	–		
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **SADR: Slave Address**

The slave device address is used in Slave mode in order to be accessed by master devices in read or write mode.

SADR must be programmed before enabling the Slave mode or after a general call. Writes at other times have no effect.

32.11.4 TWI Internal Address Register

Name: TWI_IADR

Address: 0x4008400C (0), 0x4008800C (1)

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
IADR							

15	14	13	12	11	10	9	8
IADR							

7	6	5	4	3	2	1	0
IADR							

- **IADR: Internal Address**

0, 1, 2 or 3 bytes depending on IADRSZ.

32.11.5 TWI Clock Waveform Generator Register

Name: TWI_CWGR

Address: 0x40084010 (0), 0x40088010 (1)

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
					CKDIV		
15	14	13	12	11	10	9	8
CHDIV							
7	6	5	4	3	2	1	0
CLDIV							

TWI_CWGR is only used in Master mode.

- **CLDIV: Clock Low Divider**

The SCL low period is defined as follows:

$$T_{low} = ((\text{CLDIV} \times 2^{\text{CKDIV}}) + 4) \times T_{MCK}$$

- **CHDIV: Clock High Divider**

The SCL high period is defined as follows:

$$T_{high} = ((\text{CHDIV} \times 2^{\text{CKDIV}}) + 4) \times T_{MCK}$$

- **CKDIV: Clock Divider**

The CKDIV is used to increase both SCL high and low periods.

32.11.6 TWI Status Register

Name: TWI_SR

Address: 0x40084020 (0), 0x40088020 (1)

Access: Read-only

Reset: 0x0000F009

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXBUFE	RXBUFF	ENDTX	ENDRX	EOSACC	SCLWS	ARBLST	NACK
7	6	5	4	3	2	1	0
–	OVRE	GACC	SVACC	SVREAD	TXRDY	RXRDY	TXCOMP

- **TXCOMP: Transmission Completed (automatically set / reset)**

TXCOMP used in Master mode:

0 = During the length of the current frame.

1 = When both holding and shifter registers are empty and STOP condition has been sent.

TXCOMP behavior in Master mode can be seen in Figure 32-8 on page 632 and in Figure 32-10 on page 633.

TXCOMP used in Slave mode:

0 = As soon as a Start is detected.

1 = After a Stop or a Repeated Start + an address different from SADR is detected.

TXCOMP behavior in Slave mode can be seen in Figure 32-28 on page 649, Figure 32-29 on page 650, Figure 32-30 on page 651 and Figure 32-31 on page 651.

- **RXRDY: Receive Holding Register Ready (automatically set / reset)**

0 = No character has been received since the last TWI_RHR read operation.

1 = A byte has been received in the TWI_RHR since the last read.

RXRDY behavior in Master mode can be seen in Figure 32-10 on page 633.

RXRDY behavior in Slave mode can be seen in Figure 32-26 on page 648, Figure 32-29 on page 650, Figure 32-30 on page 651 and Figure 32-31 on page 651.

- **TXRDY: Transmit Holding Register Ready (automatically set / reset)**

TXRDY used in Master mode:

0 = The transmit holding register has not been transferred into shift register. Set to 0 when writing into TWI_THR register.

1 = As soon as a data byte is transferred from TWI_THR to internal shifter or if a NACK error is detected, TXRDY is set at the same time as TXCOMP and NACK. TXRDY is also set when MSEN is set (enable TWI).

TXRDY behavior in Master mode can be seen in Figure 32-8 on page 632.

TXRDY used in Slave mode:

0 = As soon as data is written in the TWI_THR, until this data has been transmitted and acknowledged (ACK or NACK).

1 = It indicates that the TWI_THR is empty and that data has been transmitted and acknowledged.

If TXRDY is high and if a NACK has been detected, the transmission will be stopped. Thus when TRDY = NACK = 1, the programmer must not fill TWI_THR to avoid losing it.

TXRDY behavior in Slave mode can be seen in Figure 32-25 on page 647, Figure 32-28 on page 649, Figure 32-30 on page 651 and Figure 32-31 on page 651.

- **SVREAD: Slave Read (automatically set / reset)**

This bit is only used in Slave mode. When SVACC is low (no Slave access has been detected) SVREAD is irrelevant.

0 = Indicates that a write access is performed by a Master.

1 = Indicates that a read access is performed by a Master.

SVREAD behavior can be seen in Figure 32-25 on page 647, Figure 32-26 on page 648, Figure 32-30 on page 651 and Figure 32-31 on page 651.

- **SVACC: Slave Access (automatically set / reset)**

This bit is only used in Slave mode.

0 = TWI is not addressed. SVACC is automatically cleared after a NACK or a STOP condition is detected.

1 = Indicates that the address decoding sequence has matched (A Master has sent SADR). SVACC remains high until a NACK or a STOP condition is detected.

SVACC behavior can be seen in Figure 32-25 on page 647, Figure 32-26 on page 648, Figure 32-30 on page 651 and Figure 32-31 on page 651.

- **GACC: General Call Access (clear on read)**

This bit is only used in Slave mode.

0 = No General Call has been detected.

1 = A General Call has been detected. After the detection of General Call, if need be, the programmer may acknowledge this access and decode the following bytes and respond according to the value of the bytes.

GACC behavior can be seen in Figure 32-27 on page 648.

- **OVRE: Overrun Error (clear on read)**

This bit is only used in Master mode.

0 = TWI_RHR has not been loaded while RXRDY was set

1 = TWI_RHR has been loaded while RXRDY was set. Reset by read in TWI_SR when TXCOMP is set.

- **NACK: Not Acknowledged (clear on read)**

NACK used in Master mode:

0 = Each data byte has been correctly received by the far-end side TWI slave component.

1 = A data byte has not been acknowledged by the slave component. Set at the same time as TXCOMP.

NACK used in Slave Read mode:

0 = Each data byte has been correctly received by the Master.

1 = In read mode, a data byte has not been acknowledged by the Master. When NACK is set the programmer must not fill TWI_THR even if TXRDY is set, because it means that the Master will stop the data transfer or re initiate it.

Note that in Slave Write mode all data are acknowledged by the TWI.

- **ARBLST: Arbitration Lost (clear on read)**

This bit is only used in Master mode.

0: Arbitration won.

1: Arbitration lost. Another master of the TWI bus has won the multi-master arbitration. TXCOMP is set at the same time.

- **SCLWS: Clock Wait State (automatically set / reset)**

This bit is only used in Slave mode.

0 = The clock is not stretched.

1 = The clock is stretched. TWI_THR / TWI_RHR buffer is not filled / emptied before the emission / reception of a new character.

SCLWS behavior can be seen in Figure 32-28 on page 649 and Figure 32-29 on page 650.

- **EOSACC: End Of Slave Access (clear on read)**

This bit is only used in Slave mode.

0 = A slave access is being performing.

1 = The Slave Access is finished. End Of Slave Access is automatically set as soon as SVACC is reset.

EOSACC behavior can be seen in Figure 32-30 on page 651 and Figure 32-31 on page 651

- **ENDRX: End of RX buffer**

0 = The Receive Counter Register has not reached 0 since the last write in TWI_RCR or TWI_RNCR.

1 = The Receive Counter Register has reached 0 since the last write in TWI_RCR or TWI_RNCR.

- **ENDTX: End of TX buffer**

0 = The Transmit Counter Register has not reached 0 since the last write in TWI_TCR or TWI_TNCR.

1 = The Transmit Counter Register has reached 0 since the last write in TWI_TCR or TWI_TNCR.

- **RXBUFF: RX Buffer Full**

0 = TWI_RCR or TWI_RNCR have a value other than 0.

1 = Both TWI_RCR and TWI_RNCR have a value of 0.

- **TXBUFE: TX Buffer Empty**

0 = TWI_TCR or TWI_TNCR have a value other than 0.

1 = Both TWI_TCR and TWI_TNCR have a value of 0.

32.11.7 TWI Interrupt Enable Register

Name: TWI_IER

Address: 0x40084024 (0), 0x40088024 (1)

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXBUFE	RXBUFF	ENDTX	ENDRX	EOSACC	SCL_WS	ARBLST	NACK
7	6	5	4	3	2	1	0
–	OVRE	GACC	SVACC	–	TXRDY	RXRDY	TXCOMP

- **TXCOMP: Transmission Completed Interrupt Enable**
- **RXRDY: Receive Holding Register Ready Interrupt Enable**
- **TXRDY: Transmit Holding Register Ready Interrupt Enable**
- **SVACC: Slave Access Interrupt Enable**
- **GACC: General Call Access Interrupt Enable**
- **OVRE: Overrun Error Interrupt Enable**
- **NACK: Not Acknowledge Interrupt Enable**
- **ARBLST: Arbitration Lost Interrupt Enable**
- **SCL_WS: Clock Wait State Interrupt Enable**
- **EOSACC: End Of Slave Access Interrupt Enable**
- **ENDRX: End of Receive Buffer Interrupt Enable**
- **ENDTX: End of Transmit Buffer Interrupt Enable**
- **RXBUFF: Receive Buffer Full Interrupt Enable**
- **TXBUFE: Transmit Buffer Empty Interrupt Enable**

0 = No effect.

1 = Enables the corresponding interrupt.

32.11.8 TWI Interrupt Disable Register

Name: TWI_IDR

Address: 0x40084028 (0), 0x40088028 (1)

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXBUFE	RXBUFF	ENDTX	ENDRX	EOSACC	SCL_WS	ARBLST	NACK
7	6	5	4	3	2	1	0
–	OVRE	GACC	SVACC	–	TXRDY	RXRDY	TXCOMP

- **TXCOMP: Transmission Completed Interrupt Disable**
- **RXRDY: Receive Holding Register Ready Interrupt Disable**
- **TXRDY: Transmit Holding Register Ready Interrupt Disable**
- **SVACC: Slave Access Interrupt Disable**
- **GACC: General Call Access Interrupt Disable**
- **OVRE: Overrun Error Interrupt Disable**
- **NACK: Not Acknowledge Interrupt Disable**
- **ARBLST: Arbitration Lost Interrupt Disable**
- **SCL_WS: Clock Wait State Interrupt Disable**
- **EOSACC: End Of Slave Access Interrupt Disable**
- **ENDRX: End of Receive Buffer Interrupt Disable**
- **ENDTX: End of Transmit Buffer Interrupt Disable**
- **RXBUFF: Receive Buffer Full Interrupt Disable**
- **TXBUFE: Transmit Buffer Empty Interrupt Disable**

0 = No effect.

1 = Disables the corresponding interrupt.

32.11.9 TWI Interrupt Mask Register

Name: TWI_IMR

Address: 0x4008402C (0), 0x4008802C (1)

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
TXBUFE	RXBUFF	ENDTX	ENDRX	EOSACC	SCL_WS	ARBLST	NACK

7	6	5	4	3	2	1	0
–	OVRE	GACC	SVACC	–	TXRDY	RXRDY	TXCOMP

- **TXCOMP: Transmission Completed Interrupt Mask**
- **RXRDY: Receive Holding Register Ready Interrupt Mask**
- **TXRDY: Transmit Holding Register Ready Interrupt Mask**
- **SVACC: Slave Access Interrupt Mask**
- **GACC: General Call Access Interrupt Mask**
- **OVRE: Overrun Error Interrupt Mask**
- **NACK: Not Acknowledge Interrupt Mask**
- **ARBLST: Arbitration Lost Interrupt Mask**
- **SCL_WS: Clock Wait State Interrupt Mask**
- **EOSACC: End Of Slave Access Interrupt Mask**
- **ENDRX: End of Receive Buffer Interrupt Mask**
- **ENDTX: End of Transmit Buffer Interrupt Mask**
- **RXBUFF: Receive Buffer Full Interrupt Mask**
- **TXBUFE: Transmit Buffer Empty Interrupt Mask**

0 = The corresponding interrupt is disabled.

1 = The corresponding interrupt is enabled.

32.11.10 TWI Receive Holding Register

Name: TWI_RHR

Address: 0x40084030 (0), 0x40088030 (1)

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
RXDATA							

- **RXDATA: Master or Slave Receive Holding Data**

32.11.11 TWI Transmit Holding Register

Name: TWI_THR

Address: 0x40084034 (0), 0x40088034 (1)

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
TXDATA							

- **TXDATA: Master or Slave Transmit Holding Data**

33. Universal Asynchronous Receiver Transceiver (UART)

33.1 Description

The Universal Asynchronous Receiver Transmitter features a two-pin UART that can be used for communication and trace purposes and offers an ideal medium for in-situ programming solutions. Moreover, the association with two peripheral DMA controller (PDC) channels permits packet handling for these tasks with processor time reduced to a minimum.

33.2 Embedded Characteristics

- Two-pin UART
  - Implemented Features are USART Compatible
  - Independent Receiver and Transmitter with a Common Programmable Baud Rate Generator
  - Even, Odd, Mark or Space Parity Generation
  - Parity, Framing and Overrun Error Detection
  - Automatic Echo, Local Loopback and Remote Loopback Channel Modes
  - Interrupt Generation
  - Support for Two PDC Channels with Connection to Receiver and Transmitter

33.3 Block Diagram

Figure 33-1. UART Functional Block Diagram

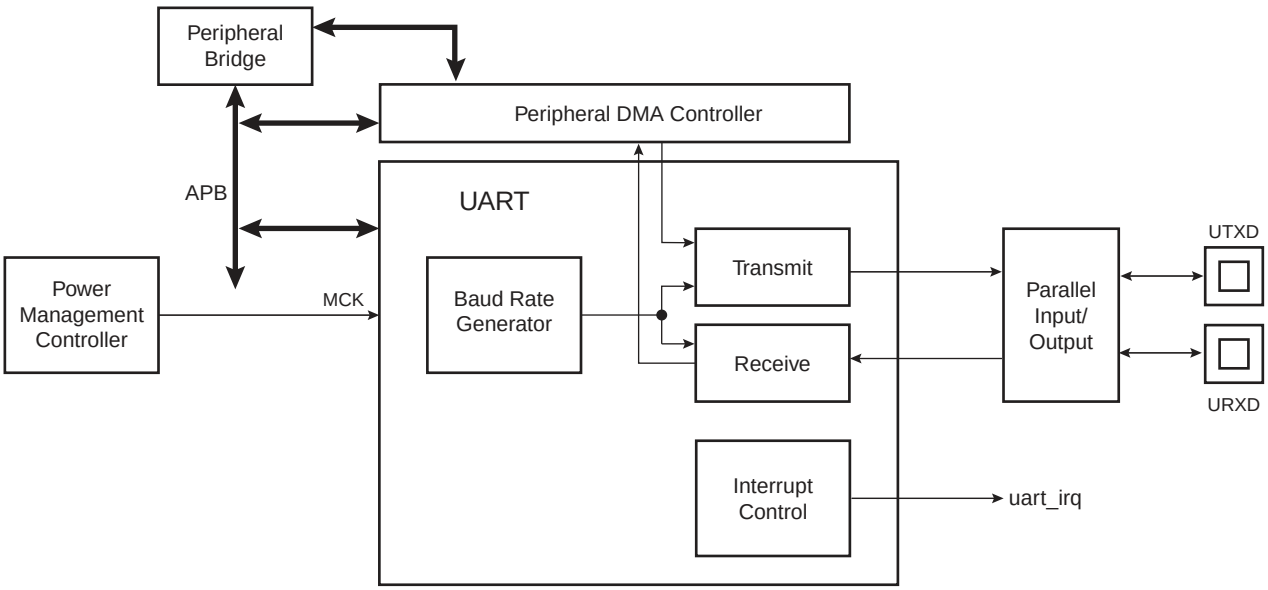


Table 33-1. UART Pin Description

Pin Name	Description	Type
URXD	UART Receive Data	Input
UTXD	UART Transmit Data	Output

33.4 Product Dependencies

33.4.1 I/O Lines

The UART pins are multiplexed with PIO lines. The programmer must first configure the corresponding PIO Controller to enable I/O line operations of the UART.

Table 33-2. I/O Lines

Instance	Signal	I/O Line	Peripheral
UART	URXD	PA11	A
UART	UTXD	PA12	A

33.4.2 Power Management

The UART clock is controllable through the Power Management Controller. In this case, the programmer must first configure the PMC to enable the UART clock. Usually, the peripheral identifier used for this purpose is 1.

33.4.3 Interrupt Source

The UART interrupt line is connected to one of the interrupt sources of the Nested Vectored Interrupt Controller (NVIC). Interrupt handling requires programming of the NVIC before configuring the UART.

33.5 UART Operations

The UART operates in asynchronous mode only and supports only 8-bit character handling (with parity). It has no clock pin.

The UART is made up of a receiver and a transmitter that operate independently, and a common baud rate generator. Receiver timeout and transmitter time guard are not implemented. However, all the implemented features are compatible with those of a standard USART.

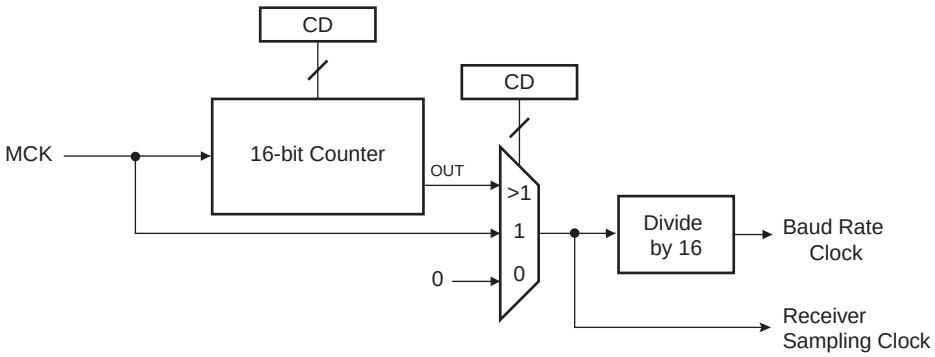
33.5.1 Baud Rate Generator

The baud rate generator provides the bit period clock named baud rate clock to both the receiver and the transmitter.

The baud rate clock is the master clock divided by 16 times the value (CD) written in UART_BRGR (Baud Rate Generator Register). If UART_BRGR is set to 0, the baud rate clock is disabled and the UART remains inactive. The maximum allowable baud rate is Master Clock divided by 16. The minimum allowable baud rate is Master Clock divided by (16 x 65536).

$$\text{Baud Rate} = \frac{\text{MCK}}{16 \times \text{CD}}$$

Figure 33-2. Baud Rate Generator



33.5.2 Receiver

33.5.2.1 Receiver Reset, Enable and Disable

After device reset, the UART receiver is disabled and must be enabled before being used. The receiver can be enabled by writing the control register UART_CR with the bit RXEN at 1. At this command, the receiver starts looking for a start bit.

The programmer can disable the receiver by writing UART_CR with the bit RXDIS at 1. If the receiver is waiting for a start bit, it is immediately stopped. However, if the receiver has already detected a start bit and is receiving the data, it waits for the stop bit before actually stopping its operation.

The programmer can also put the receiver in its reset state by writing UART_CR with the bit RSTRX at 1. In doing so, the receiver immediately stops its current operations and is disabled, whatever its current state. If RSTRX is applied when data is being processed, this data is lost.

33.5.2.2 Start Detection and Data Sampling

The UART only supports asynchronous operations, and this affects only its receiver. The UART receiver detects the start of a received character by sampling the URXD signal until it detects a valid start bit. A low level (space) on URXD is interpreted as a valid start bit if it is detected for more than 7 cycles of the sampling clock, which is 16

times the baud rate. Hence, a space that is longer than 7/16 of the bit period is detected as a valid start bit. A space which is 7/16 of a bit period or shorter is ignored and the receiver continues to wait for a valid start bit.

When a valid start bit has been detected, the receiver samples the URXD at the theoretical midpoint of each bit. It is assumed that each bit lasts 16 cycles of the sampling clock (1-bit period) so the bit sampling point is eight cycles (0.5-bit period) after the start of the bit. The first sampling point is therefore 24 cycles (1.5-bit periods) after the falling edge of the start bit was detected.

Each subsequent bit is sampled 16 cycles (1-bit period) after the previous one.

Figure 33-3. Start Bit Detection

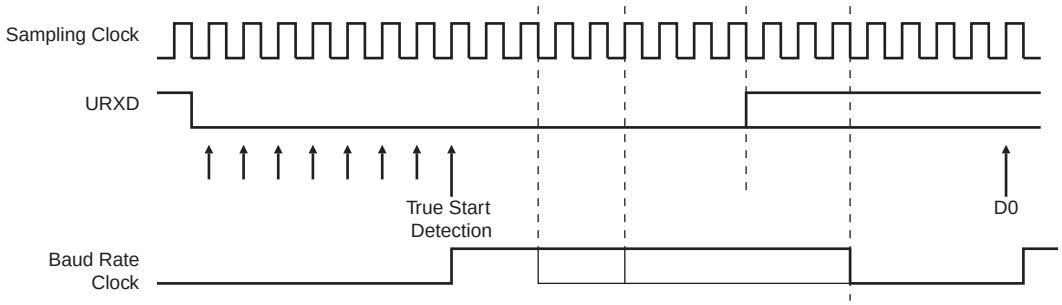
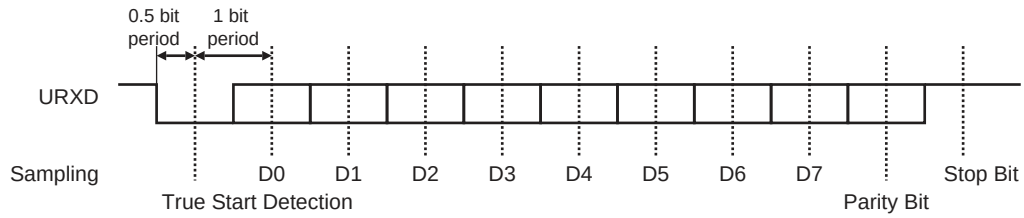


Figure 33-4. Character Reception

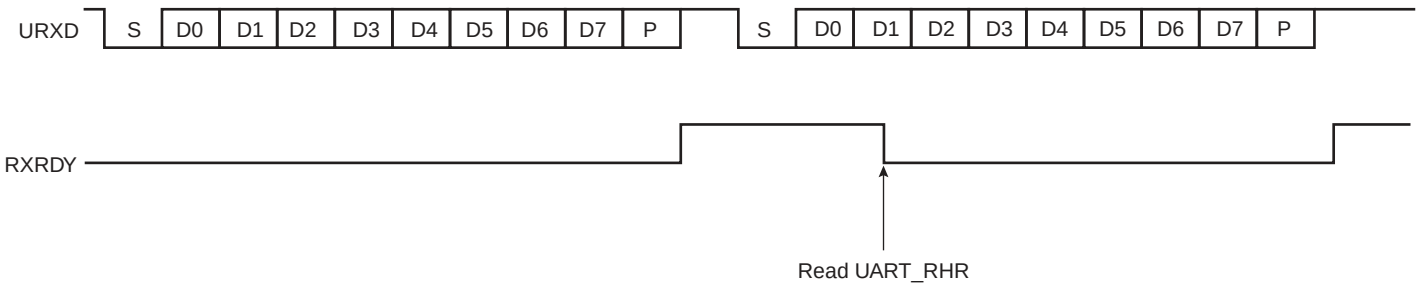
Example: 8-bit, parity enabled 1 stop



33.5.2.3 Receiver Ready

When a complete character is received, it is transferred to the UART_RHR and the RXRDY status bit in UART_SR (Status Register) is set. The bit RXRDY is automatically cleared when the receive holding register UART_RHR is read.

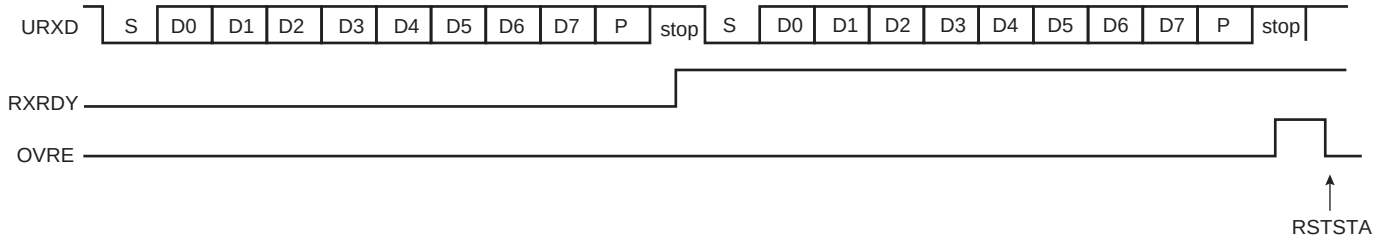
Figure 33-5. Receiver Ready



33.5.2.4 Receiver Overrun

If UART_RHR has not been read by the software (or the Peripheral Data Controller or DMA Controller) since the last transfer, the RXRDY bit is still set and a new character is received, the OVRE status bit in UART_SR is set. OVRE is cleared when the software writes the control register UART_CR with the bit RSTSTA (Reset Status) at 1.

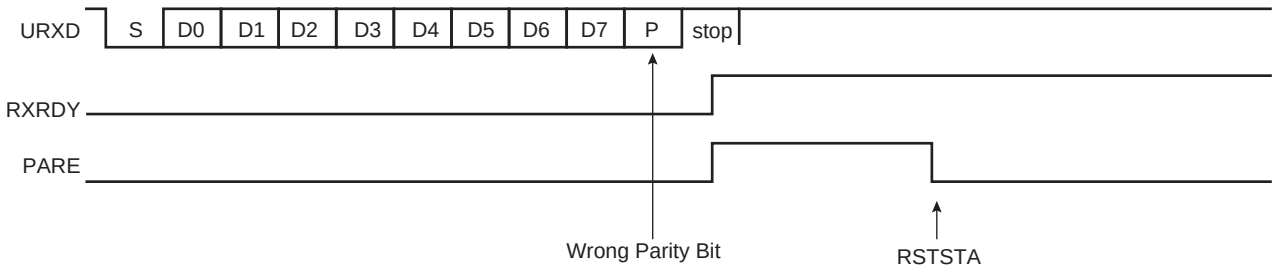
Figure 33-6. Receiver Overrun



33.5.2.5 Parity Error

Each time a character is received, the receiver calculates the parity of the received data bits, in accordance with the field PAR in UART_MR. It then compares the result with the received parity bit. If different, the parity error bit PARE in UART_SR is set at the same time the RXRDY is set. The parity bit is cleared when the control register UART_CR is written with the bit RSTSTA (Reset Status) at 1. If a new character is received before the reset status command is written, the PARE bit remains at 1.

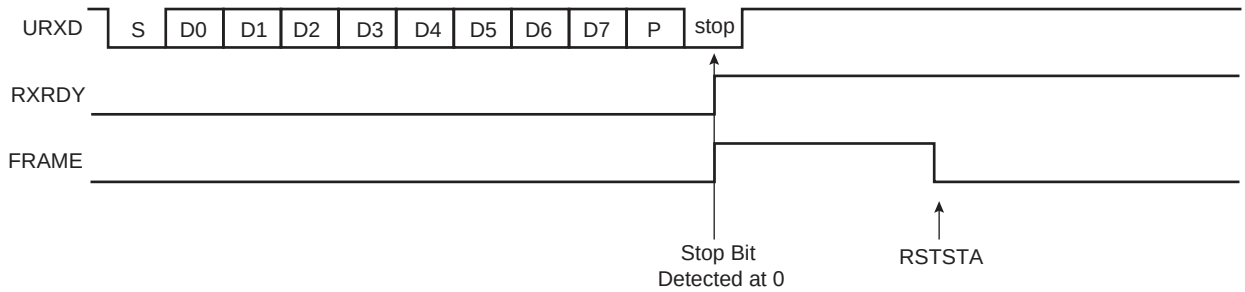
Figure 33-7. Parity Error



33.5.2.6 Receiver Framing Error

When a start bit is detected, it generates a character reception when all the data bits have been sampled. The stop bit is also sampled and when it is detected at 0, the FRAME (Framing Error) bit in UART_SR is set at the same time the RXRDY bit is set. The FRAME bit remains high until the control register UART_CR is written with the bit RSTSTA at 1.

Figure 33-8. Receiver Framing Error



33.5.3 Transmitter

33.5.3.1 Transmitter Reset, Enable and Disable

After device reset, the UART transmitter is disabled and it must be enabled before being used. The transmitter is enabled by writing the control register UART_CR with the bit TXEN at 1. From this command, the transmitter waits for a character to be written in the Transmit Holding Register (UART_THR) before actually starting the transmission.

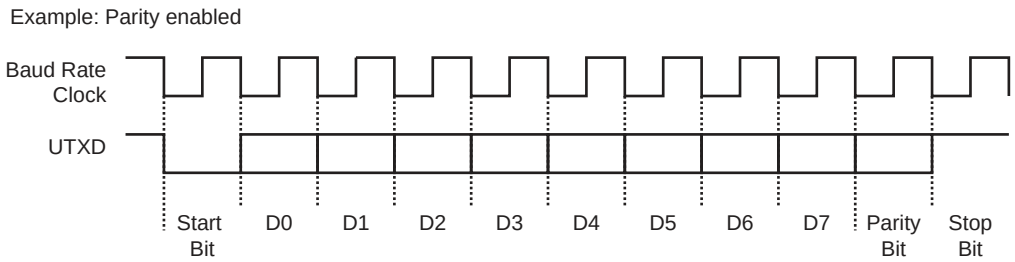
The programmer can disable the transmitter by writing UART_CR with the bit TXDIS at 1. If the transmitter is not operating, it is immediately stopped. However, if a character is being processed into the Shift Register and/or a character has been written in the Transmit Holding Register, the characters are completed before the transmitter is actually stopped.

The programmer can also put the transmitter in its reset state by writing the UART_CR with the bit RSTTX at 1. This immediately stops the transmitter, whether or not it is processing characters.

33.5.3.2 Transmit Format

The UART transmitter drives the pin UTXD at the baud rate clock speed. The line is driven depending on the format defined in the Mode Register and the data stored in the Shift Register. One start bit at level 0, then the 8 data bits, from the lowest to the highest bit, one optional parity bit and one stop bit at 1 are consecutively shifted out as shown in the following figure. The field PARE in the mode register UART_MR defines whether or not a parity bit is shifted out. When a parity bit is enabled, it can be selected between an odd parity, an even parity, or a fixed space or mark bit.

Figure 33-9. Character Transmission

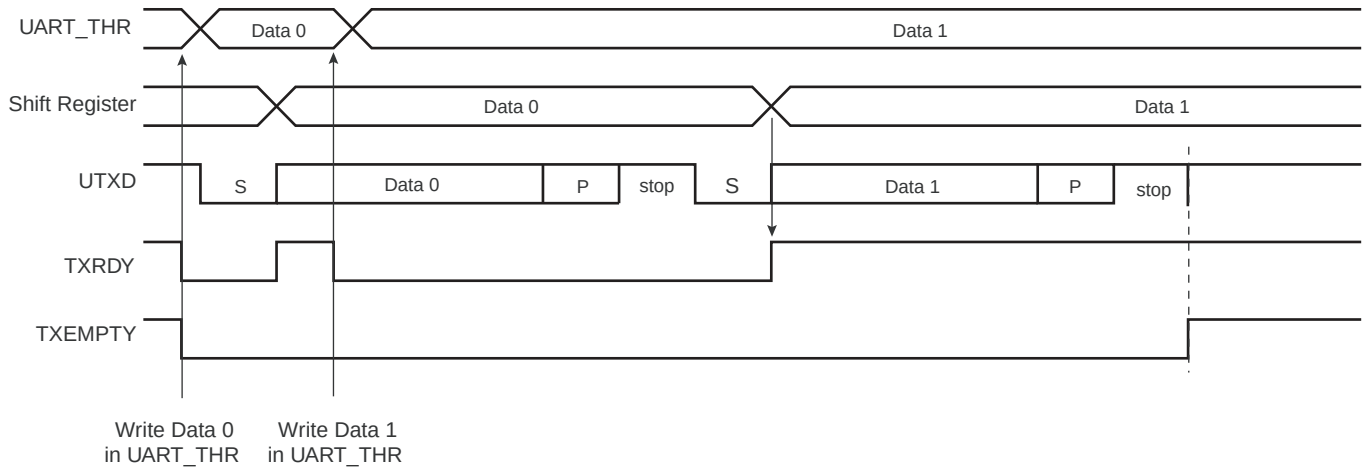


33.5.3.3 Transmitter Control

When the transmitter is enabled, the bit TXRDY (Transmitter Ready) is set in the status register UART_SR. The transmission starts when the programmer writes in the Transmit Holding Register (UART_THR), and after the written character is transferred from UART_THR to the Shift Register. The TXRDY bit remains high until a second character is written in UART_THR. As soon as the first character is completed, the last character written in UART_THR is transferred into the shift register and TXRDY rises again, showing that the holding register is empty.

When both the Shift Register and UART_THR are empty, i.e., all the characters written in UART_THR have been processed, the TXEMPTY bit rises after the last stop bit has been completed.

Figure 33-10. Transmitter Control



33.5.4 Peripheral DMA Controller

Both the receiver and the transmitter of the UART are connected to a Peripheral DMA Controller (PDC) channel.

The peripheral data controller channels are programmed via registers that are mapped within the UART user interface from the offset 0x100. The status bits are reported in the UART status register (UART_SR) and can generate an interrupt.

The RXRDY bit triggers the PDC channel data transfer of the receiver. This results in a read of the data in UART_RHR. The TXRDY bit triggers the PDC channel data transfer of the transmitter. This results in a write of data in UART_THR.

33.5.5 Test Modes

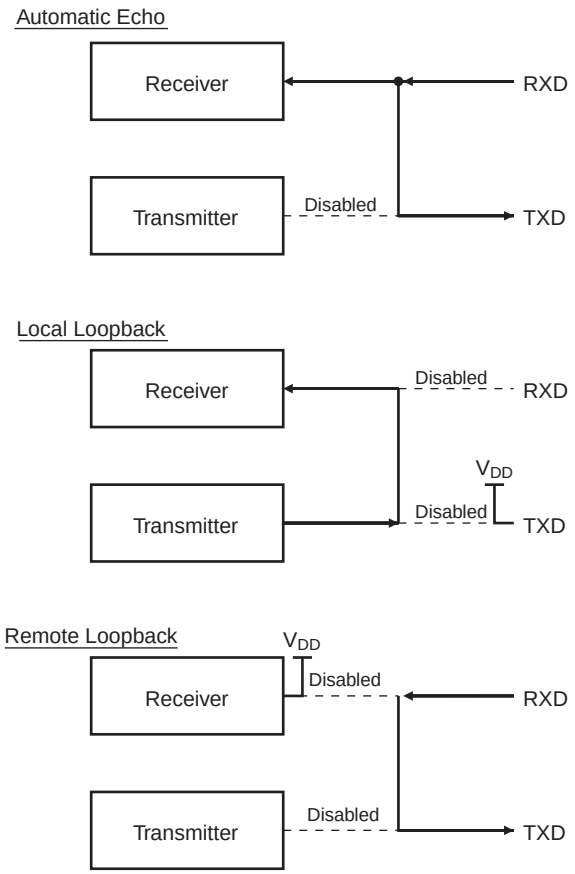
The UART supports three test modes. These modes of operation are programmed by using the field CHMODE (Channel Mode) in the mode register (UART_MR).

The Automatic Echo mode allows bit-by-bit retransmission. When a bit is received on the URXD line, it is sent to the UTXD line. The transmitter operates normally, but has no effect on the UTXD line.

The Local Loopback mode allows the transmitted characters to be received. UTXD and URXD pins are not used and the output of the transmitter is internally connected to the input of the receiver. The URXD pin level has no effect and the UTXD line is held high, as in idle state.

The Remote Loopback mode directly connects the URXD pin to the UTXD line. The transmitter and the receiver are disabled and have no effect. This mode allows a bit-by-bit retransmission.

Figure 33-11. Test Modes



33.6 Universal Asynchronous Receiver Transceiver (UART) User Interface

Table 33-3. Register Mapping

Offset	Register	Name	Access	Reset
0x0000	Control Register	UART_CR	Write-only	–
0x0004	Mode Register	UART_MR	Read-write	0x0
0x0008	Interrupt Enable Register	UART_IER	Write-only	–
0x000C	Interrupt Disable Register	UART_IDR	Write-only	–
0x0010	Interrupt Mask Register	UART_IMR	Read-only	0x0
0x0014	Status Register	UART_SR	Read-only	–
0x0018	Receive Holding Register	UART_RHR	Read-only	0x0
0x001C	Transmit Holding Register	UART_THR	Write-only	–
0x0020	Baud Rate Generator Register	UART_BRGR	Read-write	0x0
0x0024 - 0x003C	Reserved	–	–	–
0x004C - 0x00FC	Reserved	–	–	–
0x0100 - 0x0124	PDC Area	–	–	–

33.6.1 UART Control Register

Name: UART_CR

Address: 0x400E0600

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	RSTSTA
7	6	5	4	3	2	1	0
TXDIS	TXEN	RXDIS	RXEN	RSTTX	RSTRX	–	–

- **RSTRX: Reset Receiver**

0 = No effect.

1 = The receiver logic is reset and disabled. If a character is being received, the reception is aborted.

- **RSTTX: Reset Transmitter**

0 = No effect.

1 = The transmitter logic is reset and disabled. If a character is being transmitted, the transmission is aborted.

- **RXEN: Receiver Enable**

0 = No effect.

1 = The receiver is enabled if RXDIS is 0.

- **RXDIS: Receiver Disable**

0 = No effect.

1 = The receiver is disabled. If a character is being processed and RSTRX is not set, the character is completed before the receiver is stopped.

- **TXEN: Transmitter Enable**

0 = No effect.

1 = The transmitter is enabled if TXDIS is 0.

- **TXDIS: Transmitter Disable**

0 = No effect.

1 = The transmitter is disabled. If a character is being processed and a character has been written in the UART_THR and RSTTX is not set, both characters are completed before the transmitter is stopped.

- **RSTSTA: Reset Status Bits**

0 = No effect.

1 = Resets the status bits PARE, FRAME and OVRE in the UART_SR.

33.6.2 UART Mode Register

Name: UART_MR

Address: 0x400E0604

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
CHMODE		–	–	PAR			–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **PAR: Parity Type**

Value	Name	Description
0	EVEN	Even parity
1	ODD	Odd parity
2	SPACE	Space: parity forced to 0
3	MARK	Mark: parity forced to 1
4	NO	No parity

- **CHMODE: Channel Mode**

Value	Name	Description
0	NORMAL	Normal Mode
1	AUTOMATIC	Automatic Echo
2	LOCAL_LOOPBACK	Local Loopback
3	REMOTE_LOOPBACK	Remote Loopback

33.6.3 UART Interrupt Enable Register

Name: UART_IER

Address: 0x400E0608

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	RXBUFF	TXBUFE	–	TXEMPTY	–
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	–	TXRDY	RXRDY

- **RXRDY: Enable RXRDY Interrupt**
- **TXRDY: Enable TXRDY Interrupt**
- **ENDRX: Enable End of Receive Transfer Interrupt**
- **ENDTX: Enable End of Transmit Interrupt**
- **OVRE: Enable Overrun Error Interrupt**
- **FRAME: Enable Framing Error Interrupt**
- **PARE: Enable Parity Error Interrupt**
- **TXEMPTY: Enable TXEMPTY Interrupt**
- **TXBUFE: Enable Buffer Empty Interrupt**
- **RXBUFF: Enable Buffer Full Interrupt**

0 = No effect.

1 = Enables the corresponding interrupt.

33.6.4 UART Interrupt Disable Register

Name: UART_IDR

Address: 0x400E060C

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	RXBUFF	TXBUFE	–	TXEMPTY	–
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	–	TXRDY	RXRDY

- **RXRDY: Disable RXRDY Interrupt**
- **TXRDY: Disable TXRDY Interrupt**
- **ENDRX: Disable End of Receive Transfer Interrupt**
- **ENDTX: Disable End of Transmit Interrupt**
- **OVRE: Disable Overrun Error Interrupt**
- **FRAME: Disable Framing Error Interrupt**
- **PARE: Disable Parity Error Interrupt**
- **TXEMPTY: Disable TXEMPTY Interrupt**
- **TXBUFE: Disable Buffer Empty Interrupt**
- **RXBUFF: Disable Buffer Full Interrupt**

0 = No effect.

1 = Disables the corresponding interrupt.

33.6.5 UART Interrupt Mask Register

Name: UART_IMR

Address: 0x400E0610

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	RXBUFF	TXBUFE	–	TXEMPTY	–
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	–	TXRDY	RXRDY

- **RXRDY: Mask RXRDY Interrupt**
- **TXRDY: Disable TXRDY Interrupt**
- **ENDRX: Mask End of Receive Transfer Interrupt**
- **ENDTX: Mask End of Transmit Interrupt**
- **OVRE: Mask Overrun Error Interrupt**
- **FRAME: Mask Framing Error Interrupt**
- **PARE: Mask Parity Error Interrupt**
- **TXEMPTY: Mask TXEMPTY Interrupt**
- **TXBUFE: Mask TXBUFE Interrupt**
- **RXBUFF: Mask RXBUFF Interrupt**

0 = The corresponding interrupt is disabled.

1 = The corresponding interrupt is enabled.

33.6.6 UART Status Register

Name: UART_SR

Address: 0x400E0614

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	RXBUFF	TXBUFE	–	TXEMPTY	–
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	–	TXRDY	RXRDY

- **RXRDY: Receiver Ready**

0 = No character has been received since the last read of the UART_RHR or the receiver is disabled.

1 = At least one complete character has been received, transferred to UART_RHR and not yet read.

- **TXRDY: Transmitter Ready**

0 = A character has been written to UART_THR and not yet transferred to the Shift Register, or the transmitter is disabled.

1 = There is no character written to UART_THR not yet transferred to the Shift Register.

- **ENDRX: End of Receiver Transfer**

0 = The End of Transfer signal from the receiver Peripheral Data Controller channel is inactive.

1 = The End of Transfer signal from the receiver Peripheral Data Controller channel is active.

- **ENDTX: End of Transmitter Transfer**

0 = The End of Transfer signal from the transmitter Peripheral Data Controller channel is inactive.

1 = The End of Transfer signal from the transmitter Peripheral Data Controller channel is active.

- **OVRE: Overrun Error**

0 = No overrun error has occurred since the last RSTSTA.

1 = At least one overrun error has occurred since the last RSTSTA.

- **FRAME: Framing Error**

0 = No framing error has occurred since the last RSTSTA.

1 = At least one framing error has occurred since the last RSTSTA.

- **PARE: Parity Error**

0 = No parity error has occurred since the last RSTSTA.

1 = At least one parity error has occurred since the last RSTSTA.

- **TXEMPTY: Transmitter Empty**

0 = There are characters in UART_THR, or characters being processed by the transmitter, or the transmitter is disabled.

1 = There are no characters in UART_THR and there are no characters being processed by the transmitter.

- **TXBUFE: Transmission Buffer Empty**

0 = The buffer empty signal from the transmitter PDC channel is inactive.

1 = The buffer empty signal from the transmitter PDC channel is active.

- **RXBUFF: Receive Buffer Full**

0 = The buffer full signal from the receiver PDC channel is inactive.

1 = The buffer full signal from the receiver PDC channel is active.

33.6.7 UART Receiver Holding Register

Name: UART_RHR

Address: 0x400E0618

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
RXCHR							

- **RXCHR: Received Character**

Last received character if RXRDY is set.

33.6.8 UART Transmit Holding Register

Name: UART_THR

Address: 0x400E061C

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
TXCHR							

- **TXCHR: Character to be Transmitted**

Next character to be transmitted after the current character if TXRDY is not set.

33.6.9 UART Baud Rate Generator Register

Name: UART_BRGR

Address: 0x400E0620

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
CD							
7	6	5	4	3	2	1	0
CD							

- **CD: Clock Divisor**

0 = Baud Rate Clock is disabled

1 to 65,535 = MCK / (CD x 16)

34. Universal Synchronous Asynchronous Receiver Transmitter (USART)

34.1 Description

The Universal Synchronous Asynchronous Receiver Transceiver (USART) provides one full duplex universal synchronous asynchronous serial link. Data frame format is widely programmable (data length, parity, number of stop bits) to support a maximum of standards. The receiver implements parity error, framing error and overrun error detection. The receiver time-out enables handling variable-length frames and the transmitter timeguard facilitates communications with slow remote devices. Multidrop communications are also supported through address bit handling in reception and transmission.

The USART features three test modes: remote loopback, local loopback and automatic echo.

The USART supports specific operating modes providing interfaces on RS485 and SPI buses, with ISO7816 T = 0 or T = 1 smart card slots, infrared transceivers and connection to modem ports. The hardware handshaking feature enables an out-of-band flow control by automatic management of the pins RTS and CTS.

The USART supports the connection to the Peripheral DMA Controller, which enables data transfers to the transmitter and from the receiver. The PDC provides chained buffer management without any intervention of the processor.

34.2 Embedded Characteristics

- Programmable Baud Rate Generator
- 5- to 9-bit Full-duplex Synchronous or Asynchronous Serial Communications
  - 1, 1.5 or 2 Stop Bits in Asynchronous Mode or 1 or 2 Stop Bits in Synchronous Mode
  - Parity Generation and Error Detection
  - Framing Error Detection, Overrun Error Detection
  - MSB- or LSB-first
  - Optional Break Generation and Detection
  - By 8 or by 16 Over-sampling Receiver Frequency
  - Optional Hardware Handshaking RTS-CTS
  - Optional Modem Signal Management DTR-DSR-DCD-RI
  - Receiver Time-out and Transmitter Timeguard
  - Optional Multidrop Mode with Address Generation and Detection
- RS485 with Driver Control Signal
- ISO7816, T = 0 or T = 1 Protocols for Interfacing with Smart Cards
  - NACK Handling, Error Counter with Repetition and Iteration Limit
- IrDA Modulation and Demodulation
  - Communication at up to 115.2 Kbps
- SPI Mode
  - Master or Slave
  - Serial Clock Programmable Phase and Polarity
  - SPI Serial Clock (SCK) Frequency up to Internal Clock Frequency MCK/6
- Test Modes
  - Remote Loopback, Local Loopback, Automatic Echo
- Supports Connection of:
  - Two Peripheral DMA Controller Channels (PDC)
- Offers Buffer Transfer without Processor Intervention

34.3 Block Diagram

Figure 34-1. USART Block Diagram

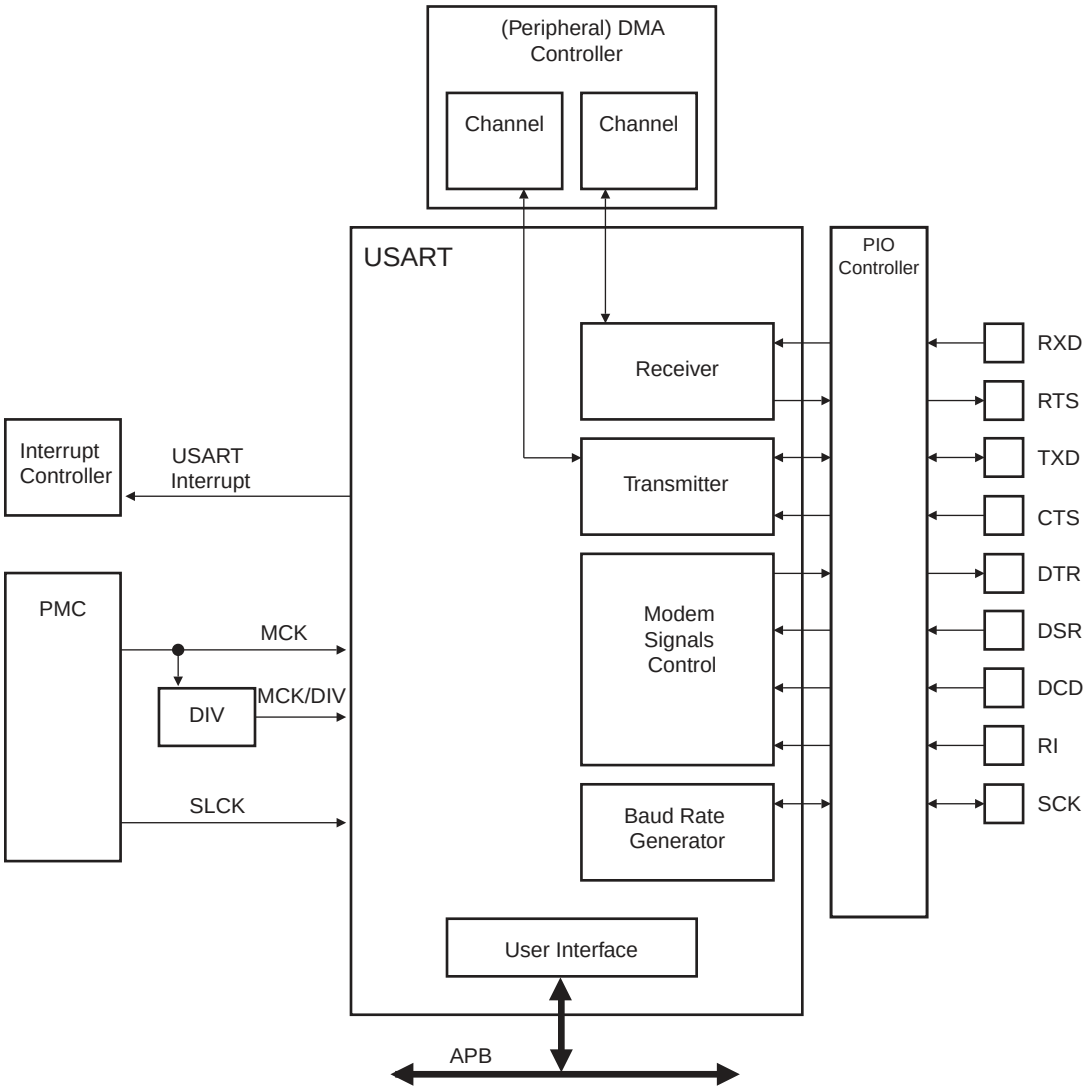
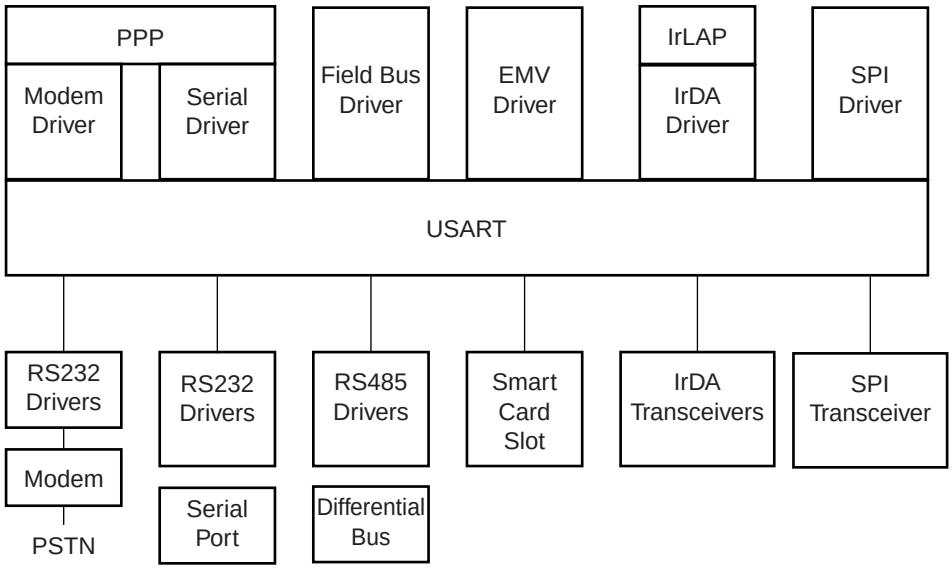


Table 34-1. SPI Operating Mode

PIN	USART	SPI Slave	SPI Master
RXD	RXD	MOSI	MISO
TXD	TXD	MISO	MOSI
RTS	RTS	–	CS
CTS	CTS	CS	–

34.4 Application Block Diagram

Figure 34-2. Application Block Diagram



34.5 I/O Lines Description

Table 34-2. I/O Line Description

Name	Description	Type	Active Level
SCK	Serial Clock	I/O	
TXD	Transmit Serial Data or Master Out Slave In (MOSI) in SPI Master Mode or Master In Slave Out (MISO) in SPI Slave Mode	I/O	
RXD	Receive Serial Data or Master In Slave Out (MISO) in SPI Master Mode or Master Out Slave In (MOSI) in SPI Slave Mode	Input	
RI	Ring Indicator	Input	Low
DSR	Data Set Ready	Input	Low
DCD	Data Carrier Detect	Input	Low
DTR	Data Terminal Ready	Output	Low
CTS	Clear to Send or Slave Select (NSS) in SPI Slave Mode	Input	Low
RTS	Request to Send or Slave Select (NSS) in SPI Master Mode	Output	Low

34.6 Product Dependencies

34.6.1 I/O Lines

The pins used for interfacing the USART may be multiplexed with the PIO lines. The programmer must first program the PIO controller to assign the desired USART pins to their peripheral function. If I/O lines of the USART are not used by the application, they can be used for other purposes by the PIO Controller.

To prevent the TXD line from falling when the USART is disabled, the use of an internal pull up is mandatory. If the hardware handshaking feature or Modem mode is used, the internal pull up on TXD must also be enabled.

All the pins of the modems may or may not be implemented on the USART. On USARTs not equipped with the corresponding pin, the associated control bits and statuses have no effect on the behavior of the USART.

Table 34-3. I/O Lines

Instance	Signal	I/O Line	Peripheral
USART0	CTS0	PB8	A
USART0	DCD0	PB11	B
USART0	DSR0	PB10	B
USART0	DTR0	PB9	B
USART0	RI0	PB12	B
USART0	RTS0	PB7	A
USART0	RXD0	PA19	A
USART0	SCK0	PA17	A
USART0	TXD0	PA18	A
USART1	CTS1	PA23	B
USART1	RTS1	PA22	B
USART1	RXD1	PA21	A
USART1	SCK1	PA24	B
USART1	TXD1	PA20	A
USART2	CTS2	PB22	B
USART2	RTS2	PB21	B
USART2	RXD2	PA23	A
USART2	SCK2	PA25	B
USART2	TXD2	PA22	A
USART3	CTS3	PC10	B
USART3	RTS3	PC11	B
USART3	RXD3	PC13	B
USART3	SCK3	PC19	A
USART3	TXD3	PC12	B

34.6.2 Power Management

The USART is not continuously clocked. The programmer must first enable the USART Clock in the Power Management Controller (PMC) before using the USART. However, if the application does not require USART operations, the USART clock can be stopped when not needed and be restarted later. In this case, the USART will resume its operations where it left off.

Configuring the USART does not require the USART clock to be enabled.

34.6.3 Interrupt

The USART interrupt line is connected on one of the internal sources of the Interrupt Controller. Using the USART interrupt requires the Interrupt Controller to be programmed first. Note that it is not recommended to use the USART interrupt line in edge sensitive mode.

34.7 Functional Description

The USART is capable of managing several types of serial synchronous or asynchronous communications.

It supports the following communication modes:

- 5- to 9-bit full-duplex asynchronous serial communication
  - MSB- or LSB-first
  - 1, 1.5 or 2 stop bits
  - Parity even, odd, marked, space or none
  - By 8 or by 16 over-sampling receiver frequency
  - Optional hardware handshaking
  - Optional modem signals management
  - Optional break management
  - Optional multidrop serial communication
- High-speed 5- to 9-bit full-duplex synchronous serial communication
  - MSB- or LSB-first
  - 1 or 2 stop bits
  - Parity even, odd, marked, space or none
  - By 8 or by 16 over-sampling frequency
  - Optional hardware handshaking
  - Optional modem signals management
  - Optional break management
  - Optional multidrop serial communication
- RS485 with driver control signal
- ISO7816, T0 or T1 protocols for interfacing with smart cards
  - NACK handling, error counter with repetition and iteration limit, inverted data.
- InfraRed IrDA Modulation and Demodulation
- SPI Mode
  - Master or Slave
  - Serial Clock Programmable Phase and Polarity
  - SPI Serial Clock (SCK) Frequency up to Internal Clock Frequency MCK/6
- Test modes
  - Remote loopback, local loopback, automatic echo

34.7.1 Baud Rate Generator

The Baud Rate Generator provides the bit period clock named the Baud Rate Clock to both the receiver and the transmitter.

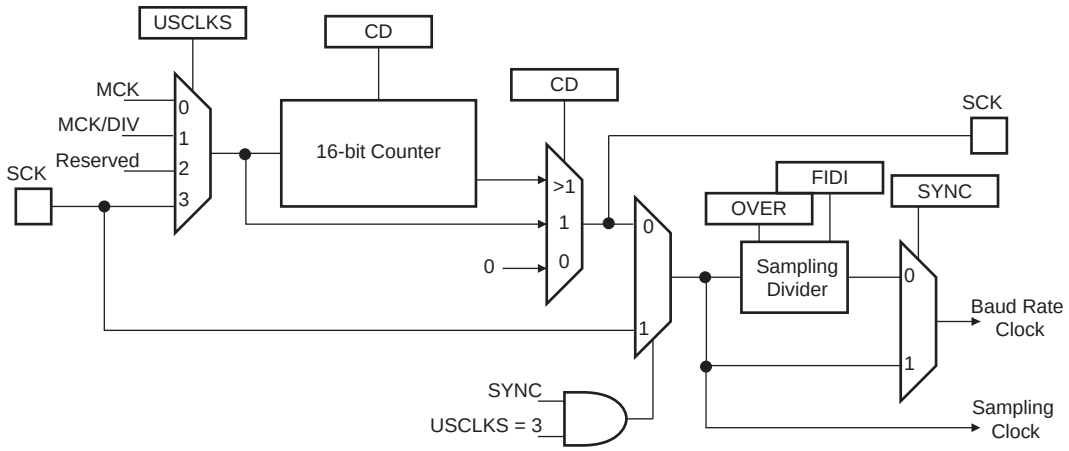
The Baud Rate Generator clock source can be selected by setting the USCLKS field in the Mode Register (US_MR) between:

- the Master Clock MCK
- a division of the Master Clock, the divider being product dependent, but generally set to 8
- the external clock, available on the SCK pin

The Baud Rate Generator is based upon a 16-bit divider, which is programmed with the CD field of the Baud Rate Generator Register (US_BRGR). If CD is programmed to 0, the Baud Rate Generator does not generate any clock. If CD is programmed to 1, the divider is bypassed and becomes inactive.

If the external SCK clock is selected, the duration of the low and high levels of the signal provided on the SCK pin must be longer than a Master Clock (MCK) period. The frequency of the signal provided on SCK must be at least 3 times lower than MCK in USART mode, or 6 in SPI mode.

Figure 34-3. Baud Rate Generator



34.7.1.1 Baud Rate in Asynchronous Mode

If the USART is programmed to operate in asynchronous mode, the selected clock is first divided by CD, which is field programmed in the Baud Rate Generator Register (US_BRGR). The resulting clock is provided to the receiver as a sampling clock and then divided by 16 or 8, depending on the programming of the OVER bit in US_MR.

If OVER is set to 1, the receiver sampling is 8 times higher than the baud rate clock. If OVER is cleared, the sampling is performed at 16 times the baud rate clock.

The following formula performs the calculation of the Baud Rate.

$$Baudrate = \frac{SelectedClock}{(8(2-Over)CD)}$$

This gives a maximum baud rate of MCK divided by 8, assuming that MCK is the highest possible clock and that OVER is programmed to 1.

Baud Rate Calculation Example

Table 34-4 shows calculations of CD to obtain a baud rate at 38400 bauds for different source clock frequencies. This table also shows the actual resulting baud rate and the error.

Table 34-4. Baud Rate Example (OVER = 0)

Source Clock	Expected Baud Rate	Calculation Result	CD	Actual Baud Rate	Error
MHz	Bit/s			Bit/s	
3 686 400	38 400	6.00	6	38 400.00	0.00%
4 915 200	38 400	8.00	8	38 400.00	0.00%
5 000 000	38 400	8.14	8	39 062.50	1.70%
7 372 800	38 400	12.00	12	38 400.00	0.00%
8 000 000	38 400	13.02	13	38 461.54	0.16%
12 000 000	38 400	19.53	20	37 500.00	2.40%
12 288 000	38 400	20.00	20	38 400.00	0.00%
14 318 180	38 400	23.30	23	38 908.10	1.31%
14 745 600	38 400	24.00	24	38 400.00	0.00%
18 432 000	38 400	30.00	30	38 400.00	0.00%
24 000 000	38 400	39.06	39	38 461.54	0.16%
24 576 000	38 400	40.00	40	38 400.00	0.00%
25 000 000	38 400	40.69	40	38 109.76	0.76%
32 000 000	38 400	52.08	52	38 461.54	0.16%
32 768 000	38 400	53.33	53	38 641.51	0.63%
33 000 000	38 400	53.71	54	38 194.44	0.54%
40 000 000	38 400	65.10	65	38 461.54	0.16%
50 000 000	38 400	81.38	81	38 580.25	0.47%

The baud rate is calculated with the following formula:

$$BaudRate = MCK/CD \times 16$$

The baud rate error is calculated with the following formula. It is not recommended to work with an error higher than 5%.

$$Error = 1 - \left(\frac{ExpectedBaudRate}{ActualBaudRate}\right)$$

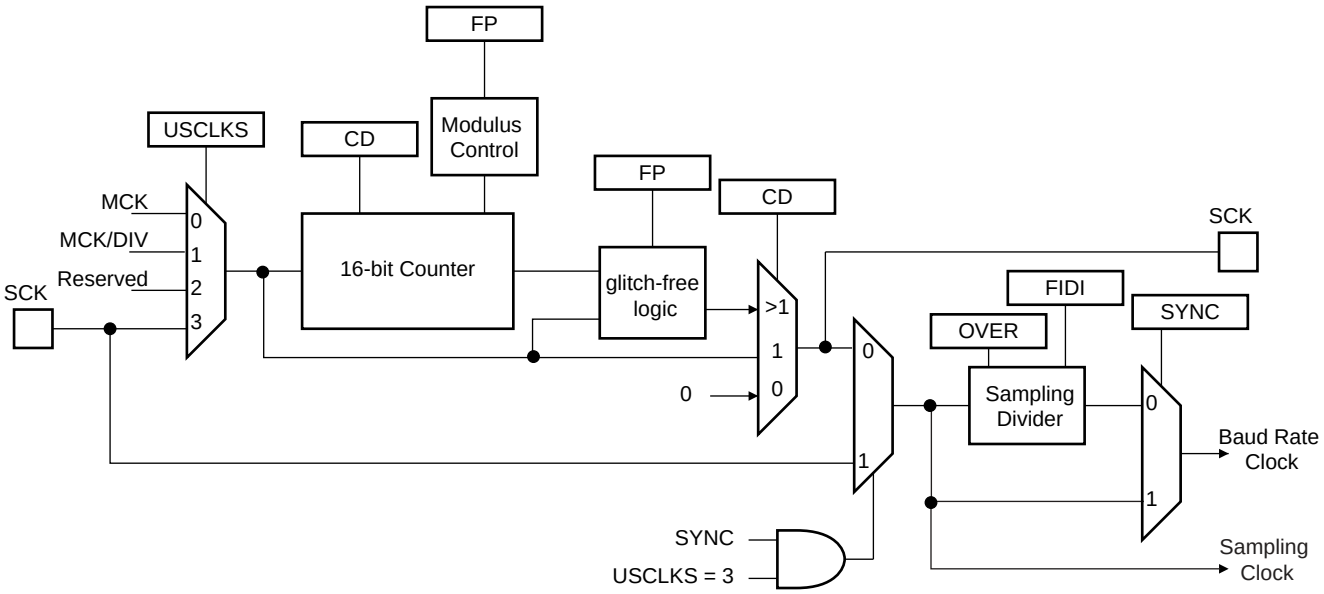
34.7.1.2 Fractional Baud Rate in Asynchronous Mode

The Baud Rate generator previously defined is subject to the following limitation: the output frequency changes by only integer multiples of the reference frequency. An approach to this problem is to integrate a fractional N clock generator that has a high resolution. The generator architecture is modified to obtain Baud Rate changes by a fraction of the reference source clock. This fractional part is programmed with the FP field in the Baud Rate Generator Register (US_BRGR). If FP is not 0, the fractional part is activated. The resolution is one eighth of the clock divider. This feature is only available when using USART normal mode. The fractional Baud Rate is calculated using the following formula:

$$Baudrate = \frac{SelectedClock}{\left(8(2-Over)\left(CD + \frac{FP}{8}\right)\right)}$$

The modified architecture is presented below:

Figure 34-4. Fractional Baud Rate Generator



34.7.1.3 Baud Rate in Synchronous Mode or SPI Mode

If the USART is programmed to operate in synchronous mode, the selected clock is simply divided by the field CD in US_BRGR.

$$BaudRate = \frac{SelectedClock}{CD}$$

In synchronous mode, if the external clock is selected (USCLKS = 3), the clock is provided directly by the signal on the USART SCK pin. No division is active. The value written in US_BRGR has no effect. The external clock frequency must be at least 3 times lower than the system clock. In synchronous mode master (USCLKS = 0 or 1, CLK0 set to 1), the receive part limits the SCK maximum frequency to MCK/3 in USART mode, or MCK/6 in SPI mode.

When either the external clock SCK or the internal clock divided (MCK/DIV) is selected, the value programmed in CD must be even if the user has to ensure a 50:50 mark/space ratio on the SCK pin. If the internal clock MCK is selected, the Baud Rate Generator ensures a 50:50 duty cycle on the SCK pin, even if the value programmed in CD is odd.

34.7.1.4 Baud Rate in ISO 7816 Mode

The ISO7816 specification defines the bit rate with the following formula:

$$B = \frac{Di}{Fi} \times f$$

where:

- B is the bit rate
- Di is the bit-rate adjustment factor
- Fi is the clock frequency division factor
- f is the ISO7816 clock frequency (Hz)

Di is a binary value encoded on a 4-bit field, named DI, as represented in Table 34-5.

Table 34-5. Binary and Decimal Values for Di

DI field	0001	0010	0011	0100	0101	0110	1000	1001
Di (decimal)	1	2	4	8	16	32	12	20

Fi is a binary value encoded on a 4-bit field, named FI, as represented in Table 34-6.

Table 34-6. Binary and Decimal Values for Fi

FI field	0000	0001	0010	0011	0100	0101	0110	1001	1010	1011	1100	1101
Fi (decimal)	372	372	558	744	1116	1488	1860	512	768	1024	1536	2048

Table 34-7 shows the resulting Fi/Di Ratio, which is the ratio between the ISO7816 clock and the baud rate clock.

Table 34-7. Possible Values for the Fi/Di Ratio

Fi/Di	372	558	774	1116	1488	1806	512	768	1024	1536	2048
1	372	558	744	1116	1488	1860	512	768	1024	1536	2048
2	186	279	372	558	744	930	256	384	512	768	1024
4	93	139.5	186	279	372	465	128	192	256	384	512
8	46.5	69.75	93	139.5	186	232.5	64	96	128	192	256
16	23.25	34.87	46.5	69.75	93	116.2	32	48	64	96	128
32	11.62	17.43	23.25	34.87	46.5	58.13	16	24	32	48	64
12	31	46.5	62	93	124	155	42.66	64	85.33	128	170.6
20	18.6	27.9	37.2	55.8	74.4	93	25.6	38.4	51.2	76.8	102.4

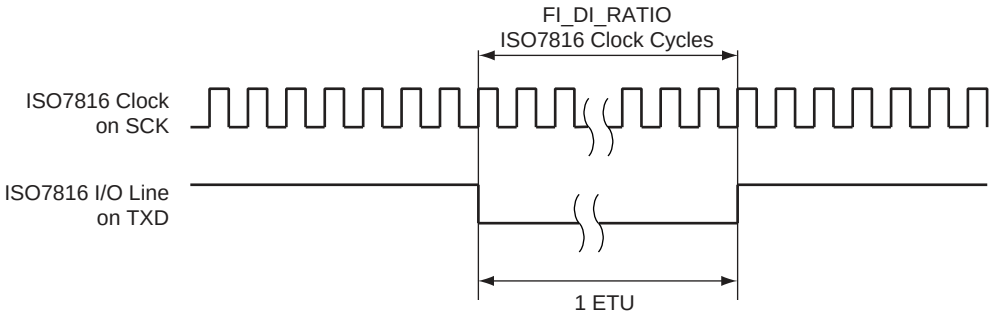
If the USART is configured in ISO7816 Mode, the clock selected by the USCLKS field in the Mode Register (US_MR) is first divided by the value programmed in the field CD in the Baud Rate Generator Register (US_BRGR). The resulting clock can be provided to the SCK pin to feed the smart card clock inputs. This means that the CLKO bit can be set in US_MR.

This clock is then divided by the value programmed in the FI_DI_RATIO field in the FI_DI_Ratio register (US_FIDI). This is performed by the Sampling Divider, which performs a division by up to 2047 in ISO7816 Mode. The non-integer values of the Fi/Di Ratio are not supported and the user must program the FI_DI_RATIO field to a value as close as possible to the expected value.

The FI_DI_RATIO field resets to the value 0x174 (372 in decimal) and is the most common divider between the ISO7816 clock and the bit rate (Fi = 372, Di = 1).

Figure 34-5 shows the relation between the Elementary Time Unit, corresponding to a bit time, and the ISO 7816 clock.

Figure 34-5. Elementary Time Unit (ETU)



34.7.2 Receiver and Transmitter Control

After reset, the receiver is disabled. The user must enable the receiver by setting the RXEN bit in the Control Register (US_CR). However, the receiver registers can be programmed before the receiver clock is enabled.

After reset, the transmitter is disabled. The user must enable it by setting the TXEN bit in the Control Register (US_CR). However, the transmitter registers can be programmed before being enabled.

The Receiver and the Transmitter can be enabled together or independently.

At any time, the software can perform a reset on the receiver or the transmitter of the USART by setting the corresponding bit, RSTRX and RSTTX respectively, in the Control Register (US_CR). The software resets clear the status flag and reset internal state machines but the user interface configuration registers hold the value configured prior to software reset. Regardless of what the receiver or the transmitter is performing, the communication is immediately stopped.

The user can also independently disable the receiver or the transmitter by setting RXDIS and TXDIS respectively in US_CR. If the receiver is disabled during a character reception, the USART waits until the end of reception of the current character, then the reception is stopped. If the transmitter is disabled while it is operating, the USART waits the end of transmission of both the current character and character being stored in the Transmit Holding Register (US_THR). If a timeguard is programmed, it is handled normally.

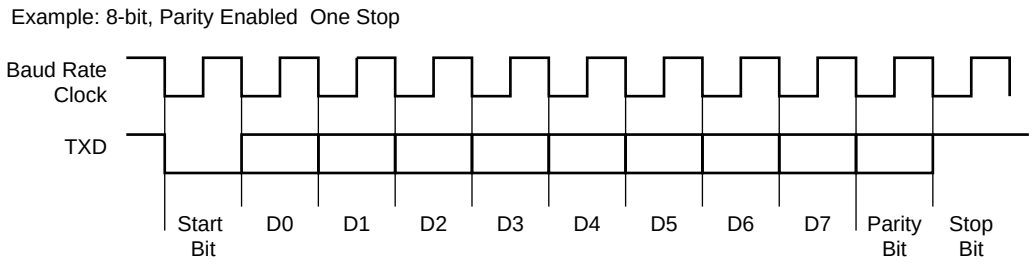
34.7.3 Synchronous and Asynchronous Modes

34.7.3.1 Transmitter Operations

The transmitter performs the same in both synchronous and asynchronous operating modes (SYNC = 0 or SYNC = 1). One start bit, up to 9 data bits, one optional parity bit and up to two stop bits are successively shifted out on the TXD pin at each falling edge of the programmed serial clock.

The number of data bits is selected by the CHRL field and the MODE 9 bit in the Mode Register (US_MR). Nine bits are selected by setting the MODE 9 bit regardless of the CHRL field. The parity bit is set according to the PAR field in US_MR. The even, odd, space, marked or none parity bit can be configured. The MSBF field in US_MR configures which data bit is sent first. If written to 1, the most significant bit is sent first. If written to 0, the less significant bit is sent first. The number of stop bits is selected by the NBSTOP field in US_MR. The 1.5 stop bit is supported in asynchronous mode only.

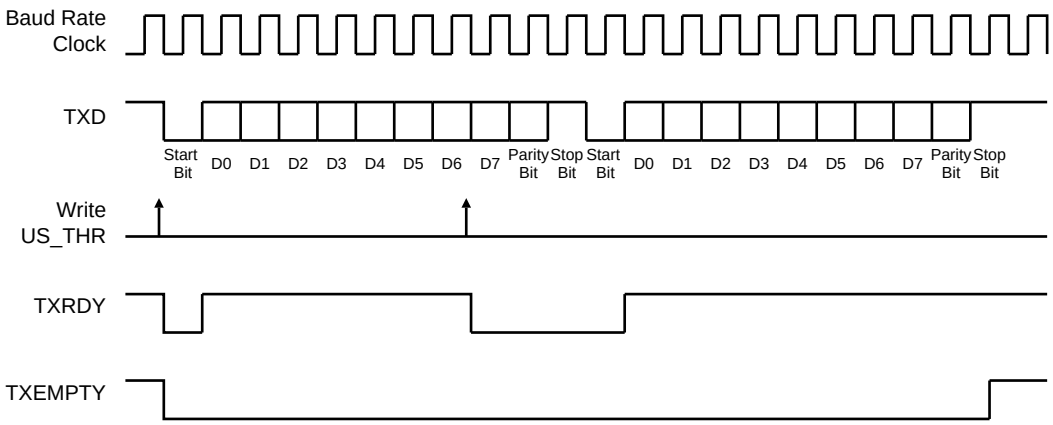
Figure 34-6. Character Transmit



The characters are sent by writing in the Transmit Holding Register (US_THR). The transmitter reports two status bits in the Channel Status Register (US_CSR): TXRDY (Transmitter Ready), which indicates that US_THR is empty and TXEMPTY, which indicates that all the characters written in US_THR have been processed. When the current character processing is completed, the last character written in US_THR is transferred into the Shift Register of the transmitter and US_THR becomes empty, thus TXRDY rises.

Both TXRDY and TXEMPTY bits are low when the transmitter is disabled. Writing a character in US_THR while TXRDY is low has no effect and the written character is lost.

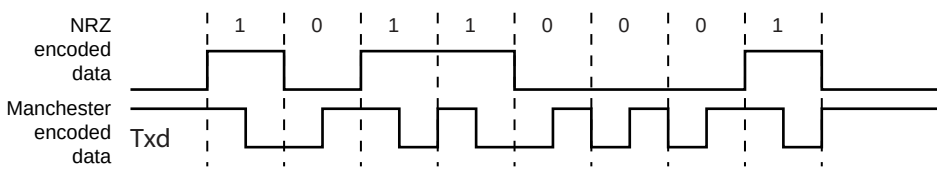
Figure 34-7. Transmitter Status



34.7.3.2 Manchester Encoder

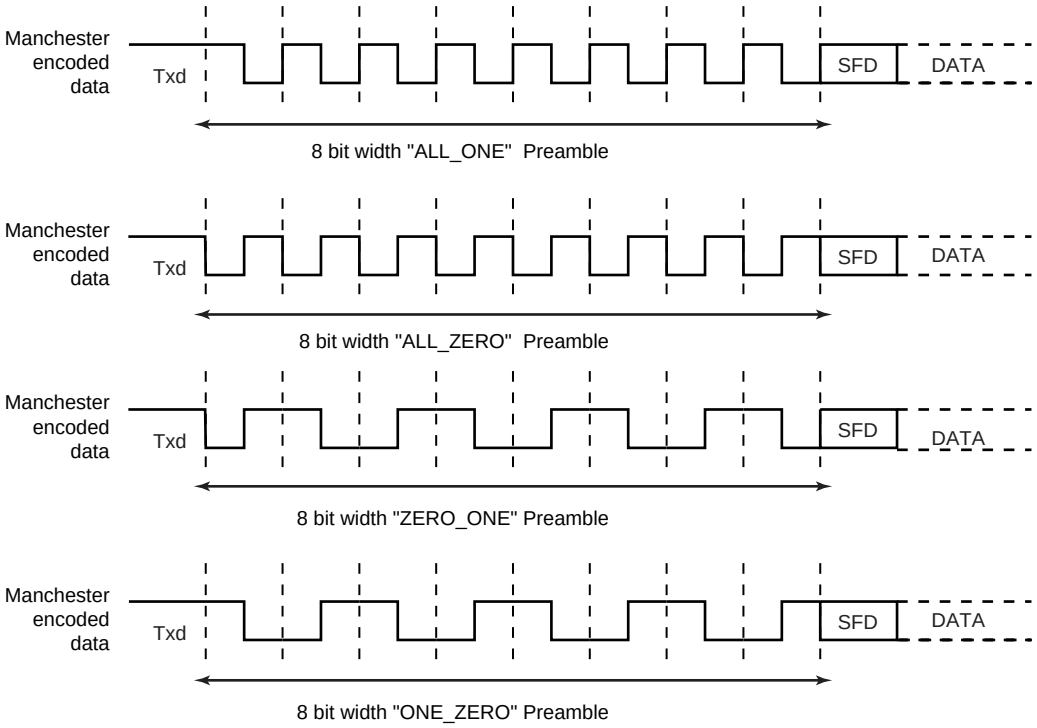
When the Manchester encoder is in use, characters transmitted through the USART are encoded based on biphase Manchester II format. To enable this mode, set the MAN field in the US_MR register to 1. Depending on polarity configuration, a logic level (zero or one), is transmitted as a coded signal one-to-zero or zero-to-one. Thus, a transition always occurs at the midpoint of each bit time. It consumes more bandwidth than the original NRZ signal (2x) but the receiver has more error control since the expected input must show a change at the center of a bit cell. An example of Manchester encoded sequence is: the byte 0xB1 or 10110001 encodes to 10 01 10 10 01 01 01 10, assuming the default polarity of the encoder. Figure 34-8 illustrates this coding scheme.

Figure 34-8. NRZ to Manchester Encoding



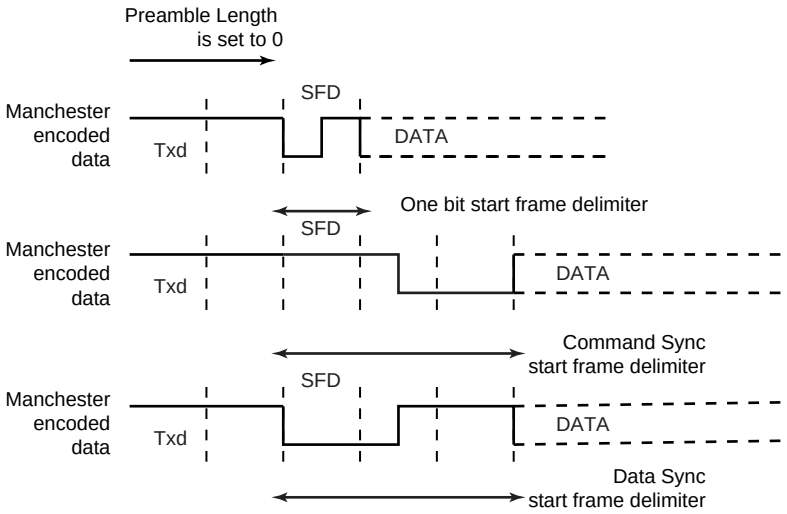
The Manchester encoded character can also be encapsulated by adding both a configurable preamble and a start frame delimiter pattern. Depending on the configuration, the preamble is a training sequence, composed of a pre-defined pattern with a programmable length from 1 to 15 bit times. If the preamble length is set to 0, the preamble waveform is not generated prior to any character. The preamble pattern is chosen among the following sequences: ALL_ONE, ALL_ZERO, ONE_ZERO or ZERO_ONE, writing the field TX_PP in the US_MAN register, the field TX_PL is used to configure the preamble length. Figure 34-9 illustrates and defines the valid patterns. To improve flexibility, the encoding scheme can be configured using the TX_MPOL field in the US_MAN register. If the TX_MPOL field is set to zero (default), a logic zero is encoded with a zero-to-one transition and a logic one is encoded with a one-to-zero transition. If the TX_MPOL field is set to one, a logic one is encoded with a one-to-zero transition and a logic zero is encoded with a zero-to-one transition.

Figure 34-9. Preamble Patterns, Default Polarity Assumed



A start frame delimiter is to be configured using the ONEBIT field in the US_MR register. It consists of a user-defined pattern that indicates the beginning of a valid data. Figure 34-10 illustrates these patterns. If the start frame delimiter, also known as start bit, is one bit, (ONEBIT to 1), a logic zero is Manchester encoded and indicates that a new character is being sent serially on the line. If the start frame delimiter is a synchronization pattern also referred to as sync (ONEBIT to 0), a sequence of 3 bit times is sent serially on the line to indicate the start of a new character. The sync waveform is in itself an invalid Manchester waveform as the transition occurs at the middle of the second bit time. Two distinct sync patterns are used: the command sync and the data sync. The command sync has a logic one level for one and a half bit times, then a transition to logic zero for the second one and a half bit times. If the MODSYNC field in the US_MR register is set to 1, the next character is a command. If it is set to 0, the next character is a data. When direct memory access is used, the MODSYNC field can be immediately updated with a modified character located in memory. To enable this mode, VAR_SYNC field in US_MR register must be set to 1. In this case, the MODSYNC field in US_MR is bypassed and the sync configuration is held in the TXSYNH in the US_THR register. The USART character format is modified and includes sync information.

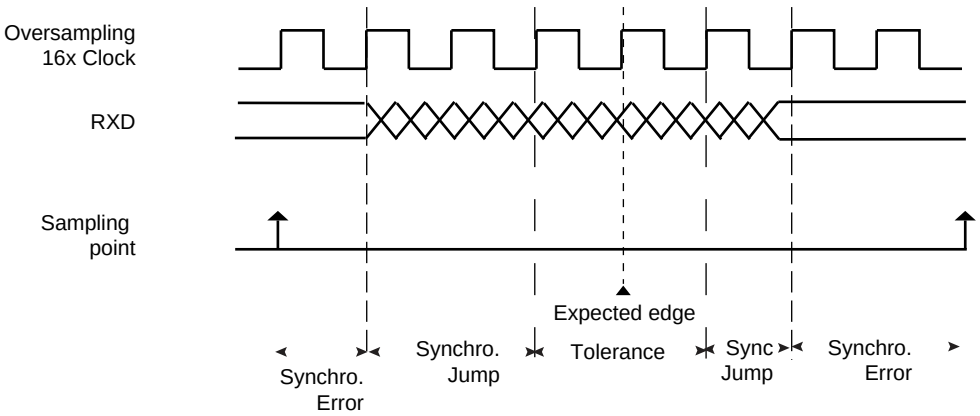
Figure 34-10. Start Frame Delimiter



Drift Compensation

Drift compensation is available only in 16X oversampling mode. An hardware recovery system allows a larger clock drift. To enable the hardware system, the bit in the USART_MAN register must be set. If the RXD edge is one 16X clock cycle from the expected edge, this is considered as normal jitter and no corrective actions is taken. If the RXD event is between 4 and 2 clock cycles before the expected edge, then the current period is shortened by one clock cycle. If the RXD event is between 2 and 3 clock cycles after the expected edge, then the current period is lengthened by one clock cycle. These intervals are considered to be drift and so corrective actions are automatically taken.

Figure 34-11. Bit Resynchronization



34.7.3.3 Asynchronous Receiver

If the USART is programmed in asynchronous operating mode (SYNC = 0), the receiver oversamples the RXD input line. The oversampling is either 16 or 8 times the Baud Rate clock, depending on the OVER bit in the Mode Register (US_MR).

The receiver samples the RXD line. If the line is sampled during one half of a bit time to 0, a start bit is detected and data, parity and stop bits are successively sampled on the bit rate clock.

If the oversampling is 16, (OVER to 0), a start is detected at the eighth sample to 0. Then, data bits, parity bit and stop bit are sampled on each 16 sampling clock cycle. If the oversampling is 8 (OVER to 1), a start bit is detected at the fourth sample to 0. Then, data bits, parity bit and stop bit are sampled on each 8 sampling clock cycle.

The number of data bits, first bit sent and parity mode are selected by the same fields and bits as the transmitter, i.e. respectively CHRL, MODE9, MSBF and PAR. For the synchronization mechanism **only**, the number of stop bits has no effect on the receiver as it considers only one stop bit, regardless of the field NBSTOP, so that resynchronization between the receiver and the transmitter can occur. Moreover, as soon as the stop bit is sampled, the receiver starts looking for a new start bit so that resynchronization can also be accomplished when the transmitter is operating with one stop bit.

Figure 34-12 and Figure 34-13 illustrate start detection and character reception when USART operates in asynchronous mode.

Figure 34-12. Asynchronous Start Detection

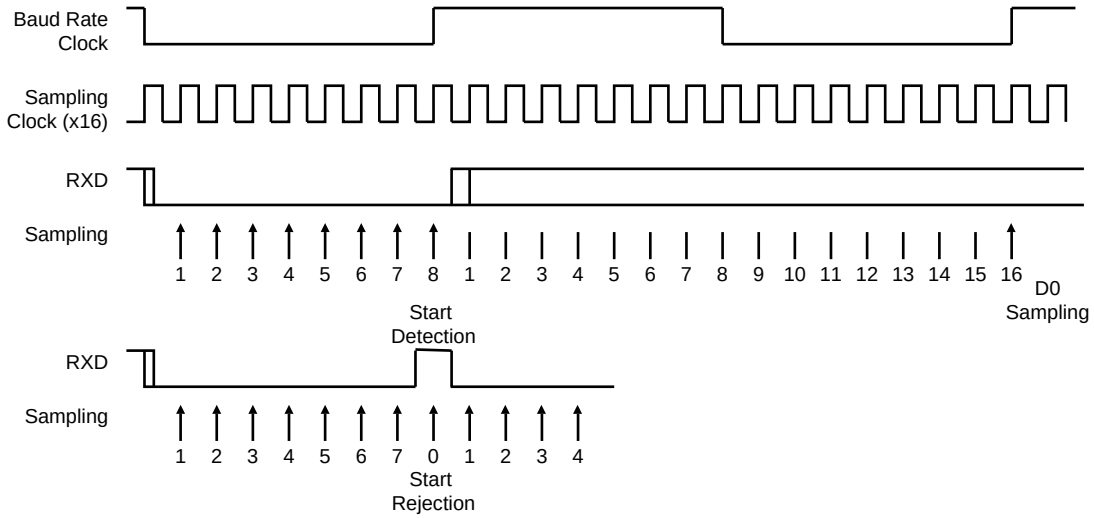
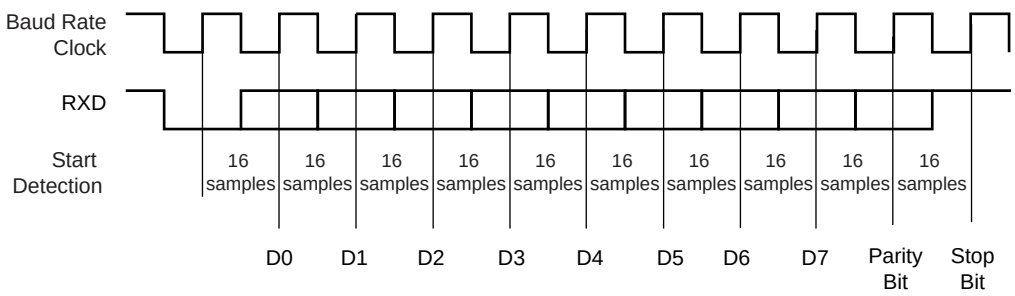


Figure 34-13. Asynchronous Character Reception

Example: 8-bit, Parity Enabled



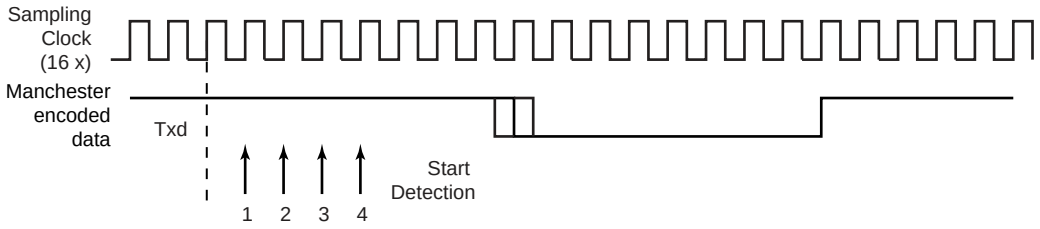
34.7.3.4 Manchester Decoder

When the MAN field in US_MR register is set to 1, the Manchester decoder is enabled. The decoder performs both preamble and start frame delimiter detection. One input line is dedicated to Manchester encoded input data.

An optional preamble sequence can be defined, its length is user-defined and totally independent of the emitter side. Use RX_PL in US_MAN register to configure the length of the preamble sequence. If the length is set to 0, no preamble is detected and the function is disabled. In addition, the polarity of the input stream is programmable with RX_MPOL field in US_MAN register. Depending on the desired application the preamble pattern matching is to be defined via the RX_PP field in US_MAN. See Figure 34-9 for available preamble patterns.

Unlike preamble, the start frame delimiter is shared between Manchester Encoder and Decoder. So, if ONEBIT field is set to 1, only a zero encoded Manchester can be detected as a valid start frame delimiter. If ONEBIT is set to 0, only a sync pattern is detected as a valid start frame delimiter. Decoder operates by detecting transition on incoming stream. If RXD is sampled during one quarter of a bit time to zero, a start bit is detected. See Figure 34-14. The sample pulse rejection mechanism applies.

Figure 34-14. Asynchronous Start Bit Detection



The receiver is activated and starts Preamble and Frame Delimiter detection, sampling the data at one quarter and then three quarters. If a valid preamble pattern or start frame delimiter is detected, the receiver continues decoding with the same synchronization. If the stream does not match a valid pattern or a valid start frame delimiter, the receiver re-synchronizes on the next valid edge.The minimum time threshold to estimate the bit value is three quarters of a bit time.

If a valid preamble (if used) followed with a valid start frame delimiter is detected, the incoming stream is decoded into NRZ data and passed to USART for processing. Figure 34-15 illustrates Manchester pattern mismatch. When incoming data stream is passed to the USART, the receiver is also able to detect Manchester code violation. A code violation is a lack of transition in the middle of a bit cell. In this case, MANE flag in US_CSR register is raised. It is cleared by writing the Control Register (US_CR) with the RSTSTA bit to 1. See Figure 34-16 for an example of Manchester error detection during data phase.

Figure 34-15. Preamble Pattern Mismatch

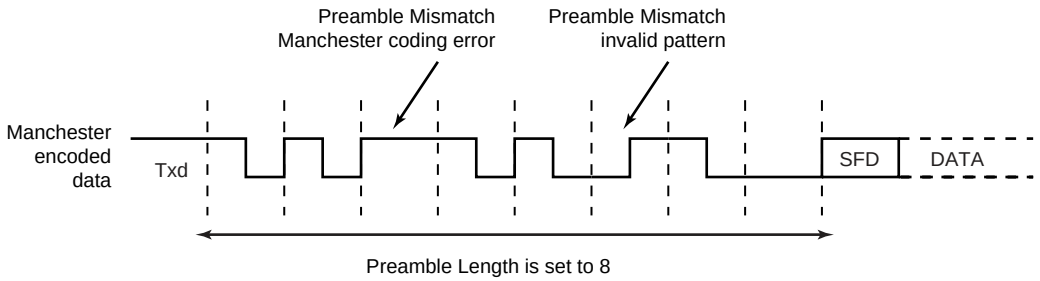
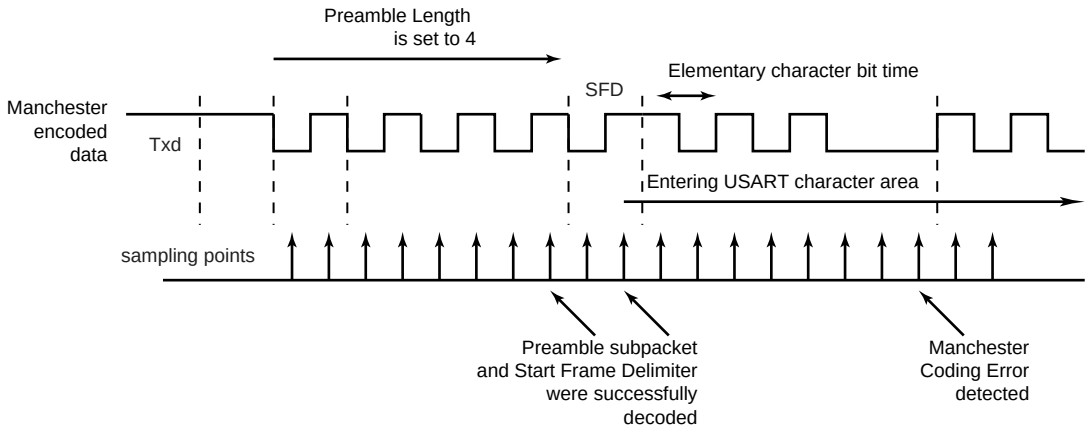


Figure 34-16. Manchester Error Flag



When the start frame delimiter is a sync pattern (ONEBIT field to 0), both command and data delimiter are supported. If a valid sync is detected, the received character is written as RXCHR field in the US_RHR register and the RXSYNH is updated. RXCHR is set to 1 when the received character is a command, and it is set to 0 if the received character is a data. This mechanism alleviates and simplifies the direct memory access as the character contains its own sync field in the same register.

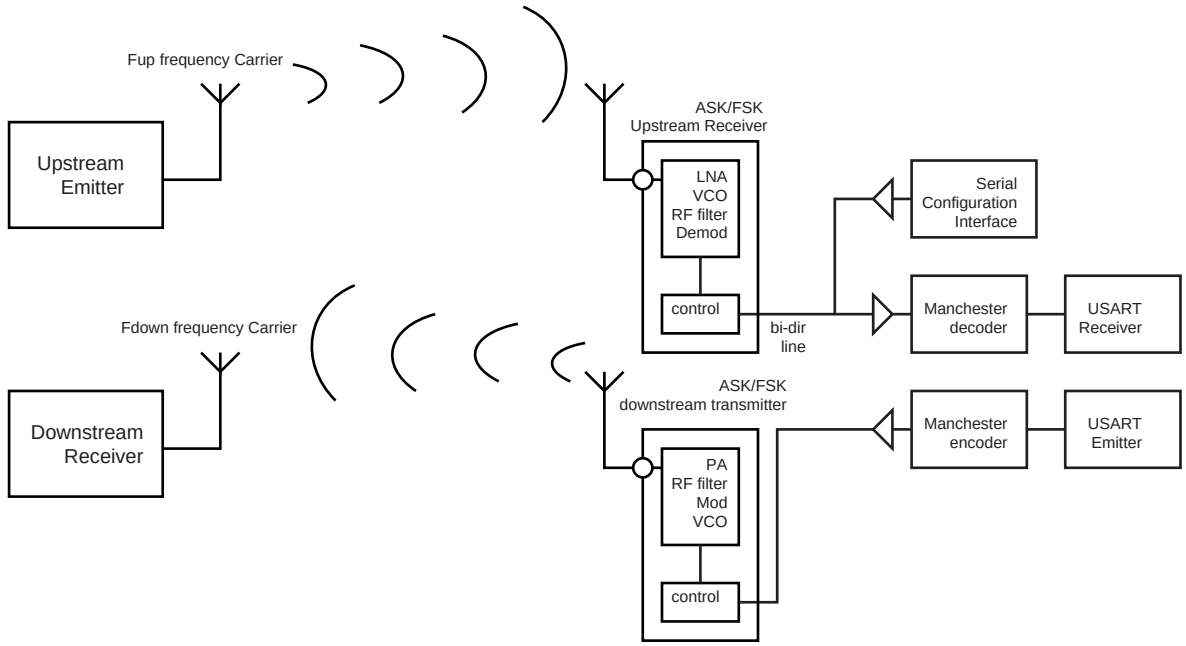
As the decoder is setup to be used in unipolar mode, the first bit of the frame has to be a zero-to-one transition.

34.7.3.5 Radio Interface: Manchester Encoded USART Application

This section describes low data rate RF transmission systems and their integration with a Manchester encoded USART. These systems are based on transmitter and receiver ICs that support ASK and FSK modulation schemes.

The goal is to perform full duplex radio transmission of characters using two different frequency carriers. See the configuration in Figure 34-17.

Figure 34-17. Manchester Encoded Characters RF Transmission



The USART module is configured as a Manchester encoder/decoder. Looking at the downstream communication channel, Manchester encoded characters are serially sent to the RF emitter. This may also include a user defined preamble and a start frame delimiter. Mostly, preamble is used in the RF receiver to distinguish between a valid data from a transmitter and signals due to noise. The Manchester stream is then modulated. See Figure 34-18 for an example of ASK modulation scheme. When a logic one is sent to the ASK modulator, the power amplifier, referred to as PA, is enabled and transmits an RF signal at downstream frequency. When a logic zero is transmitted, the RF signal is turned off. If the FSK modulator is activated, two different frequencies are used to transmit data. When a logic 1 is sent, the modulator outputs an RF signal at frequency F0 and switches to F1 if the data sent is a 0. See Figure 34-19.

From the receiver side, another carrier frequency is used. The RF receiver performs a bit check operation examining demodulated data stream. If a valid pattern is detected, the receiver switches to receiving mode. The demodulated stream is sent to the Manchester decoder. Because of bit checking inside RF IC, the data transferred to the microcontroller is reduced by a user-defined number of bits. The Manchester preamble length is to be defined in accordance with the RF IC configuration.

Figure 34-18. ASK Modulator Output

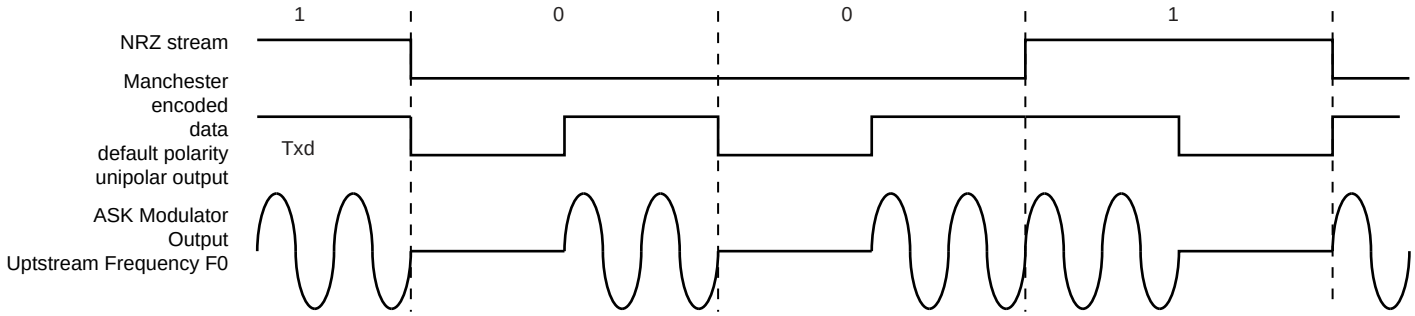
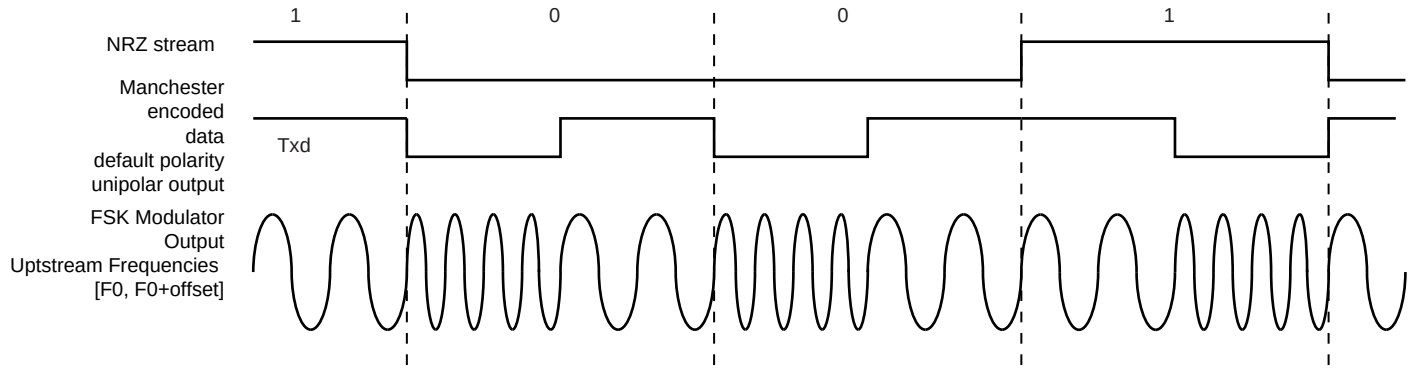


Figure 34-19. FSK Modulator Output



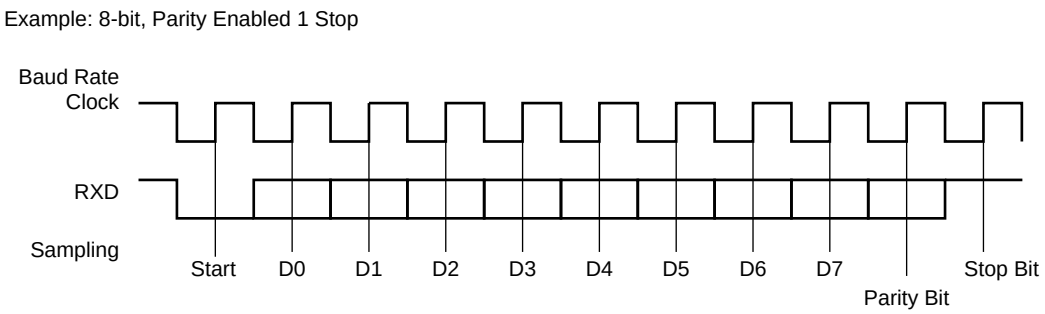
34.7.3.6 Synchronous Receiver

In synchronous mode (SYNC = 1), the receiver samples the RXD signal on each rising edge of the Baud Rate Clock. If a low level is detected, it is considered as a start. All data bits, the parity bit and the stop bits are sampled and the receiver waits for the next start bit. Synchronous mode operations provide a high speed transfer capability.

Configuration fields and bits are the same as in asynchronous mode.

Figure 34-20 illustrates a character reception in synchronous mode.

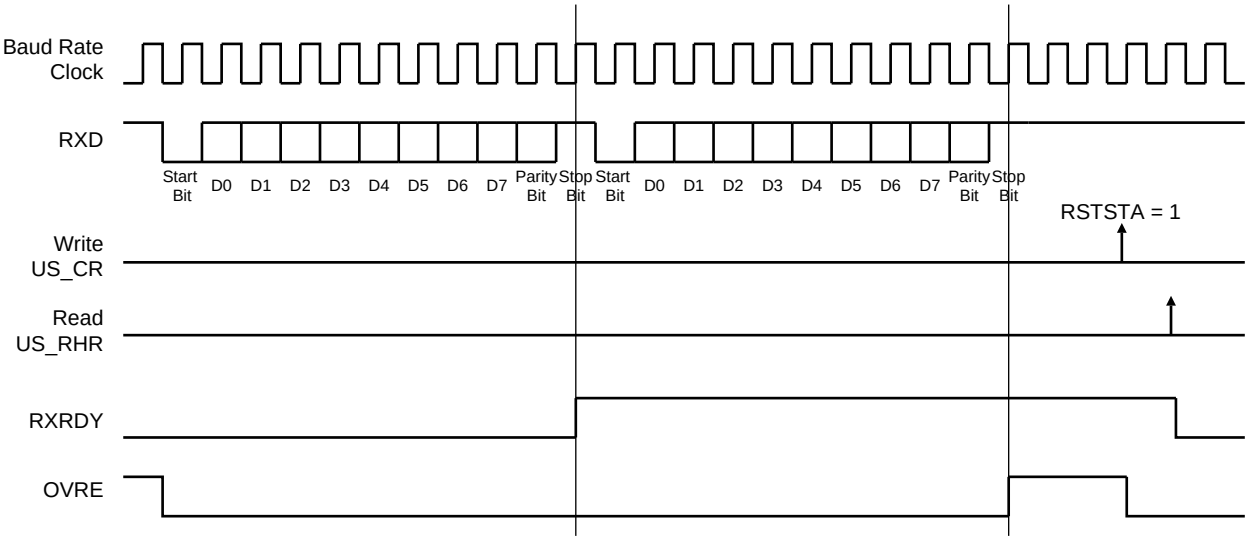
Figure 34-20. Synchronous Mode Character Reception



34.7.3.7 Receiver Operations

When a character reception is completed, it is transferred to the Receive Holding Register (US_RHR) and the RXRDY bit in the Status Register (US_CSR) rises. If a character is completed while the RXRDY is set, the OVRE (Overrun Error) bit is set. The last character is transferred into US_RHR and overwrites the previous one. The OVRE bit is cleared by writing the Control Register (US_CR) with the RSTSTA (Reset Status) bit to 1.

Figure 34-21. Receiver Status



34.7.3.8 Parity

The USART supports five parity modes selected by programming the PAR field in the Mode Register (US_MR). The PAR field also enables the Multidrop mode, see “Multidrop Mode” on page 705. Even and odd parity bit generation and error detection are supported.

If even parity is selected, the parity generator of the transmitter drives the parity bit to 0 if a number of 1s in the character data bit is even, and to 1 if the number of 1s is odd. Accordingly, the receiver parity checker counts the number of received 1s and reports a parity error if the sampled parity bit does not correspond. If odd parity is selected, the parity generator of the transmitter drives the parity bit to 1 if a number of 1s in the character data bit is even, and to 0 if the number of 1s is odd. Accordingly, the receiver parity checker counts the number of received 1s and reports a parity error if the sampled parity bit does not correspond. If the mark parity is used, the parity generator of the transmitter drives the parity bit to 1 for all characters. The receiver parity checker reports an error if the parity bit is sampled to 0. If the space parity is used, the parity generator of the transmitter drives the parity bit to 0 for all characters. The receiver parity checker reports an error if the parity bit is sampled to 1. If parity is disabled, the transmitter does not generate any parity bit and the receiver does not report any parity error.

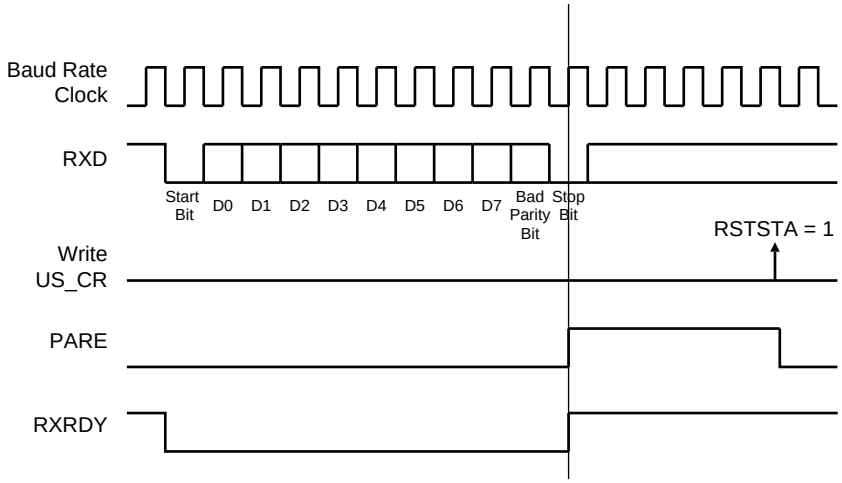
Table 34-8 shows an example of the parity bit for the character 0x41 (character ASCII “A”) depending on the configuration of the USART. Because there are two bits to 1, 1 bit is added when a parity is odd, or 0 is added when a parity is even.

Table 34-8. Parity Bit Examples

Character	Hexa	Binary	Parity Bit	Parity Mode
A	0x41	0100 0001	1	Odd
A	0x41	0100 0001	0	Even
A	0x41	0100 0001	1	Mark
A	0x41	0100 0001	0	Space
A	0x41	0100 0001	None	None

When the receiver detects a parity error, it sets the PARE (Parity Error) bit in the Channel Status Register (US_CSR). The PARE bit can be cleared by writing the Control Register (US_CR) with the RSTSTA bit to 1. Figure 34-22 illustrates the parity bit status setting and clearing.

Figure 34-22. Parity Error



34.7.3.9 Multidrop Mode

If the PAR field in the Mode Register (US_MR) is programmed to the value 0x6 or 0x07, the USART runs in Multidrop Mode. This mode differentiates the data characters and the address characters. Data is transmitted with the parity bit to 0 and addresses are transmitted with the parity bit to 1.

If the USART is configured in multidrop mode, the receiver sets the PARE parity error bit when the parity bit is high and the transmitter is able to send a character with the parity bit high when the Control Register is written with the SENDA bit to 1.

To handle parity error, the PARE bit is cleared when the Control Register is written with the bit RSTSTA to 1.

The transmitter sends an address byte (parity bit set) when SENDA is written to US_CR. In this case, the next byte written to US_THR is transmitted as an address. Any character written in US_THR without having written the command SENDA is transmitted normally with the parity to 0.

34.7.3.10 Transmitter Timeguard

The timeguard feature enables the USART interface with slow remote devices.

The timeguard function enables the transmitter to insert an idle state on the TXD line between two characters. This idle state actually acts as a long stop bit.

The duration of the idle state is programmed in the TG field of the Transmitter Timeguard Register (US_TTGR). When this field is programmed to zero no timeguard is generated. Otherwise, the transmitter holds a high level on TXD after each transmitted byte during the number of bit periods programmed in TG in addition to the number of stop bits.

As illustrated in Figure 34-23, the behavior of TXRDY and TXEMPTY status bits is modified by the programming of a timeguard. TXRDY rises only when the start bit of the next character is sent, and thus remains to 0 during the timeguard transmission if a character has been written in US_THR. TXEMPTY remains low until the timeguard transmission is completed as the timeguard is part of the current character being transmitted.

Figure 34-23. Timeguard Operations

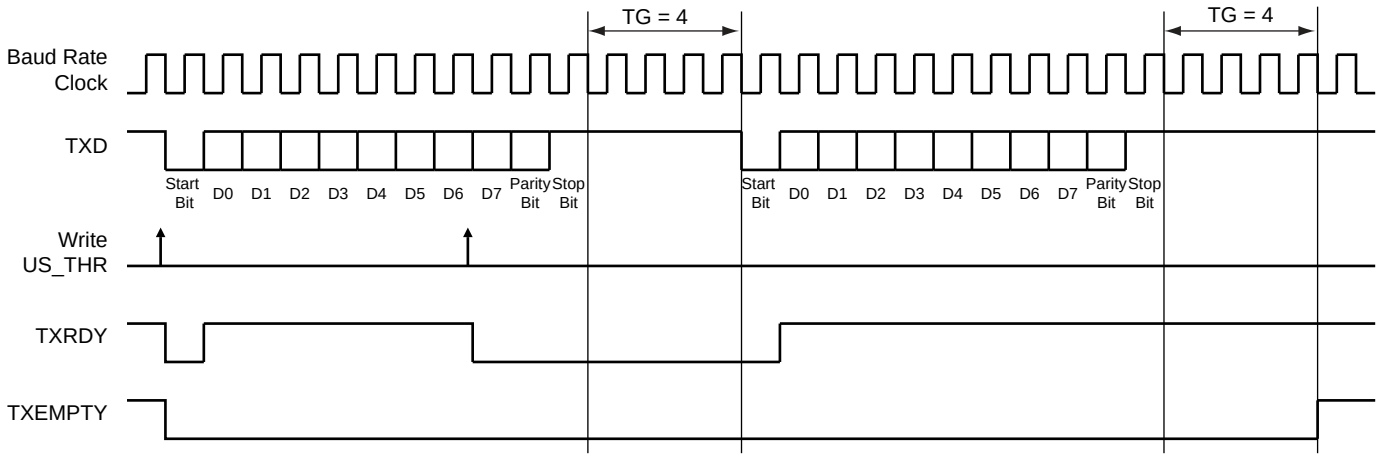


Table 34-9 indicates the maximum length of a timeguard period that the transmitter can handle in relation to the function of the Baud Rate.

Table 34-9. Maximum Timeguard Length Depending on Baud Rate

Baud Rate	Bit time	Timeguard
Bit/sec	µs	ms
1 200	833	212.50
9 600	104	26.56
14400	69.4	17.71
19200	52.1	13.28
28800	34.7	8.85
33400	29.9	7.63
56000	17.9	4.55
57600	17.4	4.43
115200	8.7	2.21

34.7.3.11 Receiver Time-out

The Receiver Time-out provides support in handling variable-length frames. This feature detects an idle condition on the RXD line. When a time-out is detected, the bit TIMEOUT in the Channel Status Register (US_CSR) rises and can generate an interrupt, thus indicating to the driver an end of frame.

The time-out delay period (during which the receiver waits for a new character) is programmed in the TO field of the Receiver Time-out Register (US_RTOR). If the TO field is programmed to 0, the Receiver Time-out is disabled and no time-out is detected. The TIMEOUT bit in US_CSR remains to 0. Otherwise, the receiver loads a 16-bit counter with the value programmed in TO. This counter is decremented at each bit period and reloaded each time a new character is received. If the counter reaches 0, the TIMEOUT bit in the Status Register rises. Then, the user can either:

- Stop the counter clock until a new character is received. This is performed by writing the Control Register (US_CR) with the STTTO (Start Time-out) bit to 1. In this case, the idle state on RXD before a new character is received will not provide a time-out. This prevents having to handle an interrupt before a character is received and allows waiting for the next idle state on RXD after a frame is received.
- Obtain an interrupt while no character is received. This is performed by writing US_CR with the RETTO (Reload and Start Time-out) bit to 1. If RETTO is performed, the counter starts counting down immediately from the value TO. This enables generation of a periodic interrupt so that a user time-out can be handled, for example when no key is pressed on a keyboard.

If STTTO is performed, the counter clock is stopped until a first character is received. The idle state on RXD before the start of the frame does not provide a time-out. This prevents having to obtain a periodic interrupt and enables a wait of the end of frame when the idle state on RXD is detected.

If RETTO is performed, the counter starts counting down immediately from the value TO. This enables generation of a periodic interrupt so that a user time-out can be handled, for example when no key is pressed on a keyboard.

Figure 34-24 shows the block diagram of the Receiver Time-out feature.

Figure 34-24. Receiver Time-out Block Diagram

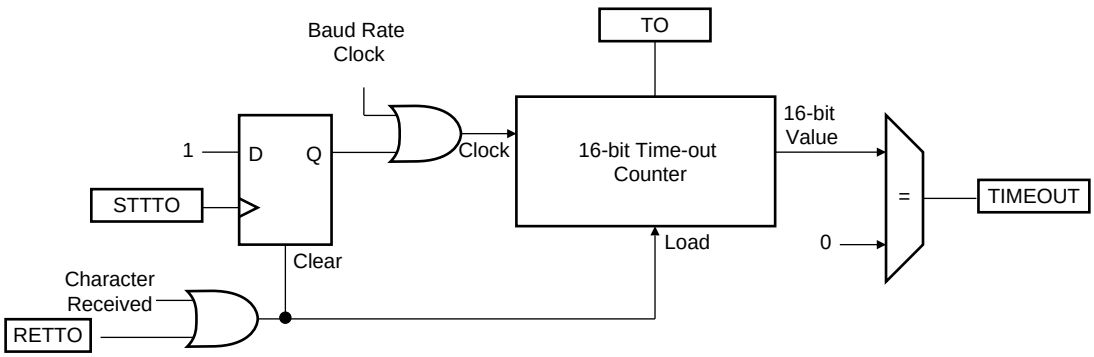


Table 34-10 gives the maximum time-out period for some standard baud rates.

Table 34-10. Maximum Time-out Period

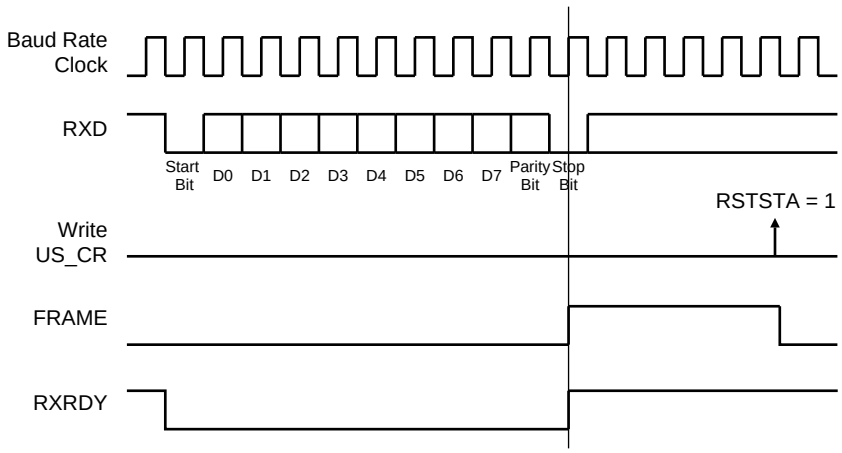
Baud Rate	Bit Time	Time-out
bit/sec	µs	ms
600	1 667	109 225
1 200	833	54 613
2 400	417	27 306
4 800	208	13 653
9 600	104	6 827
14400	69	4 551
19200	52	3 413
28800	35	2 276
33400	30	1 962
56000	18	1 170
57600	17	1 138
200000	5	328

34.7.3.12 Framing Error

The receiver is capable of detecting framing errors. A framing error happens when the stop bit of a received character is detected at level 0. This can occur if the receiver and the transmitter are fully desynchronized.

A framing error is reported on the FRAME bit of the Channel Status Register (US_CSR). The FRAME bit is asserted in the middle of the stop bit as soon as the framing error is detected. It is cleared by writing the Control Register (US_CR) with the RSTSTA bit to 1.

Figure 34-25. Framing Error Status



34.7.3.13 Transmit Break

The user can request the transmitter to generate a break condition on the TXD line. A break condition drives the TXD line low during at least one complete character. It appears the same as a 0x00 character sent with the parity and the stop bits to 0. However, the transmitter holds the TXD line at least during one character until the user requests the break condition to be removed.

A break is transmitted by writing the Control Register (US_CR) with the STTBRK bit to 1. This can be performed at any time, either while the transmitter is empty (no character in either the Shift Register or in US_THR) or when a character is being transmitted. If a break is requested while a character is being shifted out, the character is first completed before the TXD line is held low.

Once STTBRK command is requested further STTBRK commands are ignored until the end of the break is completed.

The break condition is removed by writing US_CR with the STPBRK bit to 1. If the STPBRK is requested before the end of the minimum break duration (one character, including start, data, parity and stop bits), the transmitter ensures that the break condition completes.

The transmitter considers the break as though it is a character, i.e. the STTBRK and STPBRK commands are taken into account only if the TXRDY bit in US_CSR is to 1 and the start of the break condition clears the TXRDY and TXEMPTY bits as if a character is processed.

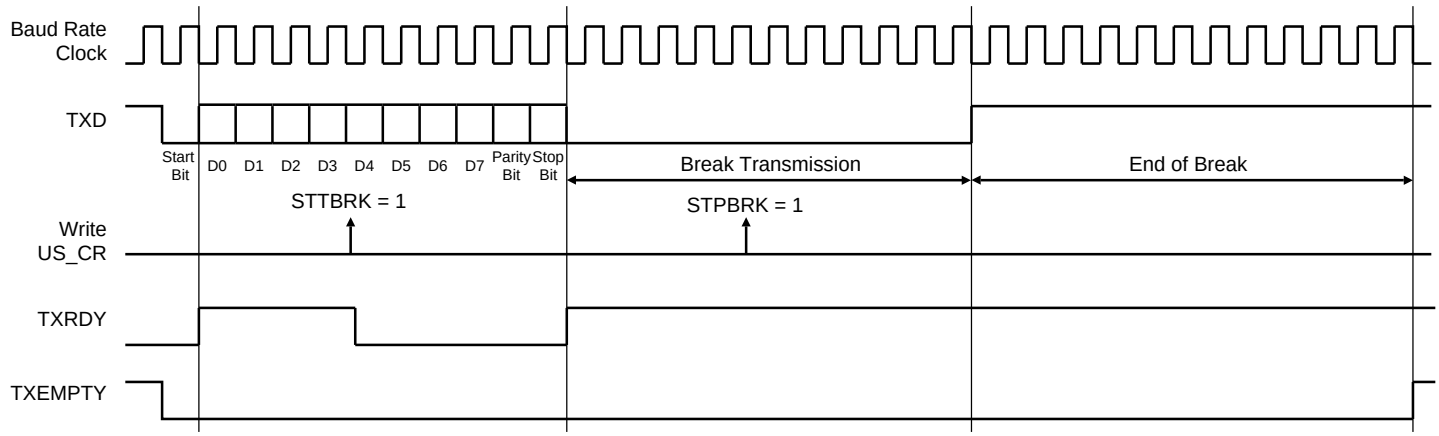
Writing US_CR with both STTBRK and STPBRK bits to 1 can lead to an unpredictable result. All STPBRK commands requested without a previous STTBRK command are ignored. A byte written into the Transmit Holding Register while a break is pending, but not started, is ignored.

After the break condition, the transmitter returns the TXD line to 1 for a minimum of 12 bit times. Thus, the transmitter ensures that the remote receiver detects correctly the end of break and the start of the next character. If the timeguard is programmed with a value higher than 12, the TXD line is held high for the timeguard period.

After holding the TXD line for this period, the transmitter resumes normal operations.

Figure 34-26 illustrates the effect of both the Start Break (STTBRK) and Stop Break (STPBRK) commands on the TXD line.

Figure 34-26. Break Transmission



34.7.3.14 Receive Break

The receiver detects a break condition when all data, parity and stop bits are low. This corresponds to detecting a framing error with data to 0x00, but FRAME remains low.

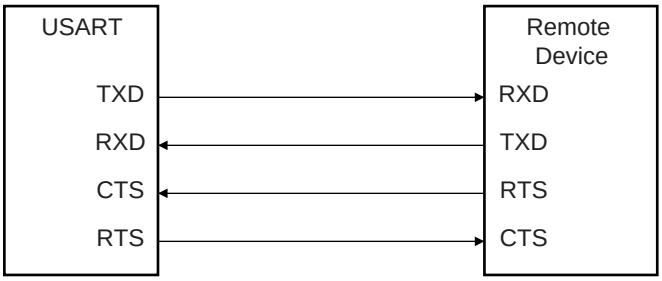
When the low stop bit is detected, the receiver asserts the RXBRK bit in US_CSR. This bit may be cleared by writing the Control Register (US_CR) with the bit RSTSTA to 1.

An end of receive break is detected by a high level for at least 2/16 of a bit period in asynchronous operating mode or one sample at high level in synchronous operating mode. The end of break detection also asserts the RXBRK bit.

34.7.3.15 Hardware Handshaking

The USART features a hardware handshaking out-of-band flow control. The RTS and CTS pins are used to connect with the remote device, as shown in Figure 34-27.

Figure 34-27. Connection with a Remote Device for Hardware Handshaking



Setting the USART to operate with hardware handshaking is performed by writing the USART_MODE field in the Mode Register (US_MR) to the value 0x2.

The USART behavior when hardware handshaking is enabled is the same as the behavior in standard synchronous or asynchronous mode, except that the receiver drives the RTS pin as described below and the level on the CTS pin modifies the behavior of the transmitter as described below. Using this mode requires using the PDC channel for reception. The transmitter can handle hardware handshaking in any case.

Figure 34-28 shows how the receiver operates if hardware handshaking is enabled. The RTS pin is driven high if the receiver is disabled and if the status RXBUFF (Receive Buffer Full) coming from the PDC channel is high. Normally, the remote device does not start transmitting while its CTS pin (driven by RTS) is high. As soon as the Receiver is enabled, the RTS falls, indicating to the remote device that it can start transmitting. Defining a new buffer to the PDC clears the status bit RXBUFF and, as a result, asserts the pin RTS low.

Figure 34-28. Receiver Behavior when Operating with Hardware Handshaking

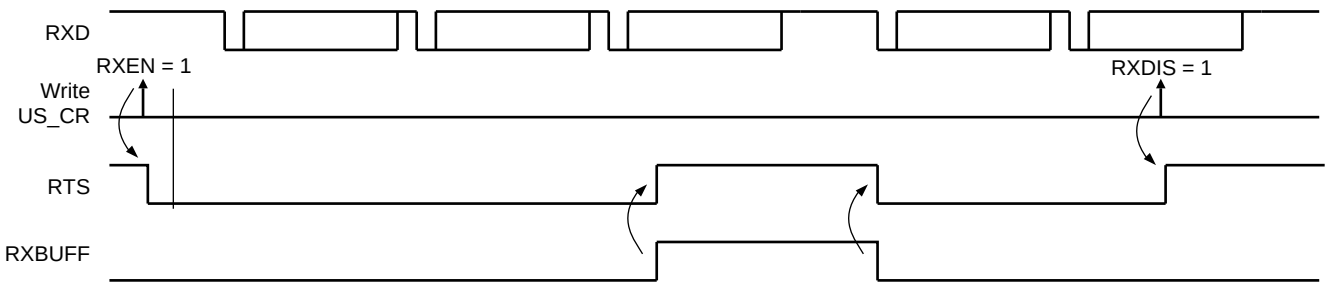
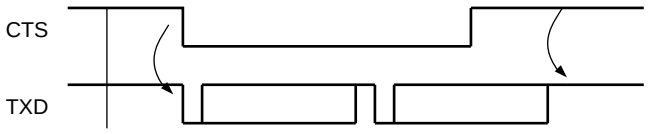


Figure 34-29 shows how the transmitter operates if hardware handshaking is enabled. The CTS pin disables the transmitter. If a character is being processing, the transmitter is disabled only after the completion of the current character and transmission of the next character happens as soon as the pin CTS falls.

Figure 34-29. Transmitter Behavior when Operating with Hardware Handshaking



34.7.4 ISO7816 Mode

The USART features an ISO7816-compatible operating mode. This mode permits interfacing with smart cards and Security Access Modules (SAM) communicating through an ISO7816 link. Both T = 0 and T = 1 protocols defined by the ISO7816 specification are supported.

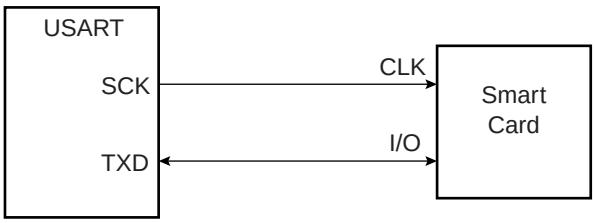
Setting the USART in ISO7816 mode is performed by writing the USART_MODE field in the Mode Register (US_MR) to the value 0x4 for protocol T = 0 and to the value 0x5 for protocol T = 1.

34.7.4.1 ISO7816 Mode Overview

The ISO7816 is a half duplex communication on only one bidirectional line. The baud rate is determined by a division of the clock provided to the remote device (see “Baud Rate Generator” on page 692).

The USART connects to a smart card as shown in Figure 34-30. The TXD line becomes bidirectional and the Baud Rate Generator feeds the ISO7816 clock on the SCK pin. As the TXD pin becomes bidirectional, its output remains driven by the output of the transmitter but only when the transmitter is active while its input is directed to the input of the receiver. The USART is considered as the master of the communication as it generates the clock.

Figure 34-30. Connection of a Smart Card to the USART



When operating in ISO7816, either in T = 0 or T = 1 modes, the character format is fixed. The configuration is 8 data bits, even parity and 1 or 2 stop bits, regardless of the values programmed in the CHRL, MODE9, PAR and CHMODE fields. MSBF can be used to transmit LSB or MSB first. Parity Bit (PAR) can be used to transmit in normal or inverse mode. Refer to “USART Mode Register” on page 730 and “PAR: Parity Type” on page 731.

The USART cannot operate concurrently in both receiver and transmitter modes as the communication is unidirectional at a time. It has to be configured according to the required mode by enabling or disabling either the receiver or the transmitter as desired. Enabling both the receiver and the transmitter at the same time in ISO7816 mode may lead to unpredictable results.

The ISO7816 specification defines an inverse transmission format. Data bits of the character must be transmitted on the I/O line at their negative value. The USART does not support this format and the user has to perform an exclusive OR on the data before writing it in the Transmit Holding Register (US_THR) or after reading it in the Receive Holding Register (US_RHR).

34.7.4.2 Protocol T = 0

In T = 0 protocol, a character is made up of one start bit, eight data bits, one parity bit and one guard time, which lasts two bit times. The transmitter shifts out the bits and does not drive the I/O line during the guard time.

If no parity error is detected, the I/O line remains to 1 during the guard time and the transmitter can continue with the transmission of the next character, as shown in Figure 34-31.

If a parity error is detected by the receiver, it drives the I/O line to 0 during the guard time, as shown in Figure 34-32. This error bit is also named NACK, for Non Acknowledge. In this case, the character lasts 1 bit time more, as the guard time length is the same and is added to the error bit time which lasts 1 bit time.

When the USART is the receiver and it detects an error, it does not load the erroneous character in the Receive Holding Register (US_RHR). It appropriately sets the PARE bit in the Status Register (US_SR) so that the software can handle the error.

Figure 34-31. T = 0 Protocol without Parity Error

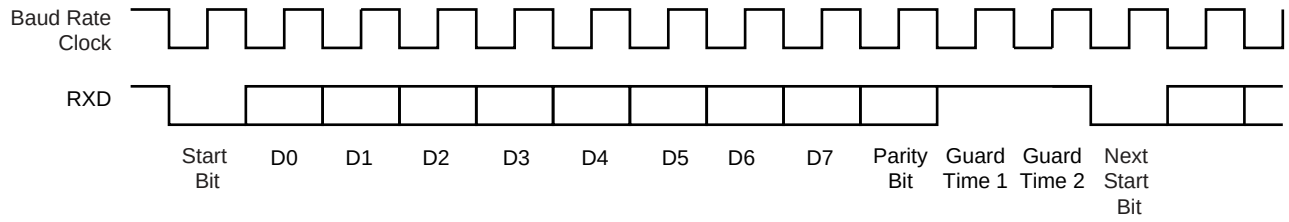
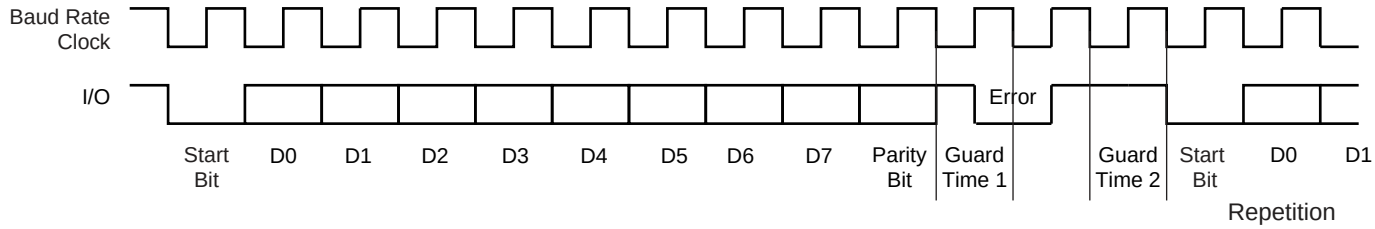


Figure 34-32. T = 0 Protocol with Parity Error



Receive Error Counter

The USART receiver also records the total number of errors. This can be read in the Number of Error (US_NER) register. The NB_ERRORS field can record up to 255 errors. Reading US_NER automatically clears the NB_ERRORS field.

Receive NACK Inhibit

The USART can also be configured to inhibit an error. This can be achieved by setting the INACK bit in the Mode Register (US_MR). If INACK is to 1, no error signal is driven on the I/O line even if a parity bit is detected.

Moreover, if INACK is set, the erroneous received character is stored in the Receive Holding Register, as if no error occurred and the RXRDY bit does rise.

Transmit Character Repetition

When the USART is transmitting a character and gets a NACK, it can automatically repeat the character before moving on to the next one. Repetition is enabled by writing the MAX_ITERATION field in the Mode Register (US_MR) at a value higher than 0. Each character can be transmitted up to eight times; the first transmission plus seven repetitions.

If MAX_ITERATION does not equal zero, the USART repeats the character as many times as the value loaded in MAX_ITERATION.

When the USART repetition number reaches MAX_ITERATION, the ITERATION bit is set in the Channel Status Register (US_CSR). If the repetition of the character is acknowledged by the receiver, the repetitions are stopped and the iteration counter is cleared.

The ITERATION bit in US_CSR can be cleared by writing the Control Register with the RSIT bit to 1.

Disable Successive Receive NACK

The receiver can limit the number of successive NACKs sent back to the remote transmitter. This is programmed by setting the bit DSNACK in the Mode Register (US_MR). The maximum number of NACK transmitted is programmed in the MAX_ITERATION field. As soon as MAX_ITERATION is reached, the character is considered as correct, an acknowledge is sent on the line and the ITERATION bit in the Channel Status Register is set.

34.7.4.3 Protocol T = 1

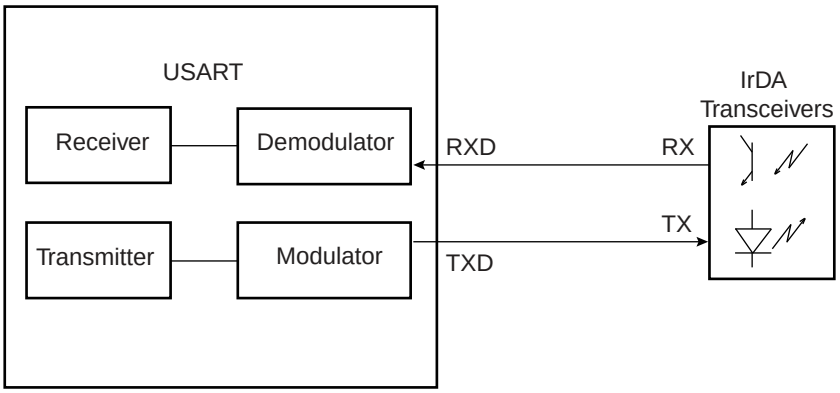
When operating in ISO7816 protocol T = 1, the transmission is similar to an asynchronous format with only one stop bit. The parity is generated when transmitting and checked when receiving. Parity error detection sets the PARE bit in the Channel Status Register (US_CSR).

34.7.5 IrDA Mode

The USART features an IrDA mode supplying half-duplex point-to-point wireless communication. It embeds the modulator and demodulator which allows a glueless connection to the infrared transceivers, as shown in Figure 34-33. The modulator and demodulator are compliant with the IrDA specification version 1.1 and support data transfer speeds ranging from 2.4 Kb/s to 115.2 Kb/s.

The USART IrDA mode is enabled by setting the USART_MODE field in the Mode Register (US_MR) to the value 0x8. The IrDA Filter Register (US_IF) allows configuring the demodulator filter. The USART transmitter and receiver operate in a normal asynchronous mode and all parameters are accessible. Note that the modulator and the demodulator are activated.

Figure 34-33. Connection to IrDA Transceivers



The receiver and the transmitter must be enabled or disabled according to the direction of the transmission to be managed.

To receive IrDA signals, the following needs to be done:

- Disable TX and Enable RX
- Configure the TXD pin as PIO and set it as an output to 0 (to avoid LED emission). Disable the internal pull-up (better for power consumption).
- Receive data

34.7.5.1 IrDA Modulation

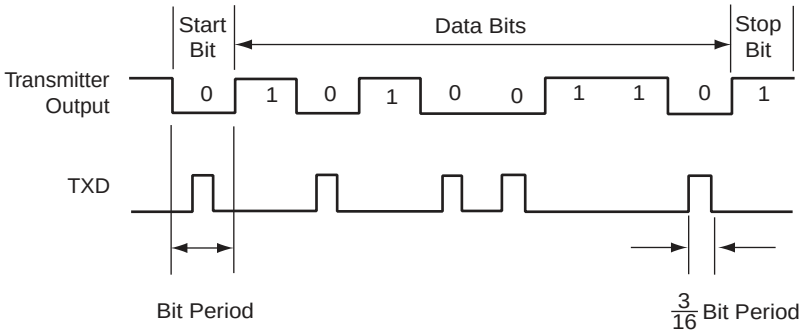
For baud rates up to and including 115.2 Kbits/sec, the RZI modulation scheme is used. “0” is represented by a light pulse of 3/16th of a bit time. Some examples of signal pulse duration are shown in Table 34-11.

Table 34-11. IrDA Pulse Duration

Baud Rate	Pulse Duration (3/16)
2.4 Kb/s	78.13 µs
9.6 Kb/s	19.53 µs
19.2 Kb/s	9.77 µs
38.4 Kb/s	4.88 µs
57.6 Kb/s	3.26 µs
115.2 Kb/s	1.63 µs

Figure 34-34 shows an example of character transmission.

Figure 34-34. IrDA Modulation



34.7.5.2 IrDA Baud Rate

Table 34-12 gives some examples of CD values, baud rate error and pulse duration. Note that the requirement on the maximum acceptable error of ±1.87% must be met.

Table 34-12. IrDA Baud Rate Error

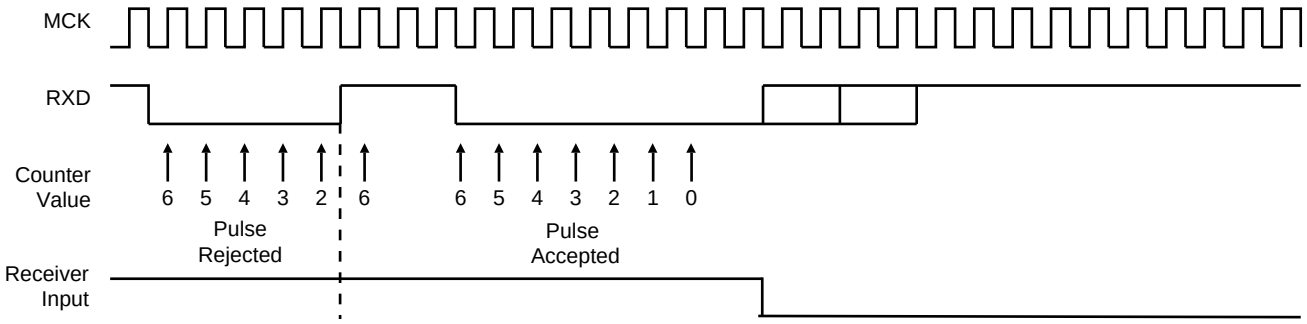
Peripheral Clock	Baud Rate	CD	Baud Rate Error	Pulse Time
3 686 400	115 200	2	0.00%	1.63
20 000 000	115 200	11	1.38%	1.63
32 768 000	115 200	18	1.25%	1.63
40 000 000	115 200	22	1.38%	1.63
3 686 400	57 600	4	0.00%	3.26
20 000 000	57 600	22	1.38%	3.26
32 768 000	57 600	36	1.25%	3.26
40 000 000	57 600	43	0.93%	3.26
3 686 400	38 400	6	0.00%	4.88
20 000 000	38 400	33	1.38%	4.88
32 768 000	38 400	53	0.63%	4.88
40 000 000	38 400	65	0.16%	4.88
3 686 400	19 200	12	0.00%	9.77
20 000 000	19 200	65	0.16%	9.77
32 768 000	19 200	107	0.31%	9.77
40 000 000	19 200	130	0.16%	9.77
3 686 400	9 600	24	0.00%	19.53
20 000 000	9 600	130	0.16%	19.53
32 768 000	9 600	213	0.16%	19.53
40 000 000	9 600	260	0.16%	19.53
3 686 400	2 400	96	0.00%	78.13
20 000 000	2 400	521	0.03%	78.13
32 768 000	2 400	853	0.04%	78.13

34.7.5.3 IrDA Demodulator

The demodulator is based on the IrDA Receive filter comprised of an 8-bit down counter which is loaded with the value programmed in US_IF. When a falling edge is detected on the RXD pin, the Filter Counter starts counting down at the Master Clock (MCK) speed. If a rising edge is detected on the RXD pin, the counter stops and is reloaded with US_IF. If no rising edge is detected when the counter reaches 0, the input of the receiver is driven low during one bit time.

Figure 34-35 illustrates the operations of the IrDA demodulator.

Figure 34-35. IrDA Demodulator Operations

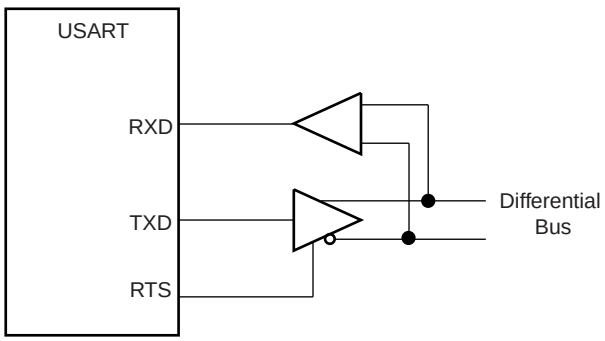


As the IrDA mode uses the same logic as the ISO7816, note that the FI_DI_RATIO field in US_FIDI must be set to a value higher than 0 in order to assure IrDA communications operate correctly.

34.7.6 RS485 Mode

The USART features the RS485 mode to enable line driver control. While operating in RS485 mode, the USART behaves as though in asynchronous or synchronous mode and configuration of all the parameters is possible. The difference is that the RTS pin is driven high when the transmitter is operating. The behavior of the RTS pin is controlled by the TXEMPTY bit. A typical connection of the USART to a RS485 bus is shown in Figure 34-36.

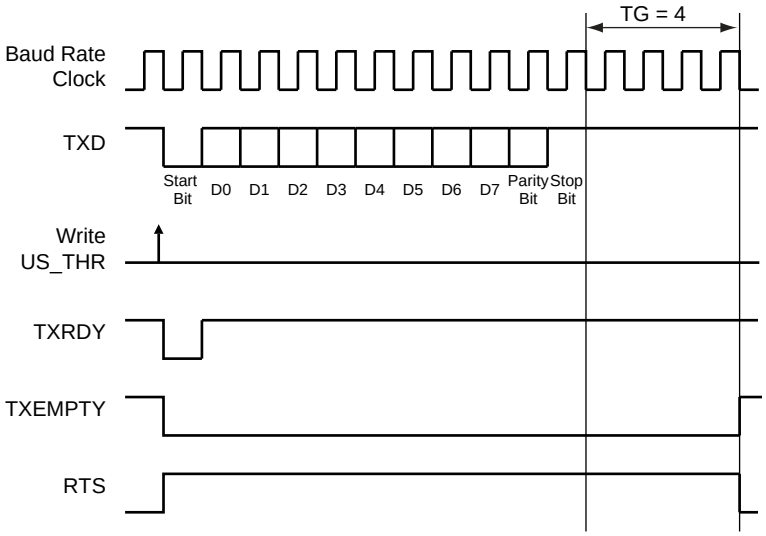
Figure 34-36. Typical Connection to a RS485 Bus



The USART is set in RS485 mode by programming the USART_MODE field in the Mode Register (US_MR) to the value 0x1.

The RTS pin is at a level inverse to the TXEMPTY bit. Significantly, the RTS pin remains high when a timeguard is programmed so that the line can remain driven after the last character completion. Figure 34-37 gives an example of the RTS waveform during a character transmission when the timeguard is enabled.

Figure 34-37. Example of RTS Drive with Timeguard



34.7.7 Modem Mode

The USART features modem mode, which enables control of the signals: DTR (Data Terminal Ready), DSR (Data Set Ready), RTS (Request to Send), CTS (Clear to Send), DCD (Data Carrier Detect) and RI (Ring Indicator). While operating in modem mode, the USART behaves as a DTE (Data Terminal Equipment) as it drives DTR and RTS and can detect level change on DSR, DCD, CTS and RI.

Setting the USART in modem mode is performed by writing the USART_MODE field in the Mode Register (US_MR) to the value 0x3. While operating in modem mode the USART behaves as though in asynchronous mode and all the parameter configurations are available.

Table 34-13 gives the correspondence of the USART signals with modem connection standards.

Table 34-13. Circuit References

USART Pin	V24	CCITT	Direction
TXD	2	103	From terminal to modem
RTS	4	105	From terminal to modem
DTR	20	108.2	From terminal to modem
RXD	3	104	From modem to terminal
CTS	5	106	From terminal to modem
DSR	6	107	From terminal to modem
DCD	8	109	From terminal to modem
RI	22	125	From terminal to modem

The control of the DTR output pin is performed by writing the Control Register (US_CR) with the DTRDIS and DTREN bits respectively to 1. The disable command forces the corresponding pin to its inactive level, i.e. high. The enable command forces the corresponding pin to its active level, i.e. low. RTS output pin is automatically controlled in this mode

The level changes are detected on the RI, DSR, DCD and CTS pins. If an input change is detected, the RIIC, DSRIC, DCDIC and CTSIC bits in the Channel Status Register (US_CSR) are set respectively and can trigger an interrupt. The status is automatically cleared when US_CSR is read. Furthermore, the CTS automatically disables the transmitter when it is detected at its inactive state. If a character is being transmitted when the CTS rises, the character transmission is completed before the transmitter is actually disabled.

34.7.8 SPI Mode

The Serial Peripheral Interface (SPI) Mode is a synchronous serial data link that provides communication with external devices in Master or Slave Mode. It also enables communication between processors if an external processor is connected to the system.

The Serial Peripheral Interface is essentially a shift register that serially transmits data bits to other SPIs. During a data transfer, one SPI system acts as the “master” which controls the data flow, while the other devices act as “slaves" which have data shifted into and out by the master. Different CPUs can take turns being masters and one master may simultaneously shift data into multiple slaves. (Multiple Master Protocol is the opposite of Single Master Protocol, where one CPU is always the master while all of the others are always slaves.) However, only one slave may drive its output to write data back to the master at any given time.

A slave device is selected when its NSS signal is asserted by the master. The USART in SPI Master mode can address only one SPI Slave because it can generate only one NSS signal.

The SPI system consists of two data lines and two control lines:

- Master Out Slave In (MOSI): This data line supplies the output data from the master shifted into the input of the slave.
- Master In Slave Out (MISO): This data line supplies the output data from a slave to the input of the master.
- Serial Clock (SCK): This control line is driven by the master and regulates the flow of the data bits. The master may transmit data at a variety of baud rates. The SCK line cycles once for each bit that is transmitted.
- Slave Select (NSS): This control line allows the master to select or deselect the slave.

34.7.8.1 Modes of Operation

The USART can operate in SPI Master Mode or in SPI Slave Mode.

Operation in SPI Master Mode is programmed by writing to 0xE the USART_MODE field in the Mode Register. In this case the SPI lines must be connected as described below:

- the MOSI line is driven by the output pin TXD
- the MISO line drives the input pin RXD
- the SCK line is driven by the output pin SCK
- the NSS line is driven by the output pin RTS

Operation in SPI Slave Mode is programmed by writing to 0xF the USART_MODE field in the Mode Register. In this case the SPI lines must be connected as described below:

- the MOSI line drives the input pin RXD
- the MISO line is driven by the output pin TXD
- the SCK line drives the input pin SCK
- the NSS line drives the input pin CTS

In order to avoid unpredicted behavior, any change of the SPI Mode must be followed by a software reset of the transmitter and of the receiver (except the initial configuration after a hardware reset). (See Section 34.7.2 ”Receiver and Transmitter Control”).

34.7.8.2 Baud Rate

In SPI Mode, the baudrate generator operates in the same way as in USART synchronous mode: See “Baud Rate in Synchronous Mode or SPI Mode” on page 694. However, there are some restrictions:

In SPI Master Mode:

- the external clock SCK must not be selected (USCLKS ≠ 0x3), and the bit CLKO must be set to “1” in the Mode Register (US_MR), in order to generate correctly the serial clock on the SCK pin.
- to obtain correct behavior of the receiver and the transmitter, the value programmed in CD must be superior or equal to 6.
- if the internal clock divided (MCK/DIV) is selected, the value programmed in CD must be even to ensure a 50:50 mark/space ratio on the SCK pin, this value can be odd if the internal clock is selected (MCK).

In SPI Slave Mode:

- the external clock (SCK) selection is forced regardless of the value of the USCLKS field in the Mode Register (US_MR). Likewise, the value written in US_BRGR has no effect, because the clock is provided directly by the signal on the USART SCK pin.
- to obtain correct behavior of the receiver and the transmitter, the external clock (SCK) frequency must be at least 6 times lower than the system clock.

34.7.8.3 Data Transfer

Up to 9 data bits are successively shifted out on the TXD pin at each rising or falling edge (depending of CPOL and CPHA) of the programmed serial clock. There is no Start bit, no Parity bit and no Stop bit.

The number of data bits is selected by the CHRL field and the MODE 9 bit in the Mode Register (US_MR). The 9 bits are selected by setting the MODE 9 bit regardless of the CHRL field. The MSB data bit is always sent first in SPI Mode (Master or Slave).

Four combinations of polarity and phase are available for data transfers. The clock polarity is programmed with the CPOL bit in the Mode Register. The clock phase is programmed with the CPHA bit. These two parameters determine the edges of the clock signal upon which data is driven and sampled. Each of the two parameters has two possible states, resulting in four possible combinations that are incompatible with one another. Thus, a master/slave pair must use the same parameter pair values to communicate. If multiple slaves are used and fixed in different configurations, the master must reconfigure itself each time it needs to communicate with a different slave.

Table 34-14. SPI Bus Protocol Mode

SPI Bus Protocol Mode	CPOL	CPHA
0	0	1
1	0	0
2	1	1
3	1	0

Figure 34-38. SPI Transfer Format (CPHA=1, 8 bits per transfer)

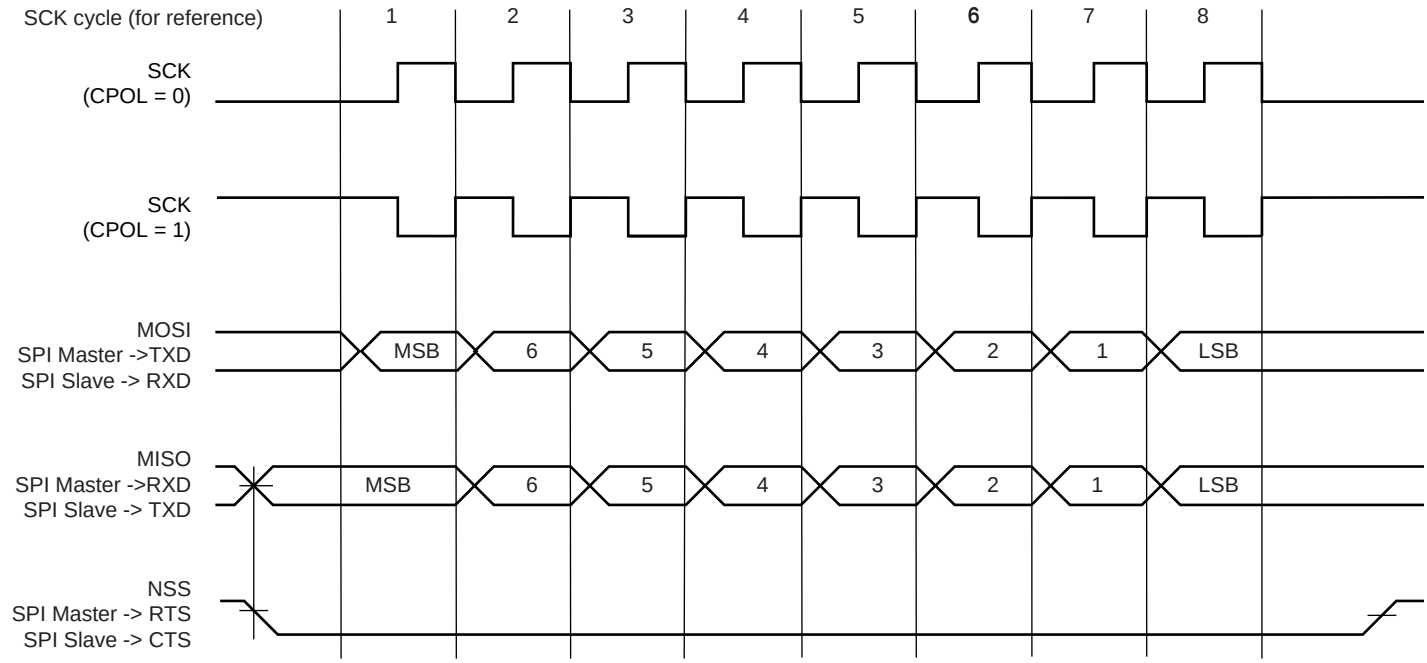
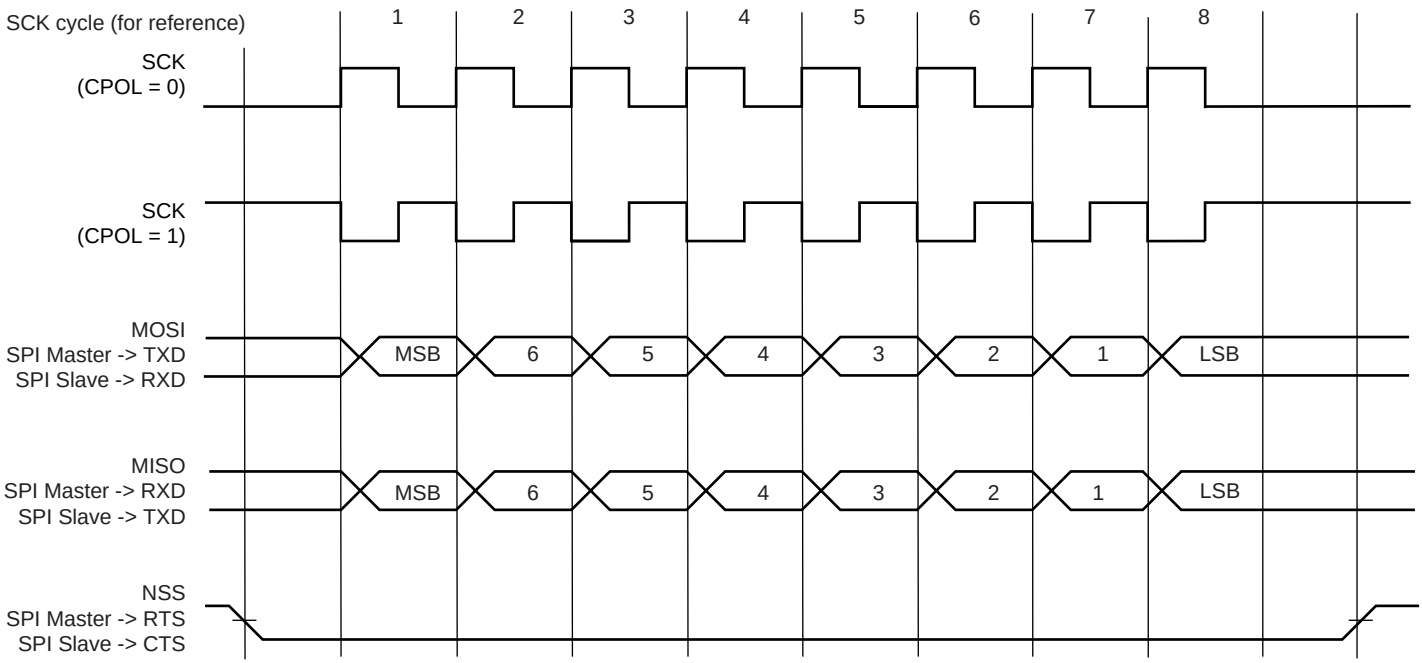


Figure 34-39. SPI Transfer Format (CPHA=0, 8 bits per transfer)



34.7.8.4 Receiver and Transmitter Control

See “Receiver and Transmitter Control” on page 696.

34.7.8.5 Character Transmission

The characters are sent by writing in the Transmit Holding Register (US_THR). An additional condition for transmitting a character can be added when the USART is configured in SPI master mode. In the USART_MR register, the value configured on INACK field can prevent any character transmission (even if US_THR has been written) while the receiver side is not ready (character not read). When INACK equals 0, the character is transmitted whatever the receiver status. If INACK is set to 1, the transmitter waits for the receiver holding register to be read before transmitting the character (RXRDY flag cleared), thus preventing any overflow (character loss) on the receiver side.

The transmitter reports two status bits in the Channel Status Register (US_CSR): TXRDY (Transmitter Ready), which indicates that US_THR is empty and TXEMPTY, which indicates that all the characters written in US_THR have been processed. When the current character processing is completed, the last character written in US_THR is transferred into the Shift Register of the transmitter and US_THR becomes empty, thus TXRDY rises.

Both TXRDY and TXEMPTY bits are low when the transmitter is disabled. Writing a character in US_THR while TXRDY is low has no effect and the written character is lost.

If the USART is in SPI Slave Mode and if a character must be sent while the Transmit Holding Register (US_THR) is empty, the UNRE (Underrun Error) bit is set. The TXD transmission line stays at high level during all this time. The UNRE bit is cleared by writing the Control Register (US_CR) with the RSTSTA (Reset Status) bit to 1.

In SPI Master Mode, the slave select line (NSS) is asserted at low level 1 Tbit (Time bit) before the transmission of the MSB bit and released at high level 1 Tbit after the transmission of the LSB bit. So, the slave select line (NSS) is always released between each character transmission and a minimum delay of 3 Tbits always inserted. However, in order to address slave devices supporting the CSAAT mode (Chip Select Active After Transfer), the slave select line (NSS) can be forced at low level by writing the Control Register (US_CR) with the RTSEN bit to 1. The slave select line (NSS) can be released at high level only by writing the Control Register (US_CR) with the RTSDIS bit to 1 (for example, when all data have been transferred to the slave device).

In SPI Slave Mode, the transmitter does not require a falling edge of the slave select line (NSS) to initiate a character transmission but only a low level. However, this low level must be present on the slave select line (NSS) at least 1 Tbit before the first serial clock cycle corresponding to the MSB bit.

34.7.8.6 Character Reception

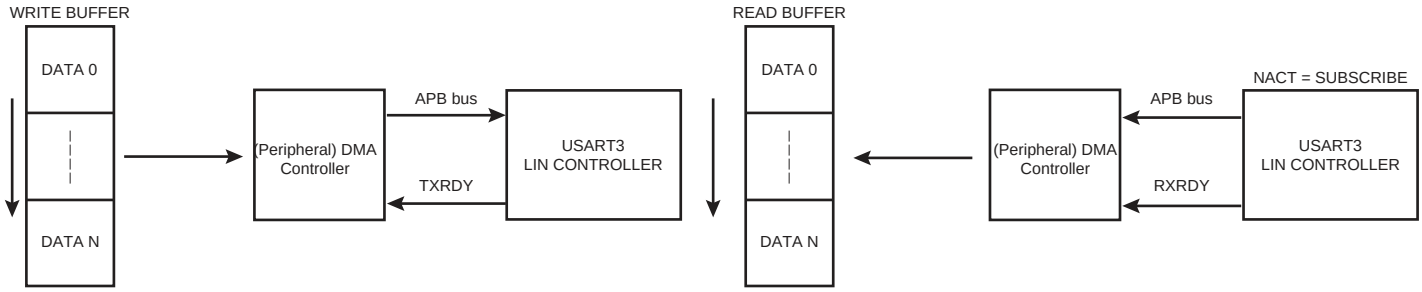
When a character reception is completed, it is transferred to the Receive Holding Register (US_RHR) and the RXRDY bit in the Status Register (US_CSR) rises. If a character is completed while RXRDY is set, the OVRE (Overrun Error) bit is set. The last character is transferred into US_RHR and overwrites the previous one. The OVRE bit is cleared by writing the Control Register (US_CR) with the RSTSTA (Reset Status) bit to 1.

To ensure correct behavior of the receiver in SPI Slave Mode, the master device sending the frame must ensure a minimum delay of 1 Tbit between each character transmission. The receiver does not require a falling edge of the slave select line (NSS) to initiate a character reception but only a low level. However, this low level must be present on the slave select line (NSS) at least 1 Tbit before the first serial clock cycle corresponding to the MSB bit.

34.7.8.7 Receiver Timeout

Because the receiver baudrate clock is active only during data transfers in SPI Mode, a receiver timeout is impossible in this mode, whatever the Time-out value is (field TO) in the Time-out Register (US_RTOR).

34.7.9 Test Modes

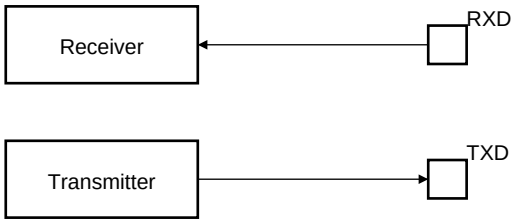


The USART can be programmed to operate in three different test modes. The internal loopback capability allows on-board diagnostics. In the loopback mode the USART interface pins are disconnected or not and reconfigured for loopback internally or externally.

34.7.9.1 Normal Mode

Normal mode connects the RXD pin on the receiver input and the transmitter output on the TXD pin.

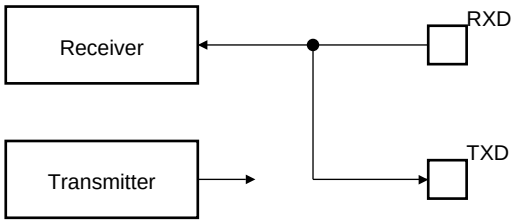
Figure 34-40. Normal Mode Configuration



34.7.9.2 Automatic Echo Mode

Automatic echo mode allows bit-by-bit retransmission. When a bit is received on the RXD pin, it is sent to the TXD pin, as shown in Figure 34-41. Programming the transmitter has no effect on the TXD pin. The RXD pin is still connected to the receiver input, thus the receiver remains active.

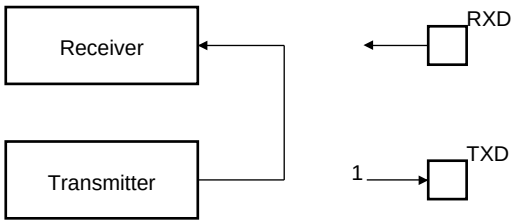
Figure 34-41. Automatic Echo Mode Configuration



34.7.9.3 Local Loopback Mode

Local loopback mode connects the output of the transmitter directly to the input of the receiver, as shown in Figure 34-42. The TXD and RXD pins are not used. The RXD pin has no effect on the receiver and the TXD pin is continuously driven high, as in idle state.

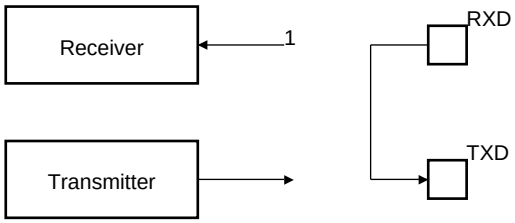
Figure 34-42. Local Loopback Mode Configuration



34.7.9.4 Remote Loopback Mode

Remote loopback mode directly connects the RXD pin to the TXD pin, as shown in Figure 34-43. The transmitter and the receiver are disabled and have no effect. This mode allows bit-by-bit retransmission.

Figure 34-43. Remote Loopback Mode Configuration



34.7.10 Write Protection Registers

To prevent any single software error that may corrupt USART behavior, certain address spaces can be write-protected by setting the WPEN bit in the USART Write Protect Mode Register (US_WPMR).

If a write access to the protected registers is detected, then the WPVS flag in the USART Write Protect Status Register (US_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is reset by writing the USART Write Protect Mode Register (US_WPMR) with the appropriate access key, WPKEY.

The protected registers are:

- "USART Mode Register"
- "USART Baud Rate Generator Register"
- "USART Receiver Time-out Register"
- "USART Transmitter Timeguard Register"
- "USART FI DI RATIO Register"
- "USART IrDA FILTER Register"
- "USART Manchester Configuration Register"

34.8 Universal Synchronous Asynchronous Receiver Transmitter (USART) User Interface

Table 34-15. Register Mapping

Offset	Register	Name	Access	Reset
0x0000	Control Register	US_CR	Write-only	–
0x0004	Mode Register	US_MR	Read-write	–
0x0008	Interrupt Enable Register	US_IER	Write-only	–
0x000C	Interrupt Disable Register	US_IDR	Write-only	–
0x0010	Interrupt Mask Register	US_IMR	Read-only	0x0
0x0014	Channel Status Register	US_CSR	Read-only	–
0x0018	Receiver Holding Register	US_RHR	Read-only	0x0
0x001C	Transmitter Holding Register	US_THR	Write-only	–
0x0020	Baud Rate Generator Register	US_BRGR	Read-write	0x0
0x0024	Receiver Time-out Register	US_RTOR	Read-write	0x0
0x0028	Transmitter Timeguard Register	US_TTGR	Read-write	0x0
0x2C - 0x3C	Reserved	–	–	–
0x0040	FI DI Ratio Register	US_FIDI	Read-write	0x174
0x0044	Number of Errors Register	US_NER	Read-only	–
0x0048	Reserved	–	–	–
0x004C	IrDA Filter Register	US_IF	Read-write	0x0
0x0050	Manchester Encoder Decoder Register	US_MAN	Read-write	0x30011004
0xE4	Write Protect Mode Register	US_WPMR	Read-write	0x0
0xE8	Write Protect Status Register	US_WPSR	Read-only	0x0
0x5C - 0xFC	Reserved	–	–	–
0x100 - 0x128	Reserved for PDC Registers	–	–	–

34.8.1 USART Control Register

Name: US_CR

Address: 0x40090000 (0), 0x40094000 (1), 0x40098000 (2), 0x4009C000 (3)

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RTSDIS/RCS	RTSEN/FCS	DTRDIS	DTREN
15	14	13	12	11	10	9	8
RETTO	RSTNACK	RSTIT	SENDA	STTTO	STPBRK	STTBRK	RSTSTA
7	6	5	4	3	2	1	0
TXDIS	TXEN	RXDIS	RXEN	RSTTX	RSTRX	–	–

- **RSTRX: Reset Receiver**

0: No effect.

1: Resets the receiver.

- **RSTTX: Reset Transmitter**

0: No effect.

1: Resets the transmitter.

- **RXEN: Receiver Enable**

0: No effect.

1: Enables the receiver, if RXDIS is 0.

- **RXDIS: Receiver Disable**

0: No effect.

1: Disables the receiver.

- **TXEN: Transmitter Enable**

0: No effect.

1: Enables the transmitter if TXDIS is 0.

- **TXDIS: Transmitter Disable**

0: No effect.

1: Disables the transmitter.

- **RSTSTA: Reset Status Bits**

0: No effect.

1: Resets the status bits PARE, FRAME, OVRE, MANERR, **UNRE** and RXBRK in US_CSR.

- **STTBRK: Start Break**

0: No effect.

1: Starts transmission of a break after the characters present in US_THR and the Transmit Shift Register have been transmitted. No effect if a break is already being transmitted.

- **STPBRK: Stop Break**

0: No effect.

1: Stops transmission of the break after a minimum of one character length and transmits a high level during 12-bit periods. No effect if no break is being transmitted.

- **STTTO: Start Time-out**

0: No effect.

1: Starts waiting for a character before clocking the time-out counter. Resets the status bit TIMEOUT in US_CSR.

- **SENDA: Send Address**

0: No effect.

1: In Multidrop Mode only, the next character written to the US_THR is sent with the address bit set.

- **RSTIT: Reset Iterations**

0: No effect.

1: Resets ITERATION in US_CSR. No effect if the ISO7816 is not enabled.

- **RSTNACK: Reset Non Acknowledge**

0: No effect

1: Resets NACK in US_CSR.

- **RETTO: Rearm Time-out**

0: No effect

1: Restart Time-out

- **DTREN: Data Terminal Ready Enable**

0: No effect.

1: Drives the pin DTR to 0.

- **DTRDIS: Data Terminal Ready Disable**

0: No effect.

1: Drives the pin DTR to 1.

- **RTSEN: Request to Send Enable**

0: No effect.

1: Drives the pin RTS to 0.

- **FCS: Force SPI Chip Select**
  – Applicable if USART operates in SPI Master Mode (USART_MODE = 0xE):

FCS = 0: No effect.

FCS = 1: Forces the Slave Select Line NSS (RTS pin) to 0, even if USART is no transmitting, in order to address SPI slave devices supporting the CSAAT Mode (Chip Select Active After Transfer).

- **RTSDIS: Request to Send Disable**

0: No effect.

1: Drives the pin RTS to 1.

- **RCS: Release SPI Chip Select**
  – Applicable if USART operates in SPI Master Mode (USART_MODE = 0xE):

RCS = 0: No effect.

RCS = 1: Releases the Slave Select Line NSS (RTS pin).

34.8.2 USART Mode Register

Name: US_MR

Address: 0x40090004 (0), 0x40094004 (1), 0x40098004 (2), 0x4009C004 (3)

Access: Read-write

31	30	29	28	27	26	25	24
ONEBIT	MODSYNC	MAN	FILTER	–	MAX_ITERATION		
23	22	21	20	19	18	17	16
INVDATA	VAR_SYNC	DSNACK	INACK	OVER	CLKO	MODE9	MSBF/CPOL
15	14	13	12	11	10	9	8
CHMODE		NBSTOP		PAR			SYNC/CPHA
7	6	5	4	3	2	1	0
CHRL		USCLKS		USART_MODE			

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **USART_MODE**

Value	Name	Description
0x0	NORMAL	Normal mode
0x1	RS485	RS485
0x2	HW_HANDSHAKING	Hardware Handshaking
0x3	MODEM	Modem
0x4	IS07816_T_0	IS07816 Protocol: T = 0
0x6	IS07816_T_1	IS07816 Protocol: T = 1
0x8	IRDA	IrDA
0xE	SPI_MASTER	SPI Master
0xF	SPI_SLAVE	SPI Slave

- **USCLKS: Clock Selection**

Value	Name	Description
0	MCK	Master Clock MCK is selected
1	DIV	Internal Clock Divided MCK/DIV (DIV=8) is selected
3	SCK	Serial Clock SLK is selected

- **CHRL: Character Length.**

Value	Name	Description
0	5_BIT	Character length is 5 bits
1	6_BIT	Character length is 6 bits
2	7_BIT	Character length is 7 bits
3	8_BIT	Character length is 8 bits

- **SYNC: Synchronous Mode Select**

0: USART operates in Asynchronous Mode.

1: USART operates in Synchronous Mode.

- **CPHA: SPI Clock Phase**
  - Applicable if USART operates in SPI Mode (USART_MODE = 0xE or 0xF):

CPHA = 0: Data is changed on the leading edge of SPCK and captured on the following edge of SPCK.

CPHA = 1: Data is captured on the leading edge of SPCK and changed on the following edge of SPCK.

CPHA determines which edge of SPCK causes data to change and which edge causes data to be captured. CPHA is used with CPOL to produce the required clock/data relationship between master and slave devices.

- **PAR: Parity Type**

Value	Name	Description
0	EVEN	Even parity
1	ODD	Odd parity
2	SPACE	Parity forced to 0 (Space)
3	MARK	Parity forced to 1 (Mark)
4	NO	No parity
6	MULTIDROP	Multidrop mode

- **NBSTOP: Number of Stop Bits**

Value	Name	Description
0	1_BIT	1 stop bit
1	1_5_BIT	1.5 stop bit (SYNC = 0) or reserved (SYNC = 1)
2	2_BIT	2 stop bits

- **CHMODE: Channel Mode**

Value	Name	Description
0	NORMAL	Normal Mode
1	AUTOMATIC	Automatic Echo. Receiver input is connected to the TXD pin.
2	LOCAL_LOOPBACK	Local Loopback. Transmitter output is connected to the Receiver Input.
3	REMOTE_LOOPBACK	Remote Loopback. RXD pin is internally connected to the TXD pin.

- **MSBF: Bit Order**

0: Least Significant Bit is sent/received first.

1: Most Significant Bit is sent/received first.

- **CPOL: SPI Clock Polarity**
  - Applicable if USART operates in SPI Mode (Slave or Master, USART_MODE = 0xE or 0xF):

CPOL = 0: The inactive state value of SPCK is logic level zero.

CPOL = 1: The inactive state value of SPCK is logic level one.

CPOL is used to determine the inactive state value of the serial clock (SPCK). It is used with CPHA to produce the required clock/data relationship between master and slave devices.

- **MODE9: 9-bit Character Length**

0: CHRL defines character length.

1: 9-bit character length.

- **CLKO: Clock Output Select**

0: The USART does not drive the SCK pin.

1: The USART drives the SCK pin if USCLKS does not select the external clock SCK.

- **OVER: Oversampling Mode**

0: 16x Oversampling.

1: 8x Oversampling.

- **INACK: Inhibit Non Acknowledge**

0: The NACK is generated.

1: The NACK is not generated.

Note: In SPI master mode, if INACK = 0 the character transmission starts as soon as a character is written into US_THR register (assuming TXRDY was set). When INACK is 1, an additional condition must be met. The character transmission starts when a character is written and only if RXRDY flag is cleared (Receiver Holding Register has been read).

- **DSNACK: Disable Successive NACK**

0: NACK is sent on the ISO line as soon as a parity error occurs in the received character (unless INACK is set).

1: Successive parity errors are counted up to the value specified in the MAX_ITERATION field. These parity errors generate a NACK on the ISO line. As soon as this value is reached, no additional NACK is sent on the ISO line. The flag ITERATION is asserted.

- **INVDATA: INverted Data**

0: The data field transmitted on TXD line is the same as the one written in US_THR register or the content read in US_RHR is the same as RXD line. Normal mode of operation.

1: The data field transmitted on TXD line is inverted (voltage polarity only) compared to the value written on US_THR register or the content read in US_RHR is inverted compared to what is received on RXD line (or ISO7816 IO line). Inverted Mode of operation, useful for contactless card application. To be used with configuration bit MSBF.

- **VAR_SYNC: Variable Synchronization of Command/Data Sync Start Frame Delimiter**

0: User defined configuration of command or data sync field depending on MODSYNC value.

1: The sync field is updated when a character is written into US_THR register.

- **MAX_ITERATION**

Defines the maximum number of iterations in mode ISO7816, protocol T= 0.

- **FILTER: Infrared Receive Line Filter**

0: The USART does not filter the receive line.

1: The USART filters the receive line using a three-sample filter (1/16-bit clock) (2 over 3 majority).

- **MAN: Manchester Encoder/Decoder Enable**

0: Manchester Encoder/Decoder are disabled.

1: Manchester Encoder/Decoder are enabled.

- **MODSYNC: Manchester Synchronization Mode**

0:The Manchester Start bit is a 0 to 1 transition

1: The Manchester Start bit is a 1 to 0 transition.

- **ONEBIT: Start Frame Delimiter Selector**

0: Start Frame delimiter is COMMAND or DATA SYNC.

1: Start Frame delimiter is One Bit.

34.8.3 USART Interrupt Enable Register

Name: US_IER

Address: 0x40090008 (0), 0x40094008 (1), 0x40098008 (2), 0x4009C008 (3)

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	MANE
23	22	21	20	19	18	17	16
–	–	–	–	CTSIC	DCDIC	DSRIC	RIIC
15	14	13	12	11	10	9	8
–	–	NACK	RXBUFF	TXBUFE	ITER/UNRE	TXEMPTY	TIMEOUT
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	RXBRK	TXRDY	RXRDY

0: No effect

1: Enables the corresponding interrupt.

- **RXRDY: RXRDY Interrupt Enable**
- **TXRDY: TXRDY Interrupt Enable**
- **RXBRK: Receiver Break Interrupt Enable**
- **ENDRX: End of Receive Transfer Interrupt Enable**
- **ENDTX: End of Transmit Interrupt Enable**
- **OVRE: Overrun Error Interrupt Enable**
- **FRAME: Framing Error Interrupt Enable**
- **PARE: Parity Error Interrupt Enable**
- **TIMEOUT: Time-out Interrupt Enable**
- **TXEMPTY: TXEMPTY Interrupt Enable**
- **ITER: Max number of Repetitions Reached**
- **UNRE: SPI Underrun Error**
- **TXBUFE: Buffer Empty Interrupt Enable**
- **RXBUFF: Buffer Full Interrupt Enable**
- **NACK: Non AcknowledgeInterrupt Enable**
- **RIIC: Ring Indicator Input Change Enable**
- **DSRIC: Data Set Ready Input Change Enable**

- **DCDIC: Data Carrier Detect Input Change Interrupt Enable**
- **CTSIC: Clear to Send Input Change Interrupt Enable**
- **MANE: Manchester Error Interrupt Enable**

34.8.4 USART Interrupt Disable Register

Name: US_IDR

Address: 0x4009000C (0), 0x4009400C (1), 0x4009800C (2), 0x4009C00C (3)

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	MANE
23	22	21	20	19	18	17	16
–	–	–	–	CTSIC	DCDIC	DSRIC	RIIC
15	14	13	12	11	10	9	8
–	–	NACK	RXBUFF	TXBUFE	ITER/UNRE	TXEMPTY	TIMEOUT
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	RXBRK	TXRDY	RXRDY

0: No effect

1: Disables the corresponding interrupt.

- **RXRDY: RXRDY Interrupt Disable**
- **TXRDY: TXRDY Interrupt Disable**
- **RXBRK: Receiver Break Interrupt Disable**
- **ENDRX: End of Receive Transfer Interrupt Disable**
- **ENDTX: End of Transmit Interrupt Disable**
- **OVRE: Overrun Error Interrupt Disable**
- **FRAME: Framing Error Interrupt Disable**
- **PARE: Parity Error Interrupt Disable**
- **TIMEOUT: Time-out Interrupt Disable**
- **TXEMPTY: TXEMPTY Interrupt Disable**
- **ITER: Max number of Repetitions Reached Disable**
- **UNRE: SPI Underrun Error Disable**
- **TXBUFE: Buffer Empty Interrupt Disable**
- **RXBUFF: Buffer Full Interrupt Disable**
- **NACK: Non AcknowledgeInterrupt Disable**
- **RIIC: Ring Indicator Input Change Disable**
- **DSRIC: Data Set Ready Input Change Disable**

- **DCDIC: Data Carrier Detect Input Change Interrupt Disable**
- **CTSIC: Clear to Send Input Change Interrupt Disable**
- **MANE: Manchester Error Interrupt Disable**

34.8.5 USART Interrupt Mask Register

Name: US_IMR

Address: 0x40090010 (0), 0x40094010 (1), 0x40098010 (2), 0x4009C010 (3)

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	MANE
23	22	21	20	19	18	17	16
–	–	–	–	CTSIC	DCDIC	DSRIC	RIIC
15	14	13	12	11	10	9	8
–	–	NACK	RXBUFF	TXBUFE	ITER/UNRE	TXEMPTY	TIMEOUT
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	RXBRK	TXRDY	RXRDY

0: The corresponding interrupt is not enabled.

1: The corresponding interrupt is enabled.

- **RXRDY: RXRDY Interrupt Mask**
- **TXRDY: TXRDY Interrupt Mask**
- **RXBRK: Receiver Break Interrupt Mask**
- **ENDRX: End of Receive Transfer Interrupt Mask**
- **ENDTX: End of Transmit Interrupt Mask**
- **OVRE: Overrun Error Interrupt Mask**
- **FRAME: Framing Error Interrupt Mask**
- **PARE: Parity Error Interrupt Mask**
- **TIMEOUT: Time-out Interrupt Mask**
- **TXEMPTY: TXEMPTY Interrupt Mask**
- **ITER: Max number of Repetitions Reached Mask**
- **UNRE: SPI Underrun Error Mask**
- **TXBUFE: Buffer Empty Interrupt Mask**
- **RXBUFF: Buffer Full Interrupt Mask**
- **NACK: Non AcknowledgeInterrupt Mask**
- **RIIC: Ring Indicator Input Change Mask**
- **DSRIC: Data Set Ready Input Change Mask**

- **DCDIC: Data Carrier Detect Input Change Interrupt Mask**
- **CTSIC: Clear to Send Input Change Interrupt Mask**
- **MANE: Manchester Error Interrupt Mask**

34.8.6 USART Channel Status Register

Name: US_CSR

Address: 0x40090014 (0), 0x40094014 (1), 0x40098014 (2), 0x4009C014 (3)

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	MANERR
23	22	21	20	19	18	17	16
CTS	DCD	DSR	RI	CTSIC	DCDIC	DSRIC	RIIC
15	14	13	12	11	10	9	8
–	–	NACK	RXBUFF	TXBUFE	ITER/UNRE	TXEMPTY	TIMEOUT
7	6	5	4	3	2	1	0
PARE	FRAME	OVRE	ENDTX	ENDRX	RXBRK	TXRDY	RXRDY

- **RXRDY: Receiver Ready**

0: No complete character has been received since the last read of US_RHR or the receiver is disabled. If characters were being received when the receiver was disabled, RXRDY changes to 1 when the receiver is enabled.

1: At least one complete character has been received and US_RHR has not yet been read.

- **TXRDY: Transmitter Ready**

0: A character is in the US_THR waiting to be transferred to the Transmit Shift Register, or an STTBRK command has been requested, or the transmitter is disabled. As soon as the transmitter is enabled, TXRDY becomes 1.

1: There is no character in the US_THR.

- **RXBRK: Break Received/End of Break**

0: No Break received or End of Break detected since the last RSTSTA.

1: Break Received or End of Break detected since the last RSTSTA.

- **ENDRX: End of Receiver Transfer**

0: The End of Transfer signal from the Receive PDC channel is inactive.

1: The End of Transfer signal from the Receive PDC channel is active.

- **ENDTX: End of Transmitter Transfer**

0: The End of Transfer signal from the Transmit PDC channel is inactive.

1: The End of Transfer signal from the Transmit PDC channel is active.

- **OVRE: Overrun Error**

0: No overrun error has occurred since the last RSTSTA.

1: At least one overrun error has occurred since the last RSTSTA.

- **FRAME: Framing Error**

0: No stop bit has been detected low since the last RSTSTA.

1: At least one stop bit has been detected low since the last RSTSTA.

- **PARE: Parity Error**

0: No parity error has been detected since the last RSTSTA.

1: At least one parity error has been detected since the last RSTSTA.

- **TIMEOUT: Receiver Time-out**

0: There has not been a time-out since the last Start Time-out command (STTTO in US_CR) or the Time-out Register is 0.

1: There has been a time-out since the last Start Time-out command (STTTO in US_CR).

- **TXEMPTY: Transmitter Empty**

0: There are characters in either US_THR or the Transmit Shift Register, or the transmitter is disabled.

1: There are no characters in US_THR, nor in the Transmit Shift Register.

- **ITER: Max number of Repetitions Reached**

0: Maximum number of repetitions has not been reached since the last RSTSTA.

1: Maximum number of repetitions has been reached since the last RSTSTA.

- **UNRE: SPI Underrun Error**

– Applicable if USART operates in SPI Slave Mode (USART_MODE = 0xF):

UNRE = 0: No SPI underrun error has occurred since the last RSTSTA.

UNRE = 1: At least one SPI underrun error has occurred since the last RSTSTA.

- **TXBUFE: Transmission Buffer Empty**

0: The signal Buffer Empty from the Transmit PDC channel is inactive.

1: The signal Buffer Empty from the Transmit PDC channel is active.

- **RXBUFF: Reception Buffer Full**

0: The signal Buffer Full from the Receive PDC channel is inactive.

1: The signal Buffer Full from the Receive PDC channel is active.

- **NACK: Non AcknowledgeInterrupt**

0: Non Acknowledge has not been detected since the last RSTNACK.

1: At least one Non Acknowledge has been detected since the last RSTNACK.

- **RIIC: Ring Indicator Input Change Flag**

0: No input change has been detected on the RI pin since the last read of US_CSR.

1: At least one input change has been detected on the RI pin since the last read of US_CSR.

- **DSRIC: Data Set Ready Input Change Flag**

0: No input change has been detected on the DSR pin since the last read of US_CSR.

1: At least one input change has been detected on the DSR pin since the last read of US_CSR.

- **DCDIC: Data Carrier Detect Input Change Flag**

0: No input change has been detected on the DCD pin since the last read of US_CSR.

1: At least one input change has been detected on the DCD pin since the last read of US_CSR.

- **CTSIC: Clear to Send Input Change Flag**

0: No input change has been detected on the CTS pin since the last read of US_CSR.

1: At least one input change has been detected on the CTS pin since the last read of US_CSR.

- **RI: Image of RI Input**

0: RI is set to 0.

1: RI is set to 1.

- **DSR: Image of DSR Input**

0: DSR is set to 0

1: DSR is set to 1.

- **DCD: Image of DCD Input**

0: DCD is set to 0.

1: DCD is set to 1.

- **CTS: Image of CTS Input**

0: CTS is set to 0.

1: CTS is set to 1.

- **MANERR: Manchester Error**

0: No Manchester error has been detected since the last RSTSTA.

1: At least one Manchester error has been detected since the last RSTSTA.

34.8.7 USART Receive Holding Register

Name: US_RHR

Address: 0x40090018 (0), 0x40094018 (1), 0x40098018 (2), 0x4009C018 (3)

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
RXSYNH	–	–	–	–	–	–	RXCHR
7	6	5	4	3	2	1	0
RXCHR							

- **RXCHR: Received Character**

Last character received if RXRDY is set.

- **RXSYNH: Received Sync**

0: Last Character received is a Data.

1: Last Character received is a Command.

34.8.8 USART Transmit Holding Register

Name: US_THR

Address: 0x4009001C (0), 0x4009401C (1), 0x4009801C (2), 0x4009C01C (3)

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
TXSYNH	–	–	–	–	–	–	TXCHR
7	6	5	4	3	2	1	0
TXCHR							

- **TXCHR: Character to be Transmitted**

Next character to be transmitted after the current character if TXRDY is not set.

- **TXSYNH: Sync Field to be transmitted**

0: The next character sent is encoded as a data. Start Frame Delimiter is DATA SYNC.

1: The next character sent is encoded as a command. Start Frame Delimiter is COMMAND SYNC.

34.8.9 USART Baud Rate Generator Register

Name: US_BRGR

Address: 0x40090020 (0), 0x40094020 (1), 0x40098020 (2), 0x4009C020 (3)

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	FP		

15	14	13	12	11	10	9	8
CD							

7	6	5	4	3	2	1	0
CD							

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **CD: Clock Divider**

CD	USART_MODE ≠ ISO7816			USART_MODE = ISO7816
	SYNC = 0		SYNC = 1 or USART_MODE = SPI (Master or Slave)	
	OVER = 0	OVER = 1		
0	Baud Rate Clock Disabled			
1 to 65535	Baud Rate = Selected Clock/(16*CD)	Baud Rate = Selected Clock/(8*CD)	Baud Rate = Selected Clock /CD	Baud Rate = Selected Clock/(FI_DI_RATIO*CD)

- **FP: Fractional Part**

0: Fractional divider is disabled.

1 - 7: Baudrate resolution, defined by FP x 1/8.

34.8.10 USART Receiver Time-out Register

Name: US_RTOR

Address: 0x40090024 (0), 0x40094024 (1), 0x40098024 (2), 0x4009C024 (3)

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
TO							

7	6	5	4	3	2	1	0
TO							

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **TO: Time-out Value**

0: The Receiver Time-out is disabled.

1 - 65535: The Receiver Time-out is enabled and the Time-out delay is TO x Bit Period.

34.8.11 USART Transmitter Timeguard Register

Name: US_TTGR

Address: 0x40090028 (0), 0x40094028 (1), 0x40098028 (2), 0x4009C028 (3)

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
TG							

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **TG: Timeguard Value**

0: The Transmitter Timeguard is disabled.

1 - 255: The Transmitter timeguard is enabled and the timeguard delay is TG x Bit Period.

34.8.12 USART FI DI RATIO Register

Name: US_FIDI

Address: 0x40090040 (0), 0x40094040 (1), 0x40098040 (2), 0x4009C040 (3)

Access: Read-write

Reset Value: 0x174

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	FI_DI_RATIO		
7	6	5	4	3	2	1	0
FI_DI_RATIO							

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **FI_DI_RATIO: FI Over DI Ratio Value**

0: If ISO7816 mode is selected, the Baud Rate Generator generates no signal.

1 - 2047: If ISO7816 mode is selected, the Baud Rate is the clock provided on SCK divided by FI_DI_RATIO.

34.8.13 USART Number of Errors Register

Name: US_NER

Address: 0x40090044 (0), 0x40094044 (1), 0x40098044 (2), 0x4009C044 (3)

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
NB_ERRORS							

- **NB_ERRORS: Number of Errors**

Total number of errors that occurred during an ISO7816 transfer. This register automatically clears when read.

34.8.14 USART IrDA FILTER Register

Name: US_IF

Address: 0x4009004C (0), 0x4009404C (1), 0x4009804C (2), 0x4009C04C (3)

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
IRDA_FILTER							

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **IRDA_FILTER: IrDA Filter**

Sets the filter of the IrDA demodulator.

34.8.15 USART Manchester Configuration Register

Name: US_MAN

Address: 0x40090050 (0), 0x40094050 (1), 0x40098050 (2), 0x4009C050 (3)

Access: Read-write

31	30	29	28	27	26	25	24
–	DRIFT	1	RX_MPOL	–	–	RX_PP	

23	22	21	20	19	18	17	16
–	–	–	–	RX_PL			

15	14	13	12	11	10	9	8
–	–	–	TX_MPOL	–	–	TX_PP	

7	6	5	4	3	2	1	0
–	–	–	–	TX_PL			

This register can only be written if the WPEN bit is cleared in “USART Write Protect Mode Register” on page 753.

- **TX_PL: Transmitter Preamble Length**

0: The Transmitter Preamble pattern generation is disabled

1 - 15: The Preamble Length is TX_PL x Bit Period

- **TX_PP: Transmitter Preamble Pattern**

The following values assume that TX_MPOL field is not set:

Value	Name	Description
00	ALL_ONE	The preamble is composed of ‘1’s
01	ALL_ZERO	The preamble is composed of ‘0’s
10	ZERO_ONE	The preamble is composed of ‘01’s
11	ONE_ZERO	The preamble is composed of ‘10’s

- **TX_MPOL: Transmitter Manchester Polarity**

0: Logic Zero is coded as a zero-to-one transition, Logic One is coded as a one-to-zero transition.

1: Logic Zero is coded as a one-to-zero transition, Logic One is coded as a zero-to-one transition.

- **RX_PL: Receiver Preamble Length**

0: The receiver preamble pattern detection is disabled

1 - 15: The detected preamble length is RX_PL x Bit Period

- **RX_PP: Receiver Preamble Pattern detected**

The following values assume that RX_MPOL field is not set:

Value	Name	Description
00	ALL_ONE	The preamble is composed of ‘1’s
01	ALL_ZERO	The preamble is composed of ‘0’s
10	ZERO_ONE	The preamble is composed of ‘01’s
11	ONE_ZERO	The preamble is composed of ‘10’s

- **RX_MPOL: Receiver Manchester Polarity**

0: Logic Zero is coded as a zero-to-one transition, Logic One is coded as a one-to-zero transition.

1: Logic Zero is coded as a one-to-zero transition, Logic One is coded as a zero-to-one transition.

- **DRIFT: Drift compensation**

0: The USART can not recover from an important clock drift

1: The USART can recover from clock drift. The 16X clock mode must be enabled.

34.8.16 USART Write Protect Mode Register

Name: US_WPMR

Address: 0x400900E4 (0), 0x400940E4 (1), 0x400980E4 (2), 0x4009C0E4 (3)

Access: Read-write

Reset: See Table 34-15

31	30	29	28	27	26	25	24
WPKEY							
23	22	21	20	19	18	17	16
WPKEY							
15	14	13	12	11	10	9	8
WPKEY							
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPEN

- **WPEN: Write Protect Enable**

0 = Disables the Write Protect if WPKEY corresponds to 0x555341 (“USA” in ASCII).

1 = Enables the Write Protect if WPKEY corresponds to 0x555341 (“USA” in ASCII).

Protects the registers:

- “USART Mode Register” on page 730
- “USART Baud Rate Generator Register” on page 745
- “USART Receiver Time-out Register” on page 746
- “USART Transmitter Timeguard Register” on page 747
- “USART FI DI RATIO Register” on page 748
- “USART IrDA FILTER Register” on page 750
- “USART Manchester Configuration Register” on page 751

- **WPKEY: Write Protect KEY**

Should be written at value 0x555341 (“USA” in ASCII). Writing any other value in this field aborts the write operation of the WPEN bit. Always reads as 0.

34.8.17 USART Write Protect Status Register

Name: US_WPSR

Address: 0x400900E8 (0), 0x400940E8 (1), 0x400980E8 (2), 0x4009C0E8 (3)

Access: Read-only

Reset: See Table 34-15

31	30	29	28	27	26	25	24
—	—	—	—	—	—	—	—
23	22	21	20	19	18	17	16
WPVSRC							
15	14	13	12	11	10	9	8
WPVSRC							
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	WPVS

- **WPVS: Write Protect Violation Status**

0 = No Write Protect Violation has occurred since the last read of the US_WPSR register.

1 = A Write Protect Violation has occurred since the last read of the US_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protect Violation Source**

When WPVS is active, this field indicates the write-protected register (through address offset or code) in which a write access has been attempted.

Note: Reading US_WPSR automatically clears all fields.

35. Timer Counter (TC)

35.1 Description

A Timer Counter (TC) module includes three identical TC channels. The number of implemented TC modules is device-specific.

Each TC channel can be independently programmed to perform a wide range of functions including frequency measurement, event counting, interval measurement, pulse generation, delay timing and pulse width modulation.

Each channel has three external clock inputs, five internal clock inputs and two multi-purpose input/output signals which can be configured by the user. Each channel drives an internal interrupt signal which can be programmed to generate processor interrupts.

The TC embeds a quadrature decoder (QDEC) connected in front of the timers and driven by TIOA0, TIOB0 and TIOB1 inputs. When enabled, the QDEC performs the input lines filtering, decoding of quadrature signals and connects to the timers/counters in order to read the position and speed of the motor through the user interface.

The TC block has two global registers which act upon all TC channels:

- Block Control Register (TC_BCR)—allows channels to be started simultaneously with the same instruction
- Block Mode Register (TC_BMR)—defines the external clock inputs for each channel, allowing them to be chained

35.2 Embedded Characteristics

- Total number of TC channels: 9
- TC channel size: 16-bit
- Wide range of functions including:
  - Frequency measurement
  - Event counting
  - Interval measurement
  - Pulse generation
  - Delay timing
  - Pulse Width Modulation
  - Up/down capabilities
  - Quadrature decoder
- Each channel is user-configurable and contains:
  - Three external clock inputs
  - Five Internal clock inputs
  - Two multi-purpose input/output signals acting as trigger event
- Internal interrupt signal

35.3 Block Diagram

Table 35-1. Timer Counter Clock Assignment

Name	Definition
TIMER_CLOCK1	MCK/2
TIMER_CLOCK2	MCK/8
TIMER_CLOCK3	MCK/32
TIMER_CLOCK4	MCK/128
TIMER_CLOCK5	SLCK

Note: 1. When SLCK is selected for Peripheral Clock (CSS = 0 in PMC Master Clock Register), SLCK input is equivalent to Peripheral Clock.

Figure 35-1. Timer Counter Block Diagram

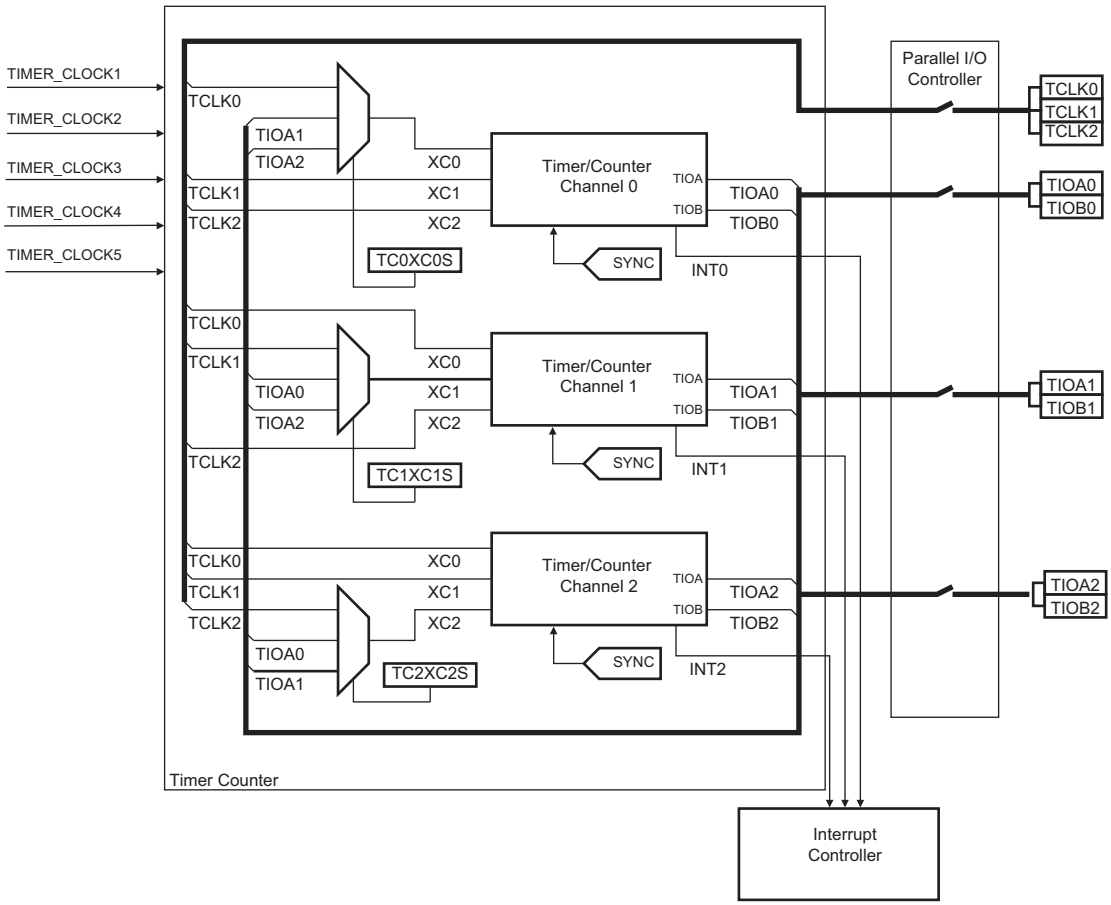


Table 35-2. Signal Name Description

Block/Channel	Signal Name	Description
Channel Signal	XC0, XC1, XC2	External Clock Inputs
	TIOA	Capture Mode: Timer Counter Input Waveform Mode: Timer Counter Output
	TIOB	Capture Mode: Timer Counter Input Waveform Mode: Timer Counter Input/Output
	INT	Interrupt Signal Output (internal signal)
	SYNC	Synchronization Input Signal (from configuration register)

35.4 Pin Name List

Table 35-3. TC Pin List

Pin Name	Description	Type
TCLK0–TCLK2	External Clock Input	Input
TIOA0–TIOA2	I/O Line A	I/O
TIOB0–TIOB2	I/O Line B	I/O

35.5 Product Dependencies

35.5.1 I/O Lines

The pins used for interfacing the compliant external devices may be multiplexed with PIO lines. The programmer must first program the PIO controllers to assign the TC pins to their peripheral functions.

Table 35-4. I/O Lines

Instance	Signal	I/O Line	Peripheral
TC0	TCLK0	PA2	A
TC0	TCLK1	PB4	A
TC0	TCLK2	PA26	B
TC0	TIOA0	PA1	A
TC0	TIOA1	PB5	A
TC0	TIOA2	PA30	B
TC0	TIOB0	PA0	A
TC0	TIOB1	PB6	A
TC0	TIOB2	PA31	B

35.5.2 Power Management

The TC is clocked through the Power Management Controller (PMC), thus the programmer must first configure the PMC to enable the Timer Counter clock of each channel.

35.5.3 Interrupt Sources

The TC has an interrupt line per channel connected to the interrupt controller. Handling the TC interrupt requires programming the interrupt controller before configuring the TC.

Table 35-5. Peripheral IDs

Instance	ID
TC0	22

35.6 Functional Description

35.6.1 Description

All channels of the Timer Counter are independent and identical in operation except when the QDEC is enabled. The registers for channel programming are listed in Table 35-6 “Register Mapping”.

35.6.2 16-bit Counter

Each 16-bit channel is organized around a 16-bit counter. The value of the counter is incremented at each positive edge of the selected clock. When the counter has reached the value 2^{16}-1 and passes to zero, an overflow occurs and the COVFS bit in the TC Status Register (TC_SR) is set.

The current value of the counter is accessible in real time by reading the TC Counter Value Register (TC_CV). The counter can be reset by a trigger. In this case, the counter value passes to zero on the next valid edge of the selected clock.

35.6.3 Clock Selection

At block level, input clock signals of each channel can either be connected to the external inputs TCLK0, TCLK1 or TCLK2, or be connected to the internal I/O signals TIOA0, TIOA1 or TIOA2 for chaining by programming the TC Block Mode Register (TC_BMR). See Figure 35-2.

Each channel can independently select an internal or external clock source for its counter:

- External clock signals(1): XC0, XC1 or XC2
- Internal clock signals: MCK/2, MCK/8, MCK/32, MCK/128, SLCK

This selection is made by the TCCLKS bits in the TC Channel Mode Register (TC_CMR).

The selected clock can be inverted with the CLKI bit in the TC_CMR. This allows counting on the opposite edges of the clock.

The burst function allows the clock to be validated when an external signal is high. The BURST parameter in the TC_CMR defines this signal (none, XC0, XC1, XC2). See Figure 35-3.

Note: 1. In all cases, if an external clock is used, the duration of each of its levels must be longer than the peripheral clock period. The external clock frequency must be at least 2.5 times lower than the peripheral clock.

Figure 35-2. Clock Chaining Selection

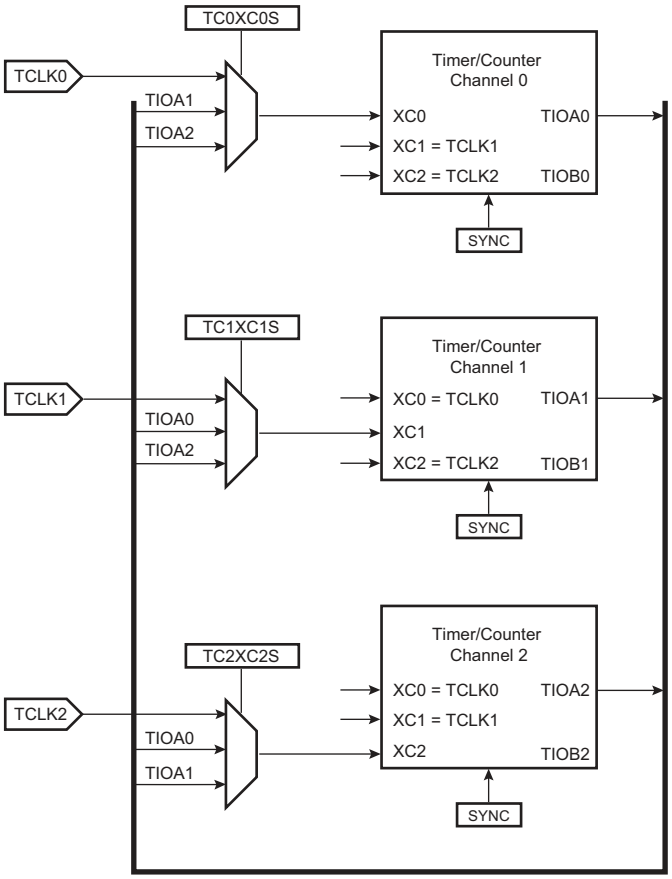
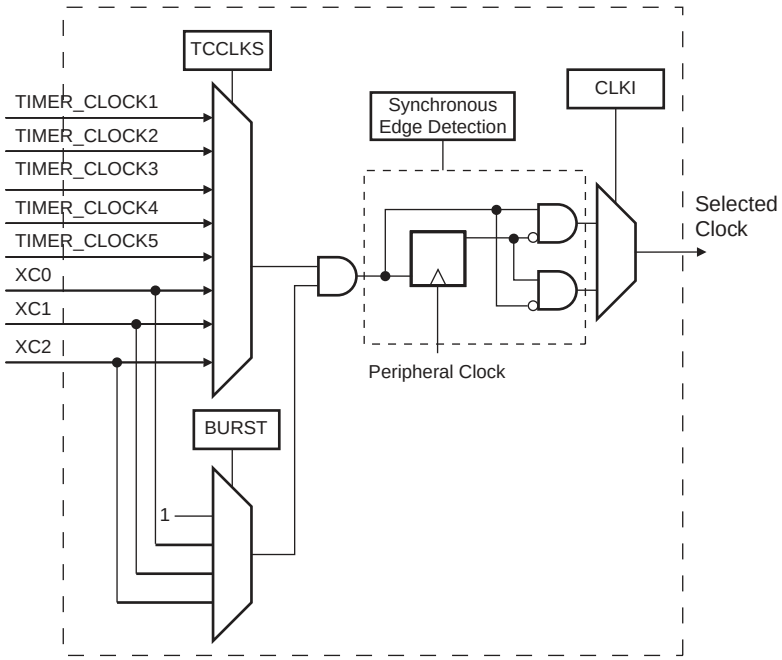


Figure 35-3. Clock Selection

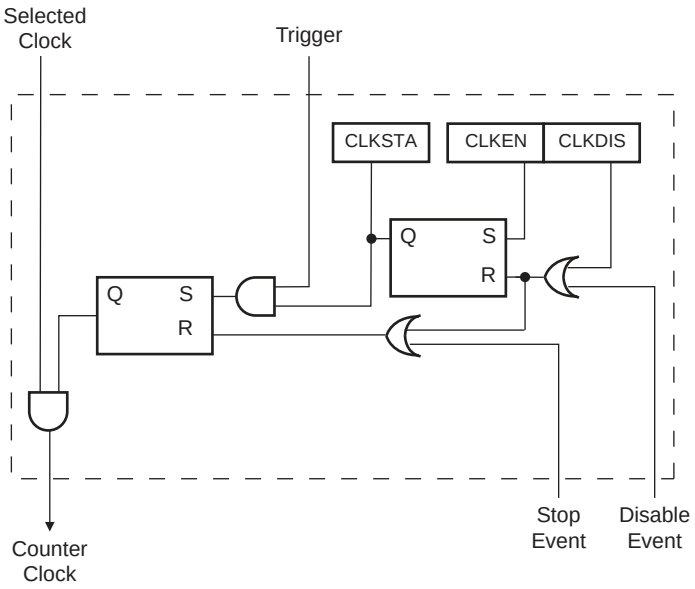


35.6.4 Clock Control

The clock of each counter can be controlled in two different ways: it can be enabled/disabled and started/stopped. See Figure 35-4.

- The clock can be enabled or disabled by the user with the CLKEN and the CLKDIS commands in the TC Channel Control Register (TC_CCR). In Capture mode it can be disabled by an RB load event if LDBDIS is set to 1 in the TC_CMR. In Waveform mode, it can be disabled by an RC Compare event if CPCDIS is set to 1 in TC_CMR. When disabled, the start or the stop actions have no effect: only a CLKEN command in the TC_CCR can re-enable the clock. When the clock is enabled, the CLKSTA bit is set in the TC_SR.
- The clock can also be started or stopped: a trigger (software, synchro, external or compare) always starts the clock. The clock can be stopped by an RB load event in Capture mode (LDBSTOP = 1 in TC_CMR) or an RC compare event in Waveform mode (CPCSTOP = 1 in TC_CMR). The start and the stop commands are effective only if the clock is enabled.

Figure 35-4. Clock Control



35.6.5 Operating Modes

Each channel can operate independently in two different modes:

- Capture mode provides measurement on signals.
- Waveform mode provides wave generation.

The TC operating mode is programmed with the WAVE bit in the TC_CMR.

In Capture mode, TIOA and TIOB are configured as inputs.

In Waveform mode, TIOA is always configured to be an output and TIOB is an output if it is not selected to be the external trigger.

35.6.6 Trigger

A trigger resets the counter and starts the counter clock. Three types of triggers are common to both modes, and a fourth external trigger is available to each mode.

Regardless of the trigger used, it will be taken into account at the following active edge of the selected clock. This means that the counter value can be read differently from zero just after a trigger, especially when a low frequency signal is selected as the clock.

The following triggers are common to both modes:

- Software Trigger: Each channel has a software trigger, available by setting SWTRG in TC_CCR.
- SYNC: Each channel has a synchronization signal SYNC. When asserted, this signal has the same effect as a software trigger. The SYNC signals of all channels are asserted simultaneously by writing TC_BCR (Block Control) with SYNC set.
- Compare RC Trigger: RC is implemented in each channel and can provide a trigger when the counter value matches the RC value if CPCTRG is set in the TC_CMR.

The channel can also be configured to have an external trigger. In Capture mode, the external trigger signal can be selected between TIOA and TIOB. In Waveform mode, an external event can be programmed on one of the following signals: TIOB, XC0, XC1 or XC2. This external event can then be programmed to perform a trigger by setting bit ENETRG in the TC_CMR.

If an external trigger is used, the duration of the pulses must be longer than the peripheral clock period in order to be detected.

35.6.7 Capture Mode

Capture mode is entered by clearing the WAVE bit in the TC_CMR.

Capture mode allows the TC channel to perform measurements such as pulse timing, frequency, period, duty cycle and phase on TIOA and TIOB signals which are considered as inputs.

Figure 35-5 shows the configuration of the TC channel when programmed in Capture mode.

35.6.8 Capture Registers A and B

Registers A and B (RA and RB) are used as capture registers. They can be loaded with the counter value when a programmable event occurs on the signal TIOA.

The LDRA field in the TC_CMR defines the TIOA selected edge for the loading of register A, and the LDRB field defines the TIOA selected edge for the loading of Register B.

RA is loaded only if it has not been loaded since the last trigger or if RB has been loaded since the last loading of RA.

RB is loaded only if RA has been loaded since the last trigger or the last loading of RB.

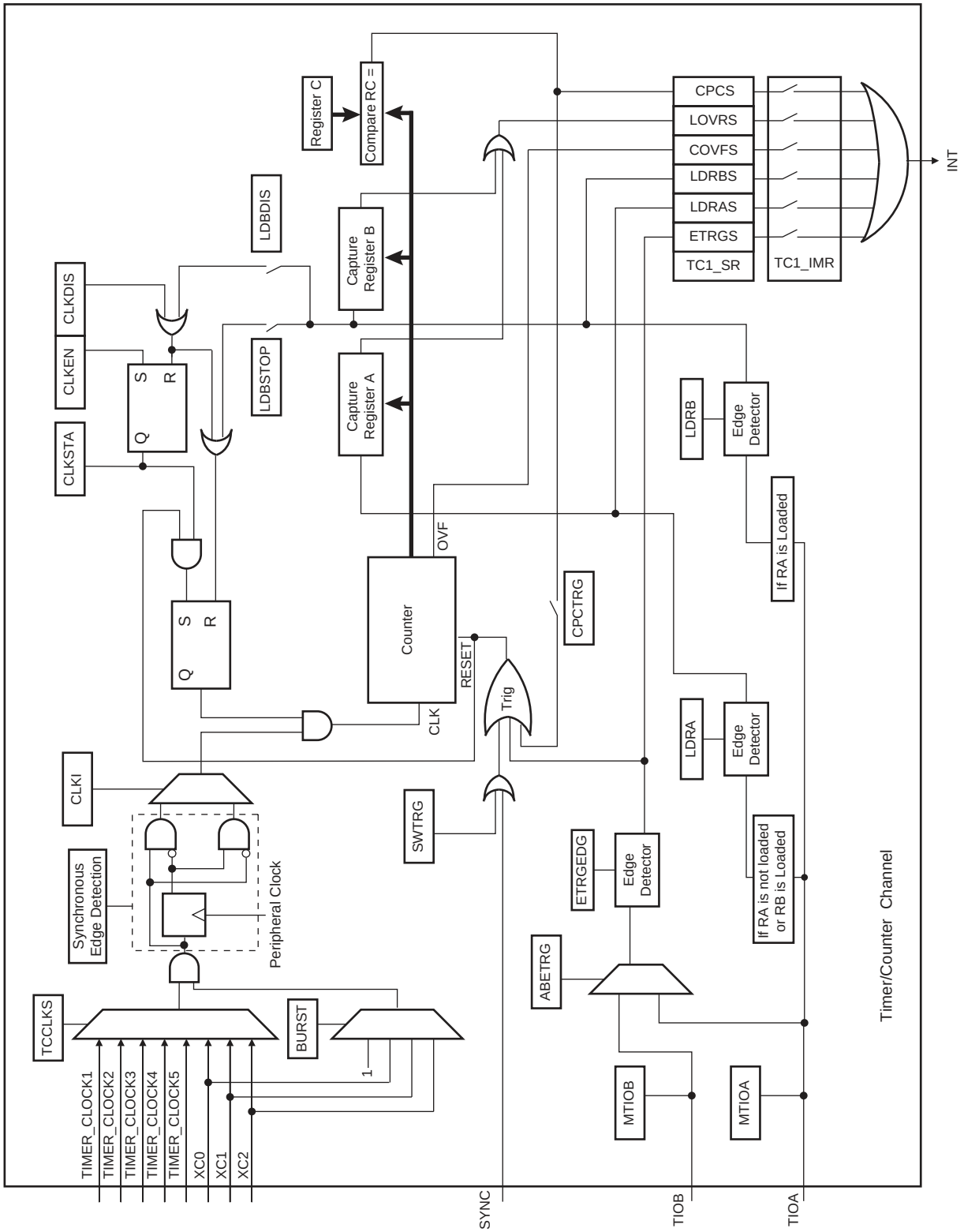
Loading RA or RB before the read of the last value loaded sets the Overrun Error Flag (LOVRS bit) in the TC_SR. In this case, the old value is overwritten.

35.6.9 Trigger Conditions

In addition to the SYNC signal, the software trigger and the RC compare trigger, an external trigger can be defined.

The ABETRG bit in the TC_CMR selects TIOA or TIOB input signal as an external trigger . The External Trigger Edge Selection parameter (ETRGEDG field in TC_CMR) defines the edge (rising, falling, or both) detected to generate an external trigger. If ETRGEDG = 0 (none), the external trigger is disabled.

Figure 35-5. Capture Mode



35.6.10 Waveform Mode

Waveform mode is entered by setting the TC_CMRx.WAVE bit.

In Waveform mode, the TC channel generates one or two PWM signals with the same frequency and independently programmable duty cycles, or generates different types of one-shot or repetitive pulses.

In this mode, TIOA is configured as an output and TIOB is defined as an output if it is not used as an external event (EEVT parameter in TC_CMR).

Figure 35-6 shows the configuration of the TC channel when programmed in Waveform operating mode.

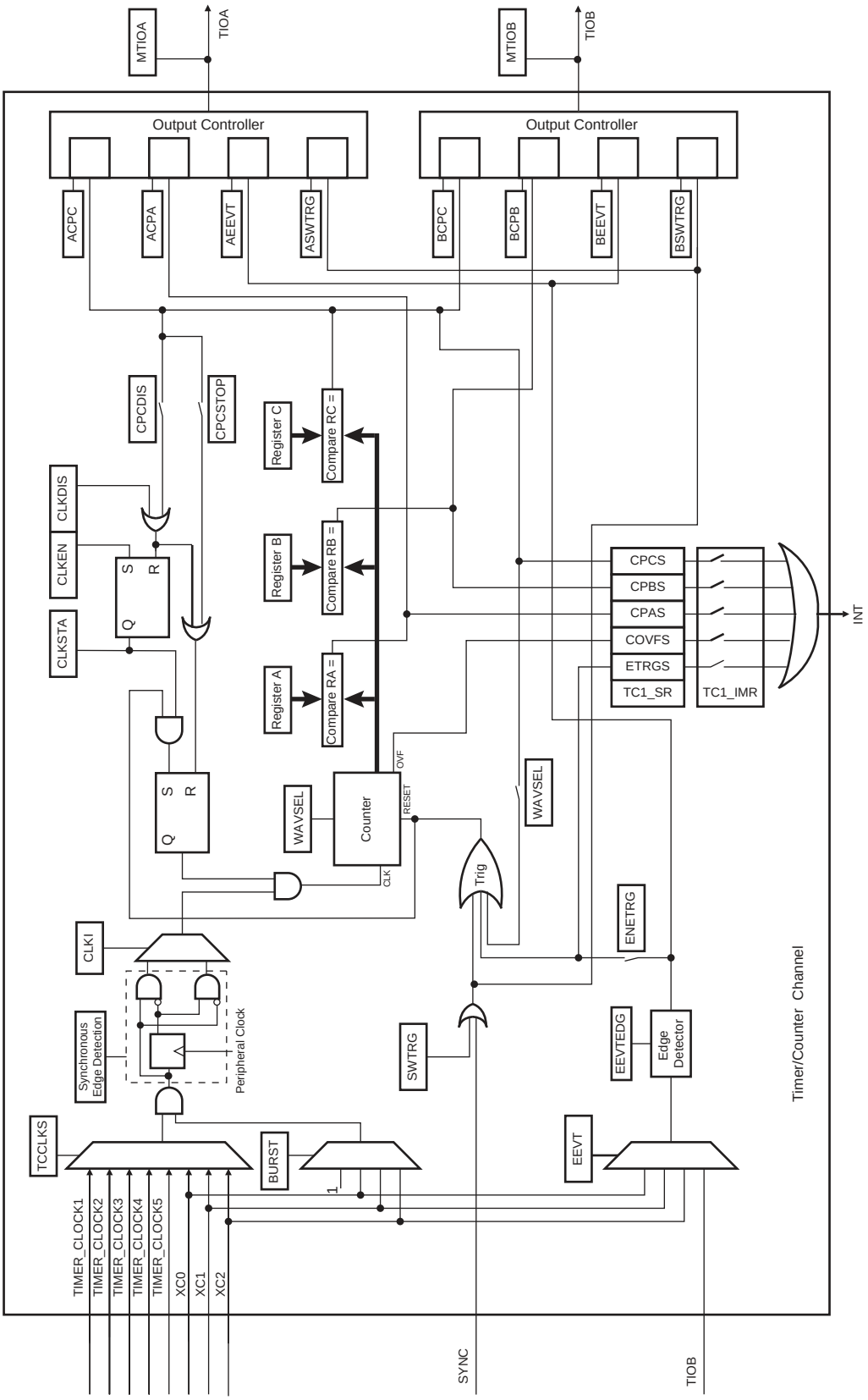
35.6.11 Waveform Selection

Depending on the WAVSEL parameter in TC_CMR, the behavior of TC_CV varies.

With any selection, TC_RA, TC_RB and TC_RC can all be used as compare registers.

RA Compare is used to control the TIOA output, RB Compare is used to control the TIOB output (if correctly configured) and RC Compare is used to control TIOA and/or TIOB outputs.

Figure 35-6. Waveform Mode



35.6.11.1 WAVSEL = 00

When WAVSEL = 00, the value of TC_CV is incremented from 0 to 2^{16}-1. Once 2^{16}-1 has been reached, the value of TC_CV is reset. Incrementation of TC_CV starts again and the cycle continues. See Figure 35-7.

An external event trigger or a software trigger can reset the value of TC_CV. It is important to note that the trigger may occur at any time. See Figure 35-8.

RC Compare cannot be programmed to generate a trigger in this configuration. At the same time, RC Compare can stop the counter clock (CPCSTOP = 1 in TC_CMR) and/or disable the counter clock (CPCDIS = 1 in TC_CMR).

Figure 35-7. WAVSEL = 00 without trigger

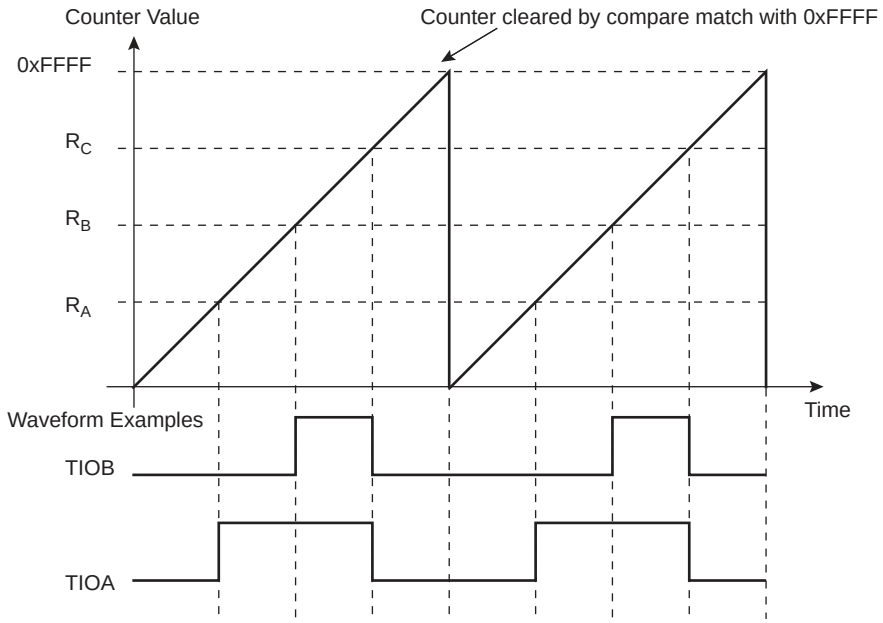
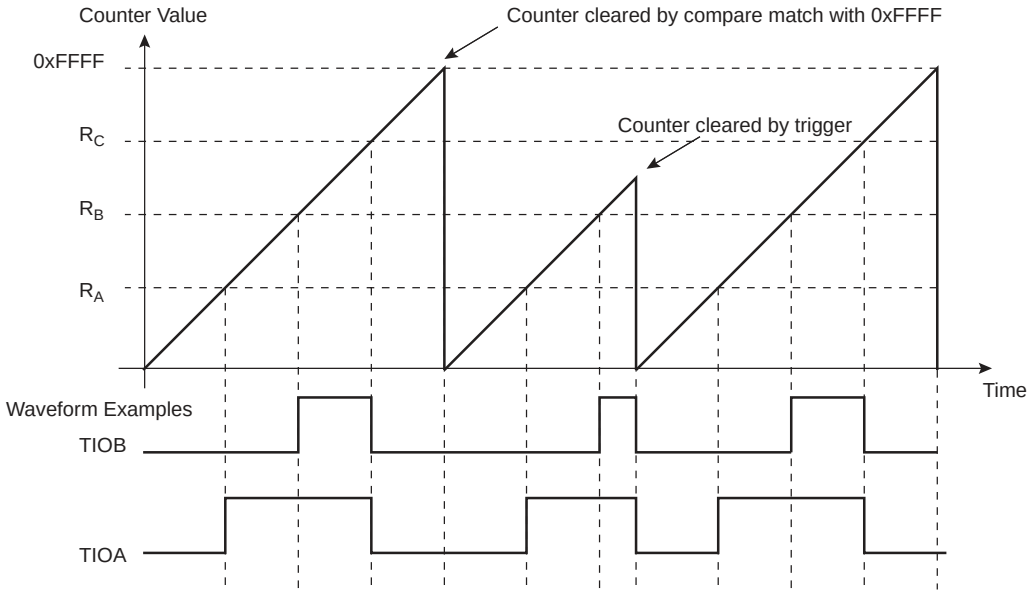


Figure 35-8. WAVSEL = 00 with Trigger



35.6.11.2 WAVSEL = 10

When WAVSEL = 10, the value of TC_CV is incremented from 0 to the value of RC, then automatically reset on a RC Compare. Once the value of TC_CV has been reset, it is then incremented and so on. See Figure 35-9.

It is important to note that TC_CV can be reset at any time by an external event or a software trigger if both are programmed correctly. See Figure 35-10.

In addition, RC Compare can stop the counter clock (CPCSTOP = 1 in TC_CMR) and/or disable the counter clock (CPCDIS = 1 in TC_CMR).

Figure 35-9. WAVSEL = 10 without Trigger

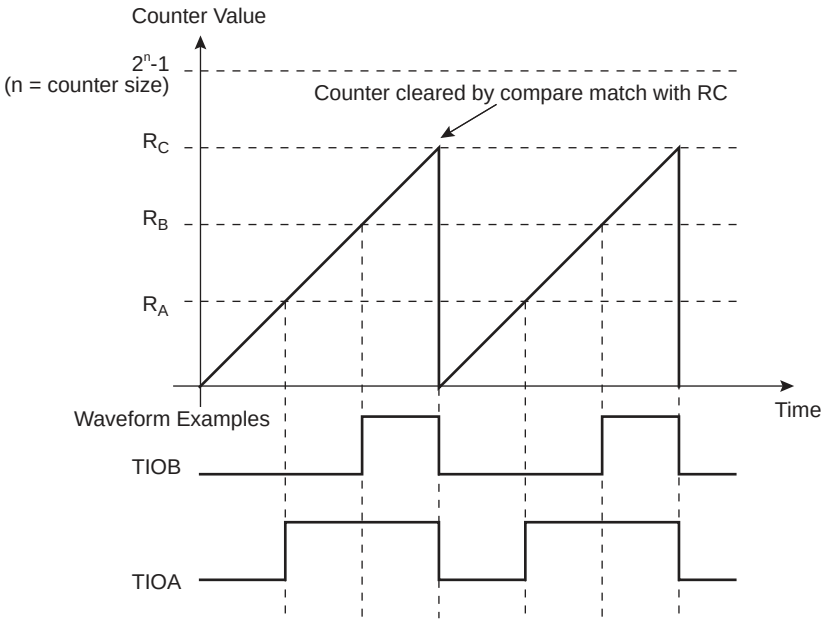
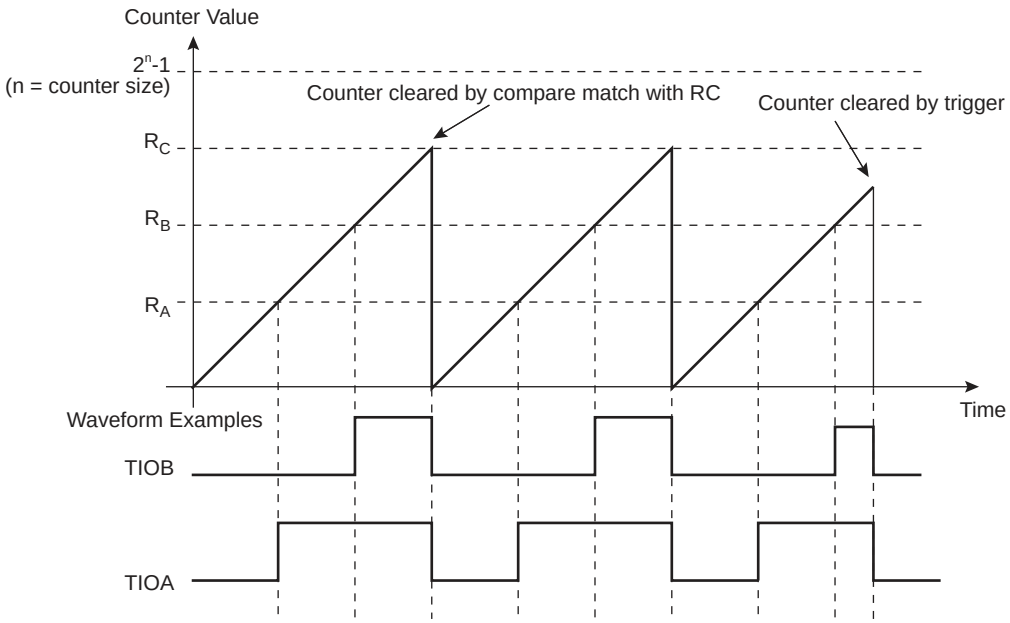


Figure 35-10. WAVSEL = 10 with Trigger



35.6.11.3 WAVSEL = 01

When WAVSEL = 01, the value of TC_CV is incremented from 0 to 2^{16}-1 . Once 2^{16}-1 is reached, the value of TC_CV is decremented to 0, then re-incremented to 2^{16}-1 and so on. See Figure 35-11.

A trigger such as an external event or a software trigger can modify TC_CV at any time. If a trigger occurs while TC_CV is incrementing, TC_CV then decrements. If a trigger is received while TC_CV is decrementing, TC_CV then increments. See Figure 35-12.

RC Compare cannot be programmed to generate a trigger in this configuration.

At the same time, RC Compare can stop the counter clock (CPCSTOP = 1) and/or disable the counter clock (CPCDIS = 1).

Figure 35-11. WAVSEL = 01 without Trigger

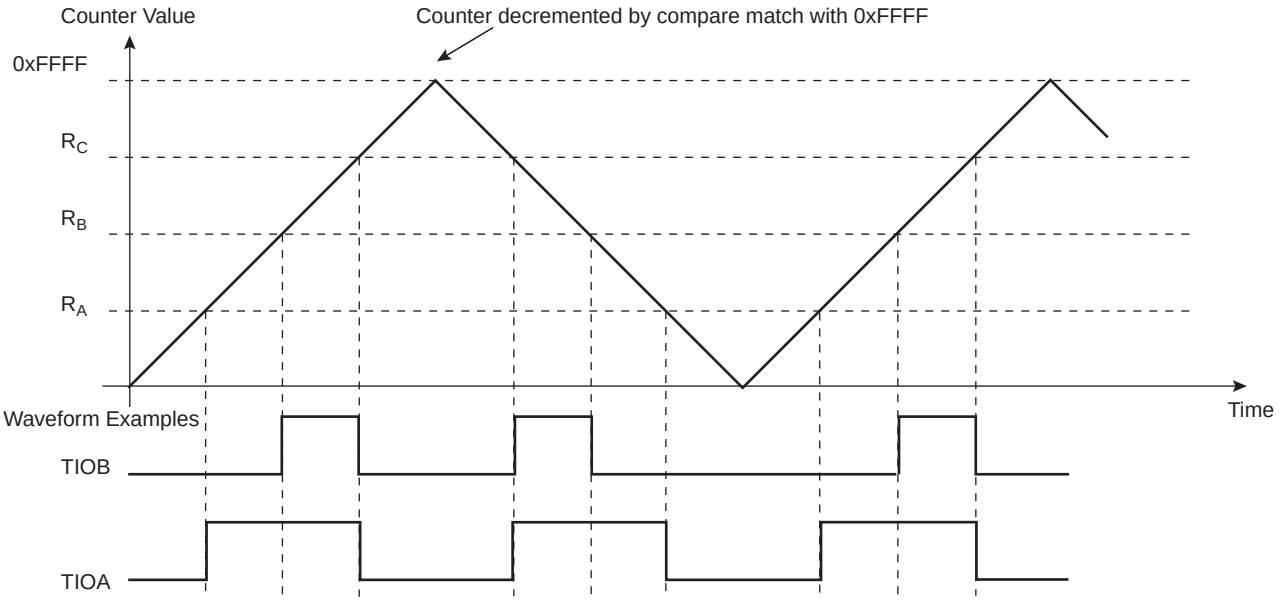
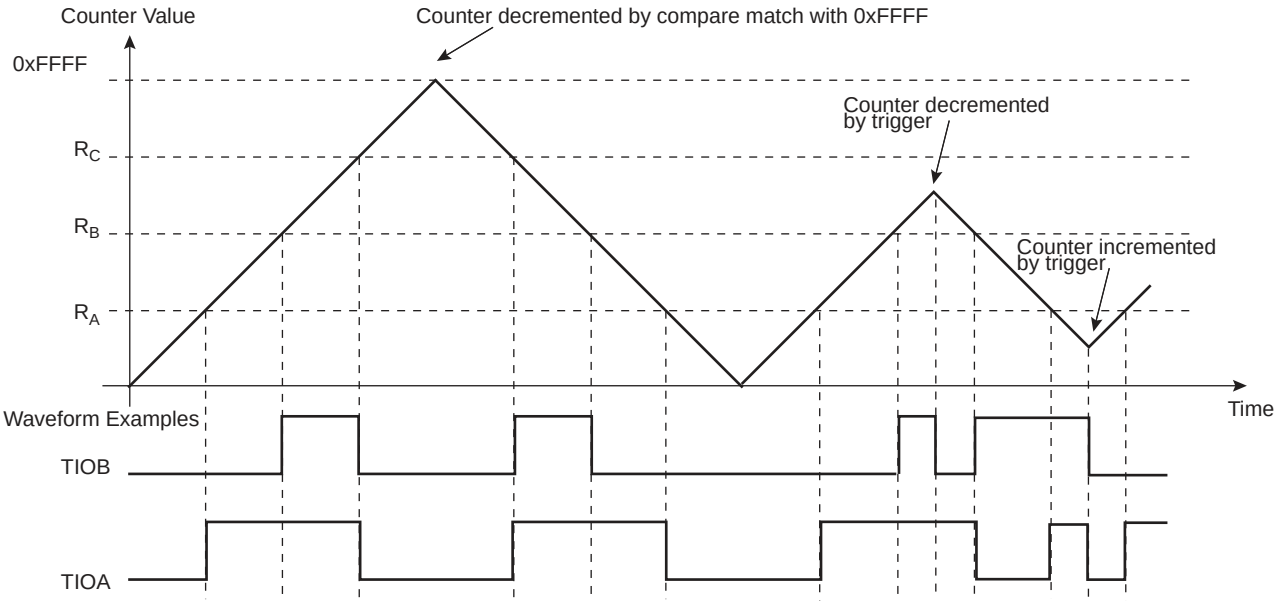


Figure 35-12. WAVSEL = 01 with Trigger



35.6.11.4 WAVSEL = 11

When WAVSEL = 11, the value of TC_CV is incremented from 0 to RC. Once RC is reached, the value of TC_CV is decremented to 0, then re-incremented to RC and so on. See Figure 35-13.

A trigger such as an external event or a software trigger can modify TC_CV at any time. If a trigger occurs while TC_CV is incrementing, TC_CV then decrements. If a trigger is received while TC_CV is decrementing, TC_CV then increments. See Figure 35-14.

RC Compare can stop the counter clock (CPCSTOP = 1) and/or disable the counter clock (CPCDIS = 1).

Figure 35-13. WAVSEL = 11 without Trigger

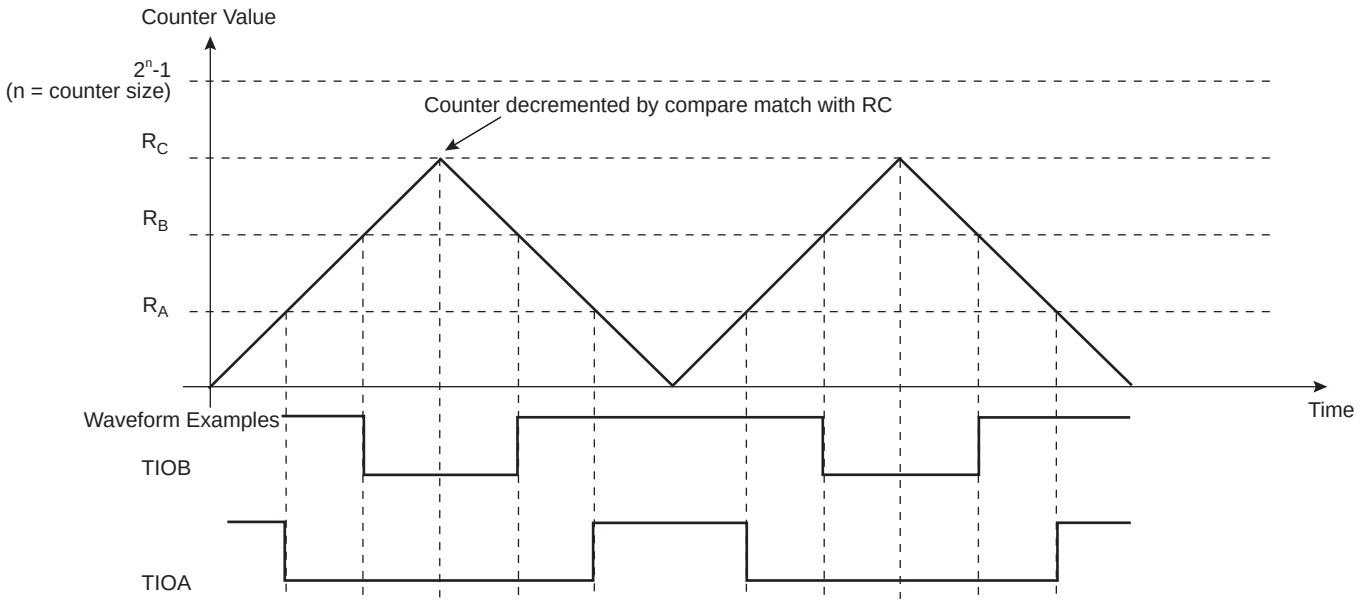
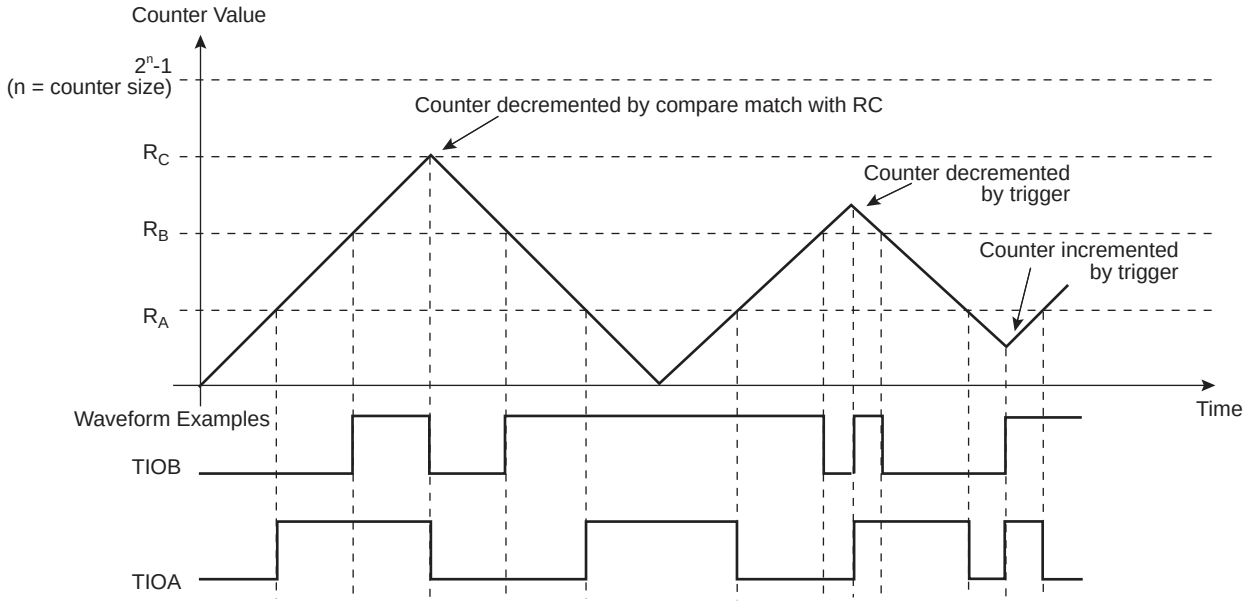


Figure 35-14. WAVSEL = 11 with Trigger



35.6.12 External Event/Trigger Conditions

An external event can be programmed to be detected on one of the clock sources (XC0, XC1, XC2) or TIOB. The external event selected can then be used as a trigger.

The EEVT parameter in TC_CMR selects the external trigger. The EEVTEDG parameter defines the trigger edge for each of the possible external triggers (rising, falling or both). If EEVTEDG is cleared (none), no external event is defined.

If TIOB is defined as an external event signal (EEVT = 0), TIOB is no longer used as an output and the compare register B is not used to generate waveforms and subsequently no IRQs. In this case the TC channel can only generate a waveform on TIOA.

When an external event is defined, it can be used as a trigger by setting bit ENETRG in the TC_CMR.

As in Capture mode, the SYNC signal and the software trigger are also available as triggers. RC Compare can also be used as a trigger depending on the parameter WAVSEL.

35.6.13 Output Controller

The output controller defines the output level changes on TIOA and TIOB following an event. TIOB control is used only if TIOB is defined as output (not as an external event).

The following events control TIOA and TIOB: software trigger, external event and RC compare. RA compare controls TIOA and RB compare controls TIOB. Each of these events can be programmed to set, clear or toggle the output as defined in the corresponding parameter in TC_CMR.

35.6.14 Quadrature Decoder

35.6.14.1 Description

The quadrature decoder (QDEC) is driven by TIOA0, TIOB0, TIOB1 input pins and drives the timer/counter of channel 0 and 1. Channel 2 can be used as a time base in case of speed measurement requirements (refer to Figure 35-15).

When writing a 0 to bit QDEN of the TC_BMR, the QDEC is bypassed and the IO pins are directly routed to the timer counter function. See

TIOA0 and TIOB0 are to be driven by the two dedicated quadrature signals from a rotary sensor mounted on the shaft of the off-chip motor.

A third signal from the rotary sensor can be processed through pin TIOB1 and is typically dedicated to be driven by an index signal if it is provided by the sensor. This signal is not required to decode the quadrature signals PHA, PHB.

Field TCCLKS of TC_CMRx must be configured to select XC0 input (i.e., 0x101). Field TC0XC0S has no effect as soon as the QDEC is enabled.

Either speed or position/revolution can be measured. Position channel 0 accumulates the edges of PHA, PHB input signals giving a high accuracy on motor position whereas channel 1 accumulates the index pulses of the sensor, therefore the number of rotations. Concatenation of both values provides a high level of precision on motion system position.

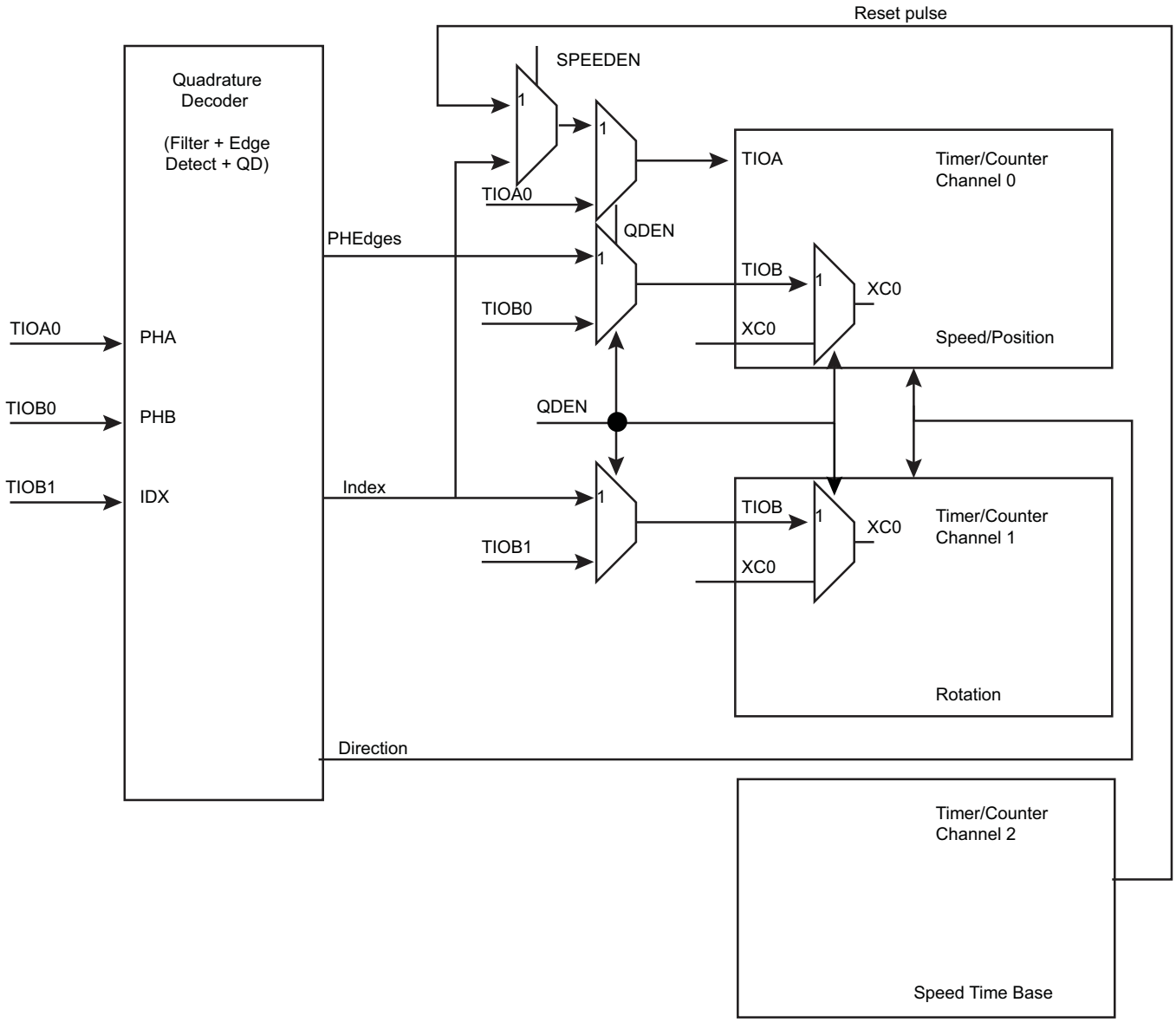
In Speed mode, position cannot be measured but revolution can be measured.

Inputs from the rotary sensor can be filtered prior to down-stream processing. Accommodation of input polarity, phase definition and other factors are configurable.

Interruptions can be generated on different events.

A compare function (using TC_RC) is available on channel 0 (speed/position) or channel 1 (rotation) and can generate an interrupt by means of the CPCS flag in the TC_SRx.

Figure 35-15. Predefined Connection of the Quadrature Decoder with Timer Counters



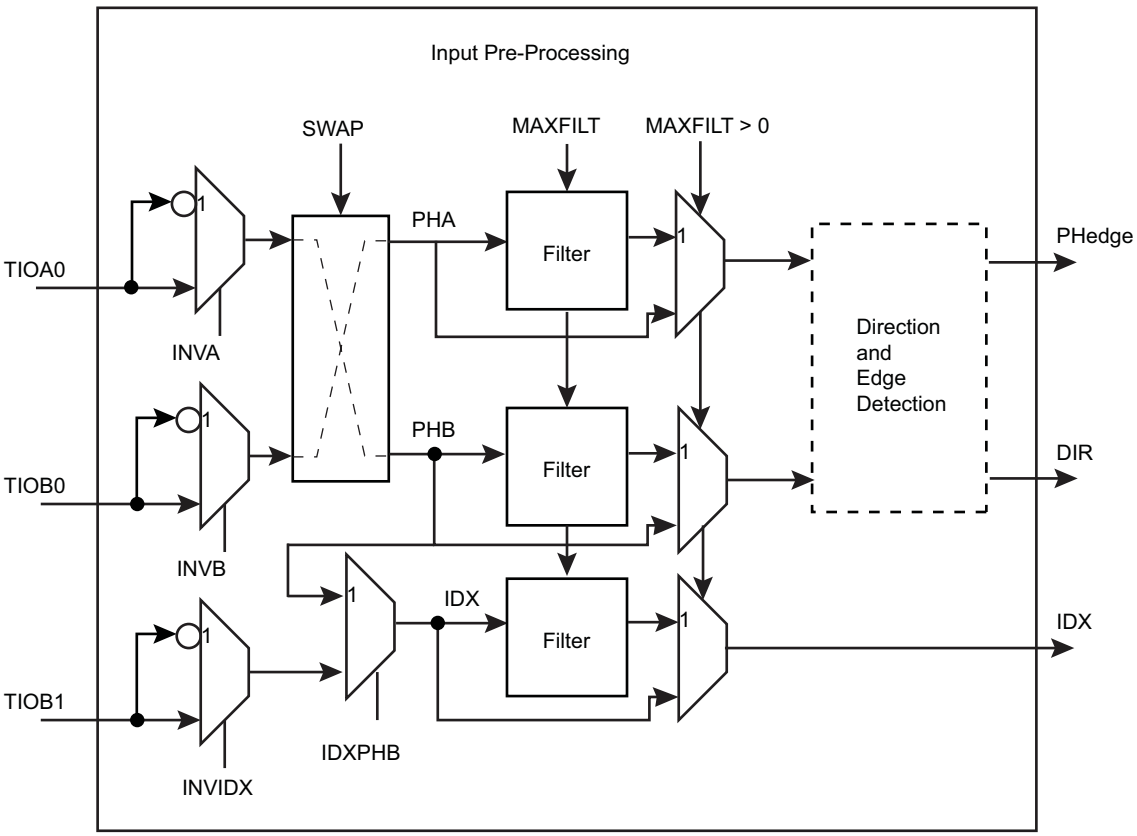
35.6.14.2 Input Pre-processing

Input pre-processing consists of capabilities to take into account rotary sensor factors such as polarities and phase definition followed by configurable digital filtering.

Each input can be negated and swapping PHA, PHB is also configurable.

The MAXFILT field in the TC_BMR is used to configure a minimum duration for which the pulse is stated as valid. When the filter is active, pulses with a duration lower than MAXFILT +1 $\times$ $t_{peripheral\ clock}$ ns are not passed to downstream logic.

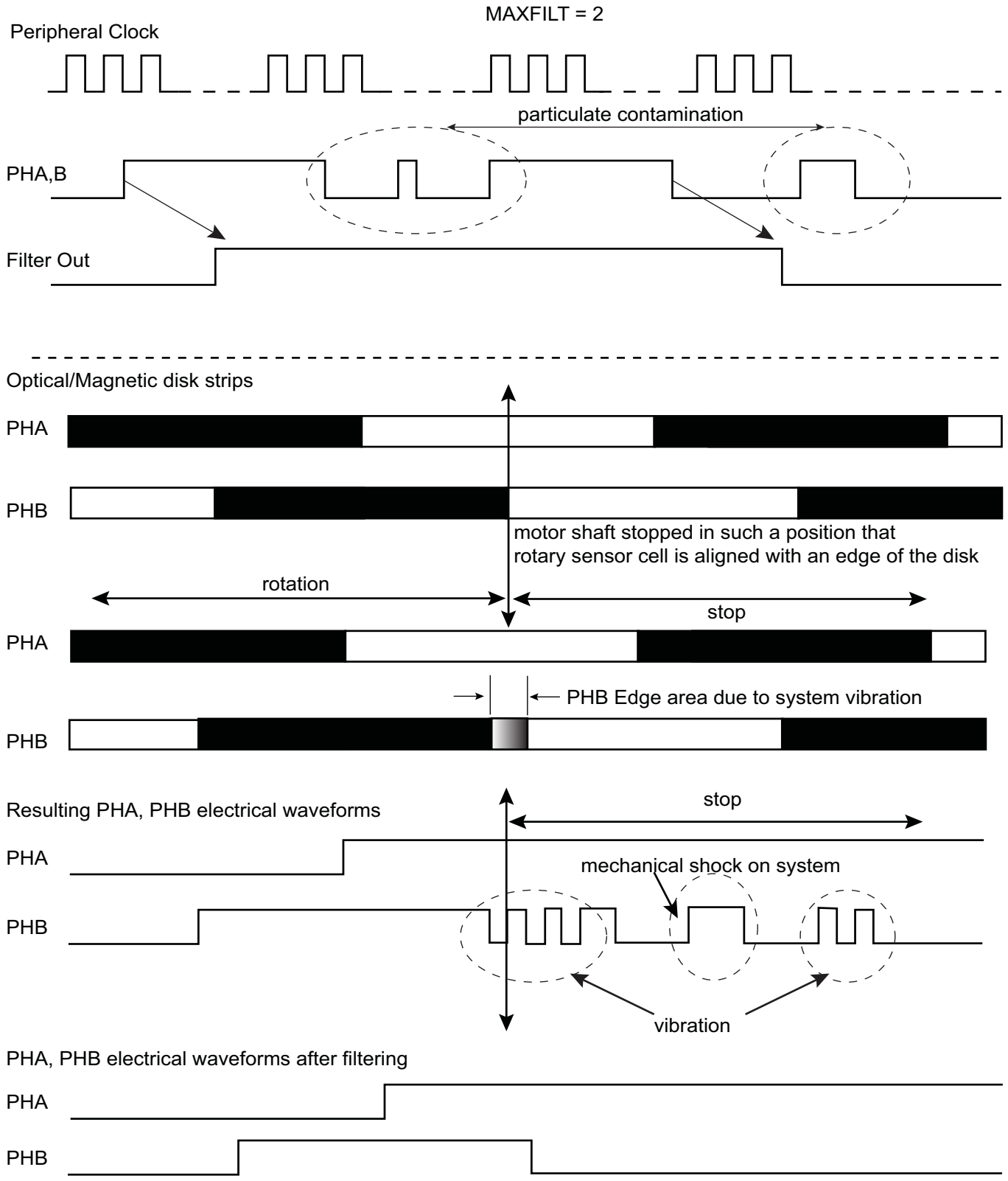
Figure 35-16. Input Stage



Input filtering can efficiently remove spurious pulses that might be generated by the presence of particulate contamination on the optical or magnetic disk of the rotary sensor.

Spurious pulses can also occur in environments with high levels of electro-magnetic interference. Or, simply if vibration occurs even when rotation is fully stopped and the shaft of the motor is in such a position that the beginning of one of the reflective or magnetic bars on the rotary sensor disk is aligned with the light or magnetic (Hall) receiver cell of the rotary sensor. Any vibration can make the PHA, PHB signals toggle for a short duration.

Figure 35-17. Filtering Examples



35.6.14.3 Direction Status and Change Detection

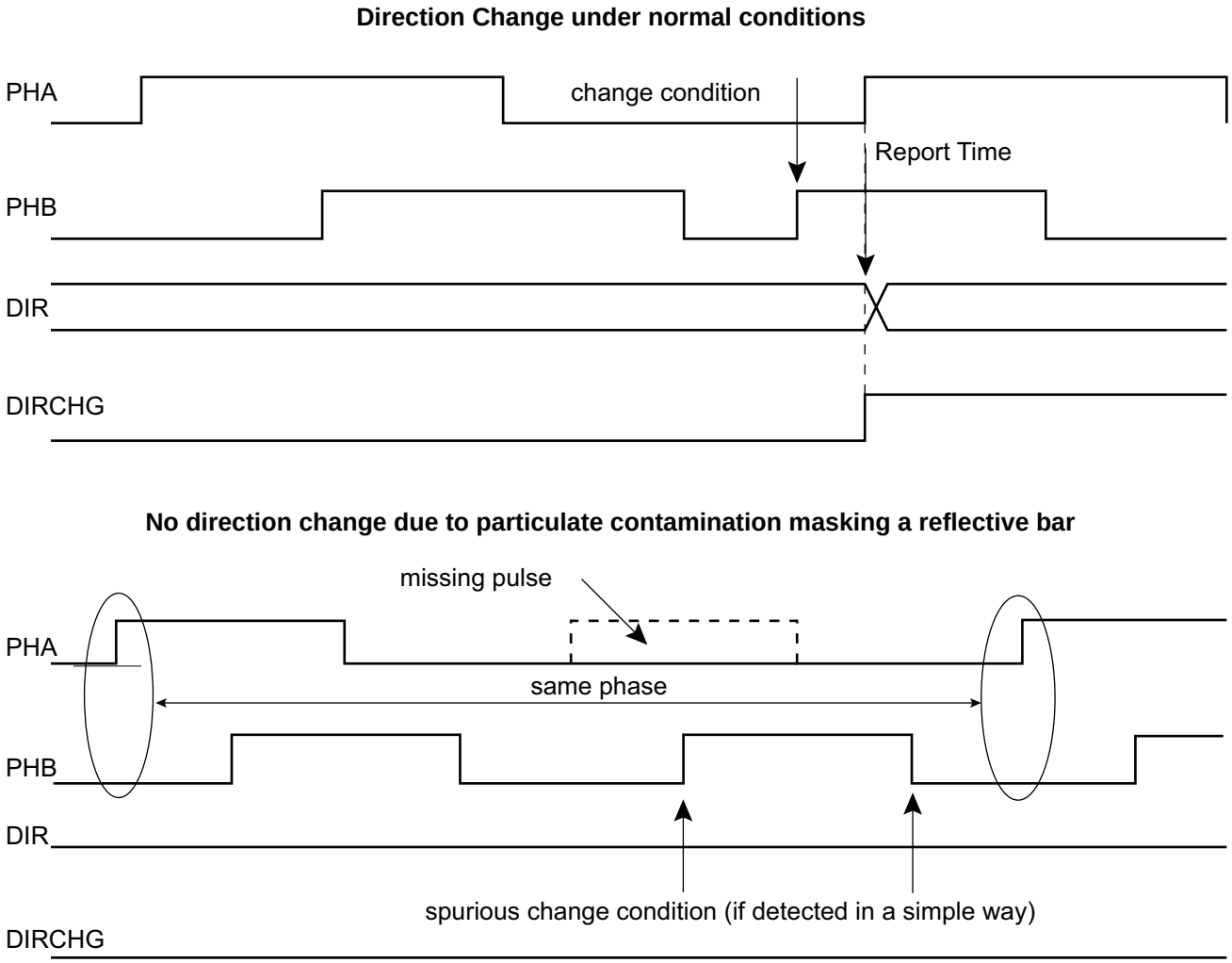
After filtering, the quadrature signals are analyzed to extract the rotation direction and edges of the two quadrature signals detected in order to be counted by timer/counter logic downstream.

The direction status can be directly read at anytime in the TC_QISR. The polarity of the direction flag status depends on the configuration written in TC_BMR. INVA, INVB, INVIDX, SWAP modify the polarity of DIR flag.

Any change in rotation direction is reported in the TC_QISR and can generate an interrupt.

The direction change condition is reported as soon as two consecutive edges on a phase signal have sampled the same value on the other phase signal and there is an edge on the other signal. The two consecutive edges of one phase signal sampling the same value on other phase signal is not sufficient to declare a direction change, for the reason that particulate contamination may mask one or more reflective bars on the optical or magnetic disk of the sensor. Refer to Figure 35-18 for waveforms.

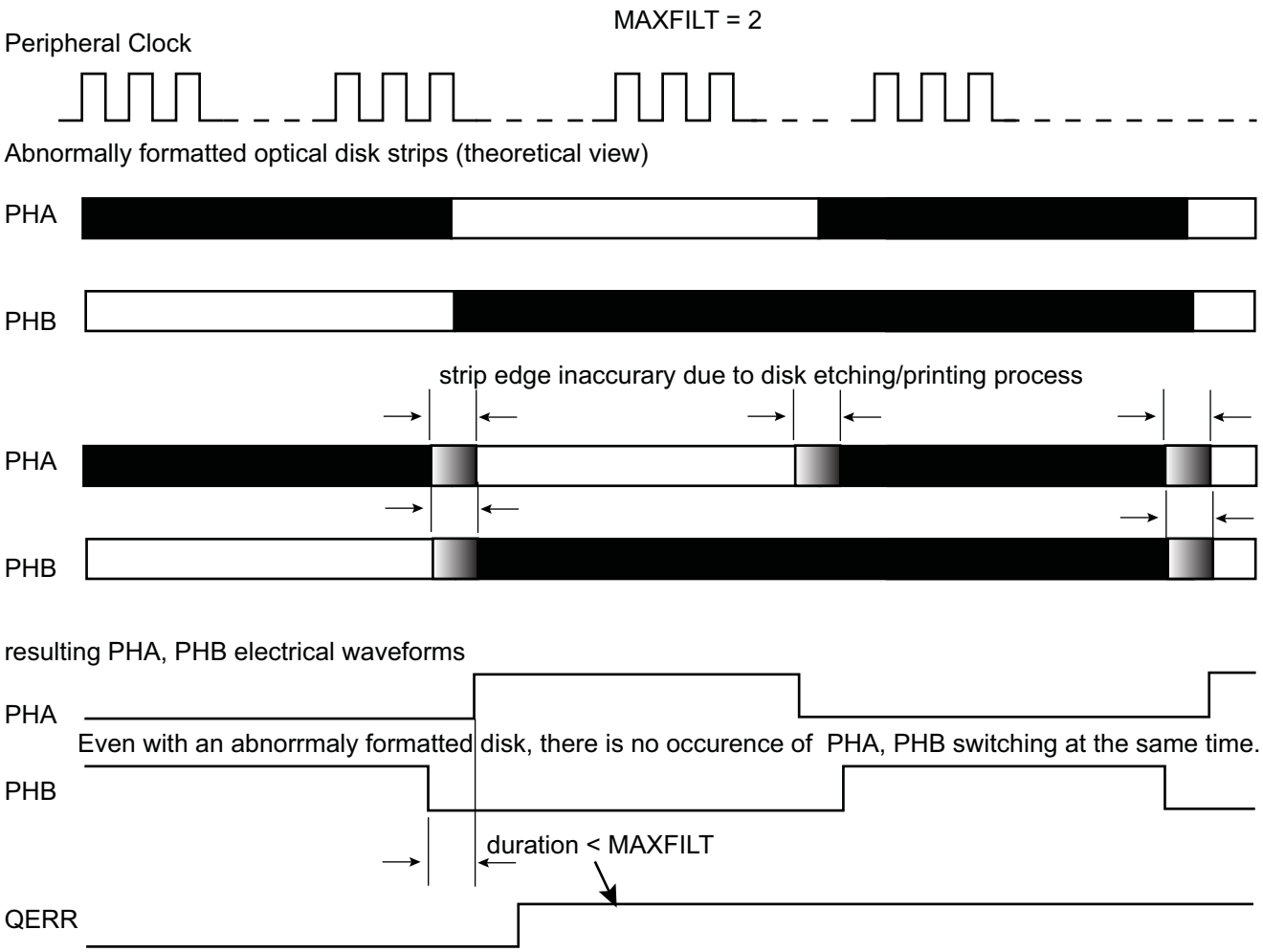
Figure 35-18. Rotation Change Detection



The direction change detection is disabled when QDTRANS is set in the TC_BMR. In this case, the DIR flag report must not be used.

A quadrature error is also reported by the QDEC via the QERR flag in the TC_QISR. This error is reported if the time difference between two edges on PHA, PHB is lower than a predefined value. This predefined value is configurable and corresponds to (MAXFILT + 1) × $t_{peripheral\ clock}$ ns. After being filtered there is no reason to have two edges closer than (MAXFILT + 1) × $t_{peripheral\ clock}$ ns under normal mode of operation.

Figure 35-19. Quadrature Error Detection



MAXFILT must be tuned according to several factors such as the peripheral clock frequency, type of rotary sensor and rotation speed to be achieved.

35.6.14.4 Position and Rotation Measurement

When the POSEN bit is set in the TC_BMR, the motor axis position is processed on channel 0 (by means of the PHA, PHB edge detections) and the number of motor revolutions are recorded on channel 1 if the IDX signal is provided on the TIOB1 input. The position measurement can be read in the TC_CV0 register and the rotation measurement can be read in the TC_CV1 register.

Channel 0 and 1 must be configured in Capture mode (TC_CMR0.WAVE = 0). ‘Rising edge’ must be selected as the External Trigger Edge (TC_CMR.ETRGEDG = 0x01) and ‘TIOA’ must be selected as the External Trigger (TC_CMR.ABETRG = 0x1).

In parallel, the number of edges are accumulated on timer/counter channel 0 and can be read on the TC_CV0 register.

Therefore, the accurate position can be read on both TC_CV registers and concatenated to form a 32-bit word.

The timer/counter channel 0 is cleared for each increment of IDX count value.

Depending on the quadrature signals, the direction is decoded and allows to count up or down in timer/counter channels 0 and 1. The direction status is reported on TC_QISR.

35.6.14.5 Speed Measurement

When SPEEDEN is set in the TC_BMR, the speed measure is enabled on channel 0.

A time base must be defined on channel 2 by writing the TC_RC2 period register. Channel 2 must be configured in Waveform mode (WAVE bit set) in TC_CMR2. The WAVSEL field must be defined with 0x10 to clear the counter by comparison and matching with TC_RC value. Field ACPC must be defined at 0x11 to toggle TIOA output.

This time base is automatically fed back to TIOA of channel 0 when QDEN and SPEEDEN are set.

Channel 0 must be configured in Capture mode (WAVE = 0 in TC_CMR0). The ABETRG bit of TC_CMR0 must be configured at 1 to select TIOA as a trigger for this channel.

EDGTRG must be set to 0x01, to clear the counter on a rising edge of the TIOA signal and field LDRA must be set accordingly to 0x01, to load TC_RA0 at the same time as the counter is cleared (LDRB must be set to 0x01). As a consequence, at the end of each time base period the differentiation required for the speed calculation is performed.

The process must be started by configuring bits CLKEN and SWTRG in the TC_CCR.

The speed can be read on field RA in TC_RA0.

Channel 1 can still be used to count the number of revolutions of the motor.

35.7 Timer Counter (TC) User Interface

Table 35-6. Register Mapping

Offset[1]	Register	Name	Access	Reset
0x00 + channel * 0x40 + 0x00	Channel Control Register	TC_CCR	Write-only	–
0x00 + channel * 0x40 + 0x04	Channel Mode Register	TC_CMR	Read/Write	0
0x00 + channel * 0x40 + 0x08	Reserved	–	–	–
0x00 + channel * 0x40 + 0x0C	Reserved	–	–	–
0x00 + channel * 0x40 + 0x10	Counter Value	TC_CV	Read-only	0
0x00 + channel * 0x40 + 0x14	Register A	TC_RA	Read/Write[2]	0
0x00 + channel * 0x40 + 0x18	Register B	TC_RB	Read/Write[2]	0
0x00 + channel * 0x40 + 0x1C	Register C	TC_RC	Read/Write	0
0x00 + channel * 0x40 + 0x20	Status Register	TC_SR	Read-only	0
0x00 + channel * 0x40 + 0x24	Interrupt Enable Register	TC_IER	Write-only	–
0x00 + channel * 0x40 + 0x28	Interrupt Disable Register	TC_IDR	Write-only	–
0x00 + channel * 0x40 + 0x2C	Interrupt Mask Register	TC_IMR	Read-only	0
0xC0	Block Control Register	TC_BCR	Write-only	–
0xC4	Block Mode Register	TC_BMR	Read/Write	0
0xC8	QDEC Interrupt Enable Register	TC_QIER	Write-only	–
0xCC	QDEC Interrupt Disable Register	TC_QIDR	Write-only	–
0xD0	QDEC Interrupt Mask Register	TC_QIMR	Read-only	0
0xD4	QDEC Interrupt Status Register	TC_QISR	Read-only	0
0xD8	Reserved	–	–	–
0xE4	Reserved	–	–	–
0xE8–0xFC	Reserved	–	–	–

Notes: 1. Channel index ranges from 0 to 2.
2. Read-only if TC_CMRx.WAVE = 0

35.7.1 TC Channel Control Register

Name: TC_CCRx [x=0..2]

Address: 0x40080000 (0)[0], 0x40080040 (0)[1], 0x40080080 (0)[2]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	SWTRG	CLKDIS	CLKEN

- **CLKEN: Counter Clock Enable Command**

0: No effect.

1: Enables the clock if CLKDIS is not 1.

- **CLKDIS: Counter Clock Disable Command**

0: No effect.

1: Disables the clock.

- **SWTRG: Software Trigger Command**

0: No effect.

1: A software trigger is performed: the counter is reset and the clock is started.

35.7.2 TC Channel Mode Register: Capture Mode

Name: TC_CMRx [x=0..2] (CAPTURE_MODE)

Address: 0x40080004 (0)[0], 0x40080044 (0)[1], 0x40080084 (0)[2]

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	LDRB		LDRA	
15	14	13	12	11	10	9	8
WAVE	CPCTRG	–	–	–	ABETRG	ETRGEDG	
7	6	5	4	3	2	1	0
LDBDIS	LDBSTOP	BURST		CLKI	TCCLKS		

- **TCCLKS: Clock Selection**

Value	Name	Description
0	TIMER_CLOCK1	Clock selected: internal MCK/2 clock signal (from PMC)
1	TIMER_CLOCK2	Clock selected: internal MCK/8 clock signal (from PMC)
2	TIMER_CLOCK3	Clock selected: internal MCK/32 clock signal (from PMC)
3	TIMER_CLOCK4	Clock selected: internal MCK/128 clock signal (from PMC)
4	TIMER_CLOCK5	Clock selected: internal SLCK clock signal (from PMC)
5	XC0	Clock selected: XC0
6	XC1	Clock selected: XC1
7	XC2	Clock selected: XC2

- **CLKI: Clock Invert**

0: Counter is incremented on rising edge of the clock.

1: Counter is incremented on falling edge of the clock.

- **BURST: Burst Signal Selection**

Value	Name	Description
0	NONE	The clock is not gated by an external signal.
1	XC0	XC0 is ANDed with the selected clock.
2	XC1	XC1 is ANDed with the selected clock.
3	XC2	XC2 is ANDed with the selected clock.

- **LDBSTOP: Counter Clock Stopped with RB Loading**

0: Counter clock is not stopped when RB loading occurs.

1: Counter clock is stopped when RB loading occurs.

- **LDBDIS: Counter Clock Disable with RB Loading**

0: Counter clock is not disabled when RB loading occurs.

1: Counter clock is disabled when RB loading occurs.

- **ETRGEDG: External Trigger Edge Selection**

Value	Name	Description
0	NONE	The clock is not gated by an external signal.
1	RISING	Rising edge
2	FALLING	Falling edge
3	EDGE	Each edge

- **ABETRG: TIOA or TIOB External Trigger Selection**

0: TIOB is used as an external trigger.

1: TIOA is used as an external trigger.

- **CPCTRG: RC Compare Trigger Enable**

0: RC Compare has no effect on the counter and its clock.

1: RC Compare resets the counter and starts the counter clock.

- **WAVE: Waveform Mode**

0: Capture mode is enabled.

1: Capture mode is disabled (Waveform mode is enabled).

- **LDRA: RA Loading Edge Selection**

Value	Name	Description
0	NONE	None
1	RISING	Rising edge of TIOA
2	FALLING	Falling edge of TIOA
3	EDGE	Each edge of TIOA

- **LDRB: RB Loading Edge Selection**

Value	Name	Description
0	NONE	None
1	RISING	Rising edge of TIOA
2	FALLING	Falling edge of TIOA
3	EDGE	Each edge of TIOA

35.7.3 TC Channel Mode Register: Waveform Mode

Name: TC_CMRx [x=0..2] (WAVEFORM_MODE)

Address: 0x40080004 (0)[0], 0x40080044 (0)[1], 0x40080084 (0)[2]

Access: Read/Write

31	30	29	28	27	26	25	24
BSWTRG		BEEVT		BCPC		BCPB	
23	22	21	20	19	18	17	16
ASWTRG		AEEVT		ACPC		ACPA	
15	14	13	12	11	10	9	8
WAVE	WAVSEL		ENETRG	EEVT		EEVTEDG	
7	6	5	4	3	2	1	0
CPCDIS	CPCSTOP	BURST		CLKI	TCCLKS		

- **TCCLKS: Clock Selection**

Value	Name	Description
0	TIMER_CLOCK1	Clock selected: internal MCK/2 clock signal (from PMC)
1	TIMER_CLOCK2	Clock selected: internal MCK/8 clock signal (from PMC)
2	TIMER_CLOCK3	Clock selected: internal MCK/32 clock signal (from PMC)
3	TIMER_CLOCK4	Clock selected: internal MCK/128 clock signal (from PMC)
4	TIMER_CLOCK5	Clock selected: internal SLCK clock signal (from PMC)
5	XC0	Clock selected: XC0
6	XC1	Clock selected: XC1
7	XC2	Clock selected: XC2

- **CLKI: Clock Invert**

0: Counter is incremented on rising edge of the clock.

1: Counter is incremented on falling edge of the clock.

- **BURST: Burst Signal Selection**

Value	Name	Description
0	NONE	The clock is not gated by an external signal.
1	XC0	XC0 is ANDed with the selected clock.
2	XC1	XC1 is ANDed with the selected clock.
3	XC2	XC2 is ANDed with the selected clock.

- **CPCSTOP: Counter Clock Stopped with RC Compare**

0: Counter clock is not stopped when counter reaches RC.

1: Counter clock is stopped when counter reaches RC.

- **CPCDIS: Counter Clock Disable with RC Compare**

0: Counter clock is not disabled when counter reaches RC.

1: Counter clock is disabled when counter reaches RC.

- **EEVTEDG: External Event Edge Selection**

Value	Name	Description
0	NONE	None
1	RISING	Rising edge
2	FALLING	Falling edge
3	EDGE	Each edge

- **EEVT: External Event Selection**

Signal selected as external event.

Value	Name	Description	TIOB Direction
0	TIOB	TIOB(1)	Input
1	XC0	XC0	Output
2	XC1	XC1	Output
3	XC2	XC2	Output

Note: 1. If TIOB is chosen as the external event signal, it is configured as an input and no longer generates waveforms and subsequently no IRQs.

- **ENETRG: External Event Trigger Enable**

0: The external event has no effect on the counter and its clock.

1: The external event resets the counter and starts the counter clock.

Note: Whatever the value programmed in ENETRG, the selected external event only controls the TIOA output and TIOB if not used as input (trigger event input or other input used).

- **WAVSEL: Waveform Selection**

Value	Name	Description
0	UP	UP mode without automatic trigger on RC Compare
1	UPDOWN	UPDOWN mode without automatic trigger on RC Compare
2	UP_RC	UP mode with automatic trigger on RC Compare
3	UPDOWN_RC	UPDOWN mode with automatic trigger on RC Compare

- **WAVE: Waveform Mode**

0: Waveform mode is disabled (Capture mode is enabled).

1: Waveform mode is enabled.

- **ACPA: RA Compare Effect on TIOA**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **ACPC: RC Compare Effect on TIOA**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **AEEVT: External Event Effect on TIOA**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **ASWTRG: Software Trigger Effect on TIOA**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **BCPB: RB Compare Effect on TIOB**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **BCPC: RC Compare Effect on TIOB**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **BEEVT: External Event Effect on TIOB**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

- **BSWTRG: Software Trigger Effect on TIOB**

Value	Name	Description
0	NONE	None
1	SET	Set
2	CLEAR	Clear
3	TOGGLE	Toggle

35.7.4 TC Counter Value Register

Name: TC_CVx [x=0..2]

Address: 0x40080010 (0)[0], 0x40080050 (0)[1], 0x40080090 (0)[2]

Access: Read-only

31	30	29	28	27	26	25	24
CV							

23	22	21	20	19	18	17	16
CV							

15	14	13	12	11	10	9	8
CV							

7	6	5	4	3	2	1	0
CV							

- **CV: Counter Value**

CV contains the counter value in real time.

IMPORTANT: For 16-bit channels, CV field size is limited to register bits 15:0.

35.7.5 TC Register A

Name: TC_RAx [x=0..2]

Address: 0x40080014 (0)[0], 0x40080054 (0)[1], 0x40080094 (0)[2]

Access: Read-only if TC_CMRx.WAVE = 0, Read/Write if TC_CMRx.WAVE = 1

31	30	29	28	27	26	25	24
RA							

23	22	21	20	19	18	17	16
RA							

15	14	13	12	11	10	9	8
RA							

7	6	5	4	3	2	1	0
RA							

- **RA: Register A**

RA contains the Register A value in real time.

IMPORTANT: For 16-bit channels, RA field size is limited to register bits 15:0.

35.7.6 TC Register B

Name: TC_RBx [x=0..2]

Address: 0x40080018 (0)[0], 0x40080058 (0)[1], 0x40080098 (0)[2]

Access: Read-only if TC_CMRx.WAVE = 0, Read/Write if TC_CMRx.WAVE = 1

31	30	29	28	27	26	25	24
RB							

23	22	21	20	19	18	17	16
RB							

15	14	13	12	11	10	9	8
RB							

7	6	5	4	3	2	1	0
RB							

- **RB: Register B**

RB contains the Register B value in real time.

IMPORTANT: For 16-bit channels, RB field size is limited to register bits 15:0.

35.7.7 TC Register C

Name: TC_RCx [x=0..2]

Address: 0x4008001C (0)[0], 0x4008005C (0)[1], 0x4008009C (0)[2]

Access: Read/Write

31	30	29	28	27	26	25	24
RC							

23	22	21	20	19	18	17	16
RC							

15	14	13	12	11	10	9	8
RC							

7	6	5	4	3	2	1	0
RC							

- **RC: Register C**

RC contains the Register C value in real time.

IMPORTANT: For 16-bit channels, RC field size is limited to register bits 15:0.

35.7.8 TC Status Register

Name: TC_SRx [x=0..2]

Address: 0x40080020 (0)[0], 0x40080060 (0)[1], 0x400800A0 (0)[2]

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	MTIOB	MTIOA	CLKSTA
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
ETRGS	LDRBS	LDRAS	CPCS	CPBS	CPAS	LOVRS	COVFS

- **COVFS: Counter Overflow Status (cleared on read)**

0: No counter overflow has occurred since the last read of the Status Register.

1: A counter overflow has occurred since the last read of the Status Register.

- **LOVRS: Load Overrun Status (cleared on read)**

0: Load overrun has not occurred since the last read of the Status Register or TC_CMRx.WAVE = 1.

1: RA or RB have been loaded at least twice without any read of the corresponding register since the last read of the Status Register, if TC_CMRx.WAVE = 0.

- **CPAS: RA Compare Status (cleared on read)**

0: RA Compare has not occurred since the last read of the Status Register or TC_CMRx.WAVE = 0.

1: RA Compare has occurred since the last read of the Status Register, if TC_CMRx.WAVE = 1.

- **CPBS: RB Compare Status (cleared on read)**

0: RB Compare has not occurred since the last read of the Status Register or TC_CMRx.WAVE = 0.

1: RB Compare has occurred since the last read of the Status Register, if TC_CMRx.WAVE = 1.

- **CPCS: RC Compare Status (cleared on read)**

0: RC Compare has not occurred since the last read of the Status Register.

1: RC Compare has occurred since the last read of the Status Register.

- **LDRAS: RA Loading Status (cleared on read)**

0: RA Load has not occurred since the last read of the Status Register or TC_CMRx.WAVE = 1.

1: RA Load has occurred since the last read of the Status Register, if TC_CMRx.WAVE = 0.

- **LDRBS: RB Loading Status (cleared on read)**

0: RB Load has not occurred since the last read of the Status Register or TC_CMRx.WAVE = 1.

1: RB Load has occurred since the last read of the Status Register, if TC_CMRx.WAVE = 0.

- **ETRGS: External Trigger Status (cleared on read)**

0: External trigger has not occurred since the last read of the Status Register.

1: External trigger has occurred since the last read of the Status Register.

- **CLKSTA: Clock Enabling Status**

0: Clock is disabled.

1: Clock is enabled.

- **MTIOA: TIOA Mirror**

0: TIOA is low. If TC_CMRx.WAVE = 0, this means that TIOA pin is low. If TC_CMRx.WAVE = 1, this means that TIOA is driven low.

1: TIOA is high. If TC_CMRx.WAVE = 0, this means that TIOA pin is high. If TC_CMRx.WAVE = 1, this means that TIOA is driven high.

- **MTIOB: TIOB Mirror**

0: TIOB is low. If TC_CMRx.WAVE = 0, this means that TIOB pin is low. If TC_CMRx.WAVE = 1, this means that TIOB is driven low.

1: TIOB is high. If TC_CMRx.WAVE = 0, this means that TIOB pin is high. If TC_CMRx.WAVE = 1, this means that TIOB is driven high.

35.7.9 TC Interrupt Enable Register

Name: TC_IERx [x=0..2]

Address: 0x40080024 (0)[0], 0x40080064 (0)[1], 0x400800A4 (0)[2]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
ETRGS	LDRBS	LDRAS	CPCS	CPBS	CPAS	LOVRS	COVFS

- **COVFS: Counter Overflow**

0: No effect.

1: Enables the Counter Overflow Interrupt.

- **LOVRS: Load Overrun**

0: No effect.

1: Enables the Load Overrun Interrupt.

- **CPAS: RA Compare**

0: No effect.

1: Enables the RA Compare Interrupt.

- **CPBS: RB Compare**

0: No effect.

1: Enables the RB Compare Interrupt.

- **CPCS: RC Compare**

0: No effect.

1: Enables the RC Compare Interrupt.

- **LDRAS: RA Loading**

0: No effect.

1: Enables the RA Load Interrupt.

- **LDRBS: RB Loading**

0: No effect.

1: Enables the RB Load Interrupt.

- **ETRGS: External Trigger**

0: No effect.

1: Enables the External Trigger Interrupt.

35.7.10 TC Interrupt Disable Register

Name: TC_IDRx [x=0..2]

Address: 0x40080028 (0)[0], 0x40080068 (0)[1], 0x400800A8 (0)[2]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
ETRGS	LDRBS	LDRAS	CPCS	CPBS	CPAS	LOVRS	COVFS

- **COVFS: Counter Overflow**

0: No effect.

1: Disables the Counter Overflow Interrupt.

- **LOVRS: Load Overrun**

0: No effect.

1: Disables the Load Overrun Interrupt (if TC_CMRx.WAVE = 0).

- **CPAS: RA Compare**

0: No effect.

1: Disables the RA Compare Interrupt (if TC_CMRx.WAVE = 1).

- **CPBS: RB Compare**

0: No effect.

1: Disables the RB Compare Interrupt (if TC_CMRx.WAVE = 1).

- **CPCS: RC Compare**

0: No effect.

1: Disables the RC Compare Interrupt.

- **LDRAS: RA Loading**

0: No effect.

1: Disables the RA Load Interrupt (if TC_CMRx.WAVE = 0).

- **LDRBS: RB Loading**

0: No effect.

1: Disables the RB Load Interrupt (if TC_CMRx.WAVE = 0).

- **ETRGS: External Trigger**

0: No effect.

1: Disables the External Trigger Interrupt.

35.7.11 TC Interrupt Mask Register

Name: TC_IMRx [x=0..2]

Address: 0x4008002C (0)[0], 0x4008006C (0)[1], 0x400800AC (0)[2]

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
ETRGS	LDRBS	LDRAS	CPCS	CPBS	CPAS	LOVRS	COVFS

- **COVFS: Counter Overflow**

0: The Counter Overflow Interrupt is disabled.

1: The Counter Overflow Interrupt is enabled.

- **LOVRS: Load Overrun**

0: The Load Overrun Interrupt is disabled.

1: The Load Overrun Interrupt is enabled.

- **CPAS: RA Compare**

0: The RA Compare Interrupt is disabled.

1: The RA Compare Interrupt is enabled.

- **CPBS: RB Compare**

0: The RB Compare Interrupt is disabled.

1: The RB Compare Interrupt is enabled.

- **CPCS: RC Compare**

0: The RC Compare Interrupt is disabled.

1: The RC Compare Interrupt is enabled.

- **LDRAS: RA Loading**

0: The Load RA Interrupt is disabled.

1: The Load RA Interrupt is enabled.

- **LDRBS: RB Loading**

0: The Load RB Interrupt is disabled.

1: The Load RB Interrupt is enabled.

- **ETRGS: External Trigger**

0: The External Trigger Interrupt is disabled.

1: The External Trigger Interrupt is enabled.

35.7.12 TC Block Control Register

Name: TC_BCR

Address: 0x400800C0

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	SYNC

- **SYNC: Synchro Command**

0: No effect.

1: Asserts the SYNC signal which generates a software trigger simultaneously for each of the channels.

35.7.13 TC Block Mode Register

Name: TC_BMR

Address: 0x400800C4

Access: Read/Write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	MAXFILT	

23	22	21	20	19	18	17	16
MAXFILT				–	–	IDXPHB	SWAP

15	14	13	12	11	10	9	8
INVIDX	INVB	INVA	EDGPHA	QDTRANS	SPEEDEN	POSEN	QDEN

7	6	5	4	3	2	1	0
–	–	TC2XC2S		TC1XC1S		TC0XC0S	

- **TC0XC0S: External Clock Signal 0 Selection**

Value	Name	Description
0	TCLK0	Signal connected to XC0: TCLK0
1	–	Reserved
2	TIOA1	Signal connected to XC0: TIOA1
3	TIOA2	Signal connected to XC0: TIOA2

- **TC1XC1S: External Clock Signal 1 Selection**

Value	Name	Description
0	TCLK1	Signal connected to XC1: TCLK1
1	–	Reserved
2	TIOA0	Signal connected to XC1: TIOA0
3	TIOA2	Signal connected to XC1: TIOA2

- **TC2XC2S: External Clock Signal 2 Selection**

Value	Name	Description
0	TCLK2	Signal connected to XC2: TCLK2
1	–	Reserved
2	TIOA0	Signal connected to XC2: TIOA0
3	TIOA1	Signal connected to XC2: TIOA1

- **QDEN: Quadrature Decoder Enabled**

0: Disabled.

1: Enables the QDEC (filter, edge detection and quadrature decoding).

Quadrature decoding (direction change) can be disabled using QDTRANS bit.

One of the POSEN or SPEEDEN bits must be also enabled.

- **POSEN: Position Enabled**

0: Disable position.

1: Enables the position measure on channel 0 and 1.

- **SPEEDEN: Speed Enabled**

0: Disabled.

1: Enables the speed measure on channel 0, the time base being provided by channel 2.

- **QDTRANS: Quadrature Decoding Transparent**

0: Full quadrature decoding logic is active (direction change detected).

1: Quadrature decoding logic is inactive (direction change inactive) but input filtering and edge detection are performed.

- **EDGPHA: Edge on PHA Count Mode**

0: Edges are detected on PHA only.

1: Edges are detected on both PHA and PHB.

- **INVA: Inverted PHA**

0: PHA (TIOA0) is directly driving the QDEC.

1: PHA is inverted before driving the QDEC.

- **INVB: Inverted PHB**

0: PHB (TIOB0) is directly driving the QDEC.

1: PHB is inverted before driving the QDEC.

- **INVIDX: Inverted Index**

0: IDX (TIOA1) is directly driving the QDEC.

1: IDX is inverted before driving the QDEC.

- **SWAP: Swap PHA and PHB**

0: No swap between PHA and PHB.

1: Swap PHA and PHB internally, prior to driving the QDEC.

- **IDXPHB: Index Pin is PHB Pin**

0: IDX pin of the rotary sensor must drive TIOA1.

1: IDX pin of the rotary sensor must drive TIOB0.

- **MAXFILT: Maximum Filter**

1–63: Defines the filtering capabilities.

Pulses with a period shorter than MAXFILT+1 peripheral clock cycles are discarded.

35.7.14 TC QDEC Interrupt Enable Register

Name: TC_QIER

Address: 0x400800C8

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	QERR	DIRCHG	IDX

- **IDX: Index**

0: No effect.

1: Enables the interrupt when a rising edge occurs on IDX input.

- **DIRCHG: Direction Change**

0: No effect.

1: Enables the interrupt when a change on rotation direction is detected.

- **QERR: Quadrature Error**

0: No effect.

1: Enables the interrupt when a quadrature error occurs on PHA, PHB.

35.7.15 TC QDEC Interrupt Disable Register

Name: TC_QIDR

Address: 0x400800CC

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	QERR	DIRCHG	IDX

- **IDX: Index**

0: No effect.

1: Disables the interrupt when a rising edge occurs on IDX input.

- **DIRCHG: Direction Change**

0: No effect.

1: Disables the interrupt when a change on rotation direction is detected.

- **QERR: Quadrature Error**

0: No effect.

1: Disables the interrupt when a quadrature error occurs on PHA, PHB.

35.7.16 TC QDEC Interrupt Mask Register

Name: TC_QIMR

Address: 0x400800D0

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	QERR	DIRCHG	IDX

- **IDX: Index**

0: The interrupt on IDX input is disabled.

1: The interrupt on IDX input is enabled.

- **DIRCHG: Direction Change**

0: The interrupt on rotation direction change is disabled.

1: The interrupt on rotation direction change is enabled.

- **QERR: Quadrature Error**

0: The interrupt on quadrature error is disabled.

1: The interrupt on quadrature error is enabled.

35.7.17 TC QDEC Interrupt Status Register

Name: TC_QISR

Address: 0x400800D4

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	DIR

7	6	5	4	3	2	1	0
–	–	–	–	–	QERR	DIRCHG	IDX

- **IDX: Index**

0: No Index input change since the last read of TC_QISR.

1: The IDX input has changed since the last read of TC_QISR.

- **DIRCHG: Direction Change**

0: No change on rotation direction since the last read of TC_QISR.

1: The rotation direction changed since the last read of TC_QISR.

- **QERR: Quadrature Error**

0: No quadrature error since the last read of TC_QISR.

1: A quadrature error occurred since the last read of TC_QISR.

- **DIR: Direction**

Returns an image of the actual rotation direction.

36. High Speed Multimedia Card Interface (HSMCI)

36.1 Description

The High Speed Multimedia Card Interface (HSMCI) supports the MultiMedia Card (MMC) Specification V4.3, the SD Memory Card Specification V2.0, the SDIO V2.0 specification and CE-ATA V1.1.

The HSMCI includes a command register, response registers, data registers, timeout counters and error detection logic that automatically handle the transmission of commands and, when required, the reception of the associated responses and data with a limited processor overhead.

The HSMCI supports stream, block and multi block data read and write, and is compatible with the DMA Controller (DMAC), minimizing processor intervention for large buffer transfers.

The HSMCI operates at a rate of up to Master Clock divided by 2 and supports the interfacing of 1 slot(s). Each slot may be used to interface with a High Speed MultiMediaCard bus (up to 30 Cards) or with an SD Memory Card. Only one slot can be selected at a time (slots are multiplexed). A bit field in the SD Card Register performs this selection.

The SD Memory Card communication is based on a 9-pin interface (clock, command, four data and three power lines) and the High Speed MultiMedia Card on a 7-pin interface (clock, command, one data, three power lines and one reserved for future use).

The SD Memory Card interface also supports High Speed MultiMedia Card operations. The main differences between SD and High Speed MultiMedia Cards are the initialization process and the bus topology.

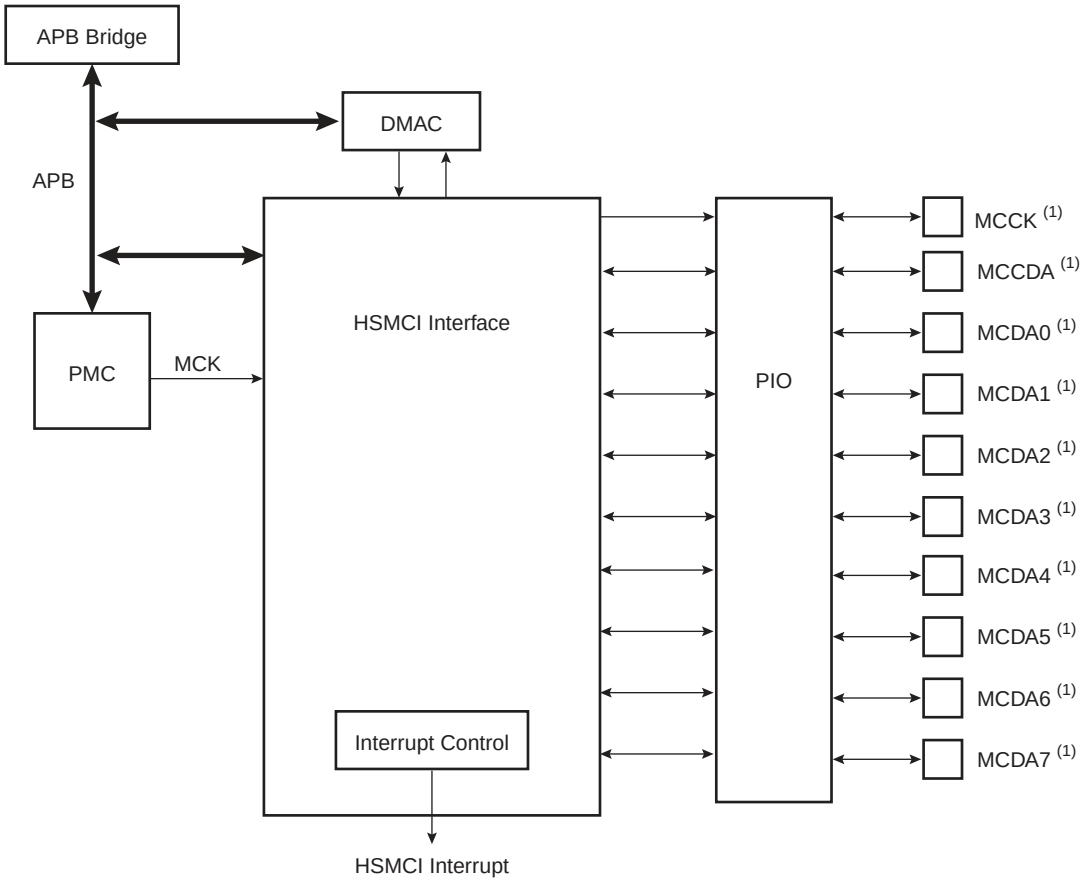
HSMCI fully supports CE-ATA Revision 1.1, built on the MMC System Specification v4.0. The module includes dedicated hardware to issue the command completion signal and capture the host command completion signal disable.

36.2 Embedded Characteristics

- Compatible with MultiMedia Card Specification Version 4.3
- Compatible with SD Memory Card Specification Version 2.0
- Compatible with SDIO Specification Version 2.0
- Compatible with CE-ATA Specification 1.1
- Cards Clock Rate Up to Master Clock Divided by 2
- Boot Operation Mode Support
- High Speed Mode Support
- Embedded Power Management to Slow Down Clock Rate When Not Used
- Supports 1 Multiplexed Slot(s)
  - Each Slot for either a High Speed MultiMediaCard Bus (Up to 30 Cards) or an SD Memory Card
- Support for Stream, Block and Multi-block Data Read and Write
- Supports Connection to DMA Controller (DMAC)
  - Minimizes Processor Intervention for Large Buffer Transfers
- Built in FIFO (from 16 to 256 bytes) with Large Memory Aperture Supporting Incremental Access
- Support for CE-ATA Completion Signal Disable Command
- Protection Against Unexpected Modification On-the-Fly of the Configuration Registers

36.3 Block Diagram

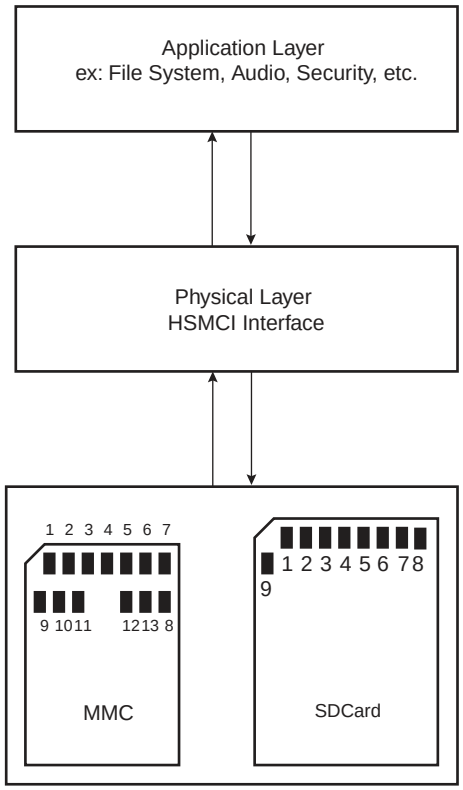
Figure 36-1. Block Diagram



Note: 1. When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA, MCDAy to HSMCIx_DAy.

36.4 Application Block Diagram

Figure 36-2. Application Block Diagram



36.5 Pin Name List

Table 36-1. I/O Lines Description for 8-bit Configuration

Pin Name[2]	Pin Description	Type[1]	Comments
MCCDA	Command/response	I/O/PP/OD	CMD of an MMC or SDCard/SDIO
MCCK	Clock	I/O	CLK of an MMC or SD Card/SDIO
MCDA0 - MCDA7	Data 0..7 of Slot A	I/O/PP	DAT[0..7] of an MMC DAT[0..3] of an SD Card/SDIO
MCDB0 - MCDB7	Data 0..7 of Slot B	I/O/PP	DAT[0..7] of an MMC DAT[0..3] of an SD Card/SDIO
MCDC0 - MCDC7	Data 0..7 of Slot C	I/O/PP	DAT[0..7] of an MMC DAT[0..3] of an SD Card/SDIO
MCDD0 - MCDD7	Data 0..7 of Slot D	I/O/PP	DAT[0..7] of an MMC DAT[0..3] of an SD Card/SDIO

Notes:
1. I: Input, O: Output, PP: Push/Pull, OD: Open Drain.
2. When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA, MCCDB to HSMCIx_CDB, MCCDC to HSMCIx_CDC, MCCDD to HSMCIx_CDD, MCDAy to HSMCIx_DAy, MCDBy to HSMCIx_DBy, MCDCy to HSMCIx_DCy, MCDDy to HSMCIx_DDy.

36.6 Product Dependencies

36.6.1 I/O Lines

The pins used for interfacing the High Speed MultiMedia Cards or SD Cards are multiplexed with PIO lines. The programmer must first program the PIO controllers to assign the peripheral functions to HSMCI pins.

Table 36-2. I/O Lines

Instance	Signal	I/O Line	Peripheral
HSMCI	MCCDA	PA4	A
HSMCI	MCCK	PA3	A
HSMCI	MCDA0	PA5	A
HSMCI	MCDA1	PA6	A
HSMCI	MCDA2	PA7	A
HSMCI	MCDA3	PA8	A
HSMCI	MCDA4	PC28	B
HSMCI	MCDA5	PC29	B
HSMCI	MCDA6	PC30	B
HSMCI	MCDA7	PC31	B

36.6.2 Power Management

The HSMCI is clocked through the Power Management Controller (PMC), so the programmer must first configure the PMC to enable the HSMCI clock.

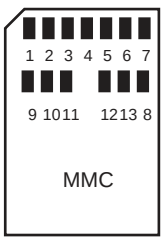
36.6.3 Interrupt

The HSMCI interface has an interrupt line connected to the Nested Vector Interrupt Controller (NVIC).

Handling the HSMCI interrupt requires programming the NVIC before configuring the HSMCI.

36.7 Bus Topology

Figure 36-3. High Speed MultiMedia Memory Card Bus Topology



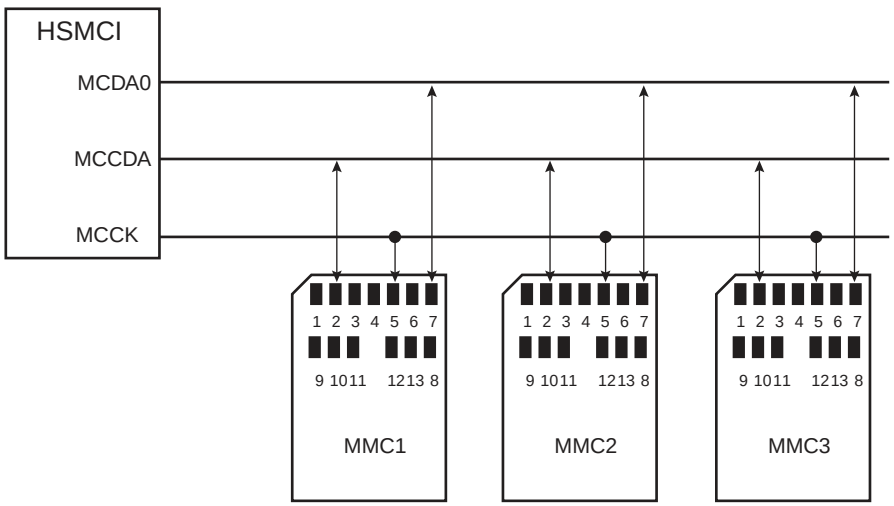
The High Speed MultiMedia Card communication is based on a 13-pin serial bus interface. It has three communication lines and four supply lines.

Table 36-3. Bus Topology

Pin Number	Name	Type[1]	Description	HSMCI Pin Name[2] (Slot z)
1	DAT[3]	I/O/PP	Data	MCDz3
2	CMD	I/O/PP/OD	Command/response	MCCDz
3	VSS1	S	Supply voltage ground	VSS
4	VDD	S	Supply voltage	VDD
5	CLK	I/O	Clock	MCCK
6	VSS2	S	Supply voltage ground	VSS
7	DAT[0]	I/O/PP	Data 0	MCDz0
8	DAT[1]	I/O/PP	Data 1	MCDz1
9	DAT[2]	I/O/PP	Data 2	MCDz2
10	DAT[4]	I/O/PP	Data 4	MCDz4
11	DAT[5]	I/O/PP	Data 5	MCDz5
12	DAT[6]	I/O/PP	Data 6	MCDz6
13	DAT[7]	I/O/PP	Data 7	MCDz7

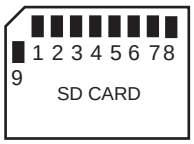
Notes: 1. I: Input, O: Output, PP: Push/Pull, OD: Open Drain.
2. When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA, MCDAy to HSMCIx_DAy.

Figure 36-4. MMC Bus Connections (One Slot)



Note: When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA MCDAy to HSMCIx_DAy.

Figure 36-5. SD Memory Card Bus Topology



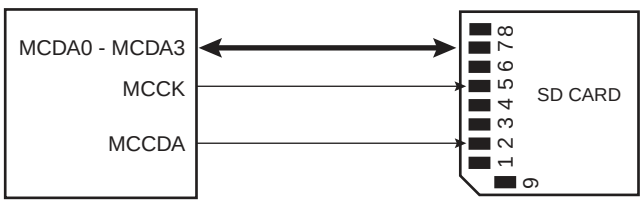
The SD Memory Card bus includes the signals listed in Table 36-4.

Table 36-4. SD Memory Card Bus Signals

Pin Number	Name	Type[1]	Description	HSMCI Pin Name[2] (Slot z)
1	CD/DAT[3]	I/O/PP	Card detect/ Data line Bit 3	MCDz3
2	CMD	PP	Command/response	MCCDz
3	VSS1	S	Supply voltage ground	VSS
4	VDD	S	Supply voltage	VDD
5	CLK	I/O	Clock	MCCK
6	VSS2	S	Supply voltage ground	VSS
7	DAT[0]	I/O/PP	Data line Bit 0	MCDz0
8	DAT[1]	I/O/PP	Data line Bit 1 or Interrupt	MCDz1
9	DAT[2]	I/O/PP	Data line Bit 2	MCDz2

Notes: 1. I: input, O: output, PP: Push Pull, OD: Open Drain.
2. When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA, MCDAy to HSMCIx_DAy.

Figure 36-6. SD Card Bus Connections with One Slot



Note: When several HSMCI (x HSMCI) are embedded in a product, MCCK refers to HSMCIx_CK, MCCDA to HSMCIx_CDA MCDAy to HSMCIx_DAy.

When the HSMCI is configured to operate with SD memory cards, the width of the data bus can be selected in the HSMCI_SDCR register. Clearing the SDCBUS bit in this register means that the width is one bit; setting it means that the width is four bits. In the case of High Speed MultiMedia cards, only the data line 0 is used. The other data lines can be used as independent PIOs.

36.8 High Speed MultiMediaCard Operations

After a power-on reset, the cards are initialized by a special message-based High Speed MultiMediaCard bus protocol. Each message is represented by one of the following tokens:

- Command: A command is a token that starts an operation. A command is sent from the host either to a single card (addressed command) or to all connected cards (broadcast command). A command is transferred serially on the CMD line.
- Response: A response is a token which is sent from an addressed card or (synchronously) from all connected cards to the host as an answer to a previously received command. A response is transferred serially on the CMD line.
- Data: Data can be transferred from the card to the host or vice versa. Data is transferred via the data line.

Card addressing is implemented using a session address assigned during the initialization phase by the bus controller to all currently connected cards. Their unique CID number identifies individual cards.

The structure of commands, responses and data blocks is described in the High Speed MultiMedia-Card System Specification. See also Table 36-5 on page 811.

High Speed MultiMediaCard bus data transfers are composed of these tokens.

There are different types of operations. Addressed operations always contain a command and a response token. In addition, some operations have a data token; the others transfer their information directly within the command or response structure. In this case, no data token is present in an operation. The bits on the DAT and the CMD lines are transferred synchronous to the clock HSMCI Clock.

Two types of data transfer commands are defined:

- Sequential commands: These commands initiate a continuous data stream. They are terminated only when a stop command follows on the CMD line. This mode reduces the command overhead to an absolute minimum.
- Block-oriented commands: These commands send a data block succeeded by CRC bits.

Both read and write operations allow either single or multiple block transmission. A multiple block transmission is terminated when a stop command follows on the CMD line similarly to the sequential read or when a multiple block transmission has a pre-defined block count (See “Data Transfer Operation” on page 813.).

The HSMCI provides a set of registers to perform the entire range of High Speed MultiMedia Card operations.

36.8.1 Command - Response Operation

After reset, the HSMCI is disabled and becomes valid after setting the MCIEN bit in the HSMCI_CR Control Register.

The PWSEN bit saves power by dividing the HSMCI clock by $2^{PWSDIV} + 1$ when the bus is inactive.

The two bits, RDPROOF and WRPROOF in the HSMCI Mode Register (HSMCI_MR) allow stopping the HSMCI Clock during read or write access if the internal FIFO is full. This will guarantee data integrity, not bandwidth.

All the timings for High Speed MultiMedia Card are defined in the High Speed MultiMediaCard System Specification.

The two bus modes (open drain and push/pull) needed to process all the operations are defined in the HSMCI command register. The HSMCI_CMDR allows a command to be carried out.

For example, to perform an ALL_SEND_CID command:

	Host Command					**N_{ID} Cycles**					**CID**			
CMD	S	T	Content	CRC	E	Z	******	Z	S	T	Content	Z	Z	Z

The command ALL_SEND_CID and the fields and values for the HSMCI_CMDR Control Register are described in Table 36-5 and Table 36-6.

Table 36-5. ALL_SEND_CID Command Description

CMD Index	Type	Argument	Resp	Abbreviation	Command Description
CMD2	bcr[1]	[31:0] stuff bits	R2	ALL_SEND_CID	Asks all cards to send their CID numbers on the CMD line

Note: 1. bcr means broadcast command with response.

Table 36-6. Fields and Values for HSMCI_CMDR Command Register

Field	Value
CMDNB (command number)	2 (CMD2)
RSPTYP (response type)	2 (R2: 136 bits response)
SPCMD (special command)	0 (not a special command)
OPCMD (open drain command)	1
MAXLAT (max latency for command to response)	0 (NID cycles ==> 5 cycles)
TRCMD (transfer command)	0 (No transfer)
TRDIR (transfer direction)	X (available only in transfer command)
TRTYP (transfer type)	X (available only in transfer command)
IOSPCMD (SDIO special command)	0 (not a special command)

The HSMCI_ARGR contains the argument field of the command.

To send a command, the user must perform the following steps:

- Fill the argument register (HSMCI_ARGR) with the command argument.
- Set the command register (HSMCI_CMDR) (see Table 36-6).

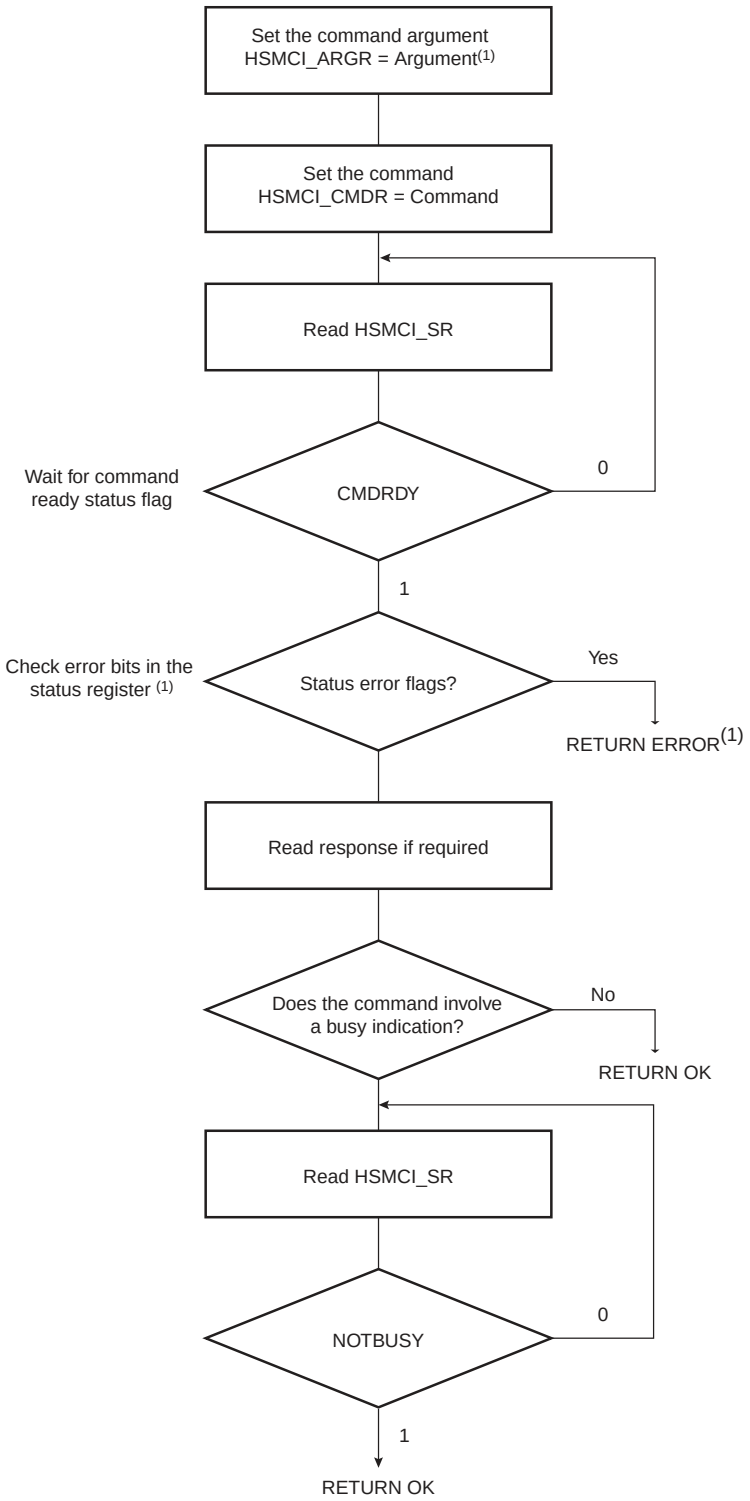
The command is sent immediately after writing the command register.

While the card maintains a busy indication (at the end of a STOP_TRANSMISSION command CMD12, for example), a new command shall not be sent. The NOTBUSY flag in the status register (HSMCI_SR) is asserted when the card releases the busy indication.

If the command requires a response, it can be read in the HSMCI response register (HSMCI_RSPR). The response size can be from 48 bits up to 136 bits depending on the command. The HSMCI embeds an error detection to prevent any corrupted data during the transfer.

The following flowchart shows how to send a command to the card and read the response if needed. In this example, the status register bits are polled but setting the appropriate bits in the interrupt enable register (HSMCI_IER) allows using an interrupt method.

Figure 36-7. Command/Response Functional Flow Diagram



Note: 1. If the command is SEND_OP_COND, the CRC error flag is always present (refer to R3 response in the High Speed MultiMedia Card specification).

36.8.2 Data Transfer Operation

The High Speed MultiMedia Card allows several read/write operations (single block, multiple blocks, stream, etc.). These kinds of transfer can be selected setting the Transfer Type (TRTYP) field in the HSMCI Command Register (HSMCI_CMDR).

These operations can be done using the features of the DMA Controller.

In all cases, the block length (BLKLEN field) must be defined either in the mode register HSMCI_MR, or in the Block Register HSMCI_BLKR. This field determines the size of the data block.

Consequent to MMC Specification 3.1, two types of multiple block read (or write) transactions are defined (the host can use either one at any time):

- Open-ended/Infinite Multiple block read (or write):

  The number of blocks for the read (or write) multiple block operation is not defined. The card will continuously transfer (or program) data blocks until a stop transmission command is received.

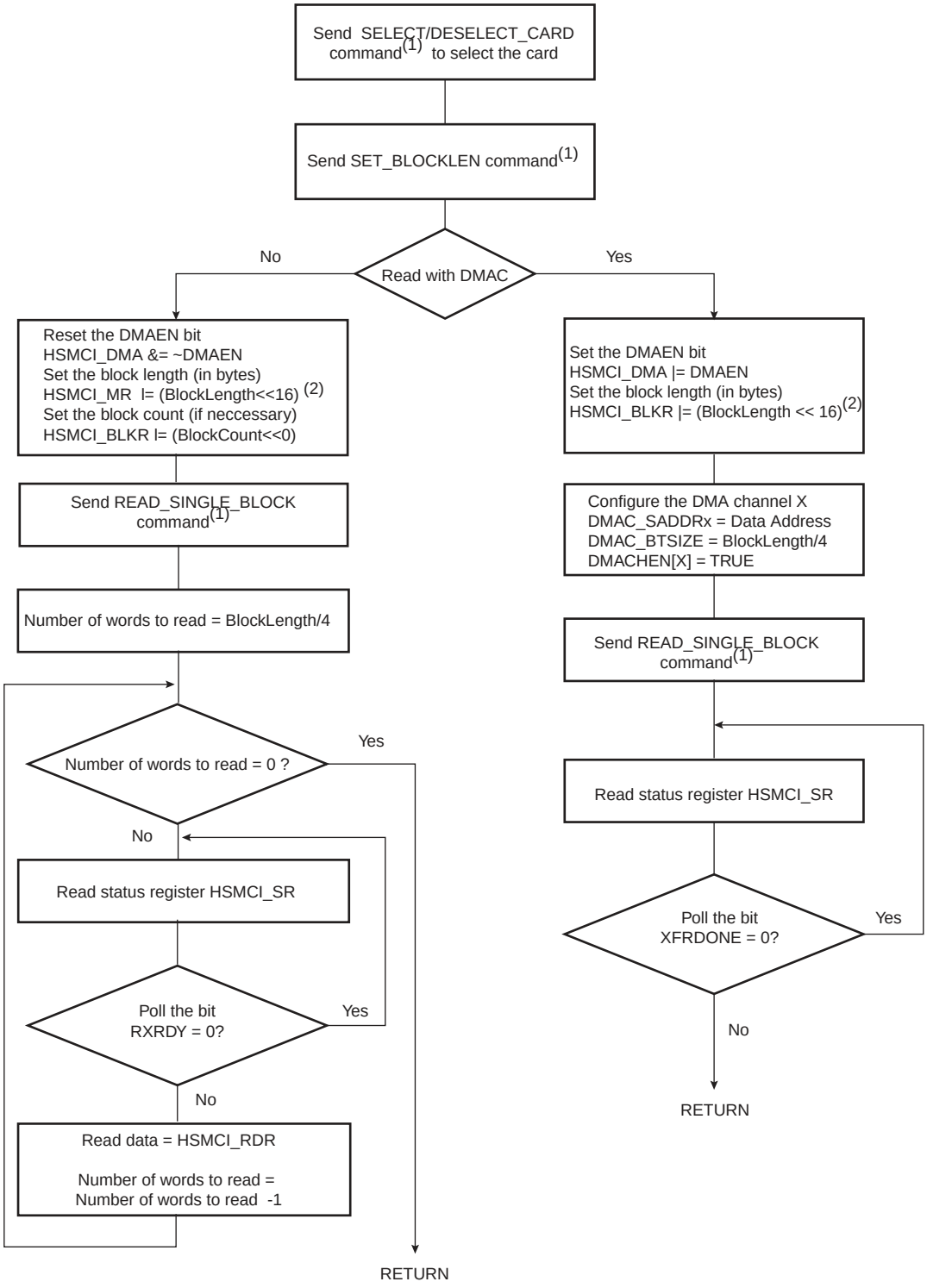
- Multiple block read (or write) with pre-defined block count (since version 3.1 and higher):

  The card will transfer (or program) the requested number of data blocks and terminate the transaction. The stop command is not required at the end of this type of multiple block read (or write), unless terminated with an error. In order to start a multiple block read (or write) with pre-defined block count, the host must correctly program the HSMCI Block Register (HSMCI_BLKR). Otherwise the card will start an open-ended multiple block read. The BCNT field of the Block Register defines the number of blocks to transfer (from 1 to 65535 blocks). Programming the value 0 in the BCNT field corresponds to an infinite block transfer.

36.8.3 Read Operation

The following flowchart (Figure 36-8) shows how to read a single block with or without use of DMAC facilities. In this example, a polling method is used to wait for the end of read. Similarly, the user can configure the interrupt enable register (HSMCI_IER) to trigger an interrupt at the end of read.

Figure 36-8. Read Functional Flow Diagram



Notes: 1. It is assumed that this command has been correctly sent (see Figure 36-7).
2. This field is also accessible in the HSMCI Block Register (HSMCI_BLKR).

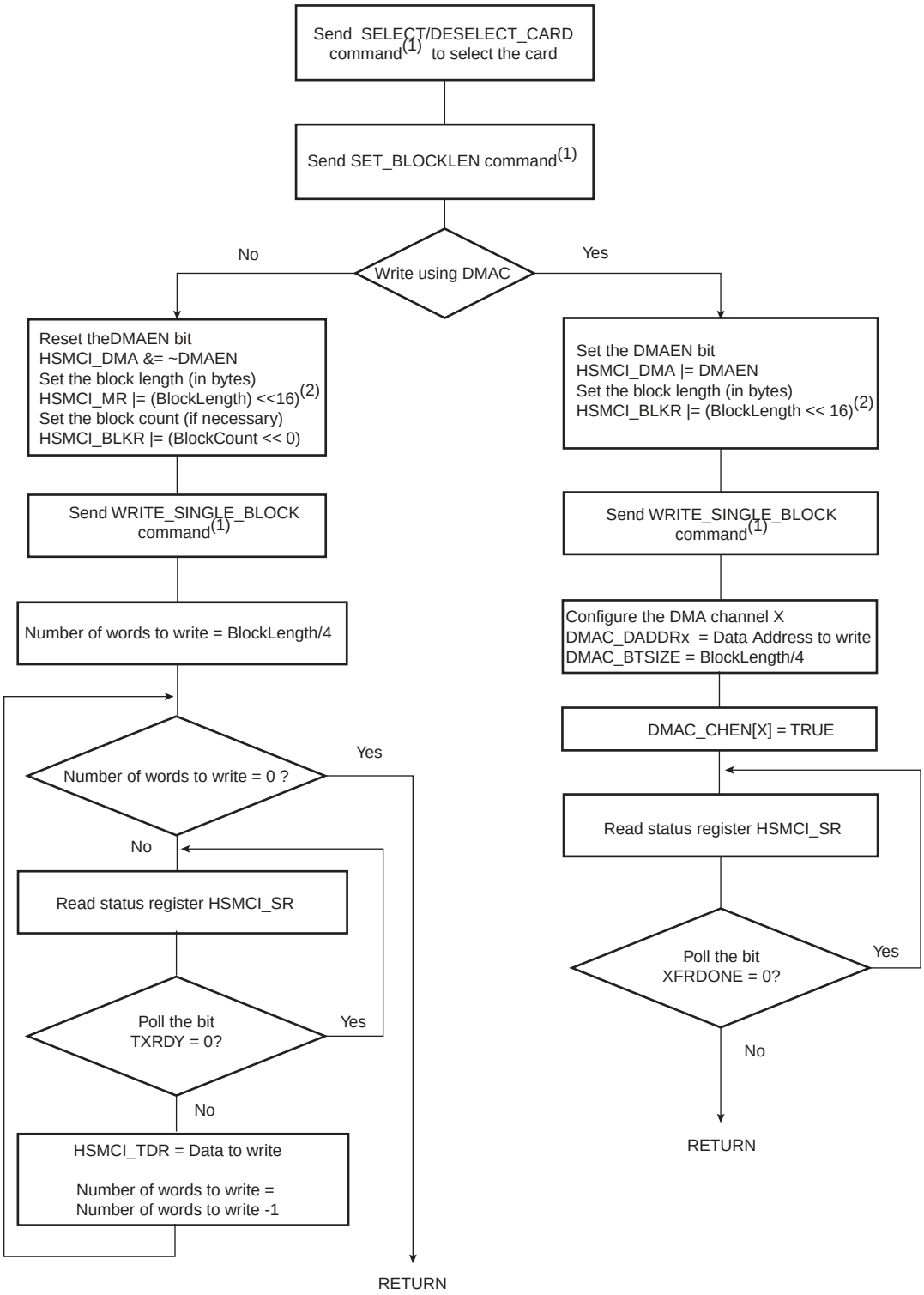
36.8.4 Write Operation

In write operation, the HSMCI Mode Register (HSMCI_MR) is used to define the padding value when writing non-multiple block size. If the bit PADV is 0, then 0x00 value is used when padding data, otherwise 0xFF is used.

If set, the bit DMAEN in the HSMCI_DMA register enables DMA transfer.

The following flowchart (Figure 36-9) shows how to write a single block with or without use of DMA facilities. Polling or interrupt method can be used to wait for the end of write according to the contents of the Interrupt Mask Register (HSMCI_IMR).

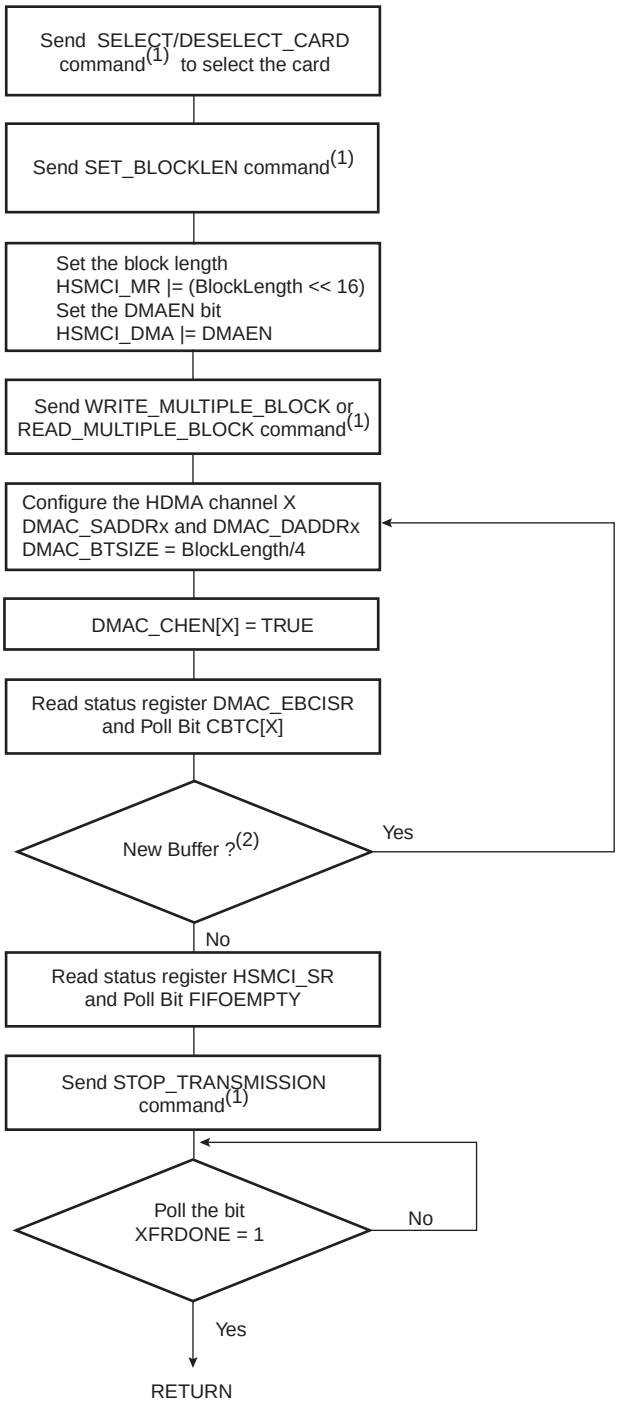
Figure 36-9. Write Functional Flow Diagram



Note: 1. It is assumed that this command has been correctly sent (see Figure 36-7).
2. This field is also accessible in the HSMCI Block Register (HSMCI_BLKR).

The following flowchart (Figure 36-10) shows how to manage read multiple block and write multiple block transfers with the DMA Controller. Polling or interrupt method can be used to wait for the end of write according to the contents of the Interrupt Mask Register (HSMCI_IMR).

Figure 36-10. Read Multiple Block and Write Multiple Block



Notes: 1. It is assumed that this command has been correctly sent (see Figure 36-7).
2. Handle errors reported in HSMCI_SR.

36.8.5 WRITE_SINGLE_BLOCK Operation using DMA Controller

1. Wait until the current command execution has successfully terminated.
   e. Check that CMDRDY and NOTBUSY fields are asserted in HSMCI_SR
2. Program the block length in the card. This value defines the value *block_length.*
3. Program the block length in the HSMCI configuration register with *block_length* value.
4. Program HSMCI_DMA register with the following fields:
   - OFFSET field with *dma_offset.*
   - CHKSIZE is user defined and set according to DMAC_DCSIZE.
   - DMAEN is set to true to enable DMA hardware handshaking in the HSMCI. This bit was previously set to false.
5. Issue a WRITE_SINGLE_BLOCK command writing HSMCI_ARG then HSMCI_CMDR.
6. Program the DMA Controller.
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers.
   d. The DMAC_SADDRx register for channel x must be set to the location of the source data. When the first data location is not word aligned, the two LSB bits define the temporary value called *dma_offset.* The two LSB bits of DMAC_SADDRx must be set to 0.
   e. The DMAC_DADDRx register for channel x must be set with the starting address of the HSMCI_FIFO address.
   f. Program DMAC_CTRLAx register of channel x with the following field's values:
      –DST_WIDTH is set to WORD.
      –SRC_WIDTH is set to WORD.
      –DCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *CEILING((block_length + dma_offset) / 4),* where the ceiling function is the function that returns the smallest integer not less than x.
   g. Program DMAC_CTRLBx register for channel x with the following field's values:
      –DST_INCR is set to INCR, the *block_length* value must not be larger than the HSMCI_FIFO aperture.
      –SRC_INCR is set to INCR.
      –FC field is programmed with memory to peripheral flow control mode.
      –both DST_DSCR and SRC_DSCR are set to 1 (descriptor fetch is disabled).
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA controller is able to prefetch data and write HSMCI simultaneously.
   h. Program DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMAC channel FIFO.
      –DST_H2SEL is set to true to enable hardware handshaking on the destination.
      –DST_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.
   i. Enable Channel x, writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.
7. Wait for XFRDONE in HSMCI_SR register.

36.8.6 READ_SINGLE_BLOCK Operation using DMA Controller

36.8.6.1 Block Length is Multiple of 4

1. Wait until the current command execution has successfully completed.
   a. Check that CMDRDY and NOTBUSY are asserted in HSMCI_SR.
2. Program the block length in the card. This value defines the value *block_length.*
3. Program the block length in the HSMCI configuration register with *block_length* value.
4. Set RDPROOF bit in HSMCI_MR to avoid overflow.
5. Program HSMCI_DMA register with the following fields:
   - ROPT field is set to 0.
   - OFFSET field is set to 0.
   - CHKSIZE is user defined.
   - DMAEN is set to true to enable DMAC hardware handshaking in the HSMCI. This bit was previously set to false.
6. Issue a READ_SINGLE_BLOCK command.
7. Program the DMA controller.
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMA transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers.
   d. The DMAC_SADDRx register for channel x must be set with the starting address of the HSMCI_FIFO address.
   e. The DMAC_DADDRx register for channel x must be word aligned.
   f. Program DMAC_CTRLAx register of channel x with the following field's values:
      –DST_WIDTH is set to WORD.
      –SRC_WIDTH is set to WORD.
      –SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *block_length/4.*
   g. Program DMAC_CTRLBx register for channel x with the following field's values:
      –DST_INCR is set to INCR.
      –SRC_INCR is set to INCR.
      –FC field is programmed with peripheral to memory flow control mode.
      –both DST_DSCR and SRC_DSCR are set to 1 (descriptor fetch is disabled).
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA controller is able to prefetch data and write HSMCI simultaneously.
   h. Program DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMA channel FIFO.
      –SRC_H2SEL is set to true to enable hardware handshaking on the destination.
      –SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.
      –Enable Channel x, writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.
8. Wait for XFRDONE in HSMCI_SR register.

36.8.6.2 Block Length is Not Multiple of 4 and Padding Not Used (ROPT field in HSMCI_DMA register set to 0)

In the previous DMA transfer flow (block length multiple of 4), the DMA controller is configured to use only WORD AHB access. When the block length is no longer a multiple of 4 this is no longer true. The DMA controller is programmed to copy exactly the block length number of bytes using 2 transfer descriptors.

1. Use the previous step until READ_SINGLE_BLOCK then
2. Program the DMA controller to use a two descriptors linked list.
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMA transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers in the Memory for the first descriptor. This descriptor will be word oriented. This descriptor is referred to as LLI_W, standing for LLI word oriented transfer.
   d. The LLI_W.DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.
   e. The LLI_W.DMAC_DADDRx field in the memory must be word aligned.
   f. Program LLI_W.DMAC_CTRLAx with the following field's values:
      –DST_WIDTH is set to WORD.
      –SRC_WIDTH is set to WORD.
      –SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *block_length/4.* If BTSIZE is zero, this descriptor is skipped later.
   g. Program LLI_W.DMAC_CTRLBx with the following field's values:
      –DST_INCR is set to INCR
      –SRC_INCR is set to INCR
      –FC field is programmed with peripheral to memory flow control mode.
      –SRC_DSCR is set to zero. (descriptor fetch is enabled for the SRC)
      –DST_DSCR is set to one. (descriptor fetch is disabled for the DST)
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, DMA controller is able to prefetch data and write HSMCI simultaneously.
   h. Program LLI_W.DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMA channel FIFO.
      –DST_REP is set to zero meaning that address are contiguous.
      –SRC_H2SEL is set to true to enable hardware handshaking on the destination.
      –SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.
   i. Program LLI_W.DMAC_DSCRx with the address of LLI_B descriptor. And set DSCRx_IF to the AHB Layer ID. This operation actually links the Word oriented descriptor on the second byte oriented descriptor. When *block_length[1:0]* is equal to 0 (multiple of 4) LLI_W.DMAC_DSCRx points to 0, only LLI_W is relevant.
   j. Program the channel registers in the Memory for the second descriptor. This descriptor will be byte oriented. This descriptor is referred to as LLI_B, standing for LLI Byte oriented.
   k. The LLI_B.DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.
   l. The LLI_B.DMAC_DADDRx is not relevant if previous word aligned descriptor was enabled. If 1, 2 or 3 bytes are transferred that address is user defined and not word aligned.
   m. Program LLI_B.DMAC_CTRLAx with the following field's values:
      –DST_WIDTH is set to BYTE.

–SRC_WIDTH is set to BYTE.

–SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.

–BTSIZE is programmed with *block_length[1:0].* (last 1, 2, or 3 bytes of the buffer).

n. Program LLI_B.DMAC_CTRLBx with the following field's values:

–DST_INCR is set to INCR

–SRC_INCR is set to INCR

–FC field is programmed with peripheral to memory flow control mode.

–Both SRC_DSCR and DST_DSCR are set to 1 (descriptor fetch is disabled) or Next descriptor location points to 0.

–DIF and SIF are set with their respective layer ID. If SIF is different from DIF, DMA Controller is able to prefetch data and write HSMCI simultaneously.

o. Program LLI_B.DMAC_CFGx memory location for channel x with the following field's values:

–FIFOCFG defines the watermark of the DMA channel FIFO.

–SRC_H2SEL is set to true to enable hardware handshaking on the destination.

–SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.

p. Program LLI_B.DMAC_DSCR with 0.

q. Program DMAC_CTRLBx register for channel x with 0. its content is updated with the LLI fetch operation.

r. Program DMAC_DSCRx with the address of LLI_W if *block_length* greater than 4 else with address of LLI_B.

s. Enable Channel x writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.

3. Wait for XFRDONE in HSMCI_SR register.

36.8.6.3 Block Length is Not Multiple of 4, with Padding Value (ROPT field in HSMCI_DMA register set to 1)

When the ROPT field is set to one, The DMA Controller performs only WORD access on the bus to transfer a non-multiple of 4 block length. Unlike previous flow, in which the transfer size is rounded to the nearest multiple of 4.

1. Program the HSMCI Interface, see previous flow.
   - ROPT field is set to 1.
2. Program the DMA Controller
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMA transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers.
   d. The DMAC_SADDRx register for channel x must be set with the starting address of the HSMCI_FIFO address.
   e. The DMAC_DADDRx register for channel x must be word aligned.
   f. Program DMAC_CTRLAx register of channel x with the following field's values:

   –DST_WIDTH is set to WORD

   –SRC_WIDTH is set to WORD

   –SCSIZE must be set according to the value of HSMCI_DMA.CHKSIZE Field.

   –BTSIZE is programmed with *CEILING(block_length/4).*

   g. Program DMAC_CTRLBx register for channel x with the following field's values:

   –DST_INCR is set to INCR

   –SRC_INCR is set to INCR

–FC field is programmed with peripheral to memory flow control mode.

–both DST_DSCR and SRC_DSCR are set to 1. (descriptor fetch is disabled)

–DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA Controller is able to prefetch data and write HSMCI simultaneously.

h. Program DMAC_CFGx register for channel x with the following field's values:

–FIFOCFG defines the watermark of the DMA channel FIFO.

–SRC_H2SEL is set to true to enable hardware handshaking on the destination.

–SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.

–Enable Channel x writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.

3. Wait for XFRDONE in HSMCI_SR register.

36.8.7 WRITE_MULTIPLE_BLOCK

36.8.7.1 One Block per Descriptor

1. Wait until the current command execution has successfully terminated.
   a. Check that CMDRDY and NOTBUSY are asserted in HSMCI_SR.
2. Program the block length in the card. This value defines the value *block_length.*
3. Program the block length in the HSMCI configuration register with *block_length* value.
4. Program HSMCI_DMA register with the following fields:
   – OFFSET field with *dma_offset.*
   – CHKSIZE is user defined.
   – DMAEN is set to true to enable DMAC hardware handshaking in the HSMCI. This bit was previously set to false.
5. Issue a WRITE_MULTIPLE_BLOCK command.
6. Program the DMA Controller to use a list of descriptors. Each descriptor transfers one block of data. Block *n* of data is transferred with descriptor LLI(n).
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the DMAC_EBCISR register.
   c. Program a List of descriptors.
   d. The LLI(n).DMAC_SADDRx memory location for channel x must be set to the location of the source data. When the first data location is not word aligned, the two LSB bits define the temporary value called *dma_offset.* The two LSB bits of LLI(n).DMAC_SADDRx must be set to 0.
   e. The LLI(n).DMAC_DADDRx register for channel x must be set with the starting address of the HSMCI_FIFO address.
   f. Program LLI(n).DMAC_CTRLAx register of channel x with the following field's values:
      –DST_WIDTH is set to WORD.
      –SRC_WIDTH is set to WORD.
      –DCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *CEILING((block_length + dma_offset)/4).*
   g. Program LLI(n).DMAC_CTRLBx register for channel x with the following field's values:
      –DST_INCR is set to INCR.
      –SRC_INCR is set to INCR.
      –DST_DSCR is set to 0 (fetch operation is enabled for the destination).
      –SRC_DSCR is set to 1 (source address is contiguous).
      –FC field is programmed with memory to peripheral flow control mode.
      –Both DST_DSCR and SRC_DSCR are set to 1 (descriptor fetch is disabled).
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, DMA Controller is able to prefetch data and write HSMCI simultaneously.
   h. Program LLI(n).DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMA channel FIFO.
      –DST_H2SEL is set to true to enable hardware handshaking on the destination.
      –SRC_REP is set to 0. (contiguous memory access at block boundary)
      –DST_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.

i. If LLI(n) is the last descriptor, then LLI(n).DSCR points to 0 else LLI(n) points to the start address of LLI(n+1).
j. Program DMAC_CTRLBx for channel register x with 0. Its content is updated with the LLI fetch operation.
k. Program DMAC_DSCRx for channel register x with the address of the first descriptor LLI(0).
l. Enable Channel x writing one to DMAC_CHER[x]. The DMA is ready and waiting for request.

7. Poll CBTC[x] bit in the DMAC_EBCISR Register.
8. If a new list of buffers shall be transferred, repeat step 6. Check and handle HSMCI errors.
9. Poll FIFOEMPTY field in the HSMCI_SR.
10. Send The STOP_TRANSMISSION command writing HSMCI_ARG then HSMCI_CMDR.
11. Wait for XFRDONE in HSMCI_SR register.

36.8.8 READ_MULTIPLE_BLOCK

36.8.8.1 Block Length is a Multiple of 4

1. Wait until the current command execution has successfully terminated.
   a. Check that CMDRDY and NOTBUSY are asserted in HSMCI_SR.
2. Program the block length in the card. This value defines the value *block_length.*
3. Program the block length in the HSMCI configuration register with *block_length* value.
4. Set RDPROOF bit in HSMCI_MR to avoid overflow.
5. Program HSMCI_DMA register with the following fields:
   - ROPT field is set to 0.
   - OFFSET field is set to 0.
   - CHKSIZE is user defined.
   - DMAEN is set to true to enable DMAC hardware handshaking in the HSMCI. This bit was previously set to false.
6. Issue a READ_MULTIPLE_BLOCK command.
7. Program the DMA Controller to use a list of descriptors:
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMA transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers in the Memory with the first descriptor. This descriptor will be word oriented. This descriptor is referred to as LLI_W(n), standing for LLI word oriented transfer for block *n*.
   d. The LLI_W(n).DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.
   e. The LLI_W(n).DMAC_DADDRx field in the memory must be word aligned.
   f. Program LLI_W(n).DMAC_CTRLAx with the following field's values:
      –DST_WIDTH is set to WORD
      –SRC_WIDTH is set to WORD
      –SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *block_length/4.*
   g. Program LLI_W(n).DMAC_CTRLBx with the following field's values:
      –DST_INCR is set to INCR.
      –SRC_INCR is set to INCR.
      –FC field is programmed with peripheral to memory flow control mode.
      –SRC_DSCR is set to 0 (descriptor fetch is enabled for the SRC).
      –DST_DSCR is set to TRUE (descriptor fetch is disabled for the DST).
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA Controller is able to prefetch data and write HSMCI simultaneously.
   h. Program LLI_W(n).DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMA channel FIFO.
      –DST_REP is set to zero. Addresses are contiguous.
      –SRC_H2SEL is set to true to enable hardware handshaking on the destination.
      –SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.

i. Program LLI_W(n).DMAC_DSCRx with the address of LLI_W(n+1) descriptor. And set the DSCRx_IF to the AHB Layer ID. This operation actually links descriptors together. If LLI_W(n) is the last descriptor then LLI_W(n).DMAC_DSCRx points to 0.

j. Program DMAC_CTRLBx register for channel x with 0. its content is updated with the LLI Fetch operation.

k. Program DMAC_DSCRx register for channel x with the address of LLI_W(0).

l. Enable Channel x writing one to DMAC_CHER[x]. The DMA is ready and waiting for request.

8. Poll CBTC[x] bit in the DMAC_EBCISR Register.
9. If a new list of buffer shall be transferred repeat step 6. Check and handle HSMCI errors.
10. Poll FIFOEMPTY field in the HSMCI_SR.
11. Send The STOP_TRANSMISSION command writing the HSMCI_ARG then the HSMCI_CMDR.
12. Wait for XFRDONE in HSMCI_SR register.

36.8.8.2 Block Length is Not Multiple of 4. (ROPT field in HSMCI_DMA register set to 0)

Two DMA Transfer descriptors are used to perform the HSMCI block transfer.

1. Use the previous step to configure the HSMCI to perform a READ_MULTIPLE_BLOCK command.
2. Issue a READ_MULTIPLE_BLOCK command.
3. Program the DMA Controller to use a list of descriptors.

a. Read the channel register to choose an available (disabled) channel.

b. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the DMAC_EBCISR register.

c. For every block of data repeat the following procedure:

d. Program the channel registers in the Memory for the first descriptor. This descriptor will be word oriented. This descriptor is referred to as LLI_W(n) standing for LLI word oriented transfer for block *n*.

e. The LLI_W(n).DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.

f. The LLI_W(n).DMAC_DADDRx field in the memory must be word aligned.

g. Program LLI_W(n).DMAC_CTRLAx with the following field's values:

–DST_WIDTH is set to WORD.

–SRC_WIDTH is set to WORD.

–SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.

–BTSIZE is programmed with *block_length/4.* If BTSIZE is zero, this descriptor is skipped later.

h. Program LLI_W(n).DMAC_CTRLBx with the following field's values:

–DST_INCR is set to INCR.

–SRC_INCR is set to INCR.

–FC field is programmed with peripheral to memory flow control mode.

–SRC_DSCR is set to 0 (descriptor fetch is enabled for the SRC).

–DST_DSCR is set to TRUE (descriptor fetch is disabled for the DST).

–DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA Controller is able to prefetch data and write HSMCI simultaneously.

i. Program LLI_W(n).DMAC_CFGx register for channel x with the following field's values:

–FIFOCFG defines the watermark of the DMA channel FIFO.

–DST_REP is set to zero. Address are contiguous.

–SRC_H2SEL is set to true to enable hardware handshaking on the destination.

–SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.

j. Program LLI_W(n).DMAC_DSCRx with the address of LLI_B(n) descriptor. And set the DSCRx_IF to the AHB Layer ID. This operation actually links the Word oriented descriptor on the second byte oriented descriptor. When *block_length[1:0]* is equal to 0 (multiple of 4) LLI_W(n).DMAC_DSCRx points to 0, only LLI_W(n) is relevant.

k. Program the channel registers in the Memory for the second descriptor. This descriptor will be byte oriented. This descriptor is referred to as LLI_B(n), standing for LLI Byte oriented.

l. The LLI_B(n).DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.

m. The LLI_B(n).DMAC_DADDRx is not relevant if previous word aligned descriptor was enabled. If 1, 2 or 3 bytes are transferred, that address is user defined and not word aligned.

n. Program LLI_B(n).DMAC_CTRLAx with the following field's values:

–DST_WIDTH is set to BYTE.

–SRC_WIDTH is set to BYTE.

–SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.

–BTSIZE is programmed with *block_length[1:0].* (last 1, 2, or 3 bytes of the buffer).

o. Program LLI_B(n).DMAC_CTRLBx with the following field's values:

–DST_INCR is set to INCR.

–SRC_INCR is set to INCR.

–FC field is programmed with peripheral to memory flow control mode.

–Both SRC_DSCR and DST_DSCR are set to 1 (descriptor fetch is disabled) or Next descriptor location points to 0.

–DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA Controller is able to prefetch data and write HSMCI simultaneously.

p. Program LLI_B(n).DMAC_CFGx memory location for channel x with the following field's values:

–FIFOCFG defines the watermark of the DMAC channel FIFO.

–SRC_H2SEL is set to true to enable hardware handshaking on the destination.

–SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller

q. Program LLI_B(n).DMAC_DSCR with address of descriptor LLI_W(n+1). If LLI_B(n) is the last descriptor, then program LLI_B(n).DMAC_DSCR with 0.

r. Program DMAC_CTRLBx register for channel x with 0, its content is updated with the LLI Fetch operation.

s. Program DMAC_DSCRx with the address of LLI_W(0) if *block_length* is greater than 4 else with address of LLI_B(0).

t. Enable Channel x writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.

4. Enable DMADONE interrupt in the HSMCI_IER register.
5. Poll CBTC[x] bit in the DMAC_EBCISR Register.
6. If a new list of buffers shall be transferred, repeat step 7. Check and handle HSMCI errors.
7. Poll FIFOEMPTY field in the HSMCI_SR.
8. Send The STOP_TRANSMISSION command writing HSMCI_ARG then HSMCI_CMDR.
9. Wait for XFRDONE in HSMCI_SR register.

36.8.8.3 Block Length is Not a Multiple of 4. (ROPT field in HSMCI_DMA register set to 1)

One DMA Transfer descriptor is used to perform the HSMCI block transfer, the DMA writes a rounded up value to the nearest multiple of 4.

1. Use the previous step to configure the HSMCI to perform a READ_MULTIPLE_BLOCK.
2. Set the ROPT field to 1 in the HSMCI_DMA register.
3. Issue a READ_MULTIPLE_BLOCK command.
4. Program the DMA controller to use a list of descriptors:
   a. Read the channel Register to choose an available (disabled) channel.
   b. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the DMAC_EBCISR register.
   c. Program the channel registers in the Memory with the first descriptor. This descriptor will be word oriented. This descriptor is referred to as LLI_W(n), standing for LLI word oriented transfer for block *n*.
   d. The LLI_W(n).DMAC_SADDRx field in memory must be set with the starting address of the HSMCI_FIFO address.
   e. The LLI_W(n).DMAC_DADDRx field in the memory must be word aligned.
   f. Program LLI_W(n).DMAC_CTRLAx with the following field's values:
      –DST_WIDTH is set to WORD.
      –SRC_WIDTH is set to WORD.
      –SCSIZE must be set according to the value of HSMCI_DMA, CHKSIZE field.
      –BTSIZE is programmed with *Ceiling(block_length/4).*
   g. Program LLI_W(n).DMAC_CTRLBx with the following field's values:
      –DST_INCR is set to INCR
      –SRC_INCR is set to INCR
      –FC field is programmed with peripheral to memory flow control mode.
      –SRC_DSCR is set to 0. (descriptor fetch is enabled for the SRC)
      –DST_DSCR is set to TRUE. (descriptor fetch is disabled for the DST)
      –DIF and SIF are set with their respective layer ID. If SIF is different from DIF, the DMA Controller is able to prefetch data and write HSMCI simultaneously.
   h. Program LLI_W(n).DMAC_CFGx register for channel x with the following field's values:
      –FIFOCFG defines the watermark of the DMA channel FIFO.
      –DST_REP is set to zero. Address are contiguous.
      –SRC_H2SEL is set to true to enable hardware handshaking on the destination.
      –SRC_PER is programmed with the hardware handshaking ID of the targeted HSMCI Host Controller.
   i. Program LLI_W(n).DMAC_DSCRx with the address of LLI_W(n+1) descriptor. And set the DSCRx_IF to the AHB Layer ID. This operation actually links descriptors together. If LLI_W(n) is the last descriptor then LLI_W(n).DMAC_DSCRx points to 0.
   j. Program DMAC_CTRLBx register for channel x with 0. its content is updated with the LLI Fetch operation.
   k. Program DMAC_DSCRx register for channel x with the address of LLI_W(0).
   l. Enable Channel x writing one to DMAC_CHER[x]. The DMAC is ready and waiting for request.
5. Poll CBTC[x] bit in the DMAC_EBCISR Register.
6. If a new list of buffers shall be transferred repeat step 7. Check and handle HSMCI errors.
7. Poll FIFOEMPTY field in the HSMCI_SR.
8. Send The STOP_TRANSMISSION command writing the HSMCI_ARG then the HSMCI_CMDR.

9. Wait for XFRDONE in HSMCI_SR register.

36.9 SD/SDIO Card Operation

The High Speed MultiMedia Card Interface allows processing of SD Memory (Secure Digital Memory Card) and SDIO (SD Input Output) Card commands.

SD/SDIO cards are based on the Multi Media Card (MMC) format, but are physically slightly thicker and feature higher data transfer rates, a lock switch on the side to prevent accidental overwriting and security features. The physical form factor, pin assignment and data transfer protocol are forward-compatible with the High Speed MultiMedia Card with some additions. SD slots can actually be used for more than flash memory cards. Devices that support SDIO can use small devices designed for the SD form factor, such as GPS receivers, Wi-Fi or Bluetooth adapters, modems, barcode readers, IrDA adapters, FM radio tuners, RFID readers, digital cameras and more.

SD/SDIO is covered by numerous patents and trademarks, and licensing is only available through the Secure Digital Card Association.

The SD/SDIO Card communication is based on a 9-pin interface (Clock, Command, 4 x Data and 3 x Power lines). The communication protocol is defined as a part of this specification. The main difference between the SD/SDIO Card and the High Speed MultiMedia Card is the initialization process.

The SD/SDIO Card Register (HSMCI_SDCR) allows selection of the Card Slot and the data bus width.

The SD/SDIO Card bus allows dynamic configuration of the number of data lines. After power up, by default, the SD/SDIO Card uses only DAT0 for data transfer. After initialization, the host can change the bus width (number of active data lines).

36.9.1 SDIO Data Transfer Type

SDIO cards may transfer data in either a multi-byte (1 to 512 bytes) or an optional block format (1 to 511 blocks), while the SD memory cards are fixed in the block transfer mode. The TRTYP field in the HSMCI Command Register (HSMCI_CMDR) allows to choose between SDIO Byte or SDIO Block transfer.

The number of bytes/blocks to transfer is set through the BCNT field in the HSMCI Block Register (HSMCI_BLKR). In SDIO Block mode, the field BLKLEN must be set to the data block size while this field is not used in SDIO Byte mode.

An SDIO Card can have multiple I/O or combined I/O and memory (called Combo Card). Within a multi-function SDIO or a Combo card, there are multiple devices (I/O and memory) that share access to the SD bus. In order to allow the sharing of access to the host among multiple devices, SDIO and combo cards can implement the optional concept of suspend/resume (Refer to the SDIO Specification for more details). To send a suspend or a resume command, the host must set the SDIO Special Command field (IOSPCMD) in the HSMCI Command Register.

36.9.2 SDIO Interrupts

Each function within an SDIO or Combo card may implement interrupts (Refer to the SDIO Specification for more details). In order to allow the SDIO card to interrupt the host, an interrupt function is added to a pin on the DAT[1] line to signal the card’s interrupt to the host. An SDIO interrupt on each slot can be enabled through the HSMCI Interrupt Enable Register. The SDIO interrupt is sampled regardless of the currently selected slot.

36.10 CE-ATA Operation

CE-ATA maps the streamlined ATA command set onto the MMC interface. The ATA task file is mapped onto MMC register space.

CE-ATA utilizes five MMC commands:

- GO_IDLE_STATE (CMD0): used for hard reset.
- STOP_TRANSMISSION (CMD12): causes the ATA command currently executing to be aborted.
- FAST_IO (CMD39): Used for single register access to the ATA taskfile registers, 8 bit access only.
- RW_MULTIPLE_REGISTERS (CMD60): used to issue an ATA command or to access the control/status registers.
- RW_MULTIPLE_BLOCK (CMD61): used to transfer data for an ATA command.

CE-ATA utilizes the same MMC command sequences for initialization as traditional MMC devices.

36.10.1 Executing an ATA Polling Command

1. Issue READ_DMA_EXT with RW_MULTIPLE_REGISTER (CMD60) for 8kB of DATA.
2. Read the ATA status register until DRQ is set.
3. Issue RW_MULTIPLE_BLOCK (CMD61) to transfer DATA.
4. Read the ATA status register until DRQ && BSY are set to 0.

36.10.2 Executing an ATA Interrupt Command

1. Issue READ_DMA_EXT with RW_MULTIPLE_REGISTER (CMD60) for 8kB of DATA with nIEN field set to zero to enable the command completion signal in the device.
2. Issue RW_MULTIPLE_BLOCK (CMD61) to transfer DATA.
3. Wait for Completion Signal Received Interrupt.

36.10.3 Aborting an ATA Command

If the host needs to abort an ATA command prior to the completion signal it must send a special command to avoid potential collision on the command line. The SPCMD field of the HSMCI_CMDR must be set to 3 to issue the CE-ATA completion Signal Disable Command.

36.10.4 CE-ATA Error Recovery

Several methods of ATA command failure may occur, including:

- No response to an MMC command, such as RW_MULTIPLE_REGISTER (CMD60).
- CRC is invalid for an MMC command or response.
- CRC16 is invalid for an MMC data packet.
- ATA Status register reflects an error by setting the ERR bit to one.
- The command completion signal does not arrive within a host specified time out period.

Error conditions are expected to happen infrequently. Thus, a robust error recovery mechanism may be used for each error event. The recommended error recovery procedure after a timeout is:

- Issue the command completion signal disable if nIEN was cleared to zero and the RW_MULTIPLE_BLOCK (CMD61) response has been received.
- Issue STOP_TRANSMISSION (CMD12) and successfully receive the R1 response.
- Issue a software reset to the CE-ATA device using FAST_IO (CMD39).

If STOP_TRANMISSION (CMD12) is successful, then the device is again ready for ATA commands. However, if the error recovery procedure does not work as expected or there is another timeout, the next step is to issue

GO_IDLE_STATE (CMD0) to the device. GO_IDLE_STATE (CMD0) is a hard reset to the device and completely resets all device states.

Note that after issuing GO_IDLE_STATE (CMD0), all device initialization needs to be completed again. If the CE-ATA device completes all MMC commands correctly but fails the ATA command with the ERR bit set in the ATA Status register, no error recovery action is required. The ATA command itself failed implying that the device could not complete the action requested, however, there was no communication or protocol failure. After the device signals an error by setting the ERR bit to one in the ATA Status register, the host may attempt to retry the command.

36.11 HSMCI Boot Operation Mode

In boot operation mode, the processor can read boot data from the slave (MMC device) by keeping the CMD line low after power-on before issuing CMD1. The data can be read from either the boot area or user area, depending on register setting. As it is not possible to boot directly on SD-CARD, a preliminary boot code must be stored in internal Flash.

36.11.1 Boot Procedure, Processor Mode

1. Configure the HSMCI data bus width programming SDCBUS Field in the HSMCI_SDCR register. The BOOT_BUS_WIDTH field located in the device Extended CSD register must be set accordingly.
2. Set the byte count to 512 bytes and the block count to the desired number of blocks, writing BLKLEN and BCNT fields of the HSMCI_BLKR Register.
3. Issue the Boot Operation Request command by writing to the HSMCI_CMDR register with SPCMD field set to BOOTREQ, TRDIR set to READ and TRCMD set to “start data transfer”.
4. The BOOT_ACK field located in the HSMCI_CMDR register must be set to one, if the BOOT_ACK field of the MMC device located in the Extended CSD register is set to one.
5. Host processor can copy boot data sequentially as soon as the RXRDY flag is asserted.
6. When Data transfer is completed, host processor shall terminate the boot stream by writing the HSMCI_CMDR register with SPCMD field set to BOOTEND.

36.11.2 Boot Procedure DMA Mode

1. Configure the HSMCI data bus width by programming SDCBUS Field in the HSMCI_SDCR register. The BOOT_BUS_WIDTH field in the device Extended CSD register must be set accordingly.
2. Set the byte count to 512 bytes and the block count to the desired number of blocks by writing BLKLEN and BCNT fields of the HSMCI_BLKR Register.
3. Enable DMA transfer in the HSMCI_DMA register.
4. Configure DMA controller, program the total amount of data to be transferred and enable the relevant channel.
5. Issue the Boot Operation Request command by writing to the HSMCI_CMDR register with SPCND set to BOOTREQ, TRDIR set to READ and TRCMD set to “start data transfer”.
6. DMA controller copies the boot partition to the memory.
7. When DMA transfer is completed, host processor shall terminate the boot stream by writing the HSMCI_CMDR register with SPCMD field set to BOOTEND.

36.12 HSMCI Transfer Done Timings

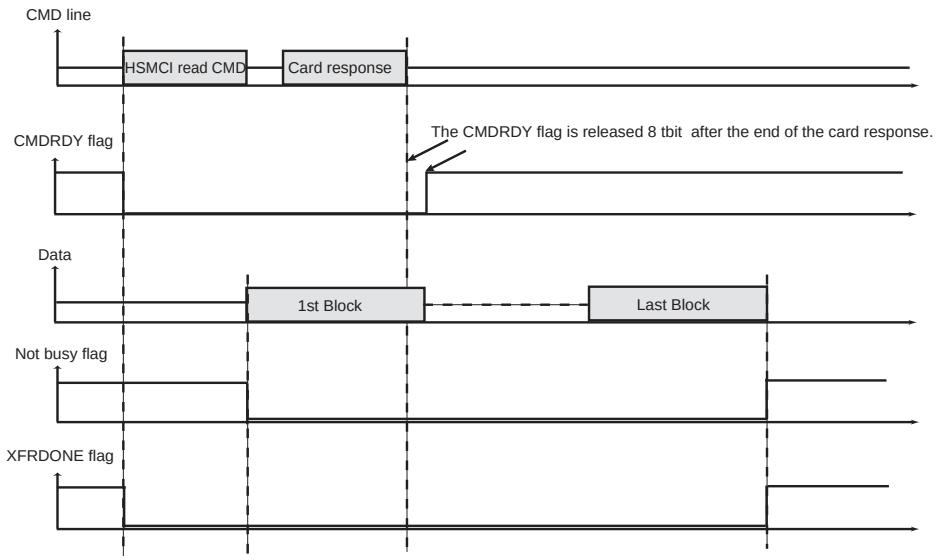
36.12.1 Definition

The XFRDONE flag in the HSMCI_SR indicates exactly when the read or write sequence is finished.

36.12.2 Read Access

During a read access, the XFRDONE flag behaves as shown in Figure 36-11.

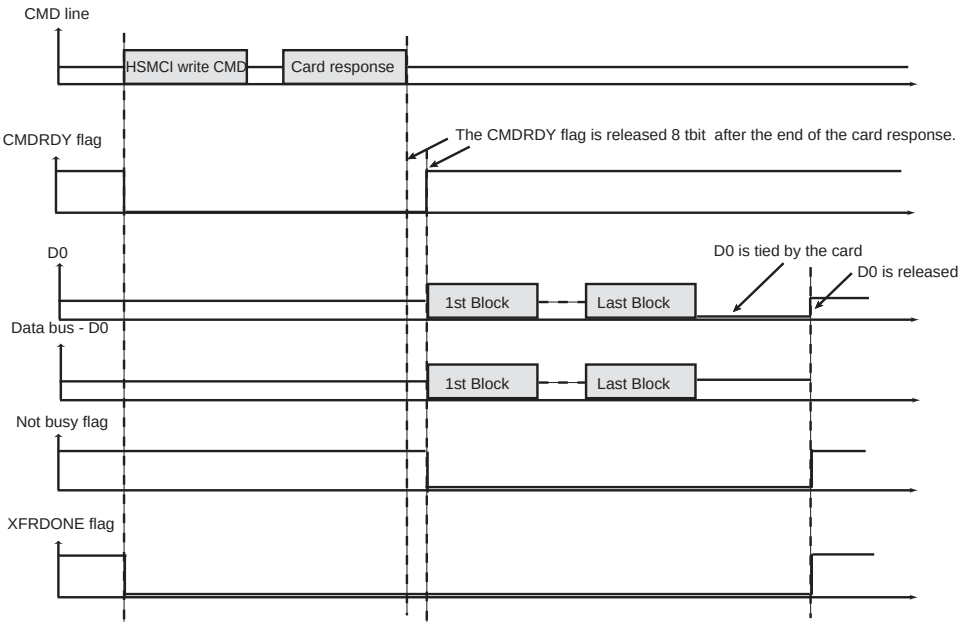
Figure 36-11. XFRDONE During a Read Access



36.12.3 Write Access

During a write access, the XFRDONE flag behaves as shown in Figure 36-12.

Figure 36-12. XFRDONE During a Write Access



36.13 Write Protection Registers

To prevent any single software error that may corrupt HSMCI behavior, the entire HSMCI address space from address offset 0x000 to 0x00FC can be write-protected by setting the WPEN bit in the "HSMCI Write Protect Mode Register" (HSMCI_WPMR).

If a write access to anywhere in the HSMCI address space from address offset 0x000 to 0x00FC is detected, then the WPVS flag in the HSMCI Write Protect Status Register (HSMCI_WPSR) is set and the field WPVSRC indicates in which register the write access has been attempted.

The WPVS flag is reset by writing the HSMCI Write Protect Mode Register (HSMCI_WPMR) with the appropriate access key, WPKEY.

The protected registers are:

- "HSMCI Mode Register" on page 836
- "HSMCI Data Timeout Register" on page 838
- "HSMCI SDCard/SDIO Register" on page 839
- "HSMCI Completion Signal Timeout Register" on page 844
- "HSMCI DMA Configuration Register" on page 858
- "HSMCI Configuration Register" on page 859

36.14 High Speed Multimedia Card Interface (HSMCI) User Interface

Table 36-7. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	HSMCI_CR	Write	–
0x04	Mode Register	HSMCI_MR	Read-write	0x0
0x08	Data Timeout Register	HSMCI_DTOR	Read-write	0x0
0x0C	SD/SDIO Card Register	HSMCI_SDCR	Read-write	0x0
0x10	Argument Register	HSMCI_ARGR	Read-write	0x0
0x14	Command Register	HSMCI_CMDR	Write	–
0x18	Block Register	HSMCI_BLKR	Read-write	0x0
0x1C	Completion Signal Timeout Register	HSMCI_CSTOR	Read-write	0x0
0x20	Response Register(1)	HSMCI_RSPR	Read	0x0
0x24	Response Register(1)	HSMCI_RSPR	Read	0x0
0x28	Response Register(1)	HSMCI_RSPR	Read	0x0
0x2C	Response Register(1)	HSMCI_RSPR	Read	0x0
0x30	Receive Data Register	HSMCI_RDR	Read	0x0
0x34	Transmit Data Register	HSMCI_TDR	Write	–
0x38 - 0x3C	Reserved	–	–	–
0x40	Status Register	HSMCI_SR	Read	0xC0E5
0x44	Interrupt Enable Register	HSMCI_IER	Write	–
0x48	Interrupt Disable Register	HSMCI_IDR	Write	–
0x4C	Interrupt Mask Register	HSMCI_IMR	Read	0x0
0x50	DMA Configuration Register	HSMCI_DMA	Read-write	0x00
0x54	Configuration Register	HSMCI_CFG	Read-write	0x00
0x58-0xE0	Reserved	–	–	–
0xE4	Write Protection Mode Register	HSMCI_WPMR	Read-write	–
0xE8	Write Protection Status Register	HSMCI_WPSR	Read-only	–
0xEC - 0xFC	Reserved	–	–	–
0x100-0x1FC	Reserved	–	–	–
0x200	FIFO Memory Aperture0	HSMCI_FIFO0	Read-write	0x0
...	...	...	...	...
0x5FC	FIFO Memory Aperture255	HSMCI_FIFO255	Read-write	0x0

Note: 1. The response register can be read by N accesses at the same HSMCI_RSPR or at consecutive addresses (0x20 to 0x2C). N depends on the size of the response.

36.14.1 HSMCI Control Register

Name: HSMCI_CR

Address: 0x40000000

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
SWRST	–	–	–	PWSDIS	PWSEN	MCIDIS	MCIEN

- **MCIEN: Multi-Media Interface Enable**

0 = No effect.

1 = Enables the Multi-Media Interface if MCDIS is 0.

- **MCIDIS: Multi-Media Interface Disable**

0 = No effect.

1 = Disables the Multi-Media Interface.

- **PWSEN: Power Save Mode Enable**

0 = No effect.

1 = Enables the Power Saving Mode if PWSDIS is 0.

Warning: Before enabling this mode, the user must set a value different from 0 in the PWSDIV field (Mode Register, HSMCI_MR).

- **PWSDIS: Power Save Mode Disable**

0 = No effect.

1 = Disables the Power Saving Mode.

- **SWRST: Software Reset**

0 = No effect.

1 = Resets the HSMCI. A software triggered hardware reset of the HSMCI interface is performed.

36.14.2 HSMCI Mode Register

Name: HSMCI_MR

Address: 0x40000004

Access: Read-write

31	30	29	28	27	26	25	24
BLKLEN							
23	22	21	20	19	18	17	16
BLKLEN							
15	14	13	12	11	10	9	8
–	PADV	FBYTE	WRPROOF	RDPROOF	PWSDIV		
7	6	5	4	3	2	1	0
CLKDIV							

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **CLKDIV: Clock Divider**

High Speed MultiMedia Card Interface clock (MCCK or HSMCI_CK) is Master Clock (MCK) divided by (2*(CLKDIV+1)).

- **PWSDIV: Power Saving Divider**

High Speed MultiMedia Card Interface clock is divided by $2^{(PWSDIV)}$ + 1 when entering Power Saving Mode.

Warning: This value must be different from 0 before enabling the Power Save Mode in the HSMCI_CR (HSMCI_PWSEN bit).

- **RDPROOF Read Proof Enable**

Enabling Read Proof allows to stop the HSMCI Clock during read access if the internal FIFO is full. This will guarantee data integrity, not bandwidth.

0 = Disables Read Proof.

1 = Enables Read Proof.

- **WRPROOF Write Proof Enable**

Enabling Write Proof allows to stop the HSMCI Clock during write access if the internal FIFO is full. This will guarantee data integrity, not bandwidth.

0 = Disables Write Proof.

1 = Enables Write Proof.

- **FBYTE: Force Byte Transfer**

Enabling Force Byte Transfer allow byte transfers, so that transfer of blocks with a size different from modulo 4 can be supported.

Warning: BLKLEN value depends on FBYTE.

0 = Disables Force Byte Transfer.

1 = Enables Force Byte Transfer.

- **PADV: Padding Value**

0 = 0x00 value is used when padding data in write transfer.

1 = 0xFF value is used when padding data in write transfer.

PADV may be only in manual transfer.

- **BLKLEN: Data Block Length**

This field determines the size of the data block.

This field is also accessible in the HSMCI Block Register (HSMCI_BLKR).

Bits 16 and 17 must be set to 0 if FBYTE is disabled.

Note: In SDIO Byte mode, BLKLEN field is not used.

36.14.3 HSMCI Data Timeout Register

Name: HSMCI_DTOR

Address: 0x40000008

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	DTOMUL			DTOCYC			

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **DTOCYC: Data Timeout Cycle Number**

These fields determine the maximum number of Master Clock cycles that the HSMCI waits between two data block transfers. It equals (DTOCYC x Multiplier).

- **DTOMUL: Data Timeout Multiplier**

Multiplier is defined by DTOMUL as shown in the following table:

Value	Name	Description
0	1	DTOCYC
1	16	DTOCYC x 16
2	128	DTOCYC x 128
3	256	DTOCYC x 256
4	1024	DTOCYC x 1024
5	4096	DTOCYC x 4096
6	65536	DTOCYC x 65536
7	1048576	DTOCYC x 1048576

If the data time-out set by DTOCYC and DTOMUL has been exceeded, the Data Time-out Error flag (DTOE) in the HSMCI Status Register (HSMCI_SR) rises.

36.14.4 HSMCI SDCard/SDIO Register

Name: HSMCI_SDCR

Address: 0x4000000C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
SDCBUS		–	–	–	–	SDCSEL	

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **SDCSEL: SDCard/SDIO Slot**

Value	Name	Description
0	SLOTA	Slot A is selected.
1	SLOTB	–
2	SLOTC	–
3	SLOTD	–

- **SDCBUS: SDCard/SDIO Bus Width**

Value	Name	Description
0	1	1 bit
1	–	Reserved
2	4	4 bit
3	8	8 bit

36.14.5 HSMCI Argument Register

Name: HSMCI_ARGR

Address: 0x40000010

Access: Read-write

31	30	29	28	27	26	25	24
ARG							
23	22	21	20	19	18	17	16
ARG							
15	14	13	12	11	10	9	8
ARG							
7	6	5	4	3	2	1	0
ARG							

- **ARG: Command Argument**

36.14.6 HSMCI Command Register

Name: HSMCI_CMDR

Address: 0x40000014

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	BOOT_ACK	ATACS	IOSPCMD	
23	22	21	20	19	18	17	16
–	–	TRTYP			TRDIR	TRCMD	
15	14	13	12	11	10	9	8
–	–	–	MAXLAT	OPDCMD	SPCMD		
7	6	5	4	3	2	1	0
RSPTYP		CMDNB					

This register is write-protected while CMDRDY is 0 in HSMCI_SR. If an Interrupt command is sent, this register is only writable by an interrupt response (field SPCMD). This means that the current command execution cannot be interrupted or modified.

- **CMDNB: Command Number**

This is the command index.

- **RSPTYP: Response Type**

Value	Name	Description
0	NORESP	No response.
1	48_BIT	48-bit response.
2	136_BIT	136-bit response.
3	R1B	R1b response type

- **SPCMD: Special Command**

Value	Name	Description
0	STD	Not a special CMD.
1	INIT	Initialization CMD: 74 clock cycles for initialization sequence.
2	SYNC	Synchronized CMD: Wait for the end of the current data block transfer before sending the pending command.
3	CE_ATA	CE-ATA Completion Signal disable Command. The host cancels the ability for the device to return a command completion signal on the command line.
4	IT_CMD	Interrupt command: Corresponds to the Interrupt Mode (CMD40).
5	IT_RESP	Interrupt response: Corresponds to the Interrupt Mode (CMD40).
6	BOR	Boot Operation Request. Start a boot operation mode, the host processor can read boot data from the MMC device directly.
7	EBO	End Boot Operation. This command allows the host processor to terminate the boot operation mode.

- **OPDCMD: Open Drain Command**

0 (PUSHPULL) = Push pull command.

1 (OPENDRAIN) = Open drain command.

- **MAXLAT: Max Latency for Command to Response**

0 (5) = 5-cycle max latency.

1 (64) = 64-cycle max latency.

- **TRCMD: Transfer Command**

Value	Name	Description
0	NO_DATA	No data transfer
1	START_DATA	Start data transfer
2	STOP_DATA	Stop data transfer
3	–	Reserved

- **TRDIR: Transfer Direction**

0 (WRITE) = Write.

1 (READ) = Read.

- **TRTYP: Transfer Type**

Value	Name	Description
0	SINGLE	MMC/SDCard Single Block
1	MULTIPLE	MMC/SDCard Multiple Block
2	STREAM	MMC Stream
4	BYTE	SDIO Byte
5	BLOCK	SDIO Block

- **IOSPCMD: SDIO Special Command**

Value	Name	Description
0	STD	Not an SDIO Special Command
1	SUSPEND	SDIO Suspend Command
2	RESUME	SDIO Resume Command

- **ATACS: ATA with Command Completion Signal**

0 (NORMAL) = Normal operation mode.

1 (COMPLETION) = This bit indicates that a completion signal is expected within a programmed amount of time (HSMCI_CSTOR).

- **BOOT_ACK: Boot Operation Acknowledge.**

The master can choose to receive the boot acknowledge from the slave when a Boot Request command is issued. When set to one this field indicates that a Boot acknowledge is expected within a programmable amount of time defined with DTOMUL and DTOCYC fields located in the HSMCI_DTOR register. If the acknowledge pattern is not received then an acknowledge timeout error is raised. If the acknowledge pattern is corrupted then an acknowledge pattern error is set.

36.14.7 HSMCI Block Register

Name: HSMCI_BLKR

Address: 0x40000018

Access: Read-write

31	30	29	28	27	26	25	24
BLKLEN							
23	22	21	20	19	18	17	16
BLKLEN							
15	14	13	12	11	10	9	8
BCNT							
7	6	5	4	3	2	1	0
BCNT							

- **BCNT: MMC/SDIO Block Count - SDIO Byte Count**

This field determines the number of data byte(s) or block(s) to transfer.

The transfer data type and the authorized values for BCNT field are determined by the TRTYP field in the HSMCI Command Register (HSMCI_CMDR):

Value	Name	Description
0	MULTIPLE	MMC/SDCARD Multiple Block From 1 to 65635: Value 0 corresponds to an infinite block transfer.
4	BYTE	SDIO Byte From 1 to 512 bytes: Value 0 corresponds to a 512-byte transfer. Values from 0x200 to 0xFFFF are forbidden.
5	BLOCK	SDIO Block From 1 to 511 blocks: Value 0 corresponds to an infinite block transfer. Values from 0x200 to 0xFFFF are forbidden.

Warning: In SDIO Byte and Block modes, writing to the 7 last bits of BCNT field is forbidden and may lead to unpredictable results.

- **BLKLEN: Data Block Length**

This field determines the size of the data block.

This field is also accessible in the HSMCI Mode Register (HSMCI_MR).

Bits 16 and 17 must be set to 0 if FBYTE is disabled.

Note: In SDIO Byte mode, BLKLEN field is not used.

36.14.8 HSMCI Completion Signal Timeout Register

Name: HSMCI_CSTOR

Address: 0x4000001C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	CSTOMUL			CSTOCYC			

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **CSTOCYC: Completion Signal Timeout Cycle Number**

These fields determine the maximum number of Master Clock cycles that the HSMCI waits between two data block transfers. Its value is calculated by (CSTOCYC x Multiplier).

- **CSTOMUL: Completion Signal Timeout Multiplier**

These fields determine the maximum number of Master Clock cycles that the HSMCI waits between two data block transfers. Its value is calculated by (CSTOCYC x Multiplier).

These fields determine the maximum number of Master Clock cycles that the HSMCI waits between the end of the data transfer and the assertion of the completion signal. The data transfer comprises data phase and the optional busy phase. If a non-DATA ATA command is issued, the HSMCI starts waiting immediately after the end of the response until the completion signal.

Multiplier is defined by CSTOMUL as shown in the following table:

Value	Name	Description
0	1	CSTOCYC x 1
1	16	CSTOCYC x 16
2	128	CSTOCYC x 128
3	256	CSTOCYC x 256
4	1024	CSTOCYC x 1024
5	4096	CSTOCYC x 4096
6	65536	CSTOCYC x 65536
7	1048576	CSTOCYC x 1048576

If the data time-out set by CSTOCYC and CSTOMUL has been exceeded, the Completion Signal Time-out Error flag (CSTOE) in the HSMCI Status Register (HSMCI_SR) rises.

36.14.9 HSMCI Response Register

Name: HSMCI_RSPR

Address: 0x40000020

Access: Read-only

31	30	29	28	27	26	25	24
RSP							
23	22	21	20	19	18	17	16
RSP							
15	14	13	12	11	10	9	8
RSP							
7	6	5	4	3	2	1	0
RSP							

- **RSP: Response**

Note: 1. The response register can be read by N accesses at the same HSMCI_RSPR or at consecutive addresses (0x20 to 0x2C). N depends on the size of the response.

36.14.10 HSMCI Receive Data Register

Name: HSMCI_RDR

Address: 0x40000030

Access: Read-only

31	30	29	28	27	26	25	24
DATA							
23	22	21	20	19	18	17	16
DATA							
15	14	13	12	11	10	9	8
DATA							
7	6	5	4	3	2	1	0
DATA							

- **DATA: Data to Read**

36.14.11 HSMCI Transmit Data Register

Name: HSMCI_TDR

Address: 0x40000034

Access: Write-only

31	30	29	28	27	26	25	24
DATA							
23	22	21	20	19	18	17	16
DATA							
15	14	13	12	11	10	9	8
DATA							
7	6	5	4	3	2	1	0
DATA							

- **DATA: Data to Write**

36.14.12 HSMCI Status Register

Name: HSMCI_SR

Address: 0x40000040

Access: Read-only

31	30	29	28	27	26	25	24
UNRE	OVRE	ACKRCVE	ACKRCV	XFRDONE	FIFOEMPTY	DMADONE	BLKOVRE
23	22	21	20	19	18	17	16
CSTOE	DTOE	DCRCE	RTOE	RENDE	RCRCE	RDIRE	RINDE
15	14	13	12	11	10	9	8
–	–	CSRCV	SDIOWAIT	–	–	–	MCI_SDIOIRQA
7	6	5	4	3	2	1	0
–	–	NOTBUSY	DTIP	BLKE	TXRDY	RXRDY	CMDRDY

- **CMDRDY: Command Ready**

0 = A command is in progress.

1 = The last command has been sent. Cleared when writing in the HSMCI_CMDR.

- **RXRDY: Receiver Ready**

0 = Data has not yet been received since the last read of HSMCI_RDR.

1 = Data has been received since the last read of HSMCI_RDR.

- **TXRDY: Transmit Ready**

0= The last data written in HSMCI_TDR has not yet been transferred in the Shift Register.

1= The last data written in HSMCI_TDR has been transferred in the Shift Register.

- **BLKE: Data Block Ended**

This flag must be used only for Write Operations.

0 = A data block transfer is not yet finished. Cleared when reading the HSMCI_SR.

1 = A data block transfer has ended, including the CRC16 Status transmission.
the flag is set for each transmitted CRC Status.

Refer to the MMC or SD Specification for more details concerning the CRC Status.

- **DTIP: Data Transfer in Progress**

0 = No data transfer in progress.

1 = The current data transfer is still in progress, including CRC16 calculation. Cleared at the end of the CRC16 calculation.

- **NOTBUSY: HSMCI Not Busy**

This flag must be used only for Write Operations.

A block write operation uses a simple busy signalling of the write operation duration on the data (DAT0) line: during a data transfer block, if the card does not have a free data receive buffer, the card indicates this condition by pulling down the data line (DAT0) to LOW. The card stops pulling down the data line as soon as at least one receive buffer for the defined data transfer block length becomes free.

The NOTBUSY flag allows to deal with these different states.

0 = The HSMCI is not ready for new data transfer. Cleared at the end of the card response.

1 = The HSMCI is ready for new data transfer. Set when the busy state on the data line has ended. This corresponds to a free internal data receive buffer of the card.

Refer to the MMC or SD Specification for more details concerning the busy behavior.

For all the read operations, the NOTBUSY flag is cleared at the end of the host command.
For the Infinite Read Multiple Blocks, the NOTBUSY flag is set at the end of the STOP_TRANSMISSION host command (CMD12).
For the Single Block Reads, the NOTBUSY flag is set at the end of the data read block.
For the Multiple Block Reads with pre-defined block count, the NOTBUSY flag is set at the end of the last received data block.

- **SDIOIRQA: SDIO Interrupt for Slot A**

0 = No interrupt detected on SDIO Slot A.

1 = An SDIO Interrupt on Slot A occurred. Cleared when reading the HSMCI_SR.

- **SDIOWAIT: SDIO Read Wait Operation Status**

0 = Normal Bus operation.

1 = The data bus has entered IO wait state.

- **CSRCV: CE-ATA Completion Signal Received**

0 = No completion signal received since last status read operation.

1 = The device has issued a command completion signal on the command line. Cleared by reading in the HSMCI_SR register.

- **RINDE: Response Index Error**

0 = No error.

1 = A mismatch is detected between the command index sent and the response index received. Cleared when writing in the HSMCI_CMDR.

- **RDIRE: Response Direction Error**

0 = No error.

1 = The direction bit from card to host in the response has not been detected.

- **RCRCE: Response CRC Error**

0 = No error.

1 = A CRC7 error has been detected in the response. Cleared when writing in the HSMCI_CMDR.

- **RENDE: Response End Bit Error**

0 = No error.

1 = The end bit of the response has not been detected. Cleared when writing in the HSMCI_CMDR.

- **RTOE: Response Time-out Error**

0 = No error.

1 = The response time-out set by MAXLAT in the HSMCI_CMDR has been exceeded. Cleared when writing in the HSMCI_CMDR.

- **DCRCE: Data CRC Error**

0 = No error.

1 = A CRC16 error has been detected in the last data block. Cleared by reading in the HSMCI_SR register.

- **DTOE: Data Time-out Error**

0 = No error.

1 = The data time-out set by DTOCYC and DTOMUL in HSMCI_DTOR has been exceeded. Cleared by reading in the HSMCI_SR register.

- **CSTOE: Completion Signal Time-out Error**

0 = No error.

1 = The completion signal time-out set by CSTOCYC and CSTOMUL in HSMCI_CSTOR has been exceeded. Cleared by reading in the HSMCI_SR register. Cleared by reading in the HSMCI_SR register.

- **BLKOVRE: DMA Block Overrun Error**

0 = No error.

1 = A new block of data is received and the DMA controller has not started to move the current pending block, a block overrun is raised. Cleared by reading in the HSMCI_SR register.

- **DMADONE: DMA Transfer done**

0 = DMA buffer transfer has not completed since the last read of HSMCI_SR register.

1 = DMA buffer transfer has completed.

- **FIFOEMPTY: FIFO empty flag**

0 = FIFO contains at least one byte.

1 = FIFO is empty.

- **XFRDONE: Transfer Done flag**

0 = A transfer is in progress.

1 = Command register is ready to operate and the data bus is in the idle state.

- **ACKRCV: Boot Operation Acknowledge Received**

0 = No Boot acknowledge received since the last read of the status register.

1 = A Boot acknowledge signal has been received. Cleared by reading the HSMCI_SR register.

- **ACKRCVE: Boot Operation Acknowledge Error**

0 = No error

1 = Corrupted Boot Acknowledge signal received.

- **OVRE: Overrun**

0 = No error.

1 = At least one 8-bit received data has been lost (not read). Cleared when sending a new data transfer command.

When FERRCTRL in HSMCI_CFG is set to 1, OVRE becomes reset after read.

- **UNRE: Underrun**

0 = No error.

1 = At least one 8-bit data has been sent without valid information (not written). Cleared when sending a new data transfer command or when setting FERRCTRL in HSMCI_CFG to 1.

When FERRCTRL in HSMCI_CFG is set to 1, UNRE becomes reset after read.

36.14.13 HSMCI Interrupt Enable Register

Name: HSMCI_IER

Address: 0x40000044

Access: Write-only

31	30	29	28	27	26	25	24
UNRE	OVRE	ACKRCVE	ACKRCV	XFRDONE	FIFOEMPTY	DMADONE	BLKOVRE
23	22	21	20	19	18	17	16
CSTOE	DTOE	DCRCE	RTOE	RENDE	RCRCE	RDIRE	RINDE
15	14	13	12	11	10	9	8
–	–	CSRCV	SDIOWAIT	–	–	–	MCI_SDIOIRQA
7	6	5	4	3	2	1	0
–	–	NOTBUSY	DTIP	BLKE	TXRDY	RXRDY	CMDRDY

- **CMDRDY: Command Ready Interrupt Enable**
- **RXRDY: Receiver Ready Interrupt Enable**
- **TXRDY: Transmit Ready Interrupt Enable**
- **BLKE: Data Block Ended Interrupt Enable**
- **DTIP: Data Transfer in Progress Interrupt Enable**
- **NOTBUSY: Data Not Busy Interrupt Enable**
- **SDIOIRQA: SDIO Interrupt for Slot A Interrupt Enable**
- **SDIOIRQD: SDIO Interrupt for Slot D Interrupt Enable**
- **SDIOWAIT: SDIO Read Wait Operation Status Interrupt Enable**
- **CSRCV: Completion Signal Received Interrupt Enable**
- **RINDE: Response Index Error Interrupt Enable**
- **RDIRE: Response Direction Error Interrupt Enable**
- **RCRCE: Response CRC Error Interrupt Enable**
- **RENDE: Response End Bit Error Interrupt Enable**
- **RTOE: Response Time-out Error Interrupt Enable**
- **DCRCE: Data CRC Error Interrupt Enable**
- **DTOE: Data Time-out Error Interrupt Enable**
- **CSTOE: Completion Signal Timeout Error Interrupt Enable**
- **BLKOVRE: DMA Block Overrun Error Interrupt Enable**

- **DMADONE: DMA Transfer completed Interrupt Enable**
- **FIFOEMPTY: FIFO empty Interrupt enable**
- **XFRDONE: Transfer Done Interrupt enable**
- **ACKRCV: Boot Acknowledge Interrupt Enable**
- **ACKRCVE: Boot Acknowledge Error Interrupt Enable**
- **OVRE: Overrun Interrupt Enable**
- **UNRE: Underrun Interrupt Enable**

0 = No effect.

1 = Enables the corresponding interrupt.

36.14.14 HSMCI Interrupt Disable Register

Name: HSMCI_IDR

Address: 0x40000048

Access: Write-only

31	30	29	28	27	26	25	24
UNRE	OVRE	ACKRCVE	ACKRCV	XFRDONE	FIFOEMPTY	DMADONE	BLKOVRE
23	22	21	20	19	18	17	16
CSTOE	DTOE	DCRCE	RTOE	RENDE	RCRCE	RDIRE	RINDE
15	14	13	12	11	10	9	8
–	–	CSRCV	SDIOWAIT	–	–	–	MCI_SDIOIRQA
7	6	5	4	3	2	1	0
–	–	NOTBUSY	DTIP	BLKE	TXRDY	RXRDY	CMDRDY

- **CMDRDY: Command Ready Interrupt Disable**
- **RXRDY: Receiver Ready Interrupt Disable**
- **TXRDY: Transmit Ready Interrupt Disable**
- **BLKE: Data Block Ended Interrupt Disable**
- **DTIP: Data Transfer in Progress Interrupt Disable**
- **NOTBUSY: Data Not Busy Interrupt Disable**
- **SDIOIRQA: SDIO Interrupt for Slot A Interrupt Disable**
- **SDIOWAIT: SDIO Read Wait Operation Status Interrupt Disable**
- **CSRCV: Completion Signal received interrupt Disable**
- **RINDE: Response Index Error Interrupt Disable**
- **RDIRE: Response Direction Error Interrupt Disable**
- **RCRCE: Response CRC Error Interrupt Disable**
- **RENDE: Response End Bit Error Interrupt Disable**
- **RTOE: Response Time-out Error Interrupt Disable**
- **DCRCE: Data CRC Error Interrupt Disable**
- **DTOE: Data Time-out Error Interrupt Disable**
- **CSTOE: Completion Signal Time out Error Interrupt Disable**
- **BLKOVRE: DMA Block Overrun Error Interrupt Disable**
- **DMADONE: DMA Transfer completed Interrupt Disable**

- **FIFOEMPTY: FIFO empty Interrupt Disable**
- **XFRDONE: Transfer Done Interrupt Disable**
- **ACKRCV: Boot Acknowledge Interrupt Disable**
- **ACKRCVE: Boot Acknowledge Error Interrupt Disable**
- **OVRE: Overrun Interrupt Disable**
- **UNRE: Underrun Interrupt Disable**

0 = No effect.

1 = Disables the corresponding interrupt.

36.14.15 HSMCI Interrupt Mask Register

Name: HSMCI_IMR

Address: 0x4000004C

Access: Read-only

31	30	29	28	27	26	25	24
UNRE	OVRE	ACKRCVE	ACKRCV	XFRDONE	FIFOEMPTY	DMADONE	BLKOVRE
23	22	21	20	19	18	17	16
CSTOE	DTOE	DCRCE	RTOE	RENDE	RCRCE	RDIRE	RINDE
15	14	13	12	11	10	9	8
–	–	CSRCV	SDIOWAIT	–	–	–	MCI_SDIOIRQA
7	6	5	4	3	2	1	0
–	–	NOTBUSY	DTIP	BLKE	TXRDY	RXRDY	CMDRDY

- **CMDRDY: Command Ready Interrupt Mask**
- **RXRDY: Receiver Ready Interrupt Mask**
- **TXRDY: Transmit Ready Interrupt Mask**
- **BLKE: Data Block Ended Interrupt Mask**
- **DTIP: Data Transfer in Progress Interrupt Mask**
- **NOTBUSY: Data Not Busy Interrupt Mask**
- **SDIOIRQA: SDIO Interrupt for Slot A Interrupt Mask**
- **SDIOWAIT: SDIO Read Wait Operation Status Interrupt Mask**
- **CSRCV: Completion Signal Received Interrupt Mask**
- **RINDE: Response Index Error Interrupt Mask**
- **RDIRE: Response Direction Error Interrupt Mask**
- **RCRCE: Response CRC Error Interrupt Mask**
- **RENDE: Response End Bit Error Interrupt Mask**
- **RTOE: Response Time-out Error Interrupt Mask**
- **DCRCE: Data CRC Error Interrupt Mask**
- **DTOE: Data Time-out Error Interrupt Mask**
- **CSTOE: Completion Signal Time-out Error Interrupt Mask**
- **BLKOVRE: DMA Block Overrun Error Interrupt Mask**
- **DMADONE: DMA Transfer Completed Interrupt Mask**

- **FIFOEMPTY: FIFO Empty Interrupt Mask**
- **XFRDONE: Transfer Done Interrupt Mask**
- **ACKRCV: Boot Operation Acknowledge Received Interrupt Mask**
- **ACKRCVE: Boot Operation Acknowledge Error Interrupt Mask**
- **OVRE: Overrun Interrupt Mask**
- **UNRE: Underrun Interrupt Mask**

0 = The corresponding interrupt is not enabled.

1 = The corresponding interrupt is enabled.

36.14.16 HSMCI DMA Configuration Register

Name: HSMCI_DMA

Address: 0x40000050

Access: Read-write

31	30	29	28	27	26	25	24
		–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	ROPT	–	–	–	DMAEN
7	6	5	4	3	2	1	0
–	–	–	CHKSIZE	–	–	OFFSET	

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **OFFSET: DMA Write Buffer Offset**

This field indicates the number of discarded bytes when the DMA writes the first word of the transfer.

- **CHKSIZE: DMA Channel Read and Write Chunk Size**

The CHKSIZE field indicates the number of data available when the DMA chunk transfer request is asserted.

Value	Name	Description
0	1	1 data available
1	4	4 data available

- **DMAEN: DMA Hardware Handshaking Enable**

0 = DMA interface is disabled.

1 = DMA Interface is enabled.

Note: To avoid unpredictable behavior, DMA hardware handshaking must be disabled when CPU transfers are performed.

- **ROPT: Read Optimization with padding**

0: BLKLEN bytes are moved from the Memory Card to the system memory, two DMA descriptors are used when the transfer size is not a multiple of 4.

1: Ceiling(BLKLEN/4) * 4 bytes are moved from the Memory Card to the system memory, only one DMA descriptor is used.

36.14.17 HSMCI Configuration Register

Name: HSMCI_CFG

Address: 0x40000054

Access: Read-write

31	30	29	28	27	26	25	24
		–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	LSYNC	–	–	–	HSMODE
7	6	5	4	3	2	1	0
–	–	–	FERRCTRL	–	–	–	FIFOMODE

This register can only be written if the WPEN bit is cleared in “HSMCI Write Protect Mode Register” on page 860.

- **FIFOMODE: HSMCI Internal FIFO control mode**

0 = A write transfer starts when a sufficient amount of data is written into the FIFO.

When the block length is greater than or equal to 3/4 of the HSMCI internal FIFO size, then the write transfer starts as soon as half the FIFO is filled. When the block length is greater than or equal to half the internal FIFO size, then the write transfer starts as soon as one quarter of the FIFO is filled. In other cases, the transfer starts as soon as the total amount of data is written in the internal FIFO.

1 = A write transfer starts as soon as one data is written into the FIFO.

- **FERRCTRL: Flow Error flag reset control mode**

0= When an underflow/overflow condition flag is set, a new Write/Read command is needed to reset the flag.

1= When an underflow/overflow condition flag is set, a read status resets the flag.

- **HSMODE: High Speed Mode**

0= Default bus timing mode.

1= If set to one, the host controller outputs command line and data lines on the rising edge of the card clock. The Host driver shall check the high speed support in the card registers.

- **LSYNC: Synchronize on the last block**

0= The pending command is sent at the end of the current data block.

1= The pending command is sent at the end of the block transfer when the transfer length is not infinite. (block count shall be different from zero)

36.14.18 HSMCI Write Protect Mode Register

Name: HSMCI_WPMR

Address: 0x400000E4

Access: Read-write

31	30	29	28	27	26	25	24
WP_KEY (0x4D => “M”)							
23	22	21	20	19	18	17	16
WP_KEY (0x43 => C”)							
15	14	13	12	11	10	9	8
WP_KEY (0x49 => “I”)							
7	6	5	4	3	2	1	0
							WP_EN

- **WP_EN: Write Protection Enable**

0 = Disables the Write Protection if WP_KEY corresponds to 0x4D4349 (“MCI’ in ASCII).

1 = Enables the Write Protection if WP_KEY corresponds to 0x4D4349 (“MCI’ in ASCII).

- **WP_KEY: Write Protection Key password**

Should be written at value **0x4D4349** (ASCII code for “MCI”). Writing any other value in this field has no effect.

Protects the registers:

- “HSMCI Mode Register” on page 836
- “HSMCI Data Timeout Register” on page 838
- “HSMCI SDCard/SDIO Register” on page 839
- “HSMCI Completion Signal Timeout Register” on page 844
- “HSMCI DMA Configuration Register” on page 858
- “HSMCI Configuration Register” on page 859

36.14.19 HSMCI Write Protect Status Register

Name: HSMCI_WPSR

Address: 0x400000E8

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
WP_VSRC							
15	14	13	12	11	10	9	8
WP_VSRC							
7	6	5	4	3	2	1	0
–	–	–	–	WP_VS			

- **WP_VS: Write Protection Violation Status**

Value	Name	Description
0	NONE	No Write Protection Violation occurred since the last read of this register (WP_SR)
1	WRITE	Write Protection detected unauthorized attempt to write a control register had occurred (since the last read.)
2	RESET	Software reset had been performed while Write Protection was enabled (since the last read).
3	BOTH	Both Write Protection violation and software reset with Write Protection enabled have occurred since the last read.

- **WP_VSRC: Write Protection Violation SouRCe**

When WPVS is active, this field indicates the write-protected register (through address offset or code) in which a write access has been attempted.

36.14.20 HSMCI FIFOx Memory Aperture

Name: HSMCI_FIFOx[x=0..255]

Address: 0x40000200

Access: Read-write

31	30	29	28	27	26	25	24
DATA							
23	22	21	20	19	18	17	16
DATA							
15	14	13	12	11	10	9	8
DATA							
7	6	5	4	3	2	1	0
DATA							

- **DATA: Data to Read or Data to Write**

37. Pulse Width Modulation (PWM)

37.1 Description

The PWM macrocell controls 4 channels independently. Each channel controls two complementary square output waveforms. Characteristics of the output waveforms such as period, duty-cycle, polarity and dead-times (also called dead-bands or non-overlapping times) are configured through the user interface. Each channel selects and uses one of the clocks provided by the clock generator. The clock generator provides several clocks resulting from the division of the PWM master clock (MCK).

All PWM macrocell accesses are made through registers mapped on the peripheral bus. All channels integrate a double buffering system in order to prevent an unexpected output waveform while modifying the period, the duty-cycle or the dead-times.

Channels can be linked together as synchronous channels to be able to update their duty-cycle or dead-times at the same time.

The update of duty-cycles of synchronous channels can be performed by the Peripheral DMA Controller Channel (PDC) which offers buffer transfer without processor Intervention.

The PWM macrocell provides 8 independent comparison units capable of comparing a programmed value to the counter of the synchronous channels (counter of channel 0). These comparisons are intended to generate software interrupts, to trigger pulses on the 2 independent event lines (in order to synchronize ADC conversions with a lot of flexibility independently of the PWM outputs), and to trigger PDC transfer requests.

The PWM outputs can be overridden synchronously or asynchronously to their channel counter.

The PWM block provides a fault protection mechanism with 4 fault inputs**,** capable of detecting a fault condition and to override the PWM outputs asynchronously.

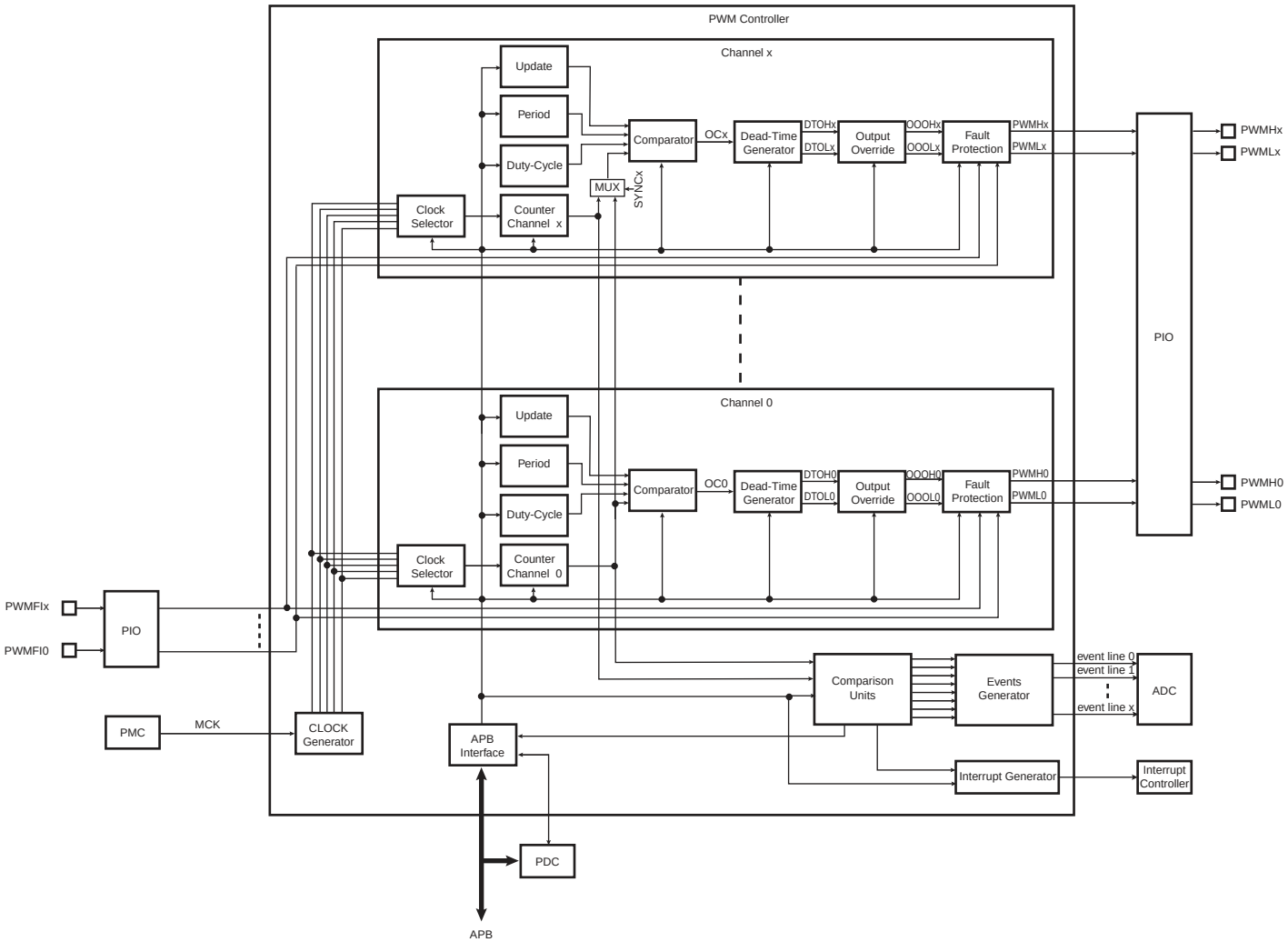
For safety usage, some control registers are write-protected.

37.2 Embedded Characteristics

- 4 Channels
- Common Clock Generator Providing Thirteen Different Clocks
  - A Modulo n Counter Providing Eleven Clocks
  - Two Independent Linear Dividers Working on Modulo n Counter Outputs
- Independent Channels
  - Independent 16-bit Counter for Each Channel
  - Independent Complementary Outputs with 12-bit Dead-Time Generator (Also Called Dead-Band or Non-Overlapping Time) for Each Channel
  - Independent Enable Disable Command for Each Channel
  - Independent Clock Selection for Each Channel
  - Independent Period, Duty-Cycle and Dead-Time for Each Channel
  - Independent Double Buffering of Period, Duty-Cycle and Dead-Times for Each Channel
  - Independent Programmable Selection of The Output Waveform Polarity for Each Channel
  - Independent Programmable Center or Left Aligned Output Waveform for Each Channel
  - Independent Output Override for Each Channel
- Synchronous Channel Mode
  - Synchronous Channels Share the Same Counter
  - Mode to Update the Synchronous Channels Registers after a Programmable Number of Periods
  - Synchronous Channels Supports Connection of one Peripheral DMA Controller Channel (PDC) Which Offers Buffer Transfer Without Processor Intervention To Update Duty-Cycle Registers
- 2 Independent Events Lines Intended to Synchronize ADC Conversions
- 8 Comparison Units Intended to Generate Interrupts, Pulses on Event Lines and PDC Transfer Requests
- 4 Programmable Fault Inputs Providing an Asynchronous Protection of PWM Outputs
  - User Driven through PIO inputs
  - PMC Driven when Crystal Oscillator Clock Fails
  - ADC Controller Driven through Configurable Comparison Function
- Write-Protect Registers

37.3 Block Diagram

Figure 37-1. Pulse Width Modulation Controller Block Diagram



37.4 I/O Lines Description

Each channel outputs two complementary external I/O lines.

Table 37-1. I/O Line Description

Name	Description	Type
PWMHx	PWM Waveform Output High for channel x	Output
PWMLx	PWM Waveform Output Low for channel x	Output
PWMFIx	PWM Fault Input x	Input

37.5 Product Dependencies

37.5.1 I/O Lines

The pins used for interfacing the PWM are multiplexed with PIO lines. The programmer must first program the PIO controller to assign the desired PWM pins to their peripheral function. If I/O lines of the PWM are not used by the application, they can be used for other purposes by the PIO controller.

All of the PWM outputs may or may not be enabled. If an application requires only four channels, then only four PIO lines will be assigned to PWM outputs.

Table 37-2. I/O Lines

Instance	Signal	I/O Line	Peripheral
PWM	PWMFI0	PA11	B
PWM	PWMFI1	PA12	B
PWM	PWMFI2	PA18	B
PWM	PWMH0	PA4	B
PWM	PWMH0	PA28	B
PWM	PWMH0	PB0	A
PWM	PWMH0	PB13	B
PWM	PWMH0	PC24	B
PWM	PWMH1	PA5	B
PWM	PWMH1	PA29	B
PWM	PWMH1	PB1	A
PWM	PWMH1	PB14	B
PWM	PWMH1	PC25	B
PWM	PWMH2	PA6	B
PWM	PWMH2	PA15	B
PWM	PWMH2	PB2	A
PWM	PWMH2	PB15	B
PWM	PWMH2	PC26	B
PWM	PWMH3	PA20	B
PWM	PWMH3	PB3	A
PWM	PWMH3	PB16	B
PWM	PWMH3	PC27	B
PWM	PWML0	PA7	B
PWM	PWML0	PB17	B
PWM	PWML0	PB25	B
PWM	PWML0	PC6	B
PWM	PWML0	PC29	A
PWM	PWML1	PA8	B
PWM	PWML1	PB18	B
PWM	PWML1	PB26	B

Table 37-2. I/O Lines (Continued)

PWM	PWML1	PC7	B
PWM	PWML1	PC30	A
PWM	PWML2	PA9	B
PWM	PWML2	PB19	B
PWM	PWML2	PB27	B
PWM	PWML2	PC8	B
PWM	PWML2	PC31	A
PWM	PWML3	PA10	B
PWM	PWML3	PB20	B
PWM	PWML3	PB28	B
PWM	PWML3	PC9	B
PWM	PWML3	PC16	B

37.5.2 Power Management

The PWM is not continuously clocked. The programmer must first enable the PWM clock in the Power Management Controller (PMC) before using the PWM. However, if the application does not require PWM operations, the PWM clock can be stopped when not needed and be restarted later. In this case, the PWM will resume its operations where it left off.

In the PWM description, Master Clock (MCK) is the clock of the peripheral bus to which the PWM is connected.

37.5.3 Interrupt Sources

The PWM interrupt line is connected on one of the internal sources of the Interrupt Controller. Using the PWM interrupt requires the Interrupt Controller to be programmed first. Note that it is not recommended to use the PWM interrupt line in edge sensitive mode.

37.5.4 Fault Inputs

The PWM has the FAULT inputs connected to the different modules. Please refer to the implementation of these module within the product for detailed information about the fault generation procedure. The PWM receives faults from PIO inputs, PMC, ADC controller,

Table 37-3. Fault Inputs

Fault Inputs	External PWM Fault Input Number	Polarity Level(1)	Fault Input ID
Main OSC	–	1	0
PA18	PWMFI2	User Defined	1
PA11	PWMFI0	User Defined	2
PA12	PWMFI1	User Defined	3

Note: 1. FPOL bit in PWMC_FMR.

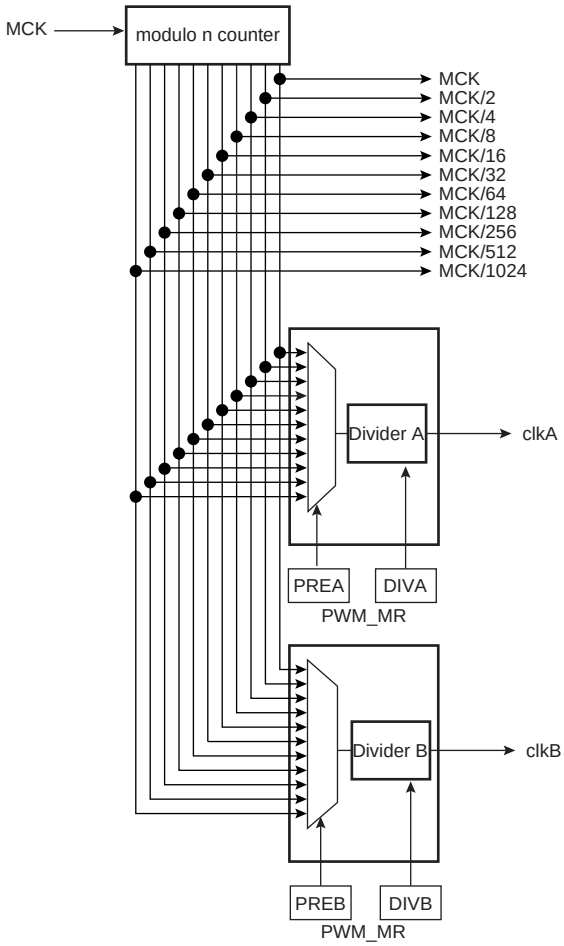
37.6 Functional Description

The PWM macrocell is primarily composed of a clock generator module and 4 channels.

- Clocked by the master clock (MCK), the clock generator module provides 13 clocks.
- Each channel can independently choose one of the clock generator outputs.
- Each channel generates an output waveform with attributes that can be defined independently for each channel through the user interface registers.

37.6.1 PWM Clock Generator

Figure 37-2. Functional View of the Clock Generator Block Diagram



The PWM master clock (MCK) is divided in the clock generator module to provide different clocks available for all channels. Each channel can independently select one of the divided clocks.

The clock generator is divided in three blocks:

- a modulo n counter which provides 11 clocks: F_{MCK}, $F_{MCK}/2$, $F_{MCK}/4$, $F_{MCK}/8$, $F_{MCK}/16$, $F_{MCK}/32$, $F_{MCK}/64$, $F_{MCK}/128$, $F_{MCK}/256$, $F_{MCK}/512$, $F_{MCK}/1024$
- two linear dividers (1, 1/2, 1/3, ... 1/255) that provide two separate clocks: clkA and clkB

Each linear divider can independently divide one of the clocks of the modulo n counter. The selection of the clock to be divided is made according to the PREA (PREB) field of the PWM Clock register (PWM_CLK). The resulting clock clkA (clkB) is the clock selected divided by DIVA (DIVB) field value.

After a reset of the PWM controller, DIVA (DIVB) and PREA (PREB) are set to 0. This implies that after reset clkA (clkB) are turned off.

At reset, all clocks provided by the modulo n counter are turned off except clock ”MCK”. This situation is also true when the PWM master clock is turned off through the Power Management Controller.

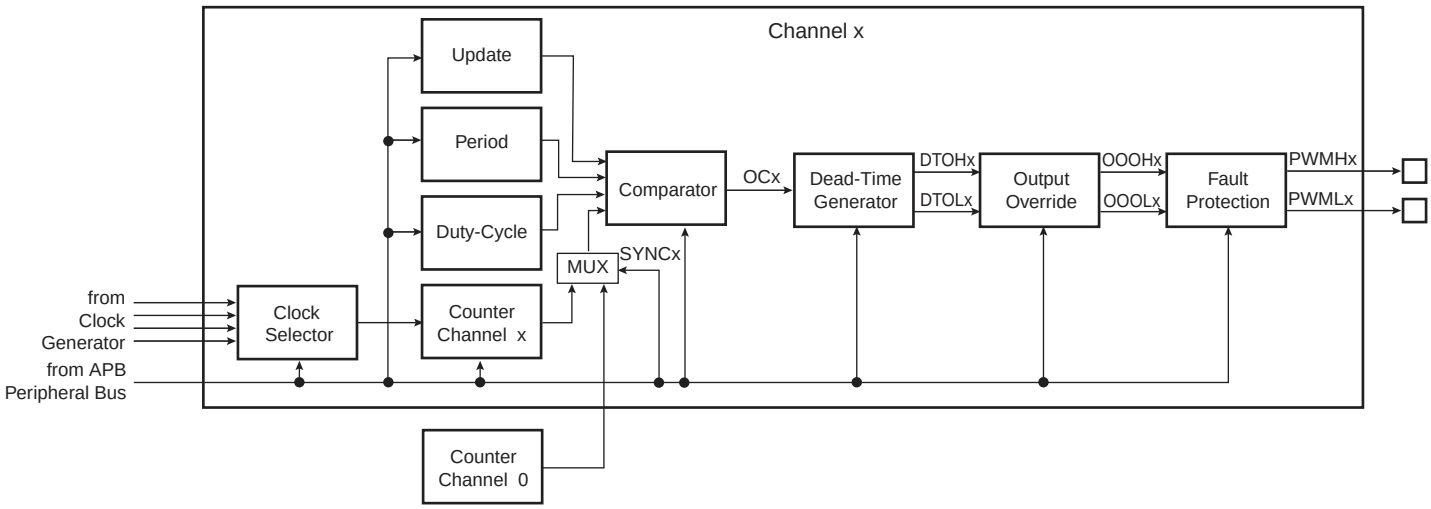
CAUTION:

- Before using the PWM macrocell, the programmer must first enable the PWM clock in the Power Management Controller (PMC).

37.6.2 PWM Channel

37.6.2.1 Channel Block Diagram

Figure 37-3. Functional View of the Channel Block Diagram



Each of the 4 channels is composed of six blocks:

- A clock selector which selects one of the clocks provided by the clock generator (described in Section 37.6.1 on page 868).
- A counter clocked by the output of the clock selector. This counter is incremented or decremented according to the channel configuration and comparators matches. The size of the counter is 16 bits.
- A comparator used to compute the OCx output waveform according to the counter value and the configuration. The counter value can be the one of the channel counter or the one of the channel 0 counter according to SYNCx bit in the “PWM Sync Channels Mode Register” on page 904 (PWM_SCM).
- A dead-time generator providing two complementary outputs (DTOHx/DTOLx) which allows to drive external power control switches safely.
- An output override block that can force the two complementary outputs to a programmed value (OOOHx/OOOLx).
- An asynchronous fault protection mechanism that has the highest priority to override the two complementary outputs in case of fault detection (PWMHx/PWMLx).

37.6.2.2 Comparator

The comparator continuously compares its counter value with the channel period defined by CPRD in the “PWM Channel Period Register” on page 935 (PWM_CPRDx) and the duty-cycle defined by CDTY in the “PWM Channel Duty Cycle Register” on page 933 (PWM_CDTYx) to generate an output signal OCx accordingly.

The different properties of the waveform of the output OCx are:

- the ***clock selection***. The channel counter is clocked by one of the clocks provided by the clock generator described in the previous section. This channel parameter is defined in the CPRE field of the “PWM Channel Mode Register” on page 931 (PWM_CMRx). This field is reset at 0.
- the ***waveform period***. This channel parameter is defined in the CPRD field of the PWM_CPRDx register.
  If the waveform is left aligned, then the output waveform period depends on the counter source clock and can be calculated:
  By using the PWM master clock (MCK) divided by an X given prescaler value (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024), the resulting period formula will be:

  $$\frac{(X \times CPRD)}{MCK}$$

  By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

  $$\frac{(CPRD \times DIVA)}{MCK} \; or \; \frac{(CPRD \times DIVB)}{MCK}$$

  If the waveform is center aligned then the output waveform period depends on the counter source clock and can be calculated:
  By using the PWM master clock (MCK) divided by an X given prescaler value
  (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024). The resulting period formula will be:

  $$\frac{(2 \times X \times CPRD)}{MCK}$$

  By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

  $$\frac{(2 \times CPRD \times DIVA)}{MCK} \; or \; \frac{(2 \times CPRD \times DIVB)}{MCK}$$

- the ***waveform duty-cycle***. This channel parameter is defined in the CDTY field of the PWM_CDTYx register.
  If the waveform is left aligned then:

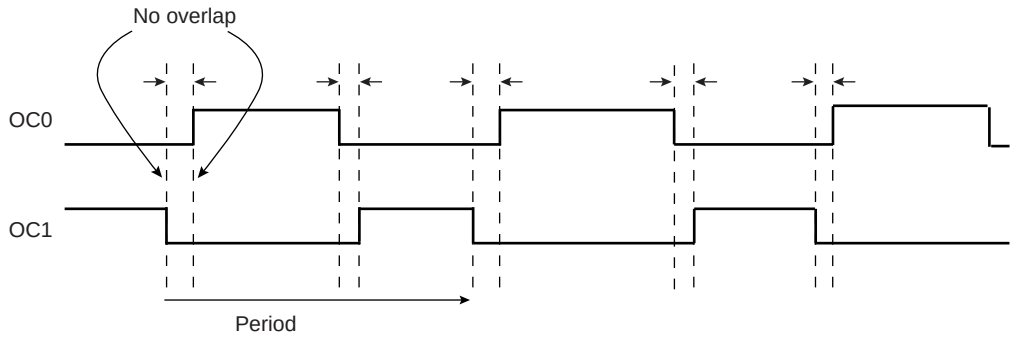
  $$\text{duty cycle} = \frac{(period - 1/\text{fchannel_x_clock} \times CDTY)}{period}$$

  If the waveform is center aligned, then:

  $$\text{duty cycle} = \frac{((period/2) - 1/\text{fchannel_x_clock} \times CDTY))}{(period/2)}$$

- the ***waveform polarity.*** At the beginning of the period, the signal can be at high or low level. This property is defined in the CPOL field of the PWM_CMRx register. By default the signal starts by a low level.
- the ***waveform alignment***. The output waveform can be left or center aligned. Center aligned waveforms can be used to generate non overlapped waveforms. This property is defined in the CALG field of the PWM_CMRx register. The default mode is left aligned.

Figure 37-4. Non Overlapped Center Aligned Waveforms



Note: 1. See Figure 37-5 on page 872 for a detailed description of center aligned waveforms.

When center aligned, the channel counter increases up to CPRD and decreases down to 0. This ends the period.

When left aligned, the channel counter increases up to CPRD and is reset. This ends the period.

Thus, for the same CPRD value, the period for a center aligned channel is twice the period for a left aligned channel.

Waveforms are fixed at 0 when:

- CDTY = CPRD and CPOL = 0
- CDTY = 0 and CPOL = 1

Waveforms are fixed at 1 (once the channel is enabled) when:

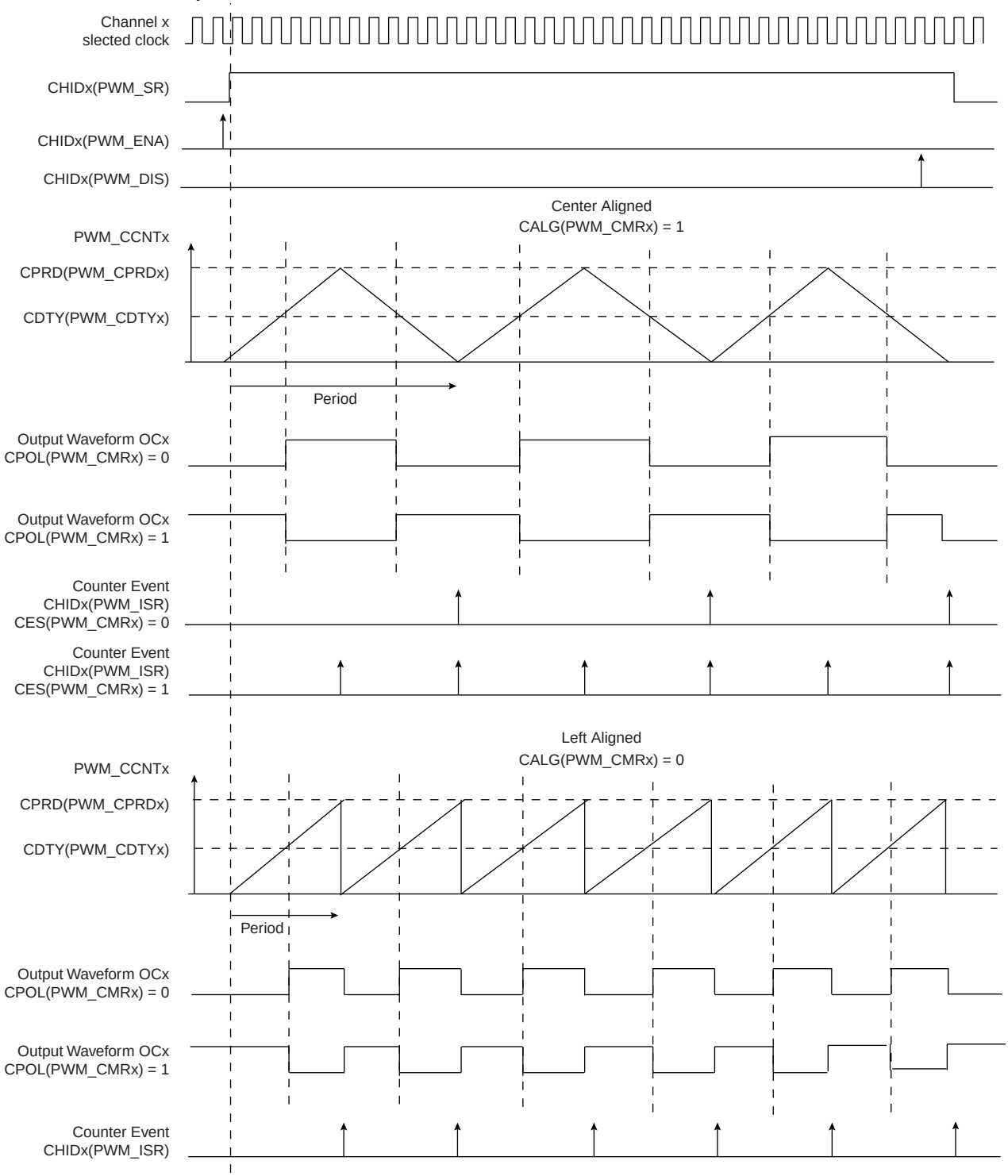
- CDTY = 0 and CPOL = 0
- CDTY = CPRD and CPOL = 1

The waveform polarity must be set before enabling the channel. This immediately affects the channel output level. Changes on channel polarity are not taken into account while the channel is enabled.

Besides generating output signals OCx, the comparator generates interrupts in function of the counter value. When the output waveform is left aligned, the interrupt occurs at the end of the counter period. When the output waveform is center aligned, the bit CES of the PWM_CMRx register defines when the channel counter interrupt occurs. If CES is set to 0, the interrupt occurs at the end of the counter period. If CES is set to 1, the interrupt occurs at the end of the counter period and at half of the counter period.

Figure 37-5 “Waveform Properties” illustrates the counter interrupts in function of the configuration.

Figure 37-5. Waveform Properties



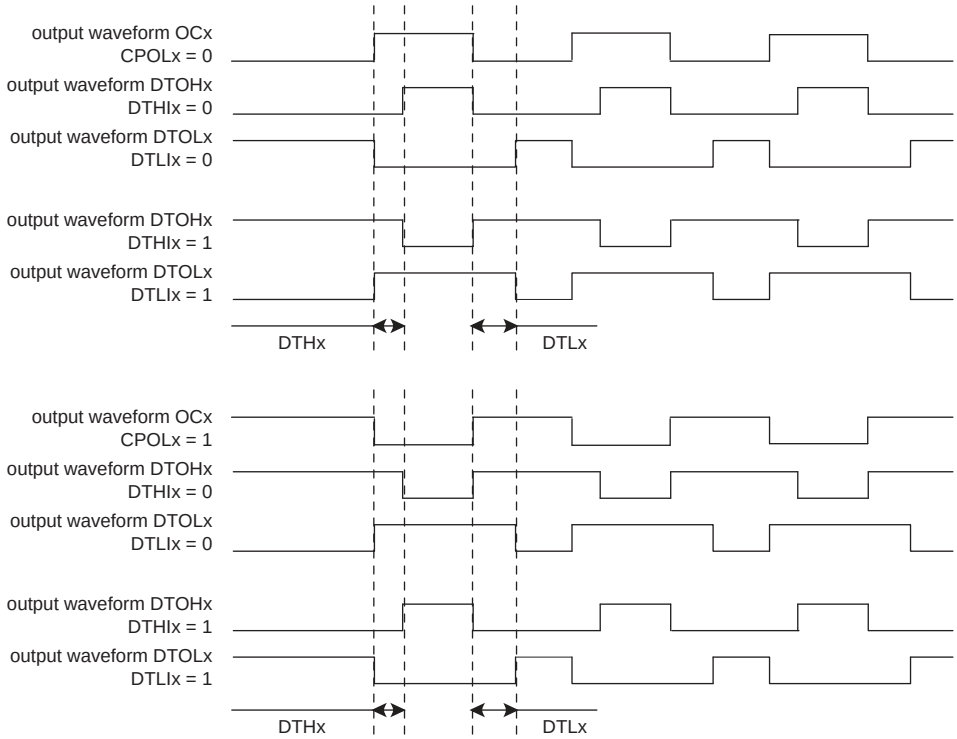
37.6.2.3 Dead-Time Generator

The dead-time generator uses the comparator output OCx to provide the two complementary outputs DTOHx and DTOLx, which allows the PWM macrocell to drive external power control switches safely. When the dead-time generator is enabled by setting the bit DTE to 1 or 0 in the "PWM Channel Mode Register" (PWM_CMRx), dead-times (also called dead-bands or non-overlapping times) are inserted between the edges of the two complementary outputs DTOHx and DTOLx. Note that enabling or disabling the dead-time generator is allowed only if the channel is disabled.

The dead-time is adjustable by the "PWM Channel Dead Time Register" (PWM_DTx). Both outputs of the dead-time generator can be adjusted separately by DTH and DTL. The dead-time values can be updated synchronously to the PWM period by using the "PWM Channel Dead Time Update Register" (PWM_DTUPDx).

The dead-time is based on a specific counter which uses the same selected clock that feeds the channel counter of the comparator. Depending on the edge and the configuration of the dead-time, DTOHx and DTOLx are delayed until the counter has reached the value defined by DTH or DTL. An inverted configuration bit (DTHI and DTLI bit in the PWM_CMRx register) is provided for each output to invert the dead-time outputs. The following figure shows the waveform of the dead-time generator.

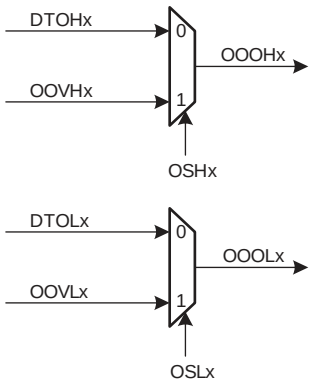
Figure 37-6. Complementary Output Waveforms



37.6.2.4 Output Override

The two complementary outputs DTOHx and DTOLx of the dead-time generator can be forced to a value defined by the software.

Figure 37-7. Override Output Selection



The fields OSHx and OSLx in the "PWM Output Selection Register" (PWM_OS) allow the outputs of the dead-time generator DTOHx and DTOLx to be overridden by the value defined in the fields OOVHx and OOVLx in the"PWM Output Override Value Register" (PWM_OOV).

The set registers "PWM Output Selection Set Register" and "PWM Output Selection Set Update Register" (PWM_OSS and PWM_OSSUPD) enable the override of the outputs of a channel regardless of other channels. In the same way, the clear registers "PWM Output Selection Clear Register" and "PWM Output Selection Clear Update Register" (PWM_OSC and PWM_OSCUPD) disable the override of the outputs of a channel regardless of other channels.

By using buffer registers PWM_OSSUPD and PWM_OSCUPD, the output selection of PWM outputs is done synchronously to the channel counter, at the beginning of the next PWM period.

By using registers PWM_OSS and PWM_OSC, the output selection of PWM outputs is done asynchronously to the channel counter, as soon as the register is written.

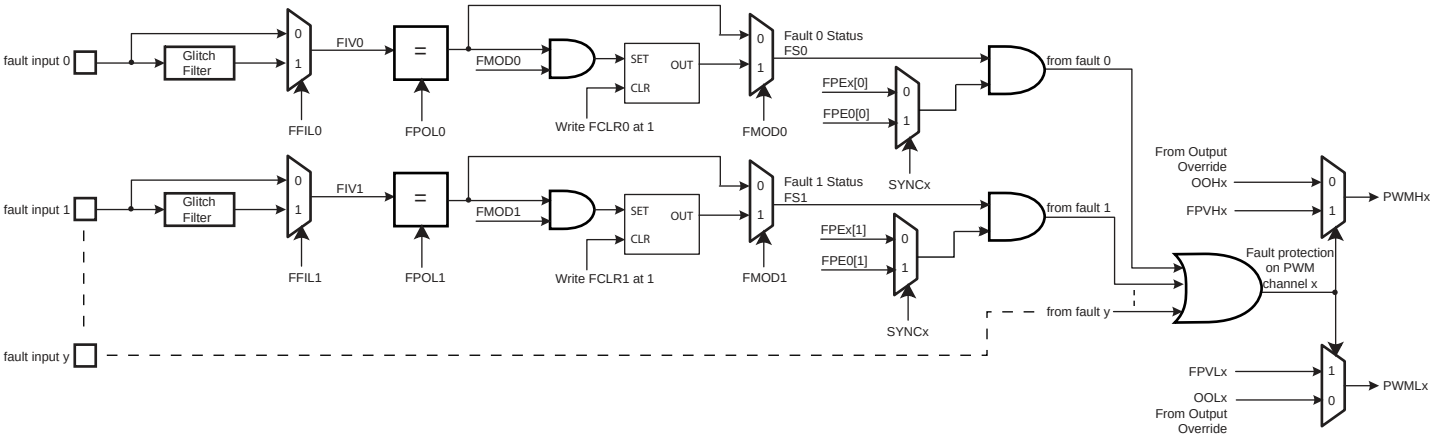
The value of the current output selection can be read in PWM_OS.

While overriding PWM outputs, the channel counters continue to run, only the PWM outputs are forced to user defined values.

37.6.2.5 Fault Protection

4 inputs provide fault protection which can force any of the PWM output pair to a programmable value. This mechanism has priority over output overriding.

Figure 37-8. Fault Protection



The polarity level of the fault inputs is configured by the FPOL field in the "PWM Fault Mode Register" (PWM_FMR). For fault inputs coming from internal peripherals such as ADC, Timer Counter, to name but a few, the polarity level must be FPOL = 1. For fault inputs coming from external GPIO pins the polarity level depends on the user's implementation.

The configuration of the Fault Activation Mode (FMOD bit in PWMC_FMR) depends on the peripheral generating the fault. If the corresponding peripheral does not have "Fault Clear" management, then the FMOD configuration to use must be FMOD = 1, to avoid spurious fault detection. Check the corresponding peripheral documentation for details on handling fault generation.

The fault inputs can be glitch filtered or not in function of the FFIL field in the PWM_FMR register. When the filter is activated, glitches on fault inputs with a width inferior to the PWM master clock (MCK) period are rejected.

A fault becomes active as soon as its corresponding fault input has a transition to the programmed polarity level. If the corresponding bit FMOD is set to 0 in the PWM_FMR register, the fault remains active as long as the fault input is at this polarity level. If the corresponding FMOD bit is set to 1, the fault remains active until the fault input is not at this polarity level anymore and until it is cleared by writing the corresponding bit FCLR in the "PWM Fault Clear Register" (PWM_FSCR). By reading the "PWM Fault Status Register" (PWM_FSR), the user can read the current level of the fault inputs by means of the field FIV, and can know which fault is currently active thanks to the FS field.

Each fault can be taken into account or not by the fault protection mechanism in each channel. To be taken into account in the channel x, the fault y must be enabled by the bit FPEx[y] in the "PWM Fault Protection Enable Registers" (PWM_FPE1). However the synchronous channels (see Section 37.6.2.6 "Synchronous Channels") do not use their own fault enable bits, but those of the channel 0 (bits FPE0[y]).

The fault protection on a channel is triggered when this channel is enabled and when any one of the faults that are enabled for this channel is active. It can be triggered even if the PWM master clock (MCK) is not running but only by a fault input that is not glitch filtered.

When the fault protection is triggered on a channel, the fault protection mechanism forces the channel outputs to the values defined by the fields FPVHx and FPVLx in the "PWM Fault Protection Value Register" (PWM_FPV) and leads to a reset of the counter of this channel. The output forcing is made asynchronously to the channel counter.

CAUTION:

- To prevent an unexpected activation of the status flag FSy in the PWM_FSR register, the FMODy bit can be set to “1” only if the FPOLy bit has been previously configured to its final value.
- To prevent an unexpected activation of the Fault Protection on the channel x, the bit FPEx[y] can be set to “1” only if the FPOLy bit has been previously configured to its final value.

If a comparison unit is enabled (see Section 37.6.3 “PWM Comparison Units”) and if a fault is triggered in the channel 0, in this case the comparison cannot match.

As soon as the fault protection is triggered on a channel, an interrupt (different from the interrupt generated at the end of the PWM period) can be generated but only if it is enabled and not masked. The interrupt is reset by reading the interrupt status register, even if the fault which has caused the trigger of the fault protection is kept active.

37.6.2.6 Synchronous Channels

Some channels can be linked together as synchronous channels. They have the same source clock, the same period, the same alignment and are started together. In this way, their counters are synchronized together.

The synchronous channels are defined by the SYNCx bits in the "PWM Sync Channels Mode Register" (PWM_SCM). Only one group of synchronous channels is allowed.

When a channel is defined as a synchronous channel, the channel 0 is automatically defined as a synchronous channel too, because the channel 0 counter configuration is used by all the synchronous channels.

If a channel x is defined as a synchronous channel, it uses the following configuration fields of the channel 0 instead of its own:

- CPRE0 field in PWM_CMR0 register instead of CPREx field in PWM_CMRx register (same source clock)
- CPRD0 field in PWM_CMR0 register instead of CPRDx field in PWM_CMRx register (same period)
- CALG0 field in PWM_CMR0 register instead of CALGx field in PWM_CMRx register (same alignment)

Thus writing these fields of a synchronous channel has no effect on the output waveform of this channel (except channel 0 of course).

Because counters of synchronous channels must start at the same time, they are all enabled together by enabling the channel 0 (by the CHID0 bit in PWM_ENA register). In the same way, they are all disabled together by disabling channel 0 (by the CHID0 bit in PWM_DIS register). However, a synchronous channel x different from channel 0 can be enabled or disabled independently from others (by the CHIDx bit in PWM_ENA and PWM_DIS registers).

Defining a channel as a synchronous channel while it is an asynchronous channel (by writing the bit SYNCx to 1 while it was at 0) is allowed only if the channel is disabled at this time (CHIDx = 0 in PWM_SR register). In the same way, defining a channel as an asynchronous channel while it is a synchronous channel (by writing the SYNCx bit to 0 while it was 1) is allowed only if the channel is disabled at this time.

The field UPDM (Update Mode) in the PWM_SCM register allow to select one of the three methods to update the registers of the synchronous channels:

- Method 1 (UPDM = 0): the period value, the duty-cycle values and the dead-time values must be written by the CPU in their respective update registers (respectively PWM_CPRDUPDx, PWM_CDTYUPDx and PWM_DTUPDx).The update is triggered at the next PWM period as soon as the bit UPDULOCK in the "PWM Sync Channels Update Control Register" (PWM_SCUC) is set to 1 (see "Method 1: Manual write of duty-cycle values and manual trigger of the update" on page 879).
- Method 2 (UPDM = 1): the period value, the duty-cycle values, the dead-time values and the update period value must be written by the CPU in their respective update registers (respectively PWM_CPRDUPDx, PWM_CDTYUPDx and PWM_DTUPD). The update of the period value and of the dead-time values is triggered at the next PWM period as soon as the bit UPDULOCK in the "PWM Sync Channels Update Control Register" (PWM_SCUC) is set to 1. The update of the duty-cycle values and the update period value is triggered automatically after an update period defined by the field UPR in the "PWM Sync Channels Update Period Register" (PWM_SCUP) (see "Method 2: Manual write of duty-cycle values and automatic trigger of the update" on page 880).
- Method 3 (UPDM = 2): same as Method 2 apart from the fact that the duty-cycle values of ALL synchronous channels are written by the Peripheral DMA Controller (PDC) (see "Method 3: Automatic write of duty-cycle values and automatic trigger of the update" on page 882). The user can choose to synchronize the PDC transfer request with a comparison match (see Section 37.6.3 "PWM Comparison Units"), by the fields PTRM and PTRCS in the PWM_SCM register.

Table 37-4. Summary of the Update of Registers of Synchronous Channels

	UPDM=0	UPDM=1	UPDM=2
Period Value (PWM_CPRDUPDx)	Write by the CPU		
	Update is triggered at the next PWM period as soon as the bit UPDULOCK is set to 1		
Dead-Time Values (PWM_DTUPDx)	Write by the CPU		
	Update is triggered at the next PWM period as soon as the bit UPDULOCK is set to 1		
Duty-Cycle Values (PWM_CDTYUPDx)	Write by the CPU	Write by the CPU	Write by the PDC
	Update is triggered at the next PWM period as soon as the bit UPDULOCK is set to 1	Update is triggered at the next PWM period as soon as the update period counter has reached the value UPR	
Update Period Value (PWM_SCUPUPD)	Not applicable	Write by the CPU	
	Not applicable	Update is triggered at the next PWM period as soon as the update period counter has reached the value UPR	

Method 1: Manual write of duty-cycle values and manual trigger of the update

In this mode, the update of the period value, the duty-cycle values and the dead-time values must be done by writing in their respective update registers with the CPU (respectively PWM_CPRDUPDx, PWM_CDTYUPDx and PWM_DTUPDx).

To trigger the update, the user must use the bit UPDULOCK of the "PWM Sync Channels Update Control Register" (PWM_SCUC) which allows to update synchronously (at the same PWM period) the synchronous channels:

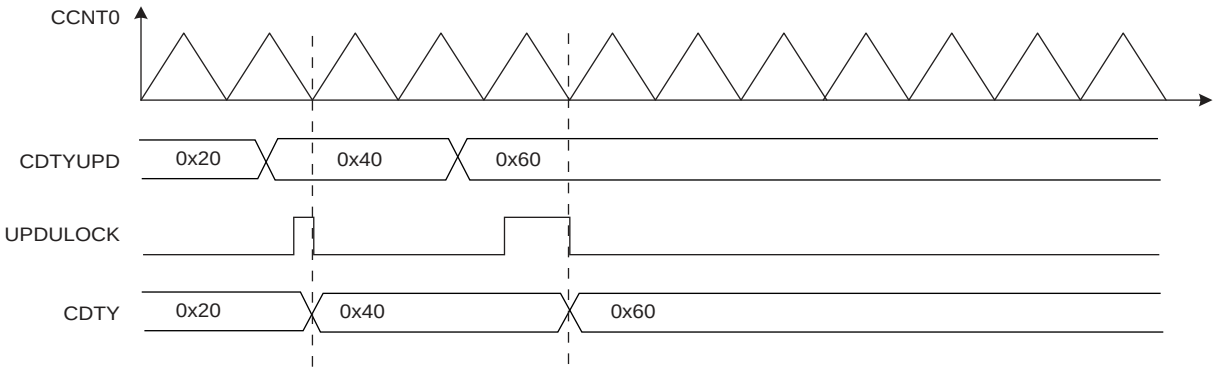
- If the bit UPDULOCK is set to 1, the update is done at the next PWM period of the synchronous channels.
- If the UPDULOCK bit is not set to 1, the update is locked and cannot be performed.

After writing the UPDULOCK bit to 1, it is held at this value until the update occurs, then it is read 0.

Sequence for Method 1:

1. Select the manual write of duty-cycle values and the manual update by setting the UPDM field to 0 in the PWM_SCM register
2. Define the synchronous channels by the SYNCx bits in the PWM_SCM register.
3. Enable the synchronous channels by writing CHID0 in the PWM_ENA register.
4. If an update of the period value and/or the duty-cycle values and/or the dead-time values is required, write registers that need to be updated (PWM_CPRDUPDx, PWM_CDTYUPDx and PWM_DTUPDx).
5. Set UPDULOCK to 1 in PWM_SCUC.
6. The update of the registers will occur at the beginning of the next PWM period. At this moment the UPDULOCK bit is reset, go to Step 4.) for new values.

Figure 37-9. Method 1 (UPDM = 0)



Method 2: Manual write of duty-cycle values and automatic trigger of the update

In this mode, the update of the period value, the duty-cycle values, the dead-time values and the update period value must be done by writing in their respective update registers with the CPU (respectively PWM_CPRDUPDx, PWM_CDTYUPDx, PWM_DTUPDx and PWM_SCUPUPD).

To trigger the update of the period value and the dead-time values, the user must use the bit UPDULOCK of the "PWM Sync Channels Update Control Register" (PWM_SCUC) which allows to update synchronously (at the same PWM period) the synchronous channels:

- If the bit UPDULOCK is set to 1, the update is done at the next PWM period of the synchronous channels.
- If the UPDULOCK bit is not set to 1, the update is locked and cannot be performed.

After writing the UPDULOCK bit to 1, it is held at this value until the update occurs, then it is read 0.

The update of the duty-cycle values and the update period is triggered automatically after an update period.

To configure the automatic update, the user must define a value for the Update Period by the UPR field in the "PWM Sync Channels Update Period Register" (PWM_SCUP). The PWM controller waits UPR+1 period of synchronous channels before updating automatically the duty values and the update period value.

The status of the duty-cycle value write is reported in the "PWM Interrupt Status Register 2" (PWM_ISR2) by the following flags:

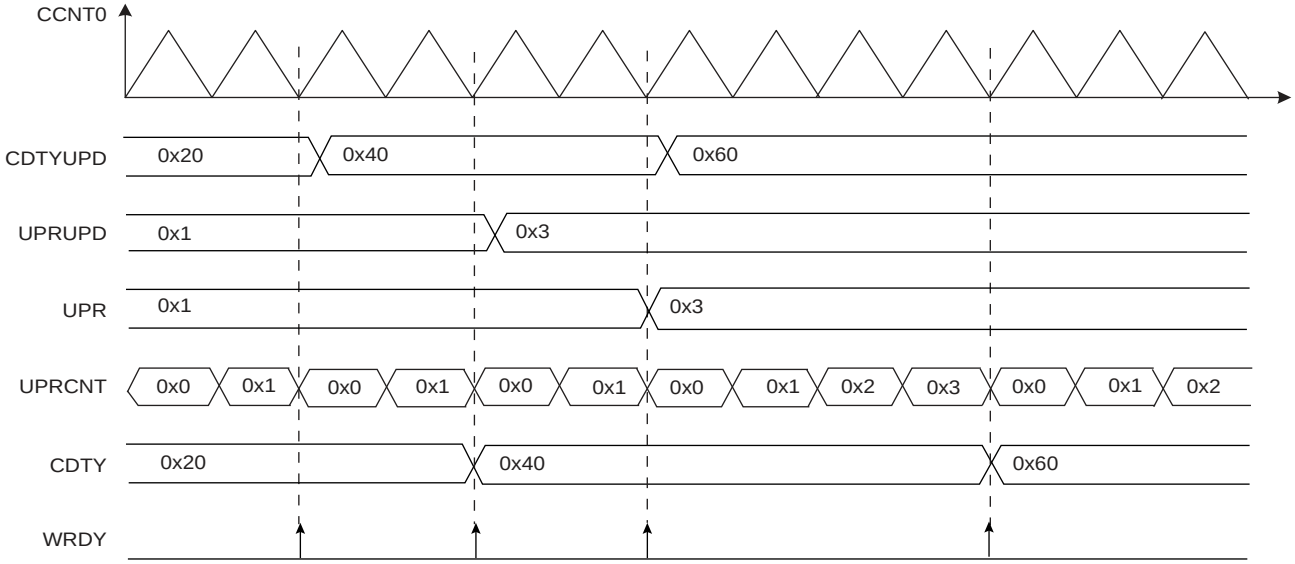
- WRDY: this flag is set to 1 when the PWM Controller is ready to receive new duty-cycle values and a new update period value. It is reset to 0 when the PWM_ISR2 register is read.

Depending on the interrupt mask in the PWM_IMR2 register, an interrupt can be generated by these flags.

Sequence for Method 2:

1. Select the manual write of duty-cycle values and the automatic update by setting the field UPDM to 1 in the PWM_SCM register
2. Define the synchronous channels by the bits SYNCx in the PWM_SCM register.
3. Define the update period by the field UPR in the PWM_SCUP register.
4. Enable the synchronous channels by writing CHID0 in the PWM_ENA register.
5. If an update of the period value and/or of the dead-time values is required, write registers that need to be updated (PWM_CPRDUPDx, PWM_DTUPDx), else go to Step 8.
6. Set UPDULOCK to 1 in PWM_SCUC.
7. The update of these registers will occur at the beginning of the next PWM period. At this moment the bit UPDULOCK is reset, go to Step 5. for new values.
8. If an update of the duty-cycle values and/or the update period is required, check first that write of new update values is possible by polling the flag WRDY (or by waiting for the corresponding interrupt) in the PWM_ISR2 register.
9. Write registers that need to be updated (PWM_CDTYUPDx, PWM_SCUPUPD).
10. The update of these registers will occur at the next PWM period of the synchronous channels when the Update Period is elapsed. Go to Step 8. for new values.

Figure 37-10. Method 2 (UPDM=1)



Method 3: Automatic write of duty-cycle values and automatic trigger of the update

In this mode, the update of the duty cycle values is made automatically by the Peripheral DMA Controller (PDC). The update of the period value, the dead-time values and the update period value must be done by writing in their respective update registers with the CPU (respectively PWM_CPRDUPDx, PWM_DTUPDx and PWM_SCUPUPD).

To trigger the update of the period value and the dead-time values, the user must use the bit UPDULOCK which allows to update synchronously (at the same PWM period) the synchronous channels:

- If the bit UPDULOCK is set to 1, the update is done at the next PWM period of the synchronous channels.
- If the UPDULOCK bit is not set to 1, the update is locked and cannot be performed.

After writing the UPDULOCK bit to 1, it is held at this value until the update occurs, then it is read 0.

The update of the duty-cycle values and the update period value is triggered automatically after an update period.

To configure the automatic update, the user must define a value for the Update Period by the field UPR in the "PWM Sync Channels Update Period Register" (PWM_SCUP). The PWM controller waits UPR+1 periods of synchronous channels before updating automatically the duty values and the update period value.

Using the PDC removes processor overhead by reducing its intervention during the transfer. This significantly reduces the number of clock cycles required for a data transfer, which improves microcontroller performance.

The PDC must write the duty-cycle values in the synchronous channels index order. For example if the channels 0, 1 and 3 are synchronous channels, the PDC must write the duty-cycle of the channel 0 first, then the duty-cycle of the channel 1, and finally the duty-cycle of the channel 3.

The status of the PDC transfer is reported in the "PWM Interrupt Status Register 2" (PWM_ISR2) by the following flags:

- WRDY: this flag is set to 1 when the PWM Controller is ready to receive new duty-cycle values and a new update period value. It is reset to 0 when the PWM_ISR2 register is read. The user can choose to synchronize the WRDY flag and the PDC transfer request with a comparison match (see Section 37.6.3 "PWM Comparison Units"), by the fields PTRM and PTRCS in the PWM_SCM register.
- ENDTX: this flag is set to 1 when a PDC transfer is completed
- TXBUFE: this flag is set to 1 when the PDC buffer is empty (no pending PDC transfers)
- UNRE: this flag is set to 1 when the update period defined by the UPR field has elapsed while the whole data has not been written by the PDC. It is reset to 0 when the PWM_ISR2 register is read.

Depending on the interrupt mask in the PWM_IMR2 register, an interrupt can be generated by these flags.

Sequence for Method 3:

1. Select the automatic write of duty-cycle values and automatic update by setting the field UPDM to 2 in the PWM_SCM register.
2. Define the synchronous channels by the bits SYNCx in the PWM_SCM register.
3. Define the update period by the field UPR in the PWM_SCUP register.
4. Define when the WRDY flag and the corresponding PDC transfer request must be set in the update period by the PTRM bit and the PTRCS field in the PWM_SCM register (at the end of the update period or when a comparison matches).
5. Define the PDC transfer settings for the duty-cycle values and enable it in the PDC registers
6. Enable the synchronous channels by writing CHID0 in the PWM_ENA register.
7. If an update of the period value and/or of the dead-time values is required, write registers that need to be updated (PWM_CPRDUPDx, PWM_DTUPDx), else go to Step 10.
8. Set UPDULOCK to 1 in PWM_SCUC.
9. The update of these registers will occur at the beginning of the next PWM period. At this moment the bit UPDULOCK is reset, go to Step 7. for new values.
10. If an update of the update period value is required, check first that write of a new update value is possible by polling the flag WRDY (or by waiting for the corresponding interrupt) in the PWM_ISR2 register, else go to Step 13.
11. Write the register that needs to be updated (PWM_SCUPUPD).
12. The update of this register will occur at the next PWM period of the synchronous channels when the Update Period is elapsed. Go to Step 10. for new values.
13. Check the end of the PDC transfer by the flag ENDTX. If the transfer has ended, define a new PDC transfer in the PDC registers for new duty-cycle values. Go to Step 5.

Figure 37-11. Method 3 (UPDM=2 and PTRM=0)

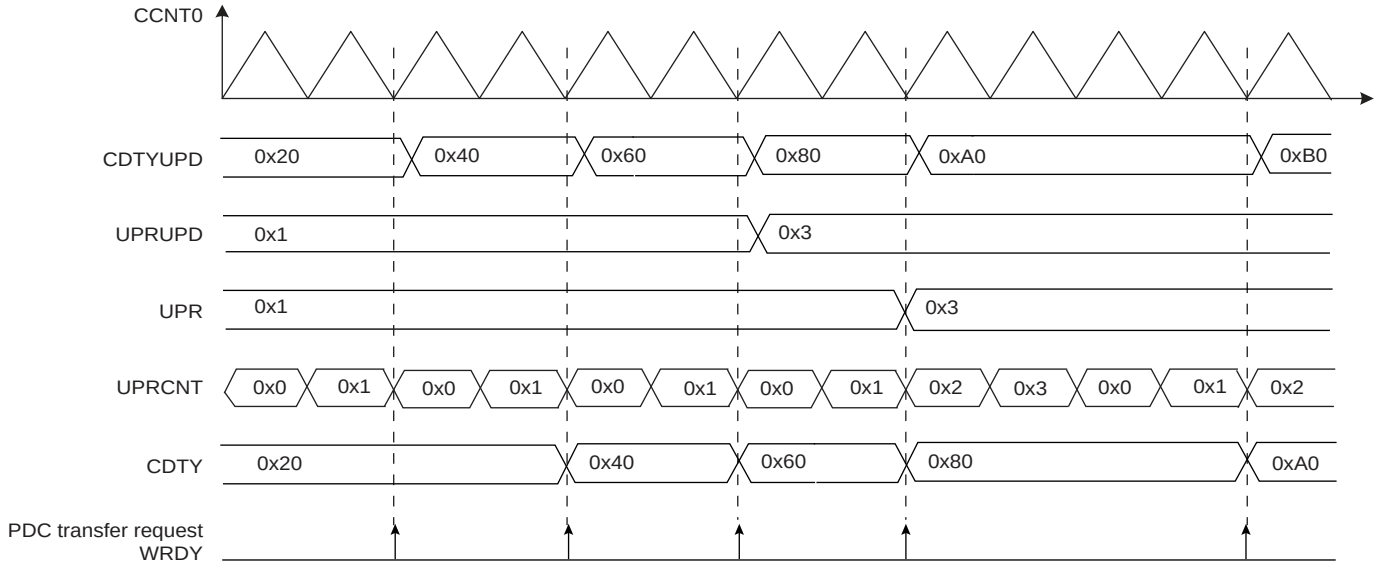
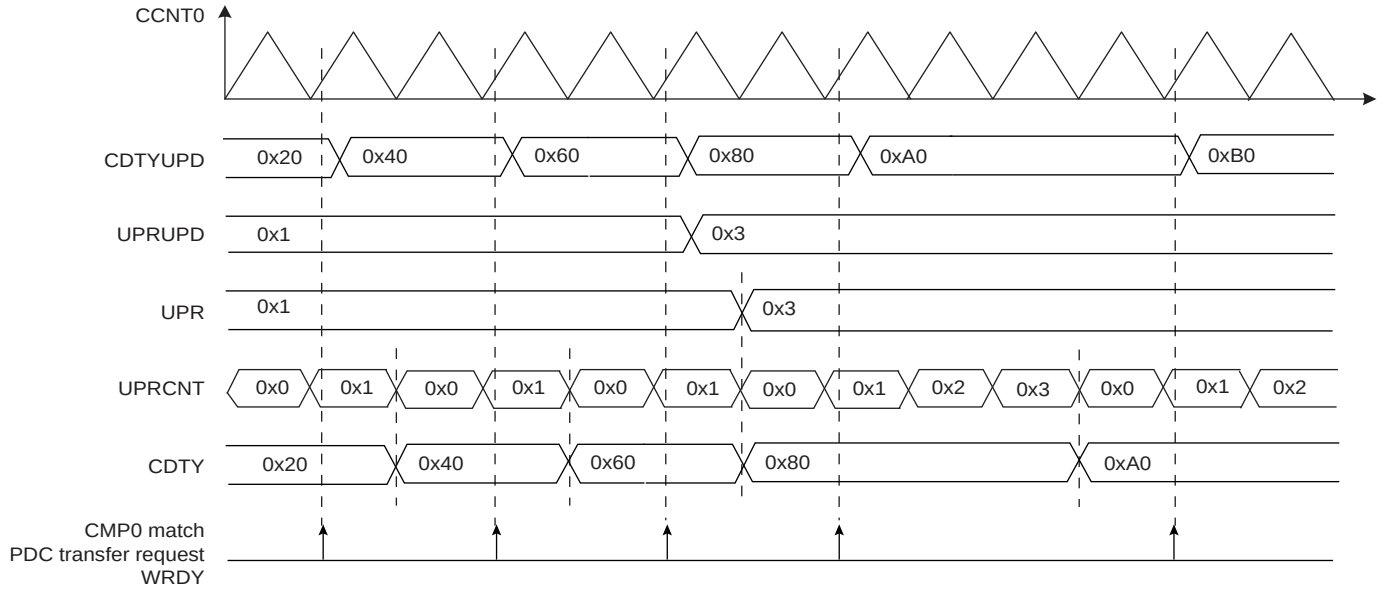


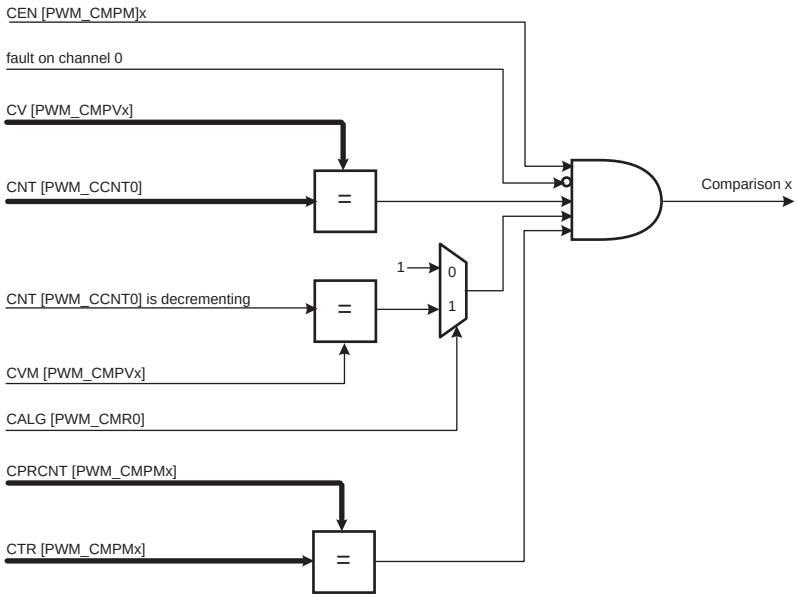
Figure 37-12. Method 3 (UPDM=2 and PTRM=1 and PTRCS=0)



37.6.3 PWM Comparison Units

The PWM provides 8 independent comparison units able to compare a programmed value with the current value of the channel 0 counter (which is the channel counter of all synchronous channels, Section 37.6.2.6 “Synchronous Channels”). These comparisons are intended to generate pulses on the event lines (used to synchronize ADC, see Section 37.6.4 “PWM Event Lines”), to generate software interrupts and to trigger PDC transfer requests for the synchronous channels (see “Method 3: Automatic write of duty-cycle values and automatic trigger of the update” on page 882).

Figure 37-13. Comparison Unit Block Diagram



The comparison x matches when it is enabled by the bit CEN in the “PWM Comparison x Mode Register” (PWM_CMPMx for the comparison x) and when the counter of the channel 0 reaches the comparison value defined by the field CV in “PWM Comparison x Value Register” (PWM_CMPVx for the comparison x). If the counter of the channel 0 is center aligned (CALG = 1 in “PWM Channel Mode Register”), the bit CVM (in PWM_CMPVx) defines if the comparison is made when the counter is counting up or counting down (in left alignment mode CALG=0, this bit is useless).

If a fault is active on the channel 0, the comparison is disabled and cannot match (see Section 37.6.2.5 “Fault Protection”).

The user can define the periodicity of the comparison x by the fields CTR and CPR (in PWM_CMPVx). The comparison is performed periodically once every CPR+1 periods of the counter of the channel 0, when the value of the comparison period counter CPRCNT (in PWM_CMPMx) reaches the value defined by CTR. CPR is the maximum value of the comparison period counter CPRCNT. If CPR=CTR=0, the comparison is performed at each period of the counter of the channel 0.

The comparison x configuration can be modified while the channel 0 is enabled by using the “PWM Comparison x Mode Update Register” (PWM_CMPMUPDx registers for the comparison x). In the same way, the comparison x value can be modified while the channel 0 is enabled by using the “PWM Comparison x Value Update Register” (PWM_CMPVUPDx registers for the comparison x).

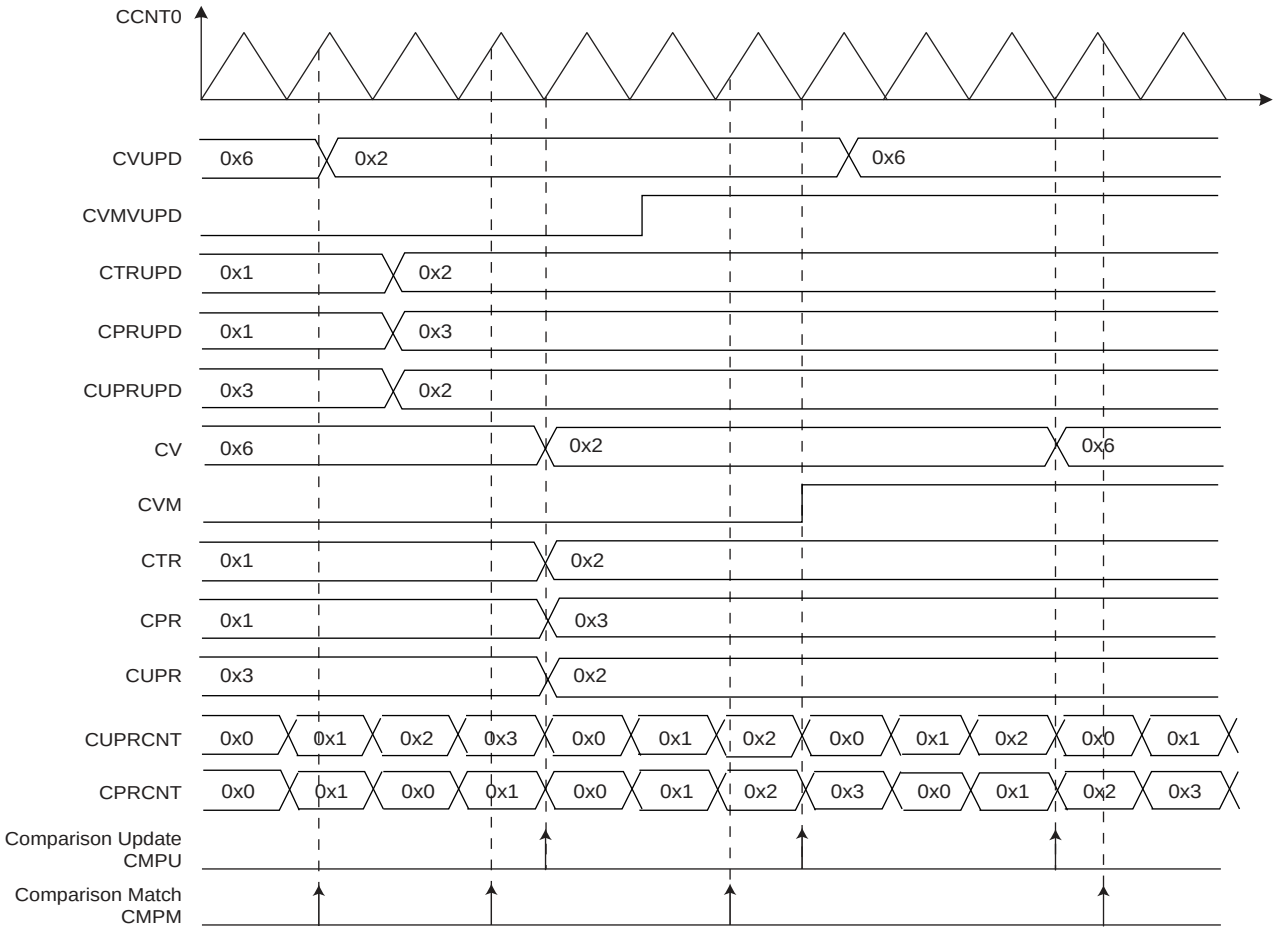
The update of the comparison x configuration and the comparison x value is triggered periodically after the comparison x update period. It is defined by the field CUPR in the PWM_CMPMx. The comparison unit has an update period counter independent from the period counter to trigger this update. When the value of the comparison update period counter CUPRCNT (in PWM_CMPMx) reaches the value defined by CUPR, the update

is triggered. The comparison x update period CUPR itself can be updated while the channel 0 is enabled by using the PWM_CMPMUPDx register.

CAUTION: to be taken into account, the write of the register PWM_CMPVUPDx must be followed by a write of the register PWM_CMPMUPDx.

The comparison match and the comparison update can be source of an interrupt, but only if it is enabled and not masked. These interrupts can be enabled by the "PWM Interrupt Enable Register 2" and disabled by the "PWM Interrupt Disable Register 2" . The comparison match interrupt and the comparison update interrupt are reset by reading the "PWM Interrupt Status Register 2" .

Figure 37-14. Comparison Waveform

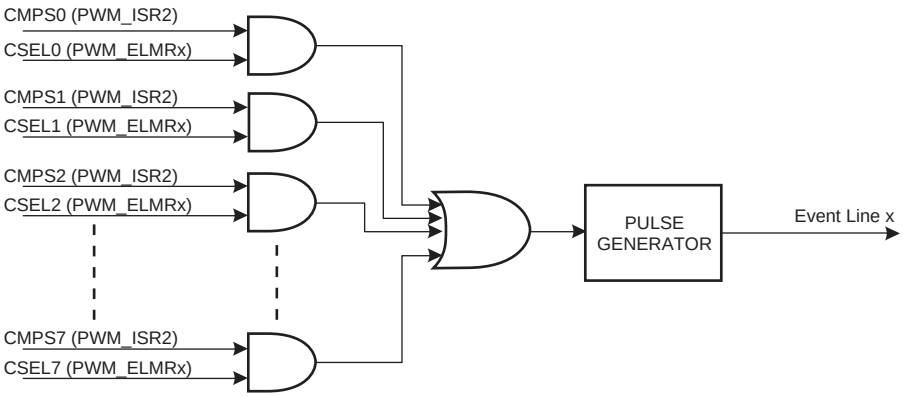


37.6.4 PWM Event Lines

The PWM provides 2 independent event lines intended to trigger actions in other peripherals (in particular for ADC (Analog-to-Digital Converter)).

A pulse (one cycle of the master clock (MCK)) is generated on an event line, when at least one of the selected comparisons is matching. The comparisons can be selected or unselected independently by the CSEL bits in the “PWM Event Line x Register” (PWM_ELMRx for the Event Line x).

Figure 37-15. Event Line Block Diagram



37.6.5 PWM Controller Operations

37.6.5.1 Initialization

Before enabling the channels, they must have been configured by the software application:

- Unlock User Interface by writing the WPCMD field in the PWM_WPCR Register.
- Configuration of the clock generator (DIVA, PREA, DIVB, PREB in the PWM_CLK register if required).
- Selection of the clock for each channel (CPRE field in the PWM_CMRx register)
- Configuration of the waveform alignment for each channel (CALG field in the PWM_CMRx register)
- Selection of the counter event selection (if CALG = 1) for each channel (CES field in the PWM_CMRx register)
- Configuration of the output waveform polarity for each channel (CPOL in the PWM_CMRx register)
- Configuration of the period for each channel (CPRD in the PWM_CPRDx register). Writing in PWM_CPRDx register is possible while the channel is disabled. After validation of the channel, the user must use PWM_CPRDUPDx register to update PWM_CPRDx as explained below.
- Configuration of the duty-cycle for each channel (CDTY in the PWM_CDTYx register). Writing in PWM_CDTYx register is possible while the channel is disabled. After validation of the channel, the user must use PWM_CDTYUPDx register to update PWM_CDTYx as explained below.
- Configuration of the dead-time generator for each channel (DTH and DTL in PWM_DTx) if enabled (DTE bit in the PWM_CMRx register). Writing in the PWM_DTx register is possible while the channel is disabled. After validation of the channel, the user must use PWM_DTUPDx register to update PWM_DTx
- Selection of the synchronous channels (SYNCx in the PWM_SCM register)
- Selection of the moment when the WRDY flag and the corresponding PDC transfer request are set (PTRM and PTRCS in the PWM_SCM register)
- Configuration of the update mode (UPDM in the PWM_SCM register)
- Configuration of the update period (UPR in the PWM_SCUP register) if needed.
- Configuration of the comparisons (PWM_CMPVx and PWM_CMPMx).
- Configuration of the event lines (PWM_ELMRx).
- Configuration of the fault inputs polarity (FPOL in PWM_FMR)
- Configuration of the fault protection (FMOD and FFIL in PWM_FMR, PWM_FPV and PWM_FPE1)
- Enable of the Interrupts (writing CHIDx and FCHIDx in PWM_IER1 register, and writing WRDYE, ENDTXE, TXBUFE, UNRE, CMPMx and CMPUx in PWM_IER2 register)
- Enable of the PWM channels (writing CHIDx in the PWM_ENA register)

37.6.5.2 Source Clock Selection Criteria

The large number of source clocks can make selection difficult. The relationship between the value in the "PWM Channel Period Register" (PWM_CPRDx) and the "PWM Channel Duty Cycle Register" (PWM_CDTYx) can help the user in choosing. The event number written in the Period Register gives the PWM accuracy. The Duty-Cycle quantum cannot be lower than $1/CPRDx$ value. The higher the value of PWM_CPRDx, the greater the PWM accuracy.

For example, if the user sets 15 (in decimal) in PWM_CPRDx, the user is able to set a value from between 1 up to 14 in PWM_CDTYx Register. The resulting duty-cycle quantum cannot be lower than 1/15 of the PWM period.

37.6.5.3 Changing the Duty-Cycle, the Period and the Dead-Times

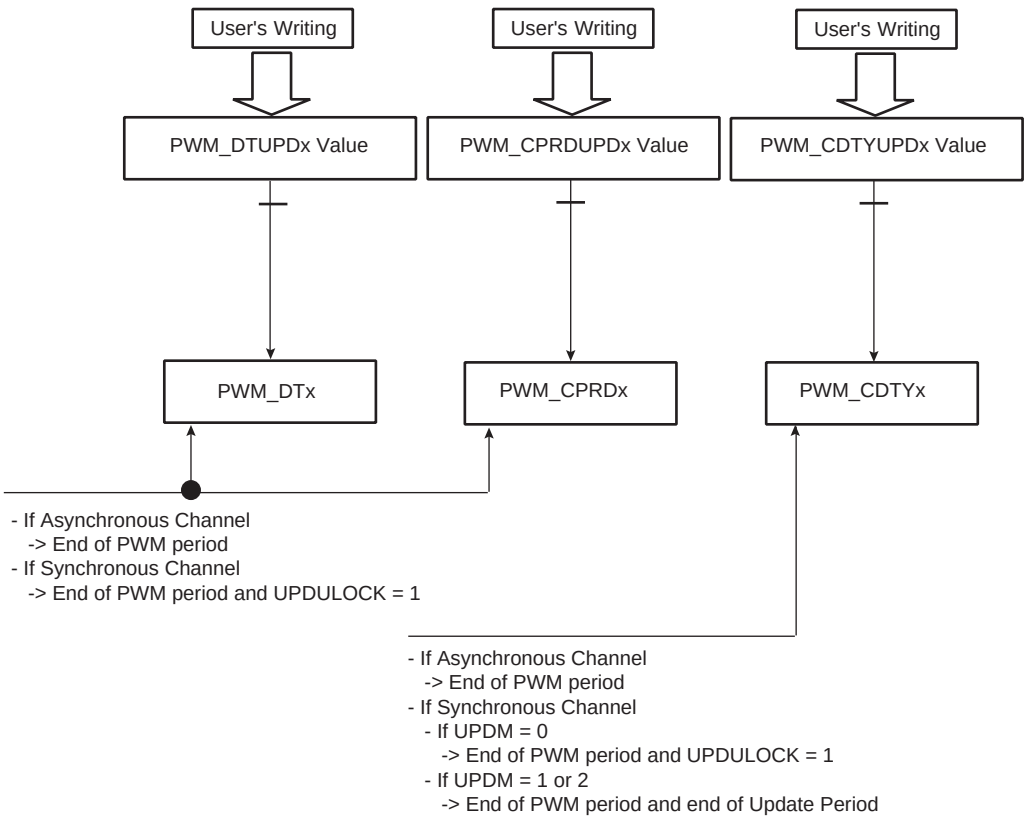
It is possible to modulate the output waveform duty-cycle, period and dead-times.

To prevent unexpected output waveform, the user must use the "PWM Channel Duty Cycle Update Register" , the "PWM Channel Period Update Register" and the "PWM Channel Dead Time Update Register" (PWM_CDTYUPDx, PWM_CPRDUPDx and PWM_DTUPDx) to change waveform parameters while the channel is still enabled.

- If the channel is an asynchronous channel (SYNCx = 0 in “PWM Sync Channels Mode Register” (PWM_SCM)), these registers hold the new period, duty-cycle and dead-times values until the end of the current PWM period and update the values for the next period.
- If the channel is a synchronous channel and update method 0 is selected (SYNCx = 1 and UPDM = 0 in PWM_SCM register), these registers hold the new period, duty-cycle and dead-times values until the bit UPDULOCK is written at “1” (in “PWM Sync Channels Update Control Register” (PWM_SCUC)) and the end of the current PWM period, then update the values for the next period.
- If the channel is a synchronous channel and update method 1 or 2 is selected (SYNCx=1 and UPDM=1 or 2 in PWM_SCM register):
  - registers PWM_CPRDUPDx and PWM_DTUPDx hold the new period and dead-times values until the bit UPDULOCK is written at “1” (in PWM_SCUC register) and the end of the current PWM period, then update the values for the next period.
  - register PWM_CDTYUPDx holds the new duty-cycle value until the end of the update period of synchronous channels (when UPRCNT is equal to UPR in “PWM Sync Channels Update Period Register” (PWM_SCUP)) and the end of the current PWM period, then updates the value for the next period.

Note: If the update registers PWM_CDTYUPDx, PWM_CPRDUPDx and PWM_DTUPDx are written several times between two updates, only the last written value is taken into account.

Figure 37-16. Synchronized Period, Duty-Cycle and Dead-Times Update



37.6.5.4 Changing the Synchronous Channels Update Period

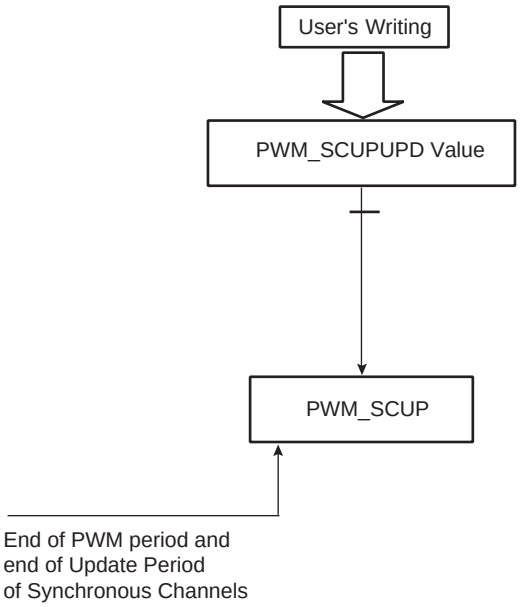
It is possible to change the update period of synchronous channels while they are enabled. (See “Method 2: Manual write of duty-cycle values and automatic trigger of the update” on page 880 and “Method 3: Automatic write of duty-cycle values and automatic trigger of the update” on page 882.)

To prevent an unexpected update of the synchronous channels registers, the user must use the “PWM Sync Channels Update Period Update Register” (PWM_SCUPUPD) to change the update period of synchronous channels while they are still enabled. This register holds the new value until the end of the update period of synchronous channels (when UPRCNT is equal to UPR in “PWM Sync Channels Update Period Register” (PWM_SCUP)) and the end of the current PWM period, then updates the value for the next period.

Note: If the update register PWM_SCUPUPD is written several times between two updates, only the last written value is taken into account.

Note: Changing the update period does make sense only if there is one or more synchronous channels and if the update method 1 or 2 is selected (UPDM = 1 or 2 in “PWM Sync Channels Mode Register”).

Figure 37-17. Synchronized Update of Update Period Value of Synchronous Channels



37.6.5.5 Changing the Comparison Value and the Comparison Configuration

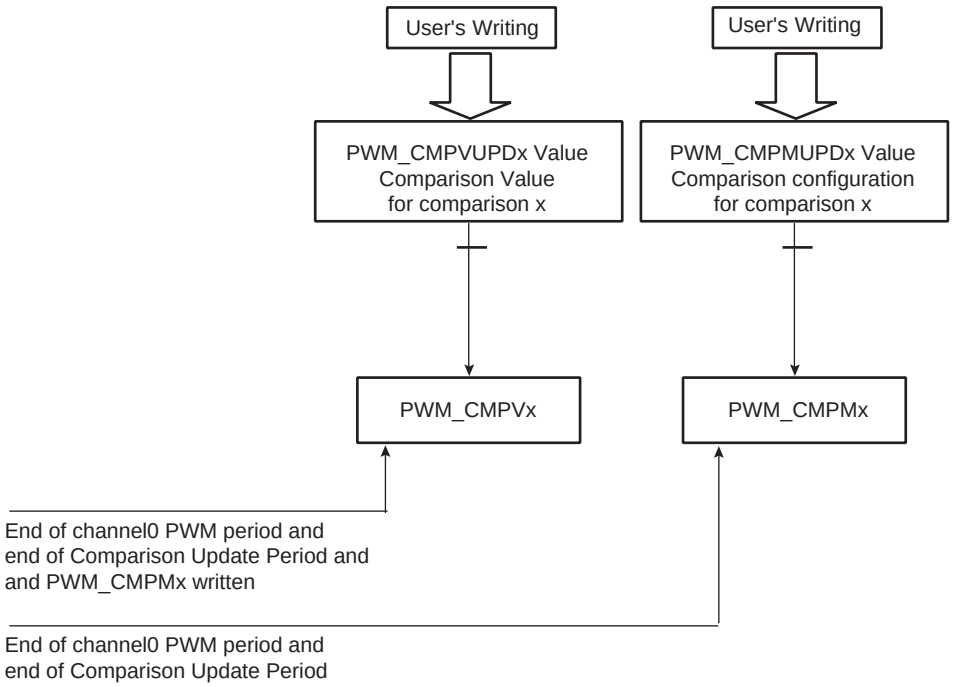
It is possible to change the comparison values and the comparison configurations while the channel 0 is enabled (see Section 37.6.3 “PWM Comparison Units”).

To prevent unexpected comparison match, the user must use the “PWM Comparison x Value Update Register” and the “PWM Comparison x Mode Update Register” (PWM_CMPVUPDx and PWM_CMPMUPDx) to change respectively the comparison values and the comparison configurations while the channel 0 is still enabled. These registers hold the new values until the end of the comparison update period (when CUPRCNT is equal to CUPR in “PWM Comparison x Mode Register” (PWM_CMPMx) and the end of the current PWM period, then update the values for the next period.

CAUTION: to be taken into account, the write of the register PWM_CMPVUPDx must be followed by a write of the register PWM_CMPMUPDx.

Note: If the update registers PWM_CMPVUPDx and PWM_CMPMUPDx are written several times between two updates, only the last written value are taken into account.

Figure 37-18. Synchronized Update of Comparison Values and Configurations



37.6.5.6 Interrupts

Depending on the interrupt mask in the PWM_IMR1 and PWM_IMR2 registers, an interrupt can be generated at the end of the corresponding channel period (CHIDx in the PWM_ISR1 register), after a fault event (FCHIDx in the PWM_ISR1 register), after a comparison match (CMPMx in the PWM_ISR2 register), after a comparison update (CMPUx in the PWM_ISR2 register) or according to the transfer mode of the synchronous channels (WRDY, ENDTX, TXBUFE and UNRE in the PWM_ISR2 register).

If the interrupt is generated by the flags CHIDx or FCHIDx, the interrupt remains active until a read operation in the PWM_ISR1 register occurs.

If the interrupt is generated by the flags WRDY or UNRE or CMPMx or CMPUx, the interrupt remains active until a read operation in the PWM_ISR2 register occurs.

A channel interrupt is enabled by setting the corresponding bit in the PWM_IER1 and PWM_IER2 registers. A channel interrupt is disabled by setting the corresponding bit in the PWM_IDR1 and PWM_IDR2 registers.

37.6.5.7 Write Protect Registers

To prevent any single software error that may corrupt PWM behavior, the registers listed below can be write-protected by writing the field WPCMD in the "PWM Write Protect Control Register" on page 924 (PWM_WPCR). They are divided into 6 groups:

- Register group 0:
  - "PWM Clock Register" on page 896
- Register group 1:
  - "PWM Disable Register" on page 898
- Register group 2:
  - "PWM Sync Channels Mode Register" on page 904
  - "PWM Channel Mode Register" on page 931
  -
- Register group 3:
  - "PWM Channel Period Register" on page 935
  - "PWM Channel Period Update Register" on page 936
- Register group 4:
  - "PWM Channel Dead Time Register" on page 938
  - "PWM Channel Dead Time Update Register" on page 939
- Register group 5:
  - "PWM Fault Mode Register" on page 918
  - "PWM Fault Protection Value Register" on page 921
  -

There are two types of Write Protect:

- Write Protect SW, which can be enabled or disabled.
- Write Protect HW, which can just be enabled, only a hardware reset of the PWM controller can disable it.

Both types of Write Protect can be applied independently to a particular register group by means of the WPCMD and WPRG fields in PWM_WPCR register. If at least one Write Protect is active, the register group is write-protected. The field WPCMD allows to perform the following actions depending on its value:

- 0 = Disabling the Write Protect SW of the register groups of which the bit WPRG is at 1.
- 1 = Enabling the Write Protect SW of the register groups of which the bit WPRG is at 1.
- 2 = Enabling the Write Protect HW of the register groups of which the bit WPRG is at 1.

At any time, the user can determine which Write Protect is active in which register group by the fields WPSWS and WPHWS in the "PWM Write Protect Status Register" on page 926 (PWM_WPSR).

If a write access in a write-protected register is detected, then the WPVS flag in the PWM_WPSR register is set and the field WPVSRC indicates in which register the write access has been attempted, through its address offset without the two LSBs.

The WPVS and PWM_WPSR fields are automatically reset after reading the PWM_WPSR register.

37.7 Pulse Width Modulation (PWM) User Interface

Table 37-5. Register Mapping

Offset	Register	Name	Access	Reset
0x00	PWM Clock Register	PWM_CLK	Read-write	0x0
0x04	PWM Enable Register	PWM_ENA	Write-only	–
0x08	PWM Disable Register	PWM_DIS	Write-only	–
0x0C	PWM Status Register	PWM_SR	Read-only	0x0
0x10	PWM Interrupt Enable Register 1	PWM_IER1	Write-only	–
0x14	PWM Interrupt Disable Register 1	PWM_IDR1	Write-only	–
0x18	PWM Interrupt Mask Register 1	PWM_IMR1	Read-only	0x0
0x1C	PWM Interrupt Status Register 1	PWM_ISR1	Read-only	0x0
0x20	PWM Sync Channels Mode Register	PWM_SCM	Read-write	0x0
0x24	Reserved	–	–	–
0x28	PWM Sync Channels Update Control Register	PWM_SCUC	Read-write	0x0
0x2C	PWM Sync Channels Update Period Register	PWM_SCUP	Read-write	0x0
0x30	PWM Sync Channels Update Period Update Register	PWM_SCUPUPD	Write-only	0x0
0x34	PWM Interrupt Enable Register 2	PWM_IER2	Write-only	–
0x38	PWM Interrupt Disable Register 2	PWM_IDR2	Write-only	–
0x3C	PWM Interrupt Mask Register 2	PWM_IMR2	Read-only	0x0
0x40	PWM Interrupt Status Register 2	PWM_ISR2	Read-only	0x0
0x44	PWM Output Override Value Register	PWM_OOV	Read-write	0x0
0x48	PWM Output Selection Register	PWM_OS	Read-write	0x0
0x4C	PWM Output Selection Set Register	PWM_OSS	Write-only	–
0x50	PWM Output Selection Clear Register	PWM_OSC	Write-only	–
0x54	PWM Output Selection Set Update Register	PWM_OSSUPD	Write-only	–
0x58	PWM Output Selection Clear Update Register	PWM_OSCUPD	Write-only	–
0x5C	PWM Fault Mode Register	PWM_FMR	Read-write	0x0
0x60	PWM Fault Status Register	PWM_FSR	Read-only	0x0
0x64	PWM Fault Clear Register	PWM_FCR	Write-only	–
0x68	PWM Fault Protection Value Register	PWM_FPV	Read-write	0x0
0x6C	PWM Fault Protection Enable Register	PWM_FPE	Read-write	0x0
0x70-0x78	Reserved	–	–	–
0x7C	PWM Event Line 0 Mode Register	PWM_ELMR0	Read-write	0x0
0x80	PWM Event Line 1 Mode Register	PWM_ELMR1	Read-write	0x0
0x84-AC	Reserved	–	–	–
0xB4-E0	Reserved	–	–	–
0xE4	PWM Write Protect Control Register	PWM_WPCR	Write-only	–
0xE8	PWM Write Protect Status Register	PWM_WPSR	Read-only	0x0

Table 37-5. Register Mapping (Continued)

Offset	Register	Name	Access	Reset
0xEC - 0xFC	Reserved	–	–	–
0x100 - 0x128	Reserved for PDC registers	–	–	–
0x12C	Reserved	–	–	–
0x130	PWM Comparison 0 Value Register	PWM_CMPV0	Read-write	0x0
0x134	PWM Comparison 0 Value Update Register	PWM_CMPVUPD0	Write-only	–
0x138	PWM Comparison 0 Mode Register	PWM_CMPM0	Read-write	0x0
0x13C	PWM Comparison 0 Mode Update Register	PWM_CMPMUPD0	Write-only	–
0x140	PWM Comparison 1 Value Register	PWM_CMPV1	Read-write	0x0
0x144	PWM Comparison 1 Value Update Register	PWM_CMPVUPD1	Write-only	–
0x148	PWM Comparison 1 Mode Register	PWM_CMPM1	Read-write	0x0
0x14C	PWM Comparison 1 Mode Update Register	PWM_CMPMUPD1	Write-only	–
0x150	PWM Comparison 2 Value Register	PWM_CMPV2	Read-write	0x0
0x154	PWM Comparison 2 Value Update Register	PWM_CMPVUPD2	Write-only	–
0x158	PWM Comparison 2 Mode Register	PWM_CMPM2	Read-write	0x0
0x15C	PWM Comparison 2 Mode Update Register	PWM_CMPMUPD2	Write-only	–
0x160	PWM Comparison 3 Value Register	PWM_CMPV3	Read-write	0x0
0x164	PWM Comparison 3 Value Update Register	PWM_CMPVUPD3	Write-only	–
0x168	PWM Comparison 3 Mode Register	PWM_CMPM3	Read-write	0x0
0x16C	PWM Comparison 3 Mode Update Register	PWM_CMPMUPD3	Write-only	–
0x170	PWM Comparison 4 Value Register	PWM_CMPV4	Read-write	0x0
0x174	PWM Comparison 4 Value Update Register	PWM_CMPVUPD4	Write-only	–
0x178	PWM Comparison 4 Mode Register	PWM_CMPM4	Read-write	0x0
0x17C	PWM Comparison 4 Mode Update Register	PWM_CMPMUPD4	Write-only	–
0x180	PWM Comparison 5 Value Register	PWM_CMPV5	Read-write	0x0
0x184	PWM Comparison 5 Value Update Register	PWM_CMPVUPD5	Write-only	–
0x188	PWM Comparison 5 Mode Register	PWM_CMPM5	Read-write	0x0
0x18C	PWM Comparison 5 Mode Update Register	PWM_CMPMUPD5	Write-only	–
0x190	PWM Comparison 6 Value Register	PWM_CMPV6	Read-write	0x0
0x194	PWM Comparison 6 Value Update Register	PWM_CMPVUPD6	Write-only	–
0x198	PWM Comparison 6 Mode Register	PWM_CMPM6	Read-write	0x0
0x19C	PWM Comparison 6 Mode Update Register	PWM_CMPMUPD6	Write-only	–
0x1A0	PWM Comparison 7 Value Register	PWM_CMPV7	Read-write	0x0
0x1A4	PWM Comparison 7 Value Update Register	PWM_CMPVUPD7	Write-only	–
0x1A8	PWM Comparison 7 Mode Register	PWM_CMPM7	Read-write	0x0
0x1AC	PWM Comparison 7 Mode Update Register	PWM_CMPMUPD7	Write-only	–
0x1B0 - 0x1FC	Reserved	–	–	–

Table 37-5. Register Mapping (Continued)

Offset	Register	Name	Access	Reset
0x200 + ch_num * 0x20 + 0x00	PWM Channel Mode Register[1]	PWM_CMR	Read-write	0x0
0x200 + ch_num * 0x20 + 0x04	PWM Channel Duty Cycle Register[1]	PWM_CDTY	Read-write	0x0
0x200 + ch_num * 0x20 + 0x08	PWM Channel Duty Cycle Update Register[1]	PWM_CDTYUPD	Write-only	–
0x200 + ch_num * 0x20 + 0x0C	PWM Channel Period Register[1]	PWM_CPRD	Read-write	0x0
0x200 + ch_num * 0x20 + 0x10	PWM Channel Period Update Register[1]	PWM_CPRDUPD	Write-only	–
0x200 + ch_num * 0x20 + 0x14	PWM Channel Counter Register[1]	PWM_CCNT	Read-only	0x0
0x200 + ch_num * 0x20 + 0x18	PWM Channel Dead Time Register[1]	PWM_DT	Read-write	0x0
0x200 + ch_num * 0x20 + 0x1C	PWM Channel Dead Time Update Register[1]	PWM_DTUPD	Write-only	–

Notes: 1. Some registers are indexed with “ch_num” index ranging from 0 to 3.

37.7.1 PWM Clock Register

Name: PWM_CLK

Address: 0x4008C000

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	PREB			

23	22	21	20	19	18	17	16
DIVB							

15	14	13	12	11	10	9	8
–	–	–	–	PREA			

7	6	5	4	3	2	1	0
DIVA							

This register can only be written if the bits WPSWS0 and WPHWS0 are cleared in “PWM Write Protect Status Register” on page 926.

- **DIVA, DIVB: CLKA, CLKB Divide Factor**

DIVA, DIVB	CLKA, CLKB
0	CLKA, CLKB clock is turned off
1	CLKA, CLKB clock is clock selected by PREA, PREB
2-255	CLKA, CLKB clock is clock selected by PREA, PREB divided by DIVA, DIVB factor.

- **PREA, PREB: CLKA, CLKB Source Clock Selection**

PREA, PREB				Divider Input Clock
0	0	0	0	MCK
0	0	0	1	MCK/2
0	0	1	0	MCK/4
0	0	1	1	MCK/8
0	1	0	0	MCK/16
0	1	0	1	MCK/32
0	1	1	0	MCK/64
0	1	1	1	MCK/128
1	0	0	0	MCK/256
1	0	0	1	MCK/512
1	0	1	0	MCK/1024
Other				Reserved

37.7.2 PWM Enable Register

Name: PWM_ENA

Address: 0x4008C004

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Channel ID**

0 = No effect.

1 = Enable PWM output for channel x.

37.7.3 PWM Disable Register

Name: PWM_DIS

Address: 0x4008C008

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

This register can only be written if the bits WPSWS1 and WPHWS1 are cleared in “PWM Write Protect Status Register” on page 926.

- **CHIDx: Channel ID**

0 = No effect.

1 = Disable PWM output for channel x.

37.7.4 PWM Status Register

Name: PWM_SR

Address: 0x4008C00C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Channel ID**

0 = PWM output for channel x is disabled.

1 = PWM output for channel x is enabled.

37.7.5 PWM Interrupt Enable Register 1

Name: PWM_IER1

Address: 0x4008C010

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	FCHID3	FCHID2	FCHID1	FCHID0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Counter Event on Channel x Interrupt Enable**
- **FCHIDx: Fault Protection Trigger on Channel x Interrupt Enable**

37.7.6 PWM Interrupt Disable Register 1

Name: PWM_IDR1

Address: 0x4008C014

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	FCHID3	FCHID2	FCHID1	FCHID0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Counter Event on Channel x Interrupt Disable**
- **FCHIDx: Fault Protection Trigger on Channel x Interrupt Disable**

37.7.7 PWM Interrupt Mask Register 1

Name: PWM_IMR1

Address: 0x4008C018

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	FCHID3	FCHID2	FCHID1	FCHID0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Counter Event on Channel x Interrupt Mask**
- **FCHIDx: Fault Protection Trigger on Channel x Interrupt Mask**

37.7.8 PWM Interrupt Status Register 1

Name: PWM_ISR1

Address: 0x4008C01C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	FCHID3	FCHID2	FCHID1	FCHID0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	CHID3	CHID2	CHID1	CHID0

- **CHIDx: Counter Event on Channel x**

0 = No new counter event has occurred since the last read of the PWM_ISR1 register.

1 = At least one counter event has occurred since the last read of the PWM_ISR1 register.

- **FCHIDx: Fault Protection Trigger on Channel x**

0 = No new trigger of the fault protection since the last read of the PWM_ISR1 register.

1 = At least one trigger of the fault protection since the last read of the PWM_ISR1 register.

Note: Reading PWM_ISR1 automatically clears CHIDx and FCHIDx flags.

37.7.9 PWM Sync Channels Mode Register

Name: PWM_SCM

Address: 0x4008C020

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
PTRCS			PTRM	–	–	UPDM	

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	SYNC3	SYNC2	SYNC1	SYNC0

This register can only be written if the bits WPSWS2 and WPHWS2 are cleared in “PWM Write Protect Status Register” on page 926.

- **SYNCx: Synchronous Channel x**

0 = Channel x is not a synchronous channel.

1 = Channel x is a synchronous channel.

- **UPDM: Synchronous Channels Update Mode**

Value	Name	Description
0	MODE0	Manual write of double buffer registers and manual update of synchronous channels(1)
1	MODE1	Manual write of double buffer registers and automatic update of synchronous channels(2)
2	MODE2	Automatic write of duty-cycle update registers by the PDC and automatic update of synchronous channels(2)
3	–	Reserved

Notes: 1. The update occurs at the beginning of the next PWM period, when the UPDULOCK bit in “PWM Sync Channels Update Control Register” is set.

2. The update occurs when the Update Period is elapsed.

- **PTRM: PDC Transfer Request Mode**

UPDM	PTRM	WRDY Flag and PDC Transfer Request
0	x	The WRDY flag in “PWM Interrupt Status Register 2” on page 911 and the PDC transfer request are never set to 1.
1	x	The WRDY flag in “PWM Interrupt Status Register 2” on page 911 is set to 1 as soon as the update period is elapsed, the PDC transfer request is never set to 1.
2	0	The WRDY flag in “PWM Interrupt Status Register 2” on page 911 and the PDC transfer request are set to 1 as soon as the update period is elapsed.
	1	The WRDY flag in “PWM Interrupt Status Register 2” on page 911 and the PDC transfer request are set to 1 as soon as the selected comparison matches.

- **PTRCS: PDC Transfer Request Comparison Selection**

Selection of the comparison used to set the flag WRDY and the corresponding PDC transfer request.

37.7.10 PWM Sync Channels Update Control Register

Name: PWM_SCUC

Address: 0x4008C028

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	UPDULOCK

- **UPDULOCK: Synchronous Channels Update Unlock**

0 = No effect

1 = If the UPDM field is set to “0” in “PWM Sync Channels Mode Register” on page 904, writing the UPDULOCK bit to “1” triggers the update of the period value, the duty-cycle and the dead-time values of synchronous channels at the beginning of the next PWM period. If the field UPDM is set to “1” or “2”, writing the UPDULOCK bit to “1” triggers only the update of the period value and of the dead-time values of synchronous channels.

This bit is automatically reset when the update is done.

37.7.11 PWM Sync Channels Update Period Register

Name: PWM_SCUP

Address: 0x4008C02C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
UPRCNT				UPR			

- **UPR: Update Period**

Defines the time between each update of the synchronous channels if automatic trigger of the update is activated (UPDM = 1 or UPDM = 2 in “PWM Sync Channels Mode Register” on page 904). This time is equal to UPR+1 periods of the synchronous channels.

- **UPRCNT: Update Period Counter**

Reports the value of the Update Period Counter.

37.7.12 PWM Sync Channels Update Period Update Register

Name: PWM_SCUPUPD

Address: 0x4008C030

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	UPRUPD			

This register acts as a double buffer for the UPR value. This prevents an unexpected automatic trigger of the update of synchronous channels.

- **UPRUPD: Update Period Update**

Defines the wanted time between each update of the synchronous channels if automatic trigger of the update is activated (UPDM = 1 or UPDM = 2 in “PWM Sync Channels Mode Register” on page 904). This time is equal to UPR+1 periods of the synchronous channels.

37.7.13 PWM Interrupt Enable Register 2

Name: PWM_IER2

Address: 0x4008C034

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CMPU7	CMPU6	CMPU5	CMPU4	CMPU3	CMPU2	CMPU1	CMPU0

15	14	13	12	11	10	9	8
CMPM7	CMPM6	CMPM5	CMPM4	CMPM3	CMPM2	CMPM1	CMPM0

7	6	5	4	3	2	1	0
–	–	–	–	UNRE	TXBUFE	ENDTX	WRDY

- **WRDY: Write Ready for Synchronous Channels Update Interrupt Enable**
- **ENDTX: PDC End of TX Buffer Interrupt Enable**
- **TXBUFE: PDC TX Buffer Empty Interrupt Enable**
- **UNRE: Synchronous Channels Update Underrun Error Interrupt Enable**
- **CMPMx: Comparison x Match Interrupt Enable**
- **CMPUx: Comparison x Update Interrupt Enable**

37.7.14 PWM Interrupt Disable Register 2

Name: PWM_IDR2

Address: 0x4008C038

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CMPU7	CMPU6	CMPU5	CMPU4	CMPU3	CMPU2	CMPU1	CMPU0

15	14	13	12	11	10	9	8
CMPM7	CMPM6	CMPM5	CMPM4	CMPM3	CMPM2	CMPM1	CMPM0

7	6	5	4	3	2	1	0
–	–	–	–	UNRE	TXBUFE	ENDTX	WRDY

- **WRDY: Write Ready for Synchronous Channels Update Interrupt Disable**
- **ENDTX: PDC End of TX Buffer Interrupt Disable**
- **TXBUFE: PDC TX Buffer Empty Interrupt Disable**
- **UNRE: Synchronous Channels Update Underrun Error Interrupt Disable**
- **CMPMx: Comparison x Match Interrupt Disable**
- **CMPUx: Comparison x Update Interrupt Disable**

37.7.15 PWM Interrupt Mask Register 2

Name: PWM_IMR2

Address: 0x4008C03C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CMPU7	CMPU6	CMPU5	CMPU4	CMPU3	CMPU2	CMPU1	CMPU0

15	14	13	12	11	10	9	8
CMPM7	CMPM6	CMPM5	CMPM4	CMPM3	CMPM2	CMPM1	CMPM0

7	6	5	4	3	2	1	0
–	–	–	–	UNRE	TXBUFE	ENDTX	WRDY

- **WRDY: Write Ready for Synchronous Channels Update Interrupt Mask**
- **ENDTX: PDC End of TX Buffer Interrupt Mask**
- **TXBUFE: PDC TX Buffer Empty Interrupt Mask**
- **UNRE: Synchronous Channels Update Underrun Error Interrupt Mask**
- **CMPMx: Comparison x Match Interrupt Mask**
- **CMPUx: Comparison x Update Interrupt Mask**

37.7.16 PWM Interrupt Status Register 2

Name: PWM_ISR2

Address: 0x4008C040

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
CMPU7	CMPU6	CMPU5	CMPU4	CMPU3	CMPU2	CMPU1	CMPU0
15	14	13	12	11	10	9	8
CMPM7	CMPM6	CMPM5	CMPM4	CMPM3	CMPM2	CMPM1	CMPM0
7	6	5	4	3	2	1	0
–	–	–	–	UNRE	TXBUFE	ENDTX	WRDY

- **WRDY: Write Ready for Synchronous Channels Update**

0 = New duty-cycle and dead-time values for the synchronous channels cannot be written.

1 = New duty-cycle and dead-time values for the synchronous channels can be written.

- **ENDTX: PDC End of TX Buffer**

0 = The Transmit Counter register has not reached 0 since the last write of the PDC.

1 = The Transmit Counter register has reached 0 since the last write of the PDC.

- **TXBUFE: PDC TX Buffer Empty**

0 = PWM_TCR or PWM_TCNR has a value other than 0.

1 = Both PWM_TCR and PWM_TCNR have a value other than 0.

- **UNRE: Synchronous Channels Update Underrun Error**

0 = No Synchronous Channels Update Underrun has occurred since the last read of the PWM_ISR2 register.

1 = At least one Synchronous Channels Update Underrun has occurred since the last read of the PWM_ISR2 register.

- **CMPMx: Comparison x Match**

0 = The comparison x has not matched since the last read of the PWM_ISR2 register.

1 = The comparison x has matched at least one time since the last read of the PWM_ISR2 register.

- **CMPUx: Comparison x Update**

0 = The comparison x has not been updated since the last read of the PWM_ISR2 register.

1 = The comparison x has been updated at least one time since the last read of the PWM_ISR2 register.

Note: Reading PWM_ISR2 automatically clears flags WRDY, UNRE and CMPSx.

37.7.17 PWM Output Override Value Register

Name: PWM_OOV

Address: 0x4008C044

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OOVL3	OOVL2	OOVL1	OOVL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OOVH3	OOVH2	OOVH1	OOVH0

- **OOVHx: Output Override Value for PWMH output of the channel x**

0 = Override value is 0 for PWMH output of channel x.

1 = Override value is 1 for PWMH output of channel x.

- **OOVLx: Output Override Value for PWML output of the channel x**

0 = Override value is 0 for PWML output of channel x.

1 = Override value is 1 for PWML output of channel x.

37.7.18 PWM Output Selection Register

Name: PWM_OS

Address: 0x4008C048

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OSL3	OSL2	OSL1	OSL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OSH3	OSH2	OSH1	OSH0

- **OSHx: Output Selection for PWMH output of the channel x**

0 = Dead-time generator output DTOHx selected as PWMH output of channel x.

1 = Output override value OOVHx selected as PWMH output of channel x.

- **OSLx: Output Selection for PWML output of the channel x**

0 = Dead-time generator output DTOLx selected as PWML output of channel x.

1 = Output override value OOVLx selected as PWML output of channel x.

37.7.19 PWM Output Selection Set Register

Name: PWM_OSS

Address: 0x4008C04C

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OSSL3	OSSL2	OSSL1	OSSL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OSSH3	OSSH2	OSSH1	OSSH0

- **OSSHx: Output Selection Set for PWMH output of the channel x**

0 = No effect.

1 = Output override value OOVHx selected as PWMH output of channel x.

- **OSSLx: Output Selection Set for PWML output of the channel x**

0 = No effect.

1 = Output override value OOVLx selected as PWML output of channel x.

37.7.20 PWM Output Selection Clear Register

Name: PWM_OSC

Address: 0x4008C050

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OSCL3	OSCL2	OSCL1	OSCL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OSCH3	OSCH2	OSCH1	OSCH0

- **OSCHx: Output Selection Clear for PWMH output of the channel x**

0 = No effect.

1 = Dead-time generator output DTOHx selected as PWMH output of channel x.

- **OSCLx: Output Selection Clear for PWML output of the channel x**

0 = No effect.

1 = Dead-time generator output DTOLx selected as PWML output of channel x.

37.7.21 PWM Output Selection Set Update Register

Name: PWM_OSSUPD

Address: 0x4008C054

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OSSUPL3	OSSUPL2	OSSUPL1	OSSUPL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OSSUPH3	OSSUPH2	OSSUPH1	OSSUPH0

- **OSSUPHx: Output Selection Set for PWMH output of the channel x**

0 = No effect.

1 = Output override value OOVHx selected as PWMH output of channel x at the beginning of the next channel x PWM period.

- **OSSUPLx: Output Selection Set for PWML output of the channel x**

0 = No effect.

1 = Output override value OOVLx selected as PWML output of channel x at the beginning of the next channel x PWM period.

37.7.22 PWM Output Selection Clear Update Register

Name: PWM_OSCUPD

Address: 0x4008C058

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	OSCUPL3	OSCUPL2	OSCUPL1	OSCUPL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	OSCUPH3	OSCUPH2	OSCUPH1	OSCUPH0

- **OSCUPHx: Output Selection Clear for PWMH output of the channel x**

0 = No effect.

1 = Dead-time generator output DTOHx selected as PWMH output of channel x at the beginning of the next channel x PWM period.

- **OSCUPLx: Output Selection Clear for PWML output of the channel x**

0 = No effect.

1 = Dead-time generator output DTOLx selected as PWML output of channel x at the beginning of the next channel x PWM period.

37.7.23 PWM Fault Mode Register

Name: PWM_FMR

Address: 0x4008C05C

Access: Read-write

31	30	29	28	27	26	25	24
–							
23	22	21	20	19	18	17	16
FFIL							
15	14	13	12	11	10	9	8
FMOD							
7	6	5	4	3	2	1	0
FPOL							

This register can only be written if the bits WPSWS5 and WPHWS5 are cleared in “PWM Write Protect Status Register” on page 926.

- **FPOL: Fault Polarity (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = The fault y becomes active when the fault input y is at 0.

1 = The fault y becomes active when the fault input y is at 1.

- **FMOD: Fault Activation Mode (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = The fault y is active until the Fault condition is removed at the peripheral(1) level.

1 = The fault y stays active until the Fault condition is removed at the peripheral(1) level AND until it is cleared in the “PWM Fault Clear Register” .

Note: 1. The Peripheral generating the fault.

- **FFIL: Fault Filtering (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = The fault input y is not filtered.

1 = The fault input y is filtered.

CAUTION: To prevent an unexpected activation of the status flag FSy in the “PWM Fault Status Register” on page 919, the bit FMODy can be set to “1” only if the FPOLy bit has been previously configured to its final value.

37.7.24 PWM Fault Status Register

Name: PWM_FSR

Address: 0x4008C060

Access: Read-only

31	30	29	28	27	26	25	24
–							

23	22	21	20	19	18	17	16
–							

15	14	13	12	11	10	9	8
FS							

7	6	5	4	3	2	1	0
FIV							

- **FIV: Fault Input Value (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = The current sampled value of the fault input y is 0 (after filtering if enabled).

1 = The current sampled value of the fault input y is 1 (after filtering if enabled).

- **FS: Fault Status (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = The fault y is not currently active.

1 = The fault y is currently active.

37.7.25 PWM Fault Clear Register

Name: PWM_FCR

Address: 0x4008C064

Access: Write-only

31	30	29	28	27	26	25	24
–							

23	22	21	20	19	18	17	16
–							

15	14	13	12	11	10	9	8
–							

7	6	5	4	3	2	1	0
FCLR							

- **FCLR: Fault Clear (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = No effect.

1 = If bit y of FMOD field is set to 1 and if the fault input y is not at the level defined by the bit y of FPOL field, the fault y is cleared and becomes inactive (FMOD and FPOL fields belong to “PWM Fault Mode Register” on page 918), else writing this bit to 1 has no effect.

37.7.26 PWM Fault Protection Value Register

Name: PWM_FPV

Address: 0x4008C068

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	FPVL3	FPVL2	FPVL1	FPVL0
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	FPVH3	FPVH2	FPVH1	FPVH0

This register can only be written if the bits WPSWS5 and WPHWS5 are cleared in “PWM Write Protect Status Register” on page 926.

- **FPVHx: Fault Protection Value for PWMH output on channel x**

0 = PWMH output of channel x is forced to 0 when fault occurs.

1 = PWMH output of channel x is forced to 1 when fault occurs.

- **FPVLx: Fault Protection Value for PWML output on channel x**

0 = PWML output of channel x is forced to 0 when fault occurs.

1 = PWML output of channel x is forced to 1 when fault occurs.

37.7.27 PWM Fault Protection Enable Register

Name: PWM_FPE

Address: 0x4008C06C

Access: Read-write

31	30	29	28	27	26	25	24
FPE3							
23	22	21	20	19	18	17	16
FPE2							
15	14	13	12	11	10	9	8
FPE1							
7	6	5	4	3	2	1	0
FPE0							

This register can only be written if the bits WPSWS5 and WPHWS5 are cleared in “PWM Write Protect Status Register” on page 926.

Only the first 4 bits (number of fault input pins) of fields FPE0, FPE1, FPE2 and FPE3 are significant.

- **FPEx: Fault Protection Enable for channel x (fault input bit varies from 0 to 3)**

For each field bit y (fault input number):

0 = Fault y is not used for the Fault Protection of channel x.

1 = Fault y is used for the Fault Protection of channel x.

CAUTION: To prevent an unexpected activation of the Fault Protection, the bit y of FPEx field can be set to “1” only if the corresponding FPOL bit has been previously configured to its final value in “PWM Fault Mode Register” on page 918.

37.7.28 PWM Event Line x Register

Name: PWM_ELMRx

Address: 0x4008C07C

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
CSEL7	CSEL6	CSEL5	CSEL4	CSEL3	CSEL2	CSEL1	CSEL0

- **CSELy: Comparison y Selection**

0 = A pulse is not generated on the event line x when the comparison y matches.

1 = A pulse is generated on the event line x when the comparison y match.

37.7.29 PWM Write Protect Control Register

Name: PWM_WPCR

Address: 0x4008C0E4

Access: Write-only

31	30	29	28	27	26	25	24
WPKEY							

23	22	21	20	19	18	17	16
WPKEY							

15	14	13	12	11	10	9	8
WPKEY							

7	6	5	4	3	2	1	0
WPRG5	WPRG4	WPRG3	WPRG2	WPRG1	WPRG0	WPCMD	

- **WPCMD: Write Protect Command**

This command is performed only if the WPKEY value is correct.

0 = Disable the Write Protect SW of the register groups of which the bit WPRGx is at 1.

1 = Enable the Write Protect SW of the register groups of which the bit WPRGx is at 1.

2 = Enable the Write Protect HW of the register groups of which the bit WPRGx is at 1.

Moreover, to meet security requirements, in this mode of operation, the PIO lines associated with PWM can not be configured through the PIO interface, not even by the PIO controller.

3 = No effect.

Note: Only a hardware reset of the PWM controller can disable the Write Protect HW.

- **WPRGx: Write Protect Register Group x**

0 = The WPCMD command has no effect on the register group x.

1 = The WPCMD command is applied to the register group x.

- **WPKEY: Write Protect Key**

Should be written at value 0x50574D (“PWM” in ASCII). Writing any other value in this field aborts the write operation of the WPCMD field. Always reads as 0.

List of register groups:

- Register group 0:
  - “PWM Clock Register” on page 896
- Register group 1:
  - “PWM Disable Register” on page 898
- Register group 2:
  - “PWM Sync Channels Mode Register” on page 904
  - “PWM Channel Mode Register” on page 931
- Register group 3:
  - “PWM Channel Period Register” on page 935
  - “PWM Channel Period Update Register” on page 936

- Register group 4:
  - “PWM Channel Dead Time Register” on page 938
  - “PWM Channel Dead Time Update Register” on page 939
- Register group 5:
  - “PWM Fault Mode Register” on page 918
  - “PWM Fault Protection Value Register” on page 921

37.7.30 PWM Write Protect Status Register

Name: PWM_WPSR

Address: 0x4008C0E8

Access: Read-only

31	30	29	28	27	26	25	24
WPVSRC							

23	22	21	20	19	18	17	16
WPVSRC							

15	14	13	12	11	10	9	8
–	–	WPHWS5	WPHWS4	WPHWS3	WPHWS2	WPHWS1	WPHWS0

7	6	5	4	3	2	1	0
WPVS	–	WPSWS5	WPSWS4	WPSWS3	WPSWS2	WPSWS1	WPSWS0

- **WPSWSx: Write Protect SW Status**

0 = The Write Protect SW x of the register group x is disabled.

1 = The Write Protect SW x of the register group x is enabled.

- **WPHWSx: Write Protect HW Status**

0 = The Write Protect HW x of the register group x is disabled.

1 = The Write Protect HW x of the register group x is enabled.

- **WPVS: Write Protect Violation Status**

0 = No Write Protect violation has occurred since the last read of the PWM_WPSR register.

1 = At least one Write Protect violation has occurred since the last read of the PWM_WPSR register. If this violation is an unauthorized attempt to write a protected register, the associated violation is reported into field WPVSRC.

- **WPVSRC: Write Protect Violation Source**

When WPVS is active, this field indicates the write-protected register (through address offset) in which a write access has been attempted.

Note: The two LSBs of the address offset of the write-protected register are not reported

Note: Reading PWM_WPSR automatically clears WPVS and WPVSRC fields.

37.7.31 PWM Comparison x Value Register

Name: PWM_CMPVx

Address: 0x4008C130 [0], 0x4008C140 [1], 0x4008C150 [2], 0x4008C160 [3], 0x4008C170 [4], 0x4008C180 [5], 0x4008C190 [6], 0x4008C1A0 [7]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	CVM
23	22	21	20	19	18	17	16
CV							
15	14	13	12	11	10	9	8
CV							
7	6	5	4	3	2	1	0
CV							

Only the first 16 bits (channel counter size) of field CV are significant.

- **CV: Comparison x Value**

Define the comparison x value to be compared with the counter of the channel 0.

- **CVM: Comparison x Value Mode**

0 = The comparison x between the counter of the channel 0 and the comparison x value is performed when this counter is incrementing.

1 = The comparison x between the counter of the channel 0 and the comparison x value is performed when this counter is decrementing.

Note: This bit is useless if the counter of the channel 0 is left aligned (CALG = 0 in “PWM Channel Mode Register” on page 931)

37.7.32 PWM Comparison x Value Update Register

Name: PWM_CMPVUPDx

Address: 0x4008C134 [0], 0x4008C144 [1], 0x4008C154 [2], 0x4008C164 [3], 0x4008C174 [4], 0x4008C184 [5], 0x4008C194 [6], 0x4008C1A4 [7]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	CVMUPD

23	22	21	20	19	18	17	16
CVUPD							

15	14	13	12	11	10	9	8
CVUPD							

7	6	5	4	3	2	1	0
CVUPD							

This register acts as a double buffer for the CV and CVM values. This prevents an unexpected comparison x match.

Only the first 16 bits (channel counter size) of field CVUPD are significant.

- **CVUPD: Comparison x Value Update**

Define the comparison x value to be compared with the counter of the channel 0.

- **CVMUPD: Comparison x Value Mode Update**

0 = The comparison x between the counter of the channel 0 and the comparison x value is performed when this counter is incrementing.

1 = The comparison x between the counter of the channel 0 and the comparison x value is performed when this counter is decrementing.

Note: This bit is useless if the counter of the channel 0 is left aligned (CALG = 0 in “PWM Channel Mode Register” on page 931)

CAUTION: to be taken into account, the write of the register PWM_CMPVUPDx must be followed by a write of the register PWM_CMPMUPDx.

37.7.33 PWM Comparison x Mode Register

Name: PWM_CMPMx

Address: 0x4008C138 [0], 0x4008C148 [1], 0x4008C158 [2], 0x4008C168 [3], 0x4008C178 [4], 0x4008C188 [5], 0x4008C198 [6], 0x4008C1A8 [7]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
CUPRCNT				CUPR			
15	14	13	12	11	10	9	8
CPRCNT				CPR			
7	6	5	4	3	2	1	0
CTR				–	–	–	CEN

- **CEN: Comparison x Enable**

0 = The comparison x is disabled and can not match.

1 = The comparison x is enabled and can match.

- **CTR: Comparison x Trigger**

The comparison x is performed when the value of the comparison x period counter (CPRCNT) reaches the value defined by CTR.

- **CPR: Comparison x Period**

CPR defines the maximum value of the comparison x period counter (CPRCNT). The comparison x value is performed periodically once every CPR+1 periods of the channel 0 counter.

- **CPRCNT: Comparison x Period Counter**

Reports the value of the comparison x period counter.

Note: The field CPRCNT is read-only

- **CUPR: Comparison x Update Period**

Defines the time between each update of the comparison x mode and the comparison x value. This time is equal to CUPR+1 periods of the channel 0 counter.

- **CUPRCNT: Comparison x Update Period Counter**

Reports the value of the comparison x update period counter.

Note: The field CUPRCNT is read-only

37.7.34 PWM Comparison x Mode Update Register

Name: PWM_CMPMUPDx

Address: 0x4008C13C [0], 0x4008C14C [1], 0x4008C15C [2], 0x4008C16C [3], 0x4008C17C [4], 0x4008C18C [5], 0x4008C19C [6], 0x4008C1AC [7]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	CUPRUPD			
15	14	13	12	11	10	9	8
–	–	–	–	CPRUPD			
7	6	5	4	3	2	1	0
CTRUPD				–	–	–	CENUPD

This register acts as a double buffer for the CEN, CTR, CPR and CUPR values. This prevents an unexpected comparison x match.

- **CENUPD: Comparison x Enable Update**

0 = The comparison x is disabled and can not match.

1 = The comparison x is enabled and can match.

- **CTRUPD: Comparison x Trigger Update**

The comparison x is performed when the value of the comparison x period counter (CPRCNT) reaches the value defined by CTR.

- **CPRUPD: Comparison x Period Update**

CPR defines the maximum value of the comparison x period counter (CPRCNT). The comparison x value is performed periodically once every CPR+1 periods of the channel 0 counter.

- **CUPRUPD: Comparison x Update Period Update**

Defines the time between each update of the comparison x mode and the comparison x value. This time is equal to CUPR+1 periods of the channel 0 counter.

37.7.35 PWM Channel Mode Register

Name: PWM_CMRx [x=0..3]

Address: 0x4008C200 [0], 0x4008C220 [1], 0x4008C240 [2], 0x4008C260 [3]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	DTLI	DTHI	DTE
15	14	13	12	11	10	9	8
–	–	–	–	–	CES	CPOL	CALG
7	6	5	4	3	2	1	0
–	–	–	–	CPRE			

This register can only be written if the bits WPSWS2 and WPHWS2 are cleared in “PWM Write Protect Status Register” on page 926.

- **CPRE: Channel Pre-scaler**

Value	Name	Description
0b0000	MCK	Master clock
0b0001	MCK_DIV_2	Master clock/2
0b0010	MCK_DIV_4	Master clock/4
0b0011	MCK_DIV_8	Master clock/8
0b0100	MCK_DIV_16	Master clock/16
0b0101	MCK_DIV_32	Master clock/32
0b0110	MCK_DIV_64	Master clock/64
0b0111	MCK_DIV_128	Master clock/128
0b1000	MCK_DIV_256	Master clock/256
0b1001	MCK_DIV_512	Master clock/512
0b1010	MCK_DIV_1024	Master clock/1024
0b1011	CLKA	Clock A
0b1100	CLKB	Clock B

- **CALG: Channel Alignment**

0 = The period is left aligned.

1 = The period is center aligned.

- **CPOL: Channel Polarity**

0 = The OCx output waveform (output from the comparator) starts at a low level.

1 = The OCx output waveform (output from the comparator) starts at a high level.

- **CES: Counter Event Selection**

The bit CES defines when the channel counter event occurs when the period is center aligned (flag CHIDx in the “PWM Interrupt Status Register 1” on page 903).

CALG = 0 (Left Alignment):

0/1 = The channel counter event occurs at the end of the PWM period.

CALG = 1 (Center Alignment):

0 = The channel counter event occurs at the end of the PWM period.

1 = The channel counter event occurs at the end of the PWM period and at half the PWM period.

- **DTE: Dead-Time Generator Enable**

0 = The dead-time generator is disabled.

1 = The dead-time generator is enabled.

- **DTHI: Dead-Time PWMHx Output Inverted**

0 = The dead-time PWMHx output is not inverted.

1 = The dead-time PWMHx output is inverted.

- **DTLI: Dead-Time PWMLx Output Inverted**

0 = The dead-time PWMLx output is not inverted.

1 = The dead-time PWMLx output is inverted.

37.7.36 PWM Channel Duty Cycle Register

Name: PWM_CDTYx [x=0..3]

Address: 0x4008C204 [0], 0x4008C224 [1], 0x4008C244 [2], 0x4008C264 [3]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CDTY							

15	14	13	12	11	10	9	8
CDTY							

7	6	5	4	3	2	1	0
CDTY							

Only the first 16 bits (channel counter size) are significant.

- **CDTY: Channel Duty-Cycle**

Defines the waveform duty-cycle. This value must be defined between 0 and CPRD (PWM_CPRx).

37.7.37 PWM Channel Duty Cycle Update Register

Name: PWM_CDTYUPDx [x=0..3]

Address: 0x4008C208 [0], 0x4008C228 [1], 0x4008C248 [2], 0x4008C268 [3]

Access: Write-only.

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CDTYUPD							

15	14	13	12	11	10	9	8
CDTYUPD							

7	6	5	4	3	2	1	0
CDTYUPD							

This register acts as a double buffer for the CDTY value. This prevents an unexpected waveform when modifying the waveform duty-cycle.

Only the first 16 bits (channel counter size) are significant.

- **CDTYUPD: Channel Duty-Cycle Update**

Defines the waveform duty-cycle. This value must be defined between 0 and CPRD (PWM_CPRx).

37.7.38 PWM Channel Period Register

Name: PWM_CPRDx [x=0..3]

Address: 0x4008C20C [0], 0x4008C22C [1], 0x4008C24C [2], 0x4008C26C [3]

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CPRD							

15	14	13	12	11	10	9	8
CPRD							

7	6	5	4	3	2	1	0
CPRD							

This register can only be written if the bits WPSWS3 and WPHWS3 are cleared in “PWM Write Protect Status Register” on page 926.

Only the first 16 bits (channel counter size) are significant.

- **CPRD: Channel Period**

If the waveform is left-aligned, then the output waveform period depends on the channel counter source clock and can be calculated:

– By using the PWM master clock (MCK) divided by an X given prescaler value (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024). The resulting period formula will be:

$$\frac{(X \times CPRD)}{MCK}$$

– By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

$$\frac{(CRPD \times DIVA)}{MCK} \ or \ \frac{(CRPD \times DIVB)}{MCK}$$

If the waveform is center-aligned, then the output waveform period depends on the channel counter source clock and can be calculated:

– By using the PWM master clock (MCK) divided by an X given prescaler value (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024). The resulting period formula will be:

$$\frac{(2 \times X \times CPRD)}{MCK}$$

– By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

$$\frac{(2 \times CPRD \times DIVA)}{MCK} \text{ or } \frac{(2 \times CPRD \times DIVB)}{MCK}$$

37.7.39 PWM Channel Period Update Register

Name: PWM_CPRDUPDx [x=0..3]

Address: 0x4008C210 [0], 0x4008C230 [1], 0x4008C250 [2], 0x4008C270 [3]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CPRDUPD							

15	14	13	12	11	10	9	8
CPRDUPD							

7	6	5	4	3	2	1	0
CPRDUPD							

This register can only be written if the bits WPSWS3 and WPHWS3 are cleared in “PWM Write Protect Status Register” on page 926.

This register acts as a double buffer for the CPRD value. This prevents an unexpected waveform when modifying the waveform period.

Only the first 16 bits (channel counter size) are significant.

- **CPRDUPD: Channel Period Update**

If the waveform is left-aligned, then the output waveform period depends on the channel counter source clock and can be calculated:

– By using the PWM master clock (MCK) divided by an X given prescaler value (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024). The resulting period formula will be:

$$\frac{(X \times CPRDUPD)}{MCK}$$

– By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

$$\frac{(CRPDUPD \times DIVA)}{MCK} \text{ or } \frac{(CRPDUPD \times DIVB)}{MCK}$$

If the waveform is center-aligned, then the output waveform period depends on the channel counter source clock and can be calculated:

– By using the PWM master clock (MCK) divided by an X given prescaler value (with X being 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024). The resulting period formula will be:

$$\frac{(2 \times X \times CPRDUPD)}{MCK}$$

– By using the PWM master clock (MCK) divided by one of both DIVA or DIVB divider, the formula becomes, respectively:

$$\frac{(2 \times CPRDUPD \times DIVA)}{MCK} \text{ or } \frac{(2 \times CPRDUPD \times DIVB)}{MCK}$$

37.7.40 PWM Channel Counter Register

Name: PWM_CCNTx [x=0..3]

Address: 0x4008C214 [0], 0x4008C234 [1], 0x4008C254 [2], 0x4008C274 [3]

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
CNT							

15	14	13	12	11	10	9	8
CNT							

7	6	5	4	3	2	1	0
CNT							

Only the first 16 bits (channel counter size) are significant.

- **CNT: Channel Counter Register**

Channel counter value. This register is reset when:

- the channel is enabled (writing CHIDx in the PWM_ENA register).
- the channel counter reaches CPRD value defined in the PWM_CPRDx register if the waveform is left aligned.

37.7.41 PWM Channel Dead Time Register

Name: PWM_DTx [x=0..3]

Address: 0x4008C218 [0], 0x4008C238 [1], 0x4008C258 [2], 0x4008C278 [3]

Access: Read-write

31	30	29	28	27	26	25	24
DTL							

23	22	21	20	19	18	17	16
DTL							

15	14	13	12	11	10	9	8
DTH							

7	6	5	4	3	2	1	0
DTH							

This register can only be written if the bits WPSWS4 and WPHWS4 are cleared in “PWM Write Protect Status Register” on page 926.

Only the first 12 bits (dead-time counter size) of fields DTH and DTL are significant.

- **DTH: Dead-Time Value for PWMHx Output**

Defines the dead-time value for PWMHx output. This value must be defined between 0 and CPRD-CDTY (PWM_CPRx and PWM_CDTYx).

- **DTL: Dead-Time Value for PWMLx Output**

Defines the dead-time value for PWMLx output. This value must be defined between 0 and CDTY (PWM_CDTYx).

37.7.42 PWM Channel Dead Time Update Register

Name: PWM_DTUPDx [x=0..3]

Address: 0x4008C21C [0], 0x4008C23C [1], 0x4008C25C [2], 0x4008C27C [3]

Access: Write-only

31	30	29	28	27	26	25	24
DTLUPD							

23	22	21	20	19	18	17	16
DTLUPD							

15	14	13	12	11	10	9	8
DTHUPD							

7	6	5	4	3	2	1	0
DTHUPD							

This register can only be written if the bits WPSWS4 and WPHWS4 are cleared in “PWM Write Protect Status Register” on page 926.

This register acts as a double buffer for the DTH and DTL values. This prevents an unexpected waveform when modifying the dead-time values.

Only the first 12 bits (dead-time counter size) of fields DTHUPD and DTLUPD are significant.

- **DTHUPD: Dead-Time Value Update for PWMHx Output**

Defines the dead-time value for PWMHx output. This value must be defined between 0 and CPRD-CDTY (PWM_CPRx and PWM_CDTYx). This value is applied only at the beginning of the next channel x PWM period.

- **DTLUPD: Dead-Time Value Update for PWMLx Output**

Defines the dead-time value for PWMLx output. This value must be defined between 0 and CDTY (PWM_CDTYx). This value is applied only at the beginning of the next channel x PWM period.

38. USB High Speed Device Port (UDPHS)

38.1 Description

The USB High Speed Device Port (UDPHS) is compliant with the Universal Serial Bus (USB), rev 2.0 High Speed device specification.

Each endpoint can be configured in one of several USB transfer types. It can be associated with one, two or three banks of a Dual-port RAM used to store the current data payload. If two or three banks are used, one DPR bank is read or written by the processor, while the other is read or written by the USB device peripheral. This feature is mandatory for isochronous endpoints.

38.2 Embedded Characteristics

- 1 Device High Speed
- USB v2.0 High Speed Compliant, 480 Mbits Per Second
- UTMI Compliant
- 7 Endpoints
- Embedded Dual-port RAM for Endpoints
- Suspend/Resume Logic (Command of UTMI)
- Up to Three Memory Banks for Endpoints (Not for Control Endpoint)
- 4 KBytes of DPRAM

Table 38-1. UDPHS Endpoint Description

Endpoint #	Mnemonic	Nb Bank	DMA	High Band Width	Max. Endpoint Size	Endpoint Type
0	EPT_0	1	N	N	64	Control
1	EPT_1	2	Y	Y	512	Ctrl/Bulk/Iso(1)/Interrupt
2	EPT_2	2	Y	Y	512	Ctrl/Bulk/Iso(1)/Interrupt
3	EPT_3	3	Y	N	64	Ctrl/Bulk/Iso(1)/Interrupt
4	EPT_4	3	Y	N	64	Ctrl/Bulk/Iso(1)/Interrupt
5	EPT_5	3	Y	Y	1024	Ctrl/Bulk/Iso(1)/Interrupt
6	EPT_6	3	Y	Y	1024	Ctrl/Bulk/Iso(1)/Interrupt

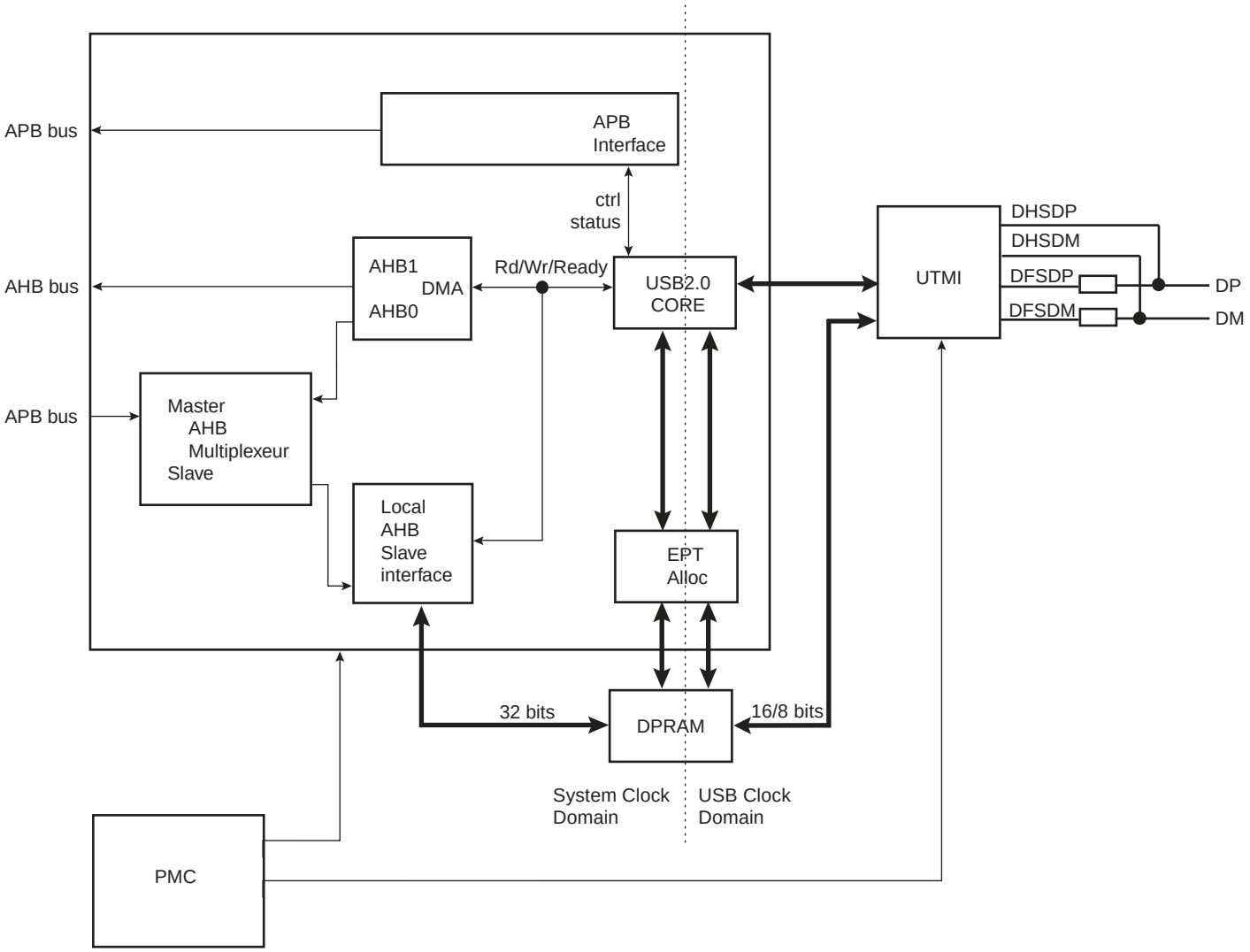
Note: 1. In Isochronous Mode (Iso), it is preferable that High Band Width capability is available.

The size of internal DPRAM is 4 KB.

Suspend and resume are automatically detected by the UDPHS device, which notifies the processor by raising an interrupt.

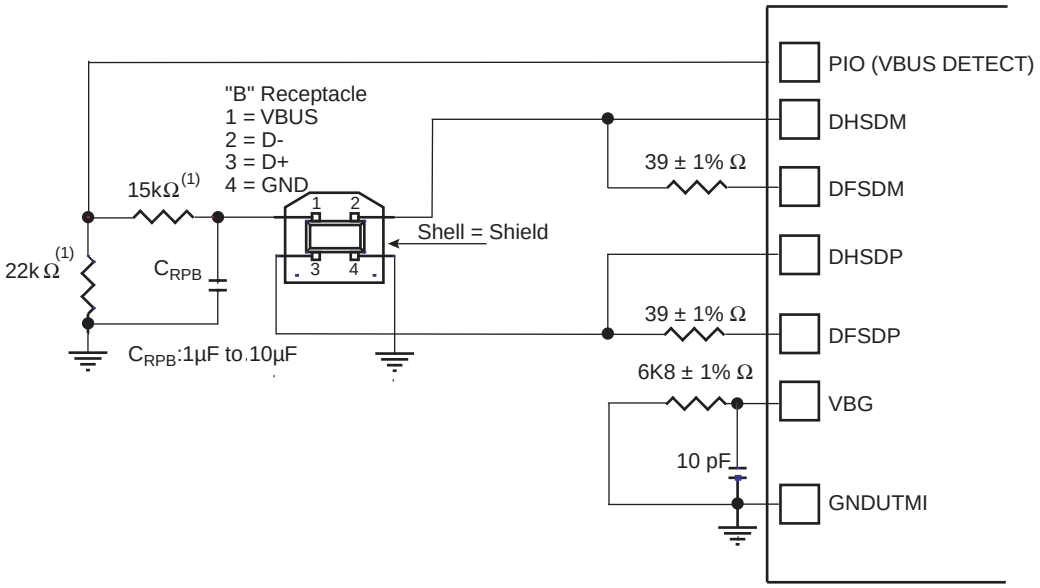
38.3 Block Diagram

Figure 38-1. Block Diagram



38.4 Typical Connection

Figure 38-2. Board Schematic



Note: The values shown on the 22 kΩ and 15 kΩ resistors are only valid with 3V3 supplied PIOs.
Both 39 Ω resistors need to be placed as close to the device pins as possible.

38.5 Product Dependencies

38.5.1 Power Management

The UDPHS is not continuously clocked.

For using the UDPHS, the programmer must first enable the UDPHS Clock in the Power Management Controller (PMC_PCER register). Then enable the PLL (PMC_UCKR register).

However, if the application does not require UDPHS operations, the UDPHS clock can be stopped when not needed and restarted later.

38.5.2 Interrupt

The UDPHS interrupt line is connected on one of the internal sources of the Interrupt Controller. Using the UDPHS interrupt requires the Interrupt Controller to be programmed first.

Table 38-2. Peripheral IDs

Instance	ID
UDPHS	29

38.6 Functional Description

38.6.1 USB V2.0 High Speed Device Port Introduction

The USB V2.0 High Speed Device Port provides communication services between host and attached USB devices. Each device is offered with a collection of communication flows (pipes) associated with each endpoint. Software on the host communicates with a USB Device through a set of communication flows.

38.6.2 USB V2.0 High Speed Transfer Types

A communication flow is carried over one of four transfer types defined by the USB device.

A device provides several logical communication pipes with the host. To each logical pipe is associated an endpoint. Transfer through a pipe belongs to one of the four transfer types:

- Control Transfers: Used to configure a device at attach time and can be used for other device-specific purposes, including control of other pipes on the device.
- Bulk Data Transfers: Generated or consumed in relatively large burst quantities and have wide dynamic latitude in transmission constraints.
- Interrupt Data Transfers: Used for timely but reliable delivery of data, for example, characters or coordinates with human-perceptible echo or feedback response characteristics.
- Isochronous Data Transfers: Occupy a prenegotiated amount of USB bandwidth with a prenegotiated delivery latency. (Also called streaming real time transfers.)

As indicated below, transfers are sequential events carried out on the USB bus.

Endpoints must be configured according to the transfer type they handle.

Table 38-3. USB Communication Flow

Transfer	Direction	Bandwidth	Endpoint Size	Error Detection	Retrying
Control	Bidirectional	Not guaranteed	8, 16, 32, 64	Yes	Automatic
Isochronous	Unidirectional	Guaranteed	8-1024	Yes	No
Interrupt	Unidirectional	Not guaranteed	8-1024	Yes	Yes
Bulk	Unidirectional	Not guaranteed	8-512	Yes	Yes

38.6.3 USB Transfer Event Definitions

A transfer is composed of one or several transactions;

Table 38-4. USB Transfer Events

CONTROL (bidirectional)	Control Transfers (1)	• Setup transaction → Data IN transactions ∅Status OUT transaction • Setup transaction → Data OUT transactions ∅Status IN transaction • Setup transaction → Status IN transaction
IN (device toward host)	Bulk IN Transfer	• Data IN transaction → Data IN transaction
	Interrupt IN Transfer	• Data IN transaction → Data IN transaction
	Isochronous IN Transfer (2)	• Data IN transaction → Data IN transaction
OUT (host toward device)	Bulk OUT Transfer	• Data OUT transaction → Data OUT transaction
	Interrupt OUT Transfer	• Data OUT transaction → Data OUT transaction
	Isochronous OUT Transfer (2)	• Data OUT transaction→ Data OUT transaction

Notes: 1. Control transfer must use endpoints with one bank and can be aborted using a stall handshake.
2. Isochronous transfers must use endpoints configured with two or three banks.

An endpoint handles all transactions related to the type of transfer for which it has been configured.

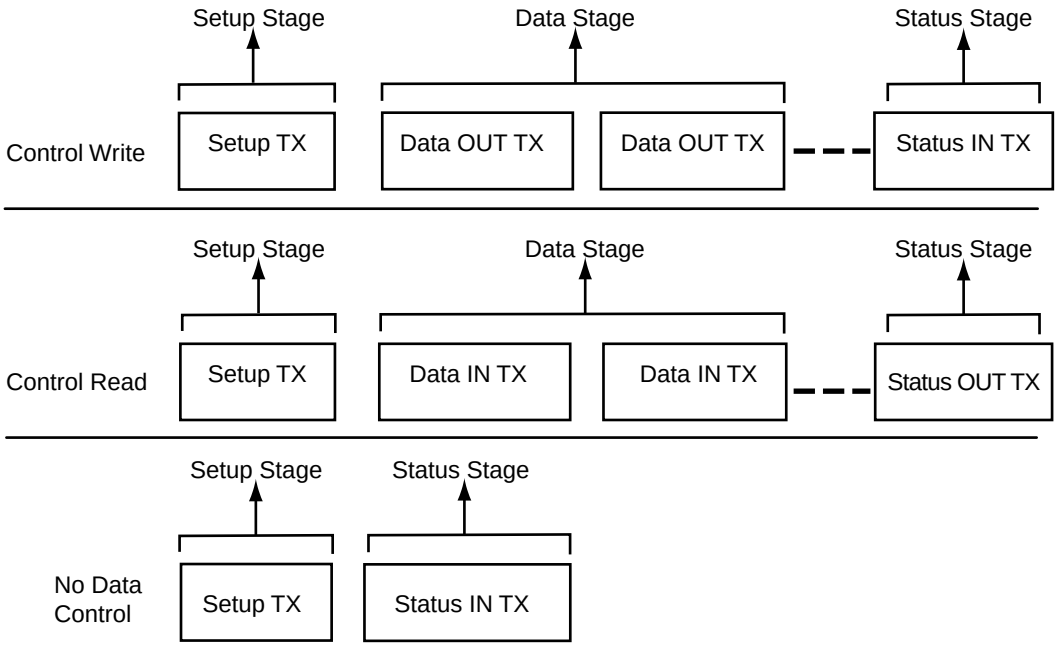
38.6.4 USB V2.0 High Speed BUS Transactions

Each transfer results in one or more transactions over the USB bus.

There are five kinds of transactions flowing across the bus in packets:

1. Setup Transaction
2. Data IN Transaction
3. Data OUT Transaction
4. Status IN Transaction
5. Status OUT Transaction

Figure 38-3. Control Read and Write Sequences



A status IN or OUT transaction is identical to a data IN or OUT transaction.

38.6.5 Endpoint Configuration

The endpoint 0 is always a control endpoint, it must be programmed and active in order to be enabled when the End Of Reset interrupt occurs.

To configure the endpoints:

- Fill the configuration register (UDPHS_EPTCFG) with the endpoint size, direction (IN or OUT), type (CTRL, Bulk, IT, ISO) and the number of banks.
- Fill the number of transactions (NB_TRANS) for isochronous endpoints.

Note: For control endpoints the direction has no effect.

- Verify that the EPT_MAPD flag is set. This flag is set if the endpoint size and the number of banks are correct compared to the FIFO maximum capacity and the maximum number of allowed banks.
- Configure control flags of the endpoint and enable it in UDPHS_EPTCTLENBx according to “UDPHS Endpoint Control Register” on page 987.

Control endpoints can generate interrupts and use only 1 bank.

All endpoints (except endpoint 0) can be configured either as Bulk, Interrupt or Isochronous. See Table 38-1. UDPHS Endpoint Description.

The maximum packet size they can accept corresponds to the maximum endpoint size.

Note: The endpoint size of 1024 is reserved for isochronous endpoints.

The size of the DPRAM is 4 KB. The DPR is shared by all active endpoints. The memory size required by the active endpoints must not exceed the size of the DPRAM.

SIZE_DPRAM = SIZE _EPT0

+ NB_BANK_EPT1 x SIZE_EPT1

+ NB_BANK_EPT2 x SIZE_EPT2

+ NB_BANK_EPT3 x SIZE_EPT3

+ NB_BANK_EPT4 x SIZE_EPT4

+ NB_BANK_EPT5 x SIZE_EPT5

+ NB_BANK_EPT6 x SIZE_EPT6

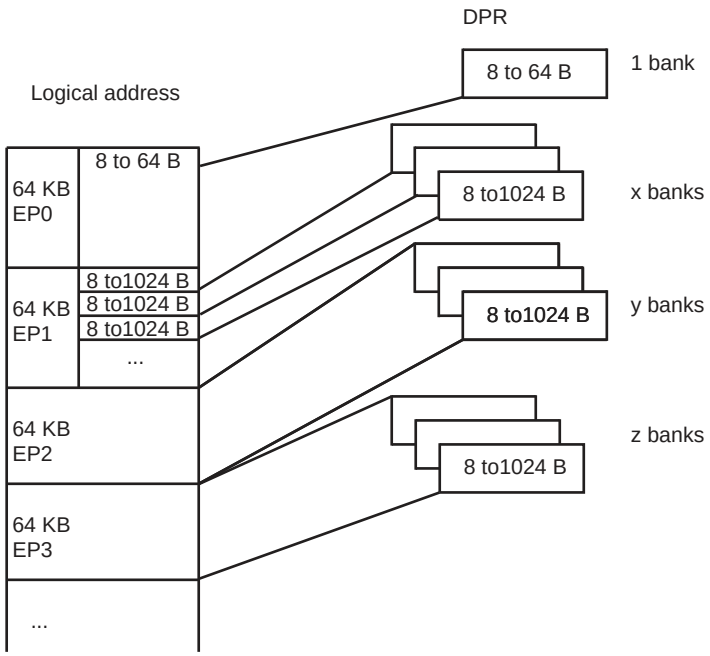
+... (refer to 38.7.11 UDPHS Endpoint Configuration Register)

If a user tries to configure endpoints with a size the sum of which is greater than the DPRAM, then the EPT_MAPD is not set.

The application has access to the physical block of DPR reserved for the endpoint through a 64 KB logical address space.

The physical block of DPR allocated for the endpoint is remapped all along the 64 KB logical address space. The application can write a 64 KB buffer linearly.

Figure 38-4. Logical Address Space for DPR Access



Configuration examples of UDPHS_EPTCTLx (UDPHS Endpoint Control Register) for Bulk IN endpoint type follow below.

- With DMA
  - AUTO_VALID: Automatically validate the packet and switch to the next bank.
  - EPT_ENABL: Enable endpoint.
- Without DMA:
  - TX_BK_RDY: An interrupt is generated after each transmission.
  - EPT_ENABL: Enable endpoint.

Configuration examples of Bulk OUT endpoint type follow below.

- With DMA
  - AUTO_VALID: Automatically validate the packet and switch to the next bank.
  - EPT_ENABL: Enable endpoint.
- Without DMA
  - RX_BK_RDY: An interrupt is sent after a new packet has been stored in the endpoint FIFO.
  - EPT_ENABL: Enable endpoint.

38.6.6 DPRAM Management

Endpoints can only be allocated in ascending order, from the endpoint 0 to the last endpoint to be allocated. The user shall therefore configure them in the same order.

The allocation of an endpoint x starts when the Number of Banks field in the UDPHS Endpoint Configuration Register (UDPHS_EPTCFGx.BK_NUMBER) is different from zero. Then, the hardware allocates a memory area in the DPRAM and inserts it between the x-1 and x+1 endpoints. The x+1 endpoint memory window slides up and its data is lost. Note that the following endpoint memory windows (from x+2) do not slide.

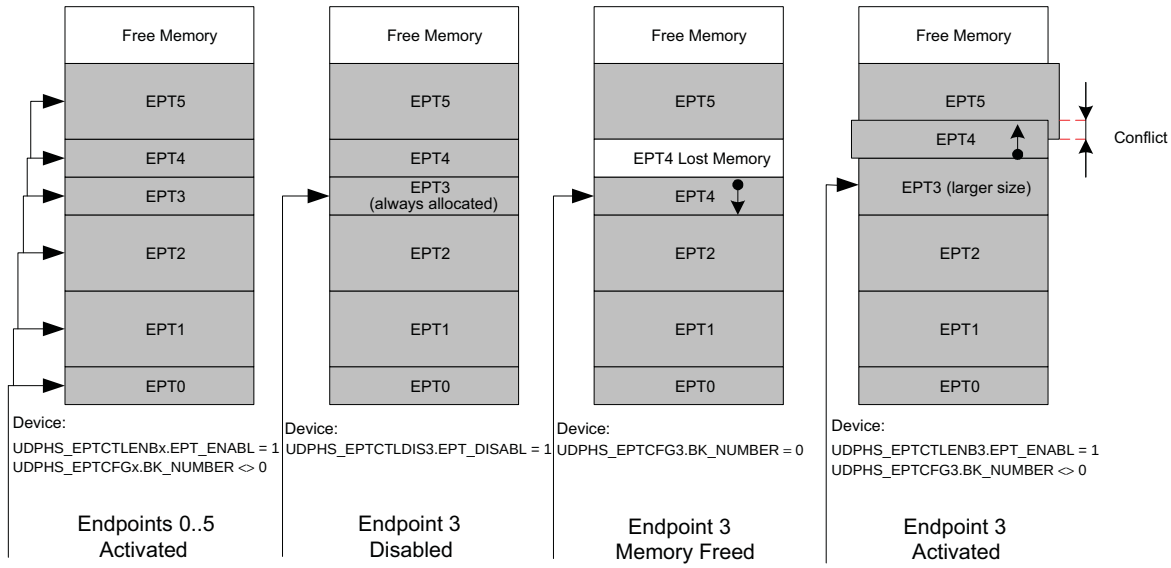
Disabling an endpoint, by writing a one to the Endpoint Disable bit in the UDPHS Endpoint Control Disable Register (UDPHS_EPTCTLDISx.EPT_DISABL), does not reset its configuration:

- the Endpoint Banks (UDPHS_EPTCFGx.BK_NUMBER),
- the Endpoint Size (UDPHS_EPTCFGx.EPT_SIZE),
- the Endpoint Direction (UDPHS_EPTCFGx.EPT_DIR),
- and the Endpoint Type (UDPHS_EPTCFGx.EPT_TYPE).

To free its memory, the user shall write a zero to the UDPHS_EPTCFGx.BK_NUMBER field. The x+1 endpoint memory window then slides down and its data is lost. Note that the following endpoint memory windows (from x+2) do not slide.

Figure 38-5 on page 947 illustrates the allocation and reorganization of the DPRAM in a typical example.

Figure 38-5. Allocation and Reorganization of the DPRAM



1. The endpoints 0 to 5 are enabled, configured and allocated in ascending order. Each endpoint then owns a memory area in the DPRAM.
2. The endpoint 3 is disabled, but its memory is kept allocated by the controller.
3. In order to free its memory, its UDPHS_EPTCFGx.BK_NUMBER field is written to zero. The endpoint 4 memory window slides down, but the endpoint 5 does not move.
4. If the user chooses to reconfigure the endpoint 3 with a larger size, the controller allocates a memory area after the endpoint 2 memory area and automatically slides up the endpoint 4 memory window. The endpoint 5 does not move and a memory conflict appears as the memory windows of the endpoints 4 and 5 overlap. The data of these endpoints is potentially lost.

Notes:
1. There is no way the data of the endpoint 0 can be lost (except if it is de-allocated) as the memory allocation and de-allocation may affect only higher endpoints.
2. Deactivating then reactivating the same endpoint with the same configuration only modifies temporarily the controller DPRAM pointer and size for this endpoint. Nothing changes in the DPRAM, higher endpoints seem not to have been moved and their data is preserved as far as nothing has been written or received into them while changing the allocation state of the first endpoint.
3. When the user writes a value different from zero to the UDPHS_EPTCFGx.BK_NUMBER field, the Endpoint Mapped bit (UDPHS_EPTCFGx.EPT_MAPD) is set only if the configured size and number of banks are correct as compared to the endpoint maximal allowed values and to the maximal FIFO size (i.e. the DPRAM size). The UDPHS_EPTCFGx.EPT_MAPD value does not consider memory allocation conflicts.

38.6.7 Transfer With DMA

USB packets of any length may be transferred when required by the UDPHS Device. These transfers always feature sequential addressing.

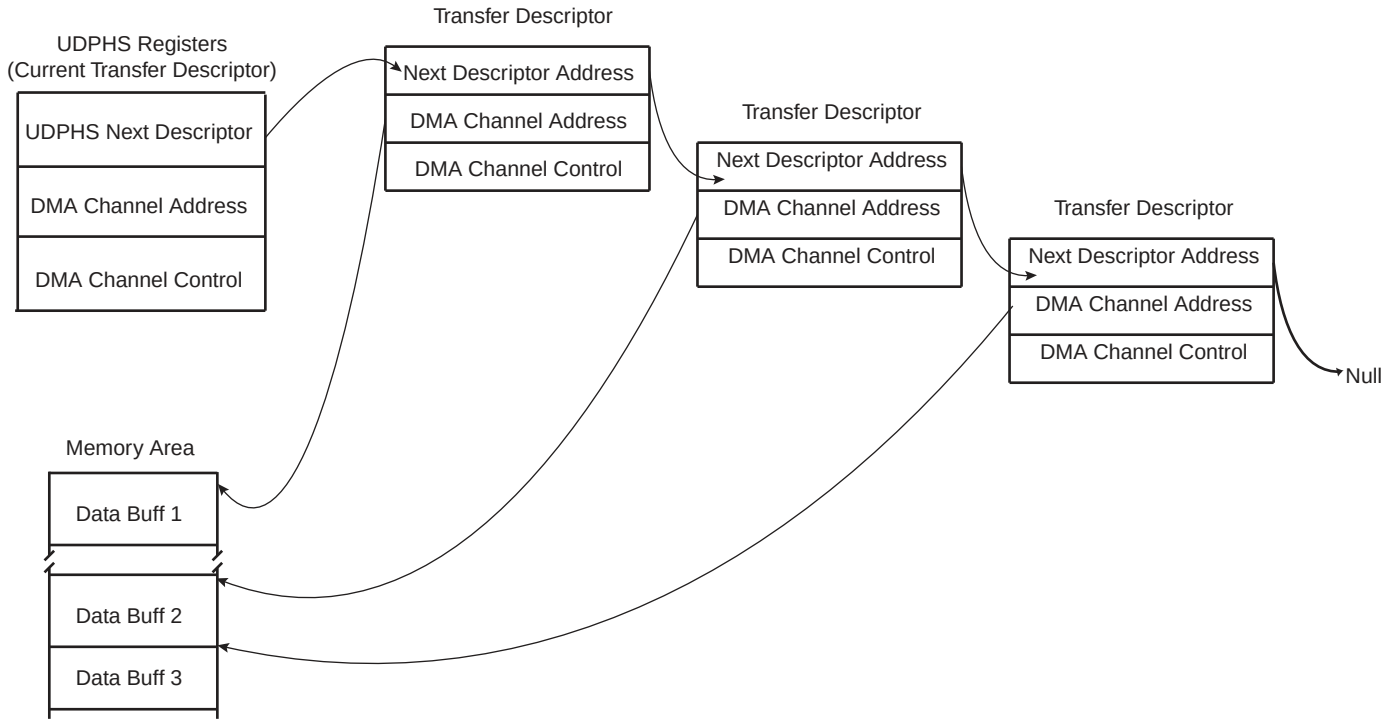
Packet data AHB bursts may be locked on a DMA buffer basis for drastic overall AHB bus bandwidth performance boost with paged memories. These clock-cycle consuming memory row (or bank) changes will then likely not occur, or occur only once instead of dozens times, during a single big USB packet DMA transfer in case another AHB master addresses the memory. This means up to 128-word single-cycle unbroken AHB bursts for Bulk endpoints and 256-word single-cycle unbroken bursts for isochronous endpoints. This maximum burst length is then controlled by the lowest programmed USB endpoint size (EPT_SIZE field in the UDPHS_EPTCFGx register) and DMA Size (BUFF_LENGTH field in the UDPHS_DMACONTROLx register).

The USB 2.0 device average throughput may be up to nearly 60 MBytes. Its internal slave average access latency decreases as burst length increases due to the 0 wait-state side effect of unchanged endpoints. If at least 0 wait-state word burst capability is also provided by the external DMA AHB bus slaves, each of both DMA AHB busses need less than 50% bandwidth allocation for full USB 2.0 bandwidth usage at 30 MHz, and less than 25% at 60 MHz.

The UDPHS DMA Channel Transfer Descriptor is described in “UDPHS DMA Channel Transfer Descriptor” on page 997.

Note: In case of debug, be careful to address the DMA to an SRAM address even if a remap is done.

Figure 38-6. Example of DMA Chained List



38.6.8 Transfer Without DMA

Important. If the DMA is not to be used, it is necessary that it be disabled because otherwise it can be enabled by previous versions of software **without warning**. If this should occur, the DMA can process data before an interrupt without knowledge of the user.

The recommended means to disable DMA is as follows:

```
// Reset IP UDPHS
    AT91C_BASE_UDPHS->UDPHS_CTRL &= ~AT91C_UDPHS_EN_UDPHS;
    AT91C_BASE_UDPHS->UDPHS_CTRL |= AT91C_UDPHS_EN_UDPHS;
// With OR without DMA !!!
    for( i=1; i<=((AT91C_BASE_UDPHS->UDPHS_IPFEATURES &
AT91C_UDPHS_DMA_CHANNEL_NBR)>>4); i++ ) {
// RESET endpoint canal DMA:
        // DMA stop channel command
        AT91C_BASE_UDPHS->UDPHS_DMA[i].UDPHS_DMACONTROL = 0;  // STOP
command
// Disable endpoint
        AT91C_BASE_UDPHS->UDPHS_EPT[i].UDPHS_EPTCTLDIS |= 0XFFFFFFFF;
// Reset endpoint config
        AT91C_BASE_UDPHS->UDPHS_EPT[i].UDPHS_EPTCTLCFG = 0;
// Reset DMA channel (Buff count and Control field)
        AT91C_BASE_UDPHS->UDPHS_DMA[i].UDPHS_DMACONTROL = 0x02;  // NON
STOP command
// Reset DMA channel 0 (STOP)
        AT91C_BASE_UDPHS->UDPHS_DMA[i].UDPHS_DMACONTROL = 0;  // STOP
command
// Clear DMA channel status (read the register for clear it)
        AT91C_BASE_UDPHS->UDPHS_DMA[i].UDPHS_DMASTATUS =
AT91C_BASE_UDPHS->UDPHS_DMA[i].UDPHS_DMASTATUS;
}
```

38.6.9 Handling Transactions with USB V2.0 Device Peripheral

38.6.9.1 Setup Transaction

The setup packet is valid in the DPR while RX_SETUP is set. Once RX_SETUP is cleared by the application, the UDPHS accepts the next packets sent over the device endpoint.

When a valid setup packet is accepted by the UDPHS:

- the UDPHS device automatically acknowledges the setup packet (sends an ACK response)
- payload data is written in the endpoint
- sets the RX_SETUP interrupt
- the BYTE_COUNT field in the UDPHS_EPTSTAx register is updated

An endpoint interrupt is generated while RX_SETUP in the UDPHS_EPTSTAx register is not cleared. This interrupt is carried out to the microcontroller if interrupts are enabled for this endpoint.

Thus, firmware must detect RX_SETUP polling UDPHS_EPTSTAx or catching an interrupt, read the setup packet in the FIFO, then clear the RX_SETUP bit in the UDPHS_EPTCLRSTA register to acknowledge the setup stage.

If STALL_SNT was set to 1, then this bit is automatically reset when a setup token is detected by the device. Then, the device still accepts the setup stage. (See Section 38.6.9.15 “STALL” on page 959).

38.6.9.2 NYET

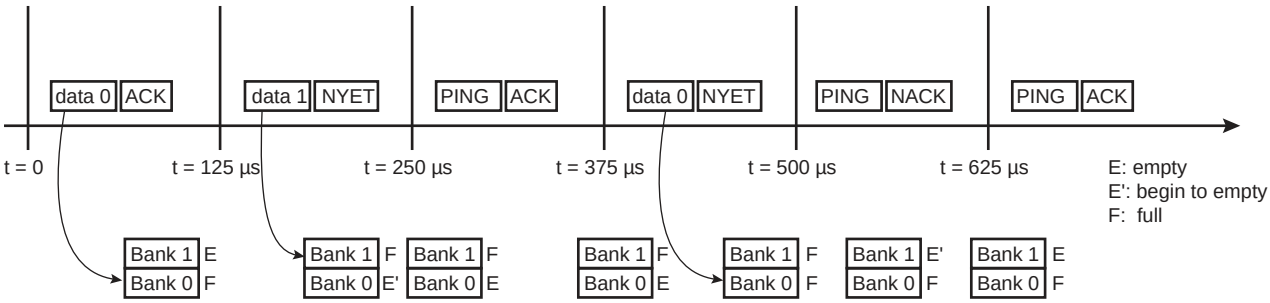
NYET is a High Speed only handshake. It is returned by a High Speed endpoint as part of the PING protocol.

High Speed devices must support an improved NAK mechanism for Bulk OUT and control endpoints (except setup stage). This mechanism allows the device to tell the host whether it has sufficient endpoint space for the next OUT transfer (see USB 2.0 spec 8.5.1 NAK Limiting via Ping Flow Control).

The NYET/ACK response to a High Speed Bulk OUT transfer and the PING response are automatically handled by hardware in the UDPHS_EPTCTLx register (except when the user wants to force a NAK response by using the NYET_DIS bit).

If the endpoint responds instead to the OUT/DATA transaction with an NYET handshake, this means that the endpoint accepted the data but does not have room for another data payload. The host controller must return to using a PING token until the endpoint indicates it has space available.

Figure 38-7. NYET Example with Two Endpoint Banks



38.6.9.3 Data IN

38.6.9.4 Bulk IN or Interrupt IN

Data IN packets are sent by the device during the data or the status stage of a control transfer or during an (interrupt/bulk/isochronous) IN transfer. Data buffers are sent packet by packet under the control of the application or under the control of the DMA channel.

There are three ways for an application to transfer a buffer in several packets over the USB:

- packet by packet (see 38.6.9.5 below)
- 64 KB (see 38.6.9.5 below)
- DMA (see 38.6.9.6 below)

38.6.9.5 Bulk IN or Interrupt IN: Sending a Packet Under Application Control (Device to Host)

The application can write one or several banks.

A simple algorithm can be used by the application to send packets regardless of the number of banks associated to the endpoint.

Algorithm Description for Each Packet:

- The application waits for TX_PK_RDY flag to be cleared in the UDPHS_EPTSTAx register before it can perform a write access to the DPR.
- The application writes one USB packet of data in the DPR through the 64 KB endpoint logical memory window.
- The application sets TX_PK_RDY flag in the UDPHS_EPTSETSTAx register.

The application is notified that it is possible to write a new packet to the DPR by the TX_PK_RDY interrupt. This interrupt can be enabled or masked by setting the TX_PK_RDY bit in the UDPHS_EPTCTLENB/UDPHS_EPTCTLDIS register.

Algorithm Description to Fill Several Packets:

Using the previous algorithm, the application is interrupted for each packet. It is possible to reduce the application overhead by writing linearly several banks at the same time. The AUTO_VALID bit in the UDPHS_EPTCTLx must be set by writing the AUTO_VALID bit in the UDPHS_EPTCTLENBx register.

The auto-valid-bank mechanism allows the transfer of data (IN and OUT) without the intervention of the CPU. This means that bank validation (set TX_PK_RDY or clear the RX_BK_RDY bit) is done by hardware.

- The application checks the BUSY_BANK_STA field in the UDPHS_EPTSTAx register. The application must wait that at least one bank is free.
- The application writes a number of bytes inferior to the number of free DPR banks for the endpoint. Each time the application writes the last byte of a bank, the TX_PK_RDY signal is automatically set by the UDPHS.
- If the last packet is incomplete (i.e., the last byte of the bank has not been written) the application must set the TX_PK_RDY bit in the UDPHS_EPTSETSTAx register.

The application is notified that all banks are free, so that it is possible to write another burst of packets by the BUSY_BANK interrupt. This interrupt can be enabled or masked by setting the BUSY_BANK flag in the UDPHS_EPTCTLENB and UDPHS_EPTCTLDIS registers.

This algorithm must not be used for isochronous transfer. In this case, the ping-pong mechanism does not operate.

A Zero Length Packet can be sent by setting just the TX_PKTRDY flag in the UDPHS_EPTSETSTAx register.

38.6.9.6 Bulk IN or Interrupt IN: Sending a Buffer Using DMA (Device to Host)

The UDPHS integrates a DMA host controller. This DMA controller can be used to transfer a buffer from the memory to the DPR or from the DPR to the processor memory under the UDPHS control. The DMA can be used for all transfer types except control transfer.

Example DMA configuration:

1. Program UDPHS_DMAADDRESS x with the address of the buffer that should be transferred.
2. Enable the interrupt of the DMA in UDPHS_IEN
3. Program UDPHS_ DMACONTROLx:
   - Size of buffer to send: size of the buffer to be sent to the host.
   - END_B_EN: The endpoint can validate the packet (according to the values programmed in the AUTO_VALID and SHRT_PCKT fields of UDPHS_EPTCTLx.) (See “UDPHS Endpoint Control Register” on page 987 and Figure 38-12. Autovalid with DMA)
   - END_BUFFIT: generate an interrupt when the BUFF_COUNT in UDPHS_DMASTATUSx reaches 0.
   - CHANN_ENB: Run and stop at end of buffer

The auto-valid-bank mechanism allows the transfer of data (IN & OUT) without the intervention of the CPU. This means that bank validation (set TX_PK_RDY or clear the RX_BK_RDY bit) is done by hardware.

A transfer descriptor can be used. Instead of programming the register directly, a descriptor should be programmed and the address of this descriptor is then given to UDPHS_DMANXTDSC to be processed after setting the LDNXT_DSC field (Load Next Descriptor Now) in UDPHS_DMACONTROLx register.

The structure that defines this transfer descriptor must be aligned.

Each buffer to be transferred must be described by a DMA Transfer descriptor (see “UDPHS DMA Channel Transfer Descriptor” on page 997). Transfer descriptors are chained. Before executing transfer of the buffer, the UDPHS may fetch a new transfer descriptor from the memory address pointed by the UDPHS_DMANXTDSCx register. Once the transfer is complete, the transfer status is updated in the UDPHS_DMASTATUSx register.

To chain a new transfer descriptor with the current DMA transfer, the DMA channel must be stopped. To do so, INTDIS_DMA and TX_BK_RDY may be set in the UDPHS_EPTCTLENBx register. It is also possible for the application to wait for the completion of all transfers. In this case the LDNXT_DSC field in the last transfer descriptor UDPHS_DMACONTROLx register must be set to 0 and CHANN_ENB set to 1.

Then the application can chain a new transfer descriptor.

The INTDIS_DMA can be used to stop the current DMA transfer if an enabled interrupt is triggered. This can be used to stop DMA transfers in case of errors.

The application can be notified at the end of any buffer transfer (ENB_BUFFIT bit in the UDPHS_DMACONTROLx register).

Figure 38-8. Data IN Transfer for Endpoint with One Bank

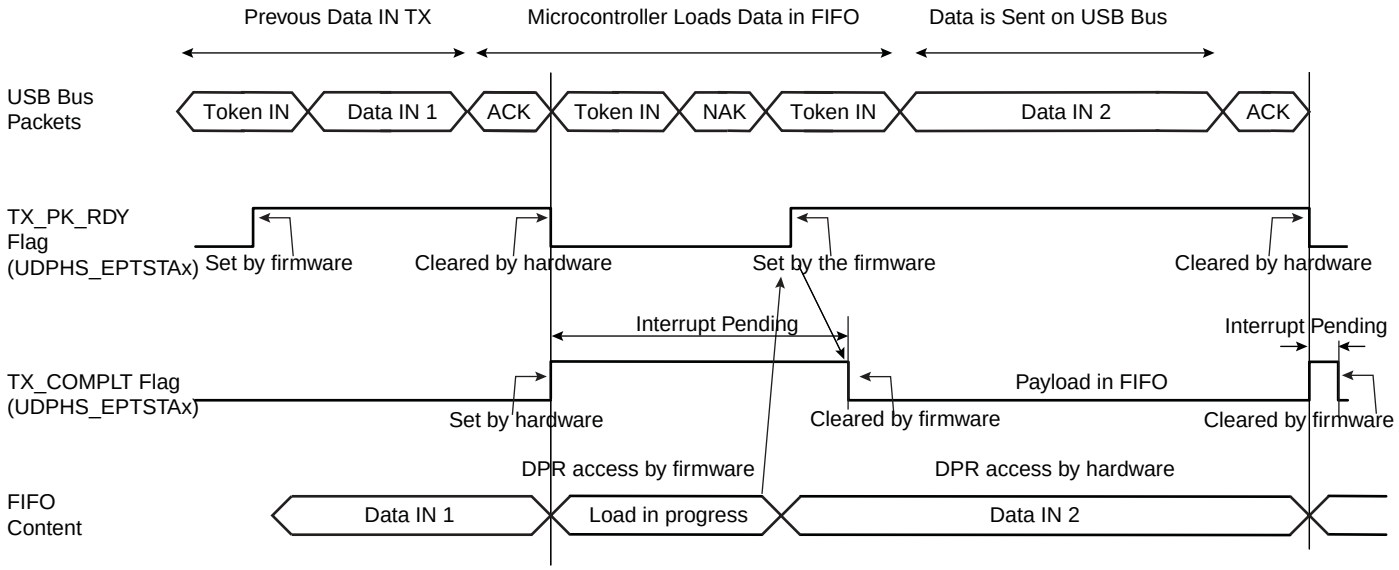


Figure 38-9. Data IN Transfer for Endpoint with Two Banks

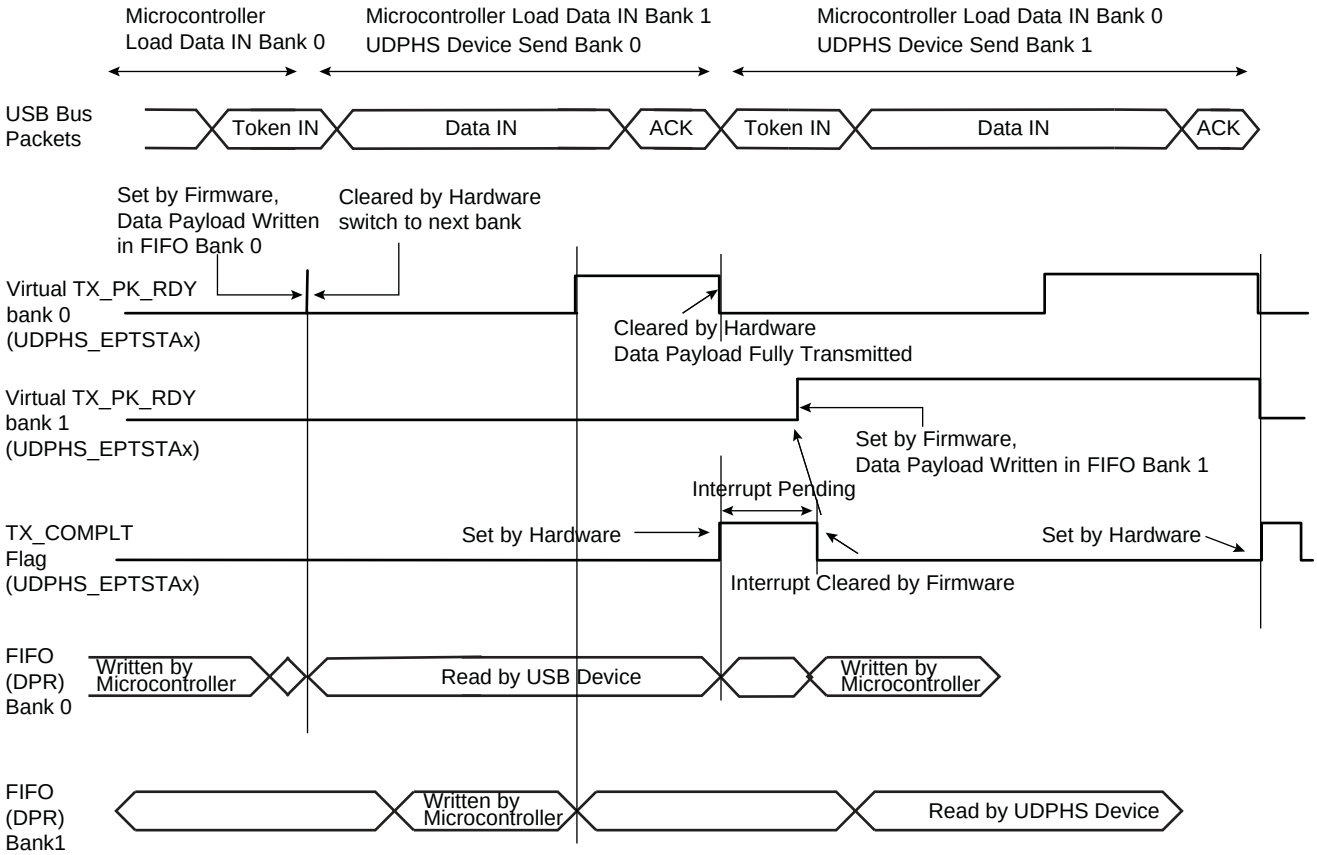
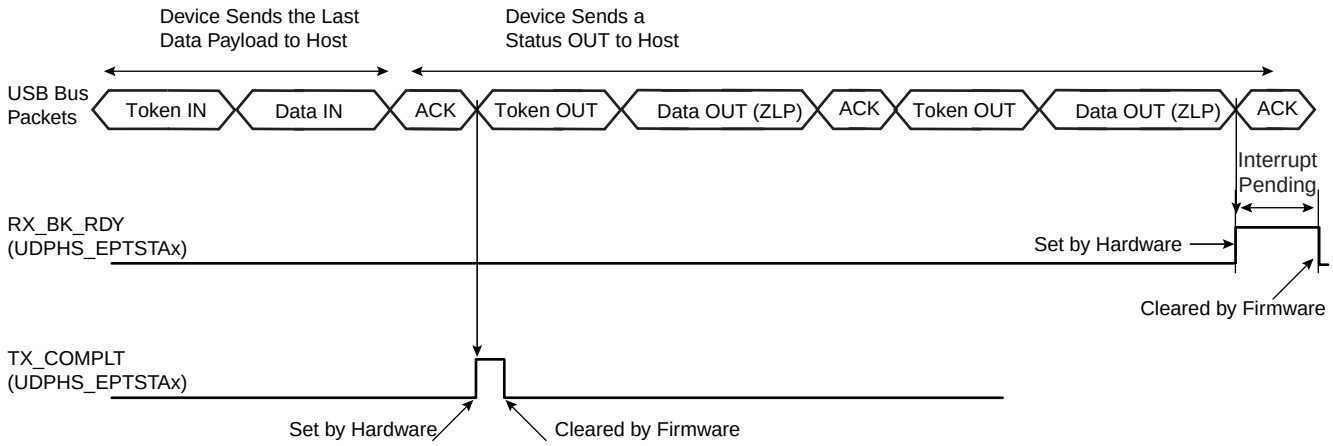
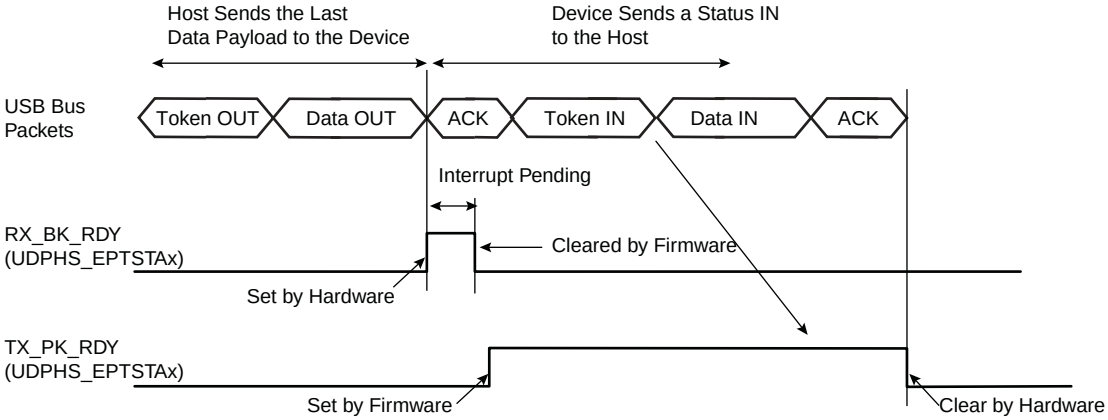


Figure 38-10. Data IN Followed By Status OUT Transfer at the End of a Control Transfer



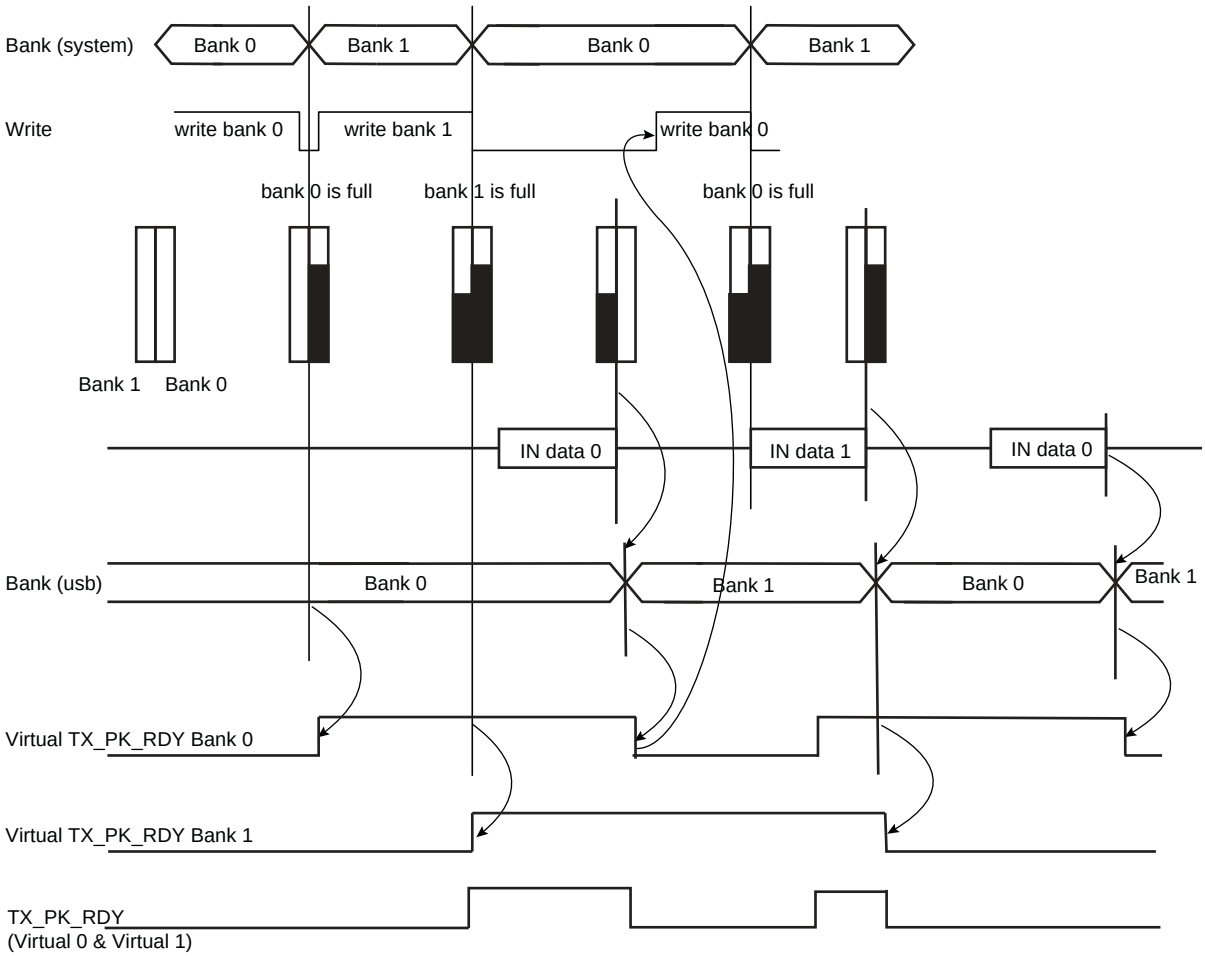
Note: A NAK handshake is always generated at the first status stage token.

Figure 38-11. Data OUT Followed by Status IN Transfer



Note: Before proceeding to the status stage, the software should determine that there is no risk of extra data from the host (data stage). If not certain (non-predictable data stage length), then the software should wait for a NAK-IN interrupt before proceeding to the status stage. This precaution should be taken to avoid collision in the FIFO.

Figure 38-12. Autovalid with DMA



Note: In the illustration above Autovalid validates a bank as full, although this might not be the case, in order to continue processing data and to send to DMA.

38.6.9.7 Isochronous IN

Isochronous-IN is used to transmit a stream of data whose timing is implied by the delivery rate. Isochronous transfer provides periodic, continuous communication between host and device.

It guarantees bandwidth and low latencies appropriate for telephony, audio, video, etc.

If the endpoint is not available (TX_PK_RDY = 0), then the device does not answer to the host. An ERR_FL_ISO interrupt is generated in the UDPHS_EPTSTAx register and once enabled, then sent to the CPU.

The STALL_SNT command bit is not used for an ISO-IN endpoint.

38.6.9.8 High Bandwidth Isochronous Endpoint Handling: IN Example

For high bandwidth isochronous endpoints, the DMA can be programmed with the number of transactions (BUFF_LENGTH field in UDPHS_DMACONTROLx) and the system should provide the required number of packets per microframe, otherwise, the host will notice a sequencing problem.

A response should be made to the first token IN recognized inside a microframe under the following conditions:

- If at least one bank has been validated, the correct DATAx corresponding to the programmed Number Of Transactions per Microframe (NB_TRANS) should be answered. In case of a subsequent missed or corrupted token IN inside the microframe, the USB 2.0 Core available data bank(s) that should normally have been transmitted during that microframe shall be flushed at its end. If this flush occurs, an error condition is flagged (ERR_FLUSH is set in UDPHS_EPTSTAx).
- If no bank is validated yet, the default DATA0 ZLP is answered and underflow is flagged (ERR_FL_ISO is set in UDPHS_EPTSTAx). Then, no data bank is flushed at microframe end.
- If no data bank has been validated at the time when a response should be made for the second transaction of NB_TRANS = 3 transactions microframe, a DATA1 ZLP is answered and underflow is flagged (ERR_FL_ISO is set in UDPHS_EPTSTAx). If and only if remaining untransmitted banks for that microframe are available at its end, they are flushed and an error condition is flagged (ERR_FLUSH is set in UDPHS_EPTSTAx).
- If no data bank has been validated at the time when a response should be made for the last programmed transaction of a microframe, a DATA0 ZLP is answered and underflow is flagged (ERR_FL_ISO is set in UDPHS_EPTSTAx). If and only if the remaining untransmitted data bank for that microframe is available at its end, it is flushed and an error condition is flagged (ERR_FLUSH is set in UDPHS_EPTSTAx).
- If at the end of a microframe no valid token IN has been recognized, no data bank is flushed and no error condition is reported.

At the end of a microframe in which at least one data bank has been transmitted, if less than NB_TRANS banks have been validated for that microframe, an error condition is flagged (ERR_TRANS is set in UDPHS_EPTSTAx).

Cases of Error (in UDPHS_EPTSTAx)

- ERR_FL_ISO: There was no data to transmit inside a microframe, so a ZLP is answered by default.
- ERR_FLUSH: At least one packet has been sent inside the microframe, but the number of token IN received is lesser than the number of transactions actually validated (TX_BK_RDY) and likewise with the NB_TRANS programmed.
- ERR_TRANS: At least one packet has been sent inside the microframe, but the number of token IN received is lesser than the number of programmed NB_TRANS transactions and the packets not requested were not validated.
- ERR_FL_ISO + ERR_FLUSH: At least one packet has been sent inside the microframe, but the data has not been validated in time to answer one of the following token IN.
- ERR_FL_ISO + ERR_TRANS: At least one packet has been sent inside the microframe, but the data has not been validated in time to answer one of the following token IN and the data can be discarded at the microframe end.

- ERR_FLUSH + ERR_TRANS: The first token IN has been answered and it was the only one received, a second bank has been validated but not the third, whereas NB_TRANS was waiting for three transactions.
- ERR_FL_ISO + ERR_FLUSH + ERR_TRANS: The first token IN has been treated, the data for the second Token IN was not available in time, but the second bank has been validated before the end of the microframe. The third bank has not been validated, but three transactions have been set in NB_TRANS.

38.6.9.9 Data OUT

38.6.9.10 Bulk OUT or Interrupt OUT

Like data IN, data OUT packets are sent by the host during the data or the status stage of control transfer or during an interrupt/bulk/isochronous OUT transfer. Data buffers are sent packet by packet under the control of the application or under the control of the DMA channel.

38.6.9.11 Bulk OUT or Interrupt OUT: Receiving a Packet Under Application Control (Host to Device)

Algorithm Description for Each Packet:

- The application enables an interrupt on RX_BK_RDY.
- When an interrupt on RX_BK_RDY is received, the application knows that UDPHS_EPTSTAx register BYTE_COUNT bytes have been received.
- The application reads the BYTE_COUNT bytes from the endpoint.
- The application clears RX_BK_RDY.

Note: If the application does not know the size of the transfer, it may **not** be a good option to use AUTO_VALID. Because if a zero-length-packet is received, the RX_BK_RDY is automatically cleared by the AUTO_VALID hardware and if the endpoint interrupt is triggered, the software will not find its originating flag when reading the UDPHS_EPTSTAx register.

Algorithm to Fill Several Packets:

- The application enables the interrupts of BUSY_BANK and AUTO_VALID.
- When a BUSY_BANK interrupt is received, the application knows that all banks available for the endpoint have been filled. Thus, the application can read all banks available.

If the application doesn't know the size of the receive buffer, instead of using the BUSY_BANK interrupt, the application must use RX_BK_RDY.

38.6.9.12 Bulk OUT or Interrupt OUT: Sending a Buffer Using DMA (Host To Device)

To use the DMA setting, the AUTO_VALID field is mandatory.

See 38.6.9.6 Bulk IN or Interrupt IN: Sending a Buffer Using DMA (Device to Host) for more information.

DMA Configuration Example:

1. First program UDPHS_DMAADDRESSx with the address of the buffer that should be transferred.
2. Enable the interrupt of the DMA in UDPHS_IEN
3. Program the DMA Channelx Control Register:
   - Size of buffer to be sent.
   - END_B_EN: Can be used for OUT packet truncation (discarding of unbuffered packet data) at the end of DMA buffer.
   - END_BUFFIT: Generate an interrupt when BUFF_COUNT in the UDPHS_DMASTATUSx register reaches 0.
   - END_TR_EN: End of transfer enable, the UDPHS device can put an end to the current DMA transfer, in case of a short packet.
   - END_TR_IT: End of transfer interrupt enable, an interrupt is sent after the last USB packet has been transferred by the DMA, if the USB transfer ended with a short packet. (Beneficial when the receive size is unknown.)
   - CHANN_ENB: Run and stop at end of buffer.

For OUT transfer, the bank will be automatically cleared by hardware when the application has read all the bytes in the bank (the bank is empty).

Notes:
1. When a zero-length-packet is received, RX_BK_RDY bit in UDPHS_EPTSTAx is cleared automatically by AUTO_VALID, and the application knows of the end of buffer by the presence of the END_TR_IT.
2. If the host sends a zero-length packet, and the endpoint is free, then the device sends an ACK. No data is written in the endpoint, the RX_BY_RDY interrupt is generated, and the BYTE_COUNT field in UDPHS_EPTSTAx is null.

Figure 38-13. Data OUT Transfer for Endpoint with One Bank

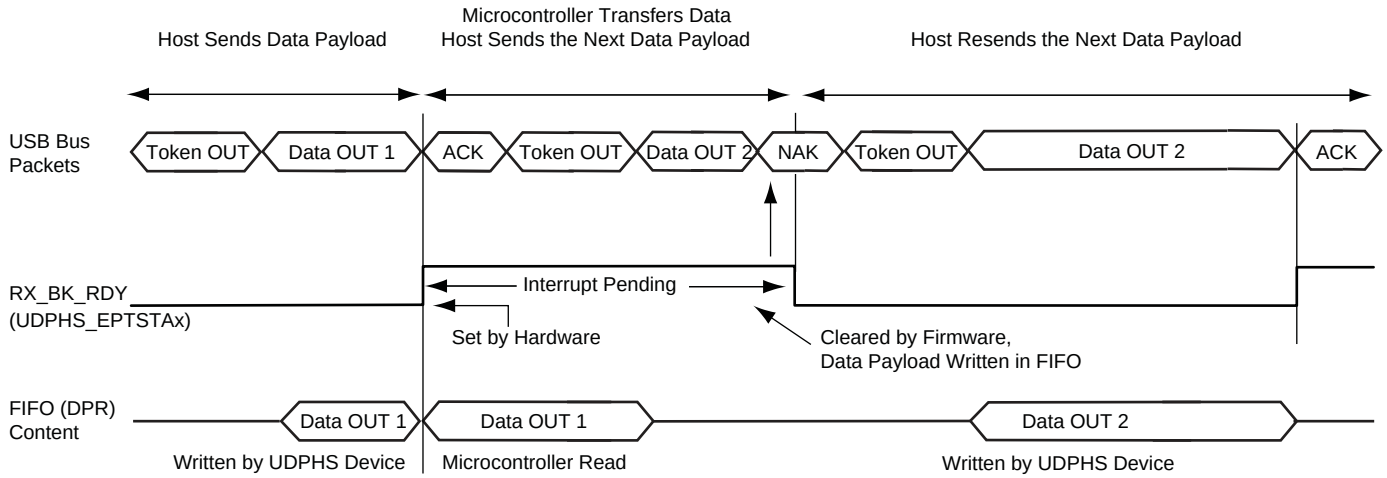
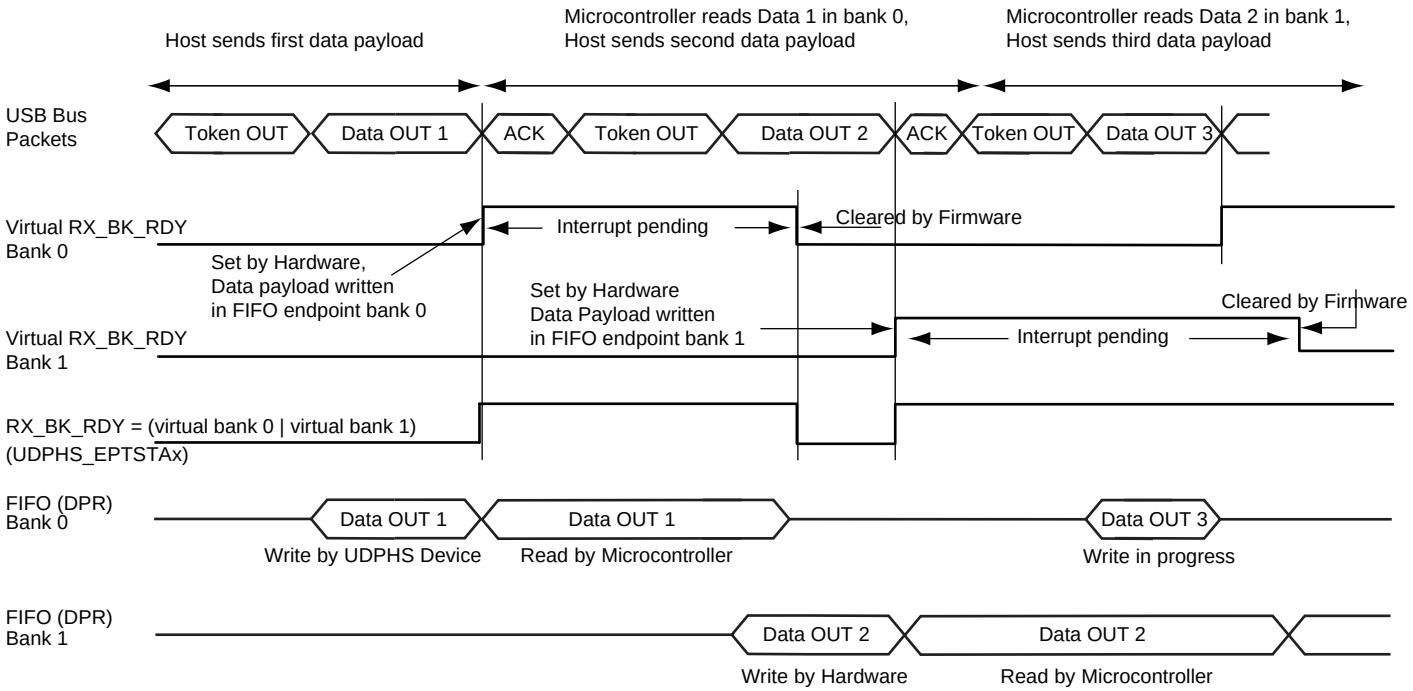
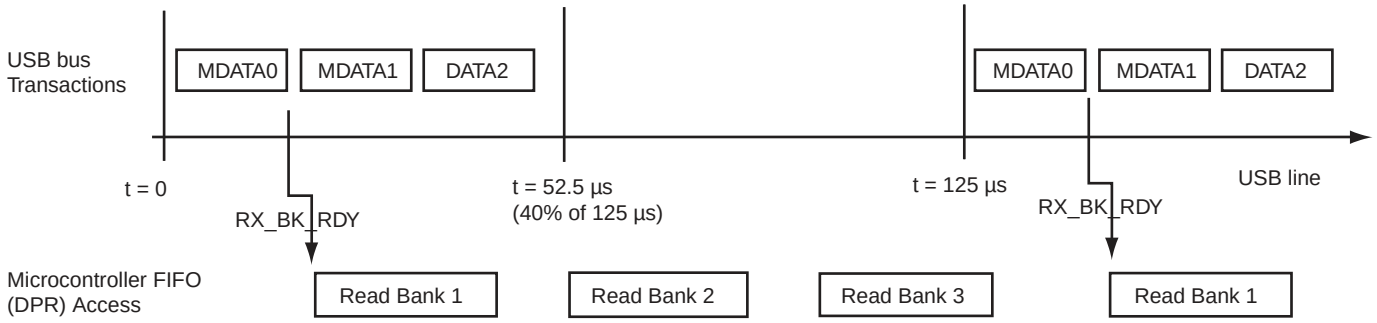


Figure 38-14. Data OUT Transfer for an Endpoint with Two Banks



38.6.9.13 High Bandwidth Isochronous Endpoint OUT

Figure 38-15. Bank Management, Example of Three Transactions per Microframe



USB 2.0 supports individual High Speed isochronous endpoints that require data rates up to 192 Mb/s (24 MB/s): 3x1024 data bytes per microframe.

To support such a rate, two or three banks may be used to buffer the three consecutive data packets. The microcontroller (or the DMA) should be able to empty the banks very rapidly (at least 24 MB/s on average).

NB_TRANS field in UDPHS_EPTCFGx register = Number Of Transactions per Microframe.

If NB_TRANS > 1 then it is High Bandwidth.

Example:

- If NB_TRANS = 3, the sequence should be either
  - MData0
  - MData0/Data1
  - MData0/Data1/Data2
- If NB_TRANS = 2, the sequence should be either
  - MData0
  - MData0/Data1
- If NB_TRANS = 1, the sequence should be
  - Data0

38.6.9.14 Isochronous Endpoint Handling: OUT Example

The user can ascertain the bank status (free or busy), and the toggle sequencing of the data packet for each bank with the UDPHS_EPTSTAx register in the three bit fields as follows:

- TOGGLESQ_STA: PID of the data stored in the current bank
- CURRENT_BANK: Number of the bank currently being accessed by the microcontroller.
- BUSY_BANK_STA: Number of busy bank

This is particularly useful in case of a missing data packet.

If the inter-packet delay between the OUT token and the Data is greater than the USB standard, then the ISO-OUT transaction is ignored. (Payload data is not written, no interrupt is generated to the CPU.)

If there is a data CRC (Cyclic Redundancy Check) error, the payload is, none the less, written in the endpoint. The ERR_CRISO flag is set in UDPHS_EPTSTAx register.

If the endpoint is already full, the packet is not written in the DPRAM. The ERR_FL_ISO flag is set in UDPHS_EPTSTAx.

If the payload data is greater than the maximum size of the endpoint, then the ERR_OVFLW flag is set. It is the task of the CPU to manage this error. The data packet is written in the endpoint (except the extra data).

If the host sends a Zero Length Packet, and the endpoint is free, no data is written in the endpoint, the RX_BK_RDY flag is set, and the BYTE_COUNT field in UDPHS_EPTSTAx register is null.

The FRCESTALL command bit is unused for an isochonous endpoint.

Otherwise, payload data is written in the endpoint, the RX_BK_RDY interrupt is generated and the BYTE_COUNT in UDPHS_EPTSTAx register is updated.

38.6.9.15STALL

STALL is returned by a function in response to an IN token or after the data phase of an OUT or in response to a PING transaction. STALL indicates that a function is unable to transmit or receive data, or that a control pipe request is not supported.

- OUT

To stall an endpoint, set the FRCESTALL bit in UDPHS_EPTSETSTAx register and after the STALL_SNT flag has been set, set the TOGGLE_SEG bit in the UDPHS_EPTCLRSTAx register.

- IN

Set the FRCESTALL bit in UDPHS_EPTSETSTAx register.

Figure 38-16. Stall Handshake Data OUT Transfer

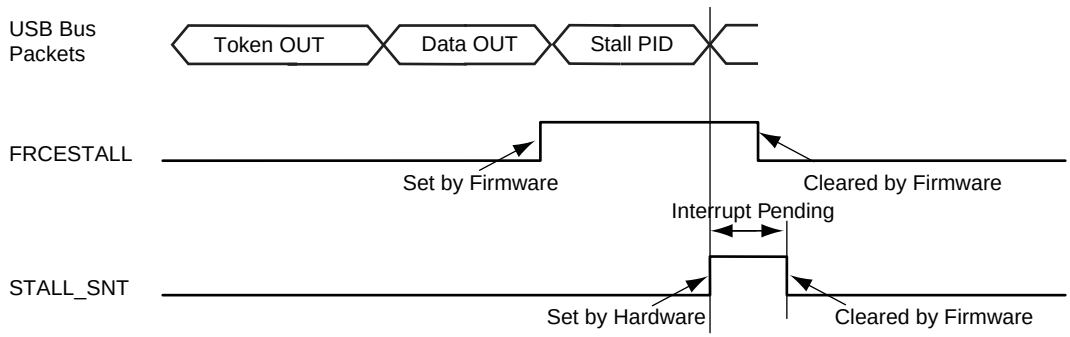
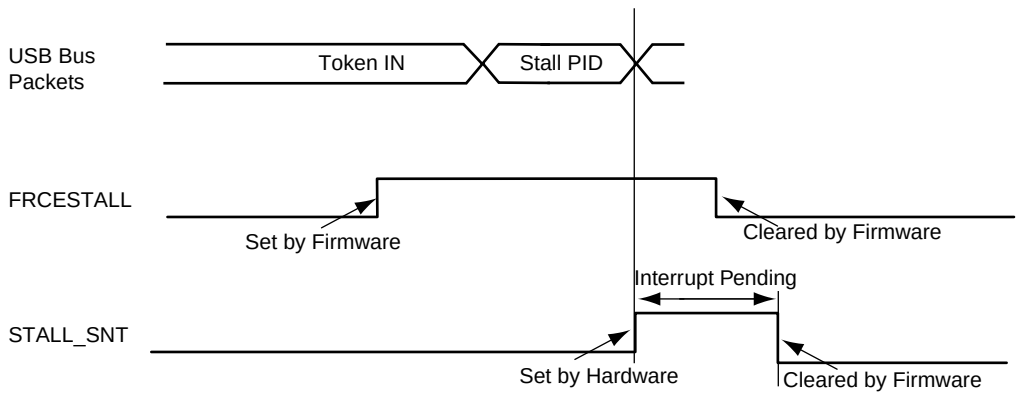


Figure 38-17. Stall Handshake Data IN Transfer



38.6.10 Speed Identification

The high speed reset is managed by the hardware.

At the connection, the host makes a reset which could be a classic reset (full speed) or a high speed reset.

At the end of the reset process (full or high), the ENDRESET interrupt is generated.

Then the CPU should read the SPEED bit in UDPHS_INTSTAx to ascertain the speed mode of the device.

38.6.11 USB V2.0 High Speed Global Interrupt

Interrupts are defined in Section 38.7.3 "UDPHS Interrupt Enable Register" (UDPHS_IEN) and in Section 38.7.4 "UDPHS Interrupt Status Register" (UDPHS_INTSTA).

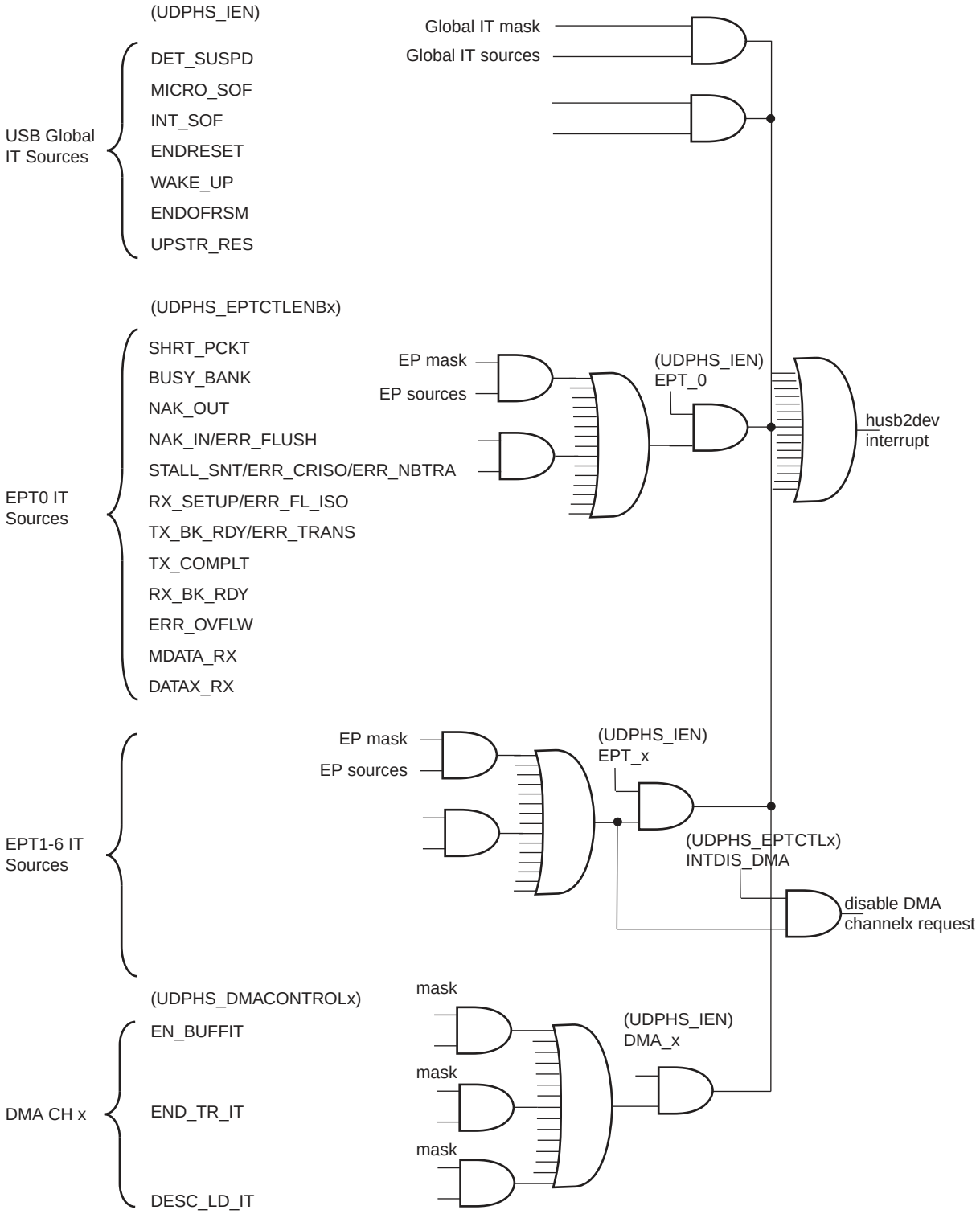
38.6.12 Endpoint Interrupts

Interrupts are enabled in UDPHS_IEN (see Section 38.7.3 "UDPHS Interrupt Enable Register") and individually masked in UDPHS_EPTCTLENBx (see Section 38.7.12 "UDPHS Endpoint Control Enable Register").

Table 38-5. Endpoint Interrupt Source Masks

SHRT_PCKT	Short Packet Interrupt
BUSY_BANK	Busy Bank Interrupt
NAK_OUT	NAKOUT Interrupt
NAK_IN/ERR_FLUSH	NAKIN/Error Flush Interrupt
STALL_SNT/ERR_CRISO/ERR_NB_TRA	Stall Sent/CRC error/Number of Transaction Error Interrupt
RX_SETUP/ERR_FL_ISO	Received SETUP/Error Flow Interrupt
TX_PK_RD /ERR_TRANS	TX Packet Read/Transaction Error Interrupt
TX_COMPLT	Transmitted IN Data Complete Interrupt
RX_BK_RDY	Received OUT Data Interrupt
ERR_OVFLW	Overflow Error Interrupt
MDATA_RX	MDATA Interrupt
DATAX_RX	DATAx Interrupt

Figure 38-18. UDPHS Interrupt Control Interface

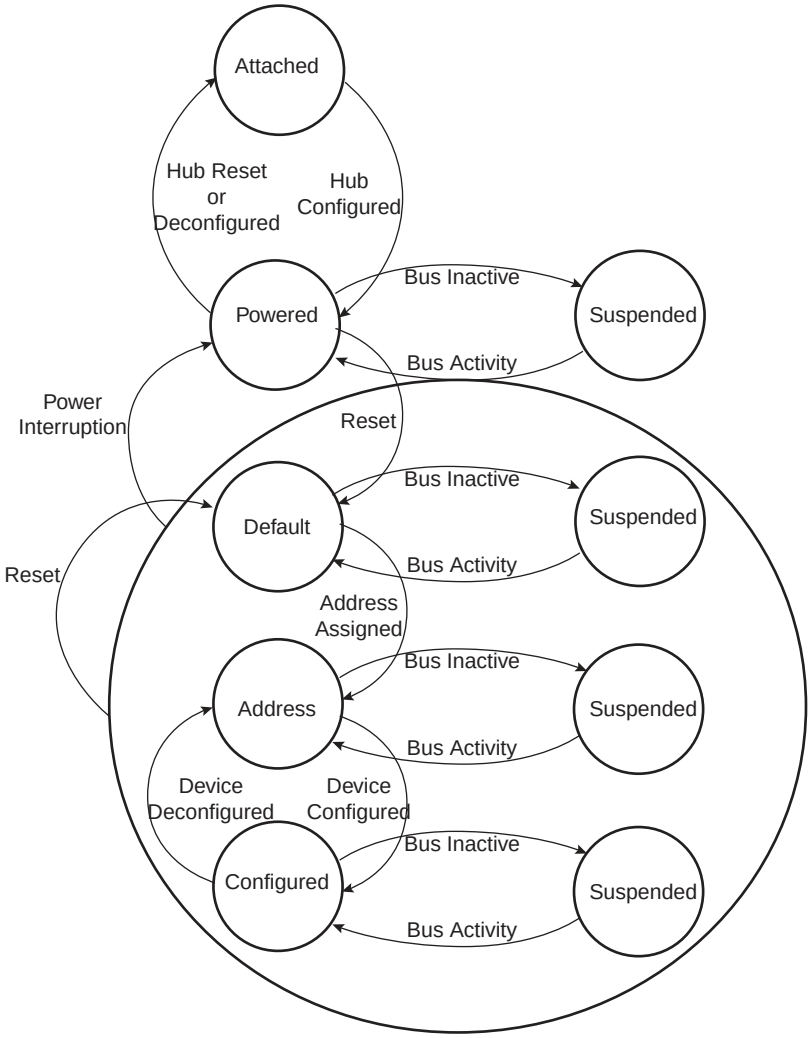


38.6.13 Power Modes

38.6.13.1Controlling Device States

A USB device has several possible states. Refer to Chapter 9 (USB Device Framework) of the Universal Serial Bus Specification, Rev 2.0.

Figure 38-19. UDPHS Device State Diagram



Movement from one state to another depends on the USB bus state or on standard requests sent through control transactions via the default endpoint (endpoint 0).

After a period of bus inactivity, the USB device enters Suspend Mode. Accepting Suspend/Resume requests from the USB host is mandatory. Constraints in Suspend Mode are very strict for bus-powered applications; devices may not consume more than 500 µA on the USB bus.

While in Suspend Mode, the host may wake up a device by sending a resume signal (bus activity) or a USB device may send a wake-up request to the host, e.g., waking up a PC by moving a USB mouse.

The wake-up feature is not mandatory for all devices and must be negotiated with the host.

38.6.13.2Not Powered State

Self powered devices can detect 5V VBUS using a PIO. When the device is not connected to a host, device power consumption can be reduced by the DETACH bit in UDPHS_CTRL. Disabling the transceiver is automatically done. HSDM, HSDP, FSDP and FSDP lines are tied to GND pull-downs integrated in the hub downstream ports.

38.6.13.3Entering Attached State

When no device is connected, the USB FSDP and FSDM signals are tied to GND by 15 KΩ pull-downs integrated in the hub downstream ports. When a device is attached to an hub downstream port, the device connects a 1.5 KΩ pull-up on FSDP. The USB bus line goes into IDLE state, FSDP is pulled-up by the device 1.5 KΩ resistor to 3.3V and FSDM is pulled-down by the 15 KΩ resistor to GND of the host.

After pull-up connection, the device enters the powered state. The transceiver remains disabled until bus activity is detected.

In case of low power consumption need, the device can be stopped. When the device detects the VBUS, the software must enable the USB transceiver by enabling the EN_UDPHS bit in UDPHS_CTRL register.

The software can detach the pull-up by setting DETACH bit in UDPHS_CTRL register.

38.6.13.4From Powered State to Default State (Reset)

After its connection to a USB host, the USB device waits for an end-of-bus reset. The unmasked flag ENDRESET is set in the UDPHS_IEN register and an interrupt is triggered.

Once the ENDRESET interrupt has been triggered, the device enters Default State. In this state, the UDPHS software must:

- Enable the default endpoint, setting the EPT_ENABL flag in the UDPHS_EPTCTLENB[0] register and, optionally, enabling the interrupt for endpoint 0 by writing 1 in EPT_0 of the UDPHS_IEN register. The enumeration then begins by a control transfer.
- Configure the Interrupt Mask Register which has been reset by the USB reset detection
- Enable the transceiver.

In this state, the EN_UDPHS bit in UDPHS_CTRL register must be enabled.

38.6.13.5From Default State to Address State (Address Assigned)

After a Set Address standard device request, the USB host peripheral enters the address state.

Warning: before the device enters address state, it must achieve the Status IN transaction of the control transfer, i.e., the UDPHS device sets its new address once the TX_COMPLT flag in the UDPHS_EPTCTL[0] register has been received and cleared.

To move to address state, the driver software sets the DEV_ADDR field and the FADDR_EN flag in the UDPHS_CTRL register.

38.6.13.6From Address State to Configured State (Device Configured)

Once a valid Set Configuration standard request has been received and acknowledged, the device enables endpoints corresponding to the current configuration. This is done by setting the BK_NUMBER, EPT_TYPE, EPT_DIR and EPT_SIZE fields in the UDPHS_EPTCFGx registers and enabling them by setting the EPT_ENABL flag in the UDPHS_EPTCTLENBx registers, and, optionally, enabling corresponding interrupts in the UDPHS_IEN register.

38.6.13.7Entering Suspend State (Bus Activity)

When a Suspend (no bus activity on the USB bus) is detected, the DET_SUSPD signal in the UDPHS_STA register is set. This triggers an interrupt if the corresponding bit is set in the UDPHS_IEN register. This flag is cleared by writing to the UDPHS_CLRINT register. Then the device enters Suspend Mode.

In this state bus powered devices must drain less than 500 µA from the 5V VBUS. As an example, the microcontroller switches to slow clock, disables the PLL and main oscillator, and goes into Idle Mode. It may also switch off other devices on the board.

The UDPHS device peripheral clocks can be switched off. Resume event is asynchronously detected.

38.6.13.8 Receiving a Host Resume

In Suspend mode, a resume event on the USB bus line is detected asynchronously, transceiver and clocks disabled (however the pull-up should not be removed).

Once the resume is detected on the bus, the signal WAKE_UP in the UDPHS_INTSTA is set. It may generate an interrupt if the corresponding bit in the UDPHS_IEN register is set. This interrupt may be used to wake-up the core, enable PLL and main oscillators and configure clocks.

38.6.13.9 Sending an External Resume

In Suspend State it is possible to wake-up the host by sending an external resume.

The device waits at least 5 ms after being entered in Suspend State before sending an external resume.

The device must force a K state from 1 to 15 ms to resume the host.

38.6.14 Test Mode

A device must support the TEST_MODE feature when in the Default, Address or Configured High Speed device states.

TEST_MODE can be:

- Test_J
- Test_K
- Test_Packet
- Test_SEO_NAK

(See Section 38.7.7 “UDPHS Test Register” on page 975 for definitions of each test mode.)

```
const char test_packet_buffer[] = {
  0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,                 // JKJKJKJK * 9
  0xAA,0xAA,0xAA,0xAA,0xAA,0xAA,0xAA,0xAA,                      // JJKKJJKK * 8
  0xEE,0xEE,0xEE,0xEE,0xEE,0xEE,0xEE,0xEE,                      // JJKKJJKK * 8
  0xFE,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF, //
JJJJJJJKKKKKKK * 8
  0x7F,0xBF,0xDF,0xEF,0xF7,0xFB,0xFD,                           // JJJJJJJK * 8
  0xFC,0x7E,0xBF,0xDF,0xEF,0xF7,0xFB,0xFD,0x7E                  // {JKKKKKKK *
10}, JK
};
```

38.7 USB High Speed Device Port (UDPHS) User Interface

Table 38-6. Register Mapping

Offset	Register	Name	Access	Reset
0x00	UDPHS Control Register	UDPHS_CTRL	Read-write	0x0000_0200
0x04	UDPHS Frame Number Register	UDPHS_FNUM	Read-only	0x0000_0000
0x08 - 0x0C	Reserved	–	–	–
0x10	UDPHS Interrupt Enable Register	UDPHS_IEN	Read-write	0x0000_0010
0x14	UDPHS Interrupt Status Register	UDPHS_INTSTA	Read-only	0x0000_0000
0x18	UDPHS Clear Interrupt Register	UDPHS_CLRINT	Write-only	–
0x1C	UDPHS Endpoints Reset Register	UDPHS_EPTRST	Write-only	–
0x20 - 0xCC	Reserved	–	–	–
0xE0	UDPHS Test Register	UDPHS_TST	Read-write	0x0000_0000
0xE4 - 0xE8	Reserved	–	–	–
0xF0	UDPHS Name1 Register	UDPHS_IPNAME1	Read-only	0x4855_5342
0xF4	UDPHS Name2 Register	UDPHS_IPNAME2	Read-only	0x3244_4556
0xF8	UDPHS Features Register	UDPHS_IPFEATURES	Read-only	
0x100 + endpoint * 0x20 + 0x00	UDPHS Endpoint Configuration Register	UDPHS_EPTCFG	Read-write	0x0000_0000
0x100 + endpoint * 0x20 + 0x04	UDPHS Endpoint Control Enable Register	UDPHS_EPTCTLENB	Write-only	–
0x100 + endpoint * 0x20 + 0x08	UDPHS Endpoint Control Disable Register	UDPHS_EPTCTLDIS	Write-only	–
0x100 + endpoint * 0x20 + 0x0C	UDPHS Endpoint Control Register	UDPHS_EPTCTL	Read-only	0x0000_0000(1)
0x100 + endpoint * 0x20 + 0x10	Reserved (for endpoint)	–	–	–
0x100 + endpoint * 0x20 + 0x14	UDPHS Endpoint Set Status Register	UDPHS_EPTSETSTA	Write-only	–
0x100 + endpoint * 0x20 + 0x18	UDPHS Endpoint Clear Status Register	UDPHS_EPTCLRSTA	Write-only	–
0x100 + endpoint * 0x20 + 0x1C	UDPHS Endpoint Status Register	UDPHS_EPTSTA	Read-only	0x0000_0040
0x120 - 0x1DC	UDPHS Endpoint1 to 6 (2) Registers			
0x300 + channel * 0x10 + 0x00	UDPHS DMA Next Descriptor Address Register	UDPHS_DMANXTDSC	Read-write	0x0000_0000
0x300 + channel * 0x10 + 0x04	UDPHS DMA Channel Address Register	UDPHS_DMAADDRESS	Read-write	0x0000_0000
0x300 + channel * 0x10 + 0x08	UDPHS DMA Channel Control Register	UDPHS_DMACONTROL	Read-write	0x0000_0000
0x300 + channel * 0x10 + 0x0C	UDPHS DMA Channel Status Register	UDPHS_DMASTATUS	Read-write	0x0000_0000
0x310 - 0x370	DMA Channel1 to 5 (3) Registers			

Notes:
1. The reset value for UDPHS_EPTCTL0 is 0x0000_0001.
2. The addresses for the UDPHS Endpoint registers shown here are for UDPHS Endpoint0. The structure of this group of registers is repeated successively for each endpoint according to the consecution of endpoint registers located between 0x120 and 0x1DC.
3. The DMA channel index refers to the corresponding EP number. When no DMA channel is assigned to one EP, the associated registers are reserved. This is the case for EP0, so DMA Channel 0 registers are reserved.

38.7.1 UDPHS Control Register

Name: UDPHS_CTRL

Address: 0x400A4000

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	PULLD_DIS	REWAKEUP	DETACH	EN_UDPHS
7	6	5	4	3	2	1	0
FADDR_EN	DEV_ADDR						

- **DEV_ADDR: UDPHS Address**

This field contains the default address (0) after power-up or UDPHS bus reset (read), or it is written with the value set by a SET_ADDRESS request received by the device firmware (write).

- **FADDR_EN: Function Address Enable**

0 = Device is not in address state (read), or only the default function address is used (write).

1 = Device is in address state (read), or this bit is set by the device firmware after a successful status phase of a SET_ADDRESS transaction (write). When set, the only address accepted by the UDPHS controller is the one stored in the UDPHS Address field. It will not be cleared afterwards by the device firmware. It is cleared by hardware on hardware reset, or when UDPHS bus reset is received.

- **EN_UDPHS: UDPHS Enable**

0 = UDPHS is disabled (read), or this bit disables and resets the UDPHS controller (write). Disable the UTMI transceiver. The UTMI may disable the pull-up.

1 = UDPHS is enabled (read), or this bit enables the UDPHS controller (write).

- **DETACH: Detach Command**

0 = UDPHS is attached (read), or this bit pulls up the DP line (attach command) (write).

1 = UDPHS is detached, UTMI transceiver is suspended (read), or this bit simulates a detach on the UDPHS line and forces the UTMI transceiver into suspend state (Suspend M = 0) (write).

See PULLD_DIS description below.

- **REWAKEUP: Send Remote Wake Up**

0 = Remote Wake Up is disabled (read), or this bit has no effect (write).

1 = Remote Wake Up is enabled (read), or this bit forces an external interrupt on the UDPHS controller for Remote Wake UP purposes.

An Upstream Resume is sent only after the UDPHS bus has been in SUSPEND state for at least 5 ms.

This bit is automatically cleared by hardware at the end of the Upstream Resume.

- **PULLD_DIS: Pull-Down Disable**

When set, there is no pull-down on DP & DM. (DM Pull-Down = DP Pull-Down = 0).

Note: If the DETACH bit is also set, device DP & DM are left in high impedance state.

(See DETACH description above.)

DETACH	PULLD_DIS	DP	DM	Condition
0	0	Pull up	Pull down	not recommended
0	1	Pull up	High impedance state	VBUS present
1	0	Pull down	Pull down	No VBUS
1	1	High impedance state	High impedance state	VBUS present & software disconnect

38.7.2 UDPHS Frame Number Register

Name: UDPHS_FNUM

Address: 0x400A4004

Access: Read-only

31	30	29	28	27	26	25	24
FNUM_ERR	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	FRAME_NUMBER					

7	6	5	4	3	2	1	0
FRAME_NUMBER					MICRO_FRAME_NUM		

- **MICRO_FRAME_NUM: Microframe Number**

Number of the received microframe (0 to 7) in one frame.This field is reset at the beginning of each new frame (1 ms).

One microframe is received each 125 microseconds (1 ms/8).

- **FRAME_NUMBER: Frame Number as defined in the Packet Field Formats**

This field is provided in the last received SOF packet (see INT_SOF in the UDPHS Interrupt Status Register).

- **FNUM_ERR: Frame Number CRC Error**

This bit is set by hardware when a corrupted Frame Number in Start of Frame packet (or Micro SOF) is received.

This bit and the INT_SOF (or MICRO_SOF) interrupt are updated at the same time.

38.7.3 UDPHS Interrupt Enable Register

Name: UDPHS_IEN

Address: 0x400A4010

Access: Read-write

31	30	29	28	27	26	25	24
–	DMA_6	DMA_5	DMA_4	DMA_3	DMA_2	DMA_1	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	EPT_6	EPT_5	EPT_4	EPT_3	EPT_2	EPT_1	EPT_0
7	6	5	4	3	2	1	0
UPSTR_RES	ENDOFRSM	WAKE_UP	ENDRESET	INT_SOF	MICRO_SOF	DET_SUSPD	–

- **DET_SUSPD: Suspend Interrupt Enable**

0 = disable Suspend Interrupt.

1 = enable Suspend Interrupt.

- **MICRO_SOF: Micro-SOF Interrupt Enable**

0 = disable Micro-SOF Interrupt.

1 = enable Micro-SOF Interrupt.

- **INT_SOF: SOF Interrupt Enable**

0 = disable SOF Interrupt.

1 = enable SOF Interrupt.

- **ENDRESET: End Of Reset Interrupt Enable**

0 = disable End Of Reset Interrupt.

1 = enable End Of Reset Interrupt. Automatically enabled after USB reset.

- **WAKE_UP: Wake Up CPU Interrupt Enable**

0 = disable Wake Up CPU Interrupt.

1 = enable Wake Up CPU Interrupt.

- **ENDOFRSM: End Of Resume Interrupt Enable**

0 = disable Resume Interrupt.

1 = enable Resume Interrupt.

- **UPSTR_RES: Upstream Resume Interrupt Enable**

0 = disable Upstream Resume Interrupt.

1 = enable Upstream Resume Interrupt.

- **EPT_x: Endpoint x Interrupt Enable**

0 = disable the interrupts for this endpoint.

1 = enable the interrupts for this endpoint.

- **DMA_x: DMA Channel x Interrupt Enable**

0 = disable the interrupts for this channel.

1 = enable the interrupts for this channel.

38.7.4 UDPHS Interrupt Status Register

Name: UDPHS_INTSTA

Address: 0x400A4014

Access: Read-only

31	30	29	28	27	26	25	24
–	DMA_6	DMA_5	DMA_4	DMA_3	DMA_2	DMA_1	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	EPT_6	EPT_5	EPT_4	EPT_3	EPT_2	EPT_1	EPT_0
7	6	5	4	3	2	1	0
UPSTR_RES	ENDOFRSM	WAKE_UP	ENDRESET	INT_SOF	MICRO_SOF	DET_SUSPD	SPEED

- **SPEED: Speed Status**

0 = reset by hardware when the hardware is in Full Speed mode.

1 = set by hardware when the hardware is in High Speed mode

- **DET_SUSPD: Suspend Interrupt**

0 = cleared by setting the DET_SUSPD bit in UDPHS_CLRINT register

1 = set by hardware when a UDPHS Suspend (Idle bus for three frame periods, a J state for 3 ms) is detected. This triggers a UDPHS interrupt when the DET_SUSPD bit is set in UDPHS_IEN register.

- **MICRO_SOF: Micro Start Of Frame Interrupt**

0 = cleared by setting the MICRO_SOF bit in UDPHS_CLRINT register.

1 = set by hardware when an UDPHS micro start of frame PID (SOF) has been detected (every 125 us) or synthesized by the macro. This triggers a UDPHS interrupt when the MICRO_SOF bit is set in UDPHS_IEN. In case of detected SOF, the MICRO_FRAME_NUM field in UDPHS_FNUM register is incremented and the FRAME_NUMBER field doesn't change.

Note: The Micro Start Of Frame Interrupt (MICRO_SOF), and the Start Of Frame Interrupt (INT_SOF) are not generated at the same time.

- **INT_SOF: Start Of Frame Interrupt**

0 = cleared by setting the INT_SOF bit in UDPHS_CLRINT.

1 = set by hardware when an UDPHS Start Of Frame PID (SOF) has been detected (every 1 ms) or synthesized by the macro. This triggers a UDPHS interrupt when the INT_SOF bit is set in UDPHS_IEN register. In case of detected SOF, in High Speed mode, the MICRO_FRAME_NUMBER field is cleared in UDPHS_FNUM register and the FRAME_NUMBER field is updated.

- **ENDRESET: End Of Reset Interrupt**

0 = cleared by setting the ENDRESET bit in UDPHS_CLRINT.

1 = set by hardware when an End Of Reset has been detected by the UDPHS controller. This triggers a UDPHS interrupt when the ENDRESET bit is set in UDPHS_IEN.

- **WAKE_UP: Wake Up CPU Interrupt**

0 = cleared by setting the WAKE_UP bit in UDPHS_CLRINT.

1 = set by hardware when the UDPHS controller is in SUSPEND state and is re-activated by a filtered non-idle signal from the UDPHS line (not by an upstream resume). This triggers a UDPHS interrupt when the WAKE_UP bit is set in UDPHS_IEN register. When receiving this interrupt, the user has to enable the device controller clock prior to operation.

Note: this interrupt is generated even if the device controller clock is disabled.

- **ENDOFRSM: End Of Resume Interrupt**

0 = cleared by setting the ENDOFRSM bit in UDPHS_CLRINT.

1 = set by hardware when the UDPHS controller detects a good end of resume signal initiated by the host. This triggers a UDPHS interrupt when the ENDOFRSM bit is set in UDPHS_IEN.

- **UPSTR_RES: Upstream Resume Interrupt**

0 = cleared by setting the UPSTR_RES bit in UDPHS_CLRINT.

1 = set by hardware when the UDPHS controller is sending a resume signal called “upstream resume”. This triggers a UDPHS interrupt when the UPSTR_RES bit is set in UDPHS_IEN.

- **EPT_x: Endpoint x Interrupt**

0 = reset when the UDPHS_EPTSTAx interrupt source is cleared.

1 = set by hardware when an interrupt is triggered by the UDPHS_EPTSTAx register and this endpoint interrupt is enabled by the EPT_x bit in UDPHS_IEN.

- **DMA_x: DMA Channel x Interrupt**

0 = reset when the UDPHS_DMASTATUSx interrupt source is cleared.

1 = set by hardware when an interrupt is triggered by the DMA Channelx and this endpoint interrupt is enabled by the DMA_x bit in UDPHS_IEN.

38.7.5 UDPHS Clear Interrupt Register

Name: UDPHS_CLRINT

Address: 0x400A4018

Access: Write only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
UPSTR_RES	ENDOFRSM	WAKE_UP	ENDRESET	INT_SOF	MICRO_SOF	DET_SUSPD	–

- **DET_SUSPD: Suspend Interrupt Clear**

0 = no effect.

1 = clear the DET_SUSPD bit in UDPHS_INTSTA.

- **MICRO_SOF: Micro Start Of Frame Interrupt Clear**

0 = no effect.

1 = clear the MICRO_SOF bit in UDPHS_INTSTA.

- **INT_SOF: Start Of Frame Interrupt Clear**

0 = no effect.

1 = clear the INT_SOF bit in UDPHS_INTSTA.

- **ENDRESET: End Of Reset Interrupt Clear**

0 = no effect.

1 = clear the ENDRESET bit in UDPHS_INTSTA.

- **WAKE_UP: Wake Up CPU Interrupt Clear**

0 = no effect.

1 = clear the WAKE_UP bit in UDPHS_INTSTA.

- **ENDOFRSM: End Of Resume Interrupt Clear**

0 = no effect.

1 = clear the ENDOFRSM bit in UDPHS_INTSTA.

- **UPSTR_RES: Upstream Resume Interrupt Clear**

0 = no effect.

1 = clear the UPSTR_RES bit in UDPHS_INTSTA.

38.7.6 UDPHS Endpoints Reset Register

Name: UDPHS_EPTRST

Address: 0x400A401C

Access: Write only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	EPT_6	EPT_5	EPT_4	EPT_3	EPT_2	EPT_1	EPT_0

- **EPT_x: Endpoint x Reset**

0 = no effect.

1 = reset the Endpointx state.

Setting this bit clears the Endpoint status UDPHS_EPTSTAx register, except for the TOGGLESQ_STA field.

38.7.7 UDPHS Test Register

Name: UDPHS_TST

Address: 0x400A40E0

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	OPMODE2	TST_PKT	TST_K	TST_J	SPEED_CFG	

- **SPEED_CFG: Speed Configuration**

Speed Configuration:

Value	Name	Description2
0	NORMAL	Normal Mode: The macro is in Full Speed mode, ready to make a High Speed identification, if the host supports it and then to automatically switch to High Speed mode
1		Reserved
2	HIGH_SPEED	Force High Speed: Set this value to force the hardware to work in High Speed mode. Only for debug or test purpose.
3	FULL_SPEED	Force Full Speed: Set this value to force the hardware to work only in Full Speed mode. In this configuration, the macro will not respond to a High Speed reset handshake.

- **TST_J: Test J Mode**

0 = no effect.

1 = set to send the J state on the UDPHS line. This enables the testing of the high output drive level on the D+ line.

- **TST_K: Test K Mode**

0 = no effect.

1 = set to send the K state on the UDPHS line. This enables the testing of the high output drive level on the D- line.

- **TST_PKT: Test Packet Mode**

0 = no effect.

1 = set to repetitively transmit the packet stored in the current bank. This enables the testing of rise and fall times, eye patterns, jitter, and any other dynamic waveform specifications.

- **OPMODE2: OpMode2**

0 = no effect.

1 = set to force the OpMode signal (UTMI interface) to “10”, to disable the bit-stuffing and the NRZI encoding.

Note: For the Test mode, Test_SE0_NAK (see Universal Serial Bus Specification, Revision 2.0: 7.1.20, Test Mode Support). Force the device in High Speed mode, and configure a bulk-type endpoint. Do not fill this endpoint for sending NAK to the host. Upon command, a port’s transceiver must enter the High Speed receive mode and remain in that mode until the exit action is taken. This enables the testing of output impedance, low level output voltage and loading characteristics. In addition, while in this mode, upstream facing ports (and only upstream facing ports) must respond to any IN token packet with a NAK handshake (only if the packet CRC is determined to be correct) within the normal allowed device response time. This enables testing of the device squelch level circuitry and, additionally, provides a general purpose stimulus/response test for basic functional testing.

38.7.8 UDPHS Name1 Register

Name: UDPHS_IPNAME1

Address: 0x400A40F0

Access: Read-only

31	30	29	28	27	26	25	24
IP_NAME1							

23	22	21	20	19	18	17	16
IP_NAME1							

15	14	13	12	11	10	9	8
IP_NAME1							

7	6	5	4	3	2	1	0
IP_NAME1							

- **IP_NAME1**

ASCII string “HUSB”

38.7.9 UDPHS Name2 Register

Name: UDPHS_IPNAME2

Address: 0x400A40F4

Access: Read-only

31	30	29	28	27	26	25	24
IP_NAME2							

23	22	21	20	19	18	17	16
IP_NAME2							

15	14	13	12	11	10	9	8
IP_NAME2							

7	6	5	4	3	2	1	0
IP_NAME2							

- **IP_NAME2**

ASCII string “2DEV”

38.7.10 UDPHS Features Register

Name: UDPHS_IPFEATURES

Address: 0x400A40F8

Access: Read-only

31	30	29	28	27	26	25	24
ISO_EPT_15	ISO_EPT_14	ISO_EPT_13	ISO_EPT_12	ISO_EPT_11	ISO_EPT_10	ISO_EPT_9	ISO_EPT_8
23	22	21	20	19	18	17	16
ISO_EPT_7	ISO_EPT_6	ISO_EPT_5	ISO_EPT_4	ISO_EPT_3	ISO_EPT_2	ISO_EPT_1	DATAB16_8
15	14	13	12	11	10	9	8
BW_DPRAM	FIFO_MAX_SIZE			DMA_FIFO_WORD_DEPTH			
7	6	5	4	3	2	1	0
DMA_B_SIZ	DMA_CHANNEL_NBR			EPT_NBR_MAX			

- **EPT_NBR_MAX: Max Number of Endpoints**

Give the max number of endpoints.

0 = if 16 endpoints are hardware implemented.

1 = if 1 endpoint is hardware implemented.

2 = if 2 endpoints are hardware implemented.

...

15 = if 15 endpoints are hardware implemented.

- **DMA_CHANNEL_NBR: Number of DMA Channels**

Give the number of DMA channels.

1 = if 1 DMA channel is hardware implemented.

2 = if 2 DMA channels are hardware implemented.

...

7 = if 7 DMA channels are hardware implemented.

- **DMA_B_SIZ: DMA Buffer Size**

0 = if the DMA Buffer size is 16 bits.

1 = if the DMA Buffer size is 24 bits.

- **DMA_FIFO_WORD_DEPTH: DMA FIFO Depth in Words**

0 = if FIFO is 16 words deep.

1 = if FIFO is 1 word deep.

2 = if FIFO is 2 words deep.

...

15 = if FIFO is 15 words deep.

- **FIFO_MAX_SIZE: DPRAM Size**

0 = if DPRAM is 128 bytes deep.

1 = if DPRAM is 256 bytes deep.

2 = if DPRAM is 512 bytes deep.

3 = if DPRAM is 1024 bytes deep.

4 = if DPRAM is 2048 bytes deep.

5 = if DPRAM is 4096 bytes deep.

6 = if DPRAM is 8192 bytes deep.

7 = if DPRAM is 16384 bytes deep.

- **BW_DPRAM: DPRAM Byte Write Capability**

0 = if DPRAM Write Data Shadow logic is implemented.

1 = if DPRAM is byte write capable.

- **DATAB16_8: UTMI DataBus16_8**

0 = if the UTMI uses an 8-bit parallel data interface (60 MHz, unidirectional).

1 = if the UTMI uses a 16-bit parallel data interface (30 MHz, bidirectional).

- **ISO_EPT_x: Endpointx High Bandwidth Isochronous Capability**

0 = if the endpoint does not have isochronous High Bandwidth Capability.

1 = if the endpoint has isochronous High Bandwidth Capability.

38.7.11 UDPHS Endpoint Configuration Register

Name: UDPHS_EPTCFGx [x=0..6]

Address: 0x400A4100 [0], 0x400A4120 [1], 0x400A4140 [2], 0x400A4160 [3], 0x400A4180 [4], 0x400A41A0 [5], 0x400A41C0 [6]

Access: Read-write

31	30	29	28	27	26	25	24
EPT_MAPD	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	NB_TRANS	
7	6	5	4	3	2	1	0
BK_NUMBER		EPT_TYPE		EPT_DIR	EPT_SIZE		

- **EPT_SIZE: Endpoint Size**

Set this field according to the endpoint size in bytes (see Section 38.6.5 ”Endpoint Configuration”).

Endpoint Size (1)

Value	Name	Description
0	8	8 bytes
1	16	16 bytes
2	32	32 bytes
3	64	64 bytes
4	128	128 bytes
5	256	256 bytes
6	512	512 bytes
7	1024	1024 bytes

Note: 1. 1024 bytes is only for isochronous endpoint.

- **EPT_DIR: Endpoint Direction**

0 = Clear this bit to configure OUT direction for Bulk, Interrupt and Isochronous endpoints.

1 = set this bit to configure IN direction for Bulk, Interrupt and Isochronous endpoints.

For Control endpoints this bit has no effect and should be left at zero.

- **EPT_TYPE: Endpoint Type**

Set this field according to the endpoint type (see Section 38.6.5 ”Endpoint Configuration”).

(Endpoint 0 should always be configured as control)

Endpoint Type

Value	Name	Description
0	CTRL8	Control endpoint
1	ISO	Isochronous endpoint
2	BULK	Bulk endpoint
3	INT	Interrupt endpoint

- **BK_NUMBER: Number of Banks**

Set this field according to the endpoint’s number of banks (see Section 38.6.5 ”Endpoint Configuration”).

Number of Banks

Value	Name	Description
0	0	Zero bank, the endpoint is not mapped in memory
1	1	One bank (bank 0)
2	2	Double bank (Ping-Pong: bank0/bank1)
3	3	Triple bank (bank0/bank1/bank2)

- **NB_TRANS: Number Of Transaction per Microframe**

The Number of transactions per microframe is set by software.

Note: Meaningful for high bandwidth isochronous endpoint only.

- **EPT_MAPD: Endpoint Mapped**

0 = the user should reprogram the register with correct values.

1 = set by hardware when the endpoint size (EPT_SIZE) and the number of banks (BK_NUMBER) are correct regarding:

– the fifo max capacity (FIFO_MAX_SIZE in UDPHS_IPFEATURES register)

– the number of endpoints/banks already allocated

– the number of allowed banks for this endpoint

38.7.12 UDPHS Endpoint Control Enable Register

Name: UDPHS_EPTCTLENBx [x=0..6]

Address: 0x400A4104 [0], 0x400A4124 [1], 0x400A4144 [2], 0x400A4164 [3], 0x400A4184 [4], 0x400A41A4 [5], 0x400A41C4 [6]

Access: Write-only

31	30	29	28	27	26	25	24
SHRT_PCKT	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	BUSY_BANK	–	–

15	14	13	12	11	10	9	8
NAK_OUT	NAK_IN/ ERR_FLUSH	STALL_SNT/ ERR_CRISO/ ERR_NBTRA	RX_SETUP/ ERR_FL_ISO	TX_PK_RDY/ ERR_TRANS	TX_COMPLT	RX_BK_RDY	ERR_OVFLW

7	6	5	4	3	2	1	0
MDATA_RX	DATAX_RX	–	NYET_DIS	INTDIS_DMA	–	AUTO_VALID	EPT_ENABL

For additional Information, see “UDPHS Endpoint Control Register” on page 987.

- **EPT_ENABL: Endpoint Enable**

0 = no effect.

1 = enable endpoint according to the device configuration.

- **AUTO_VALID: Packet Auto-Valid Enable**

0 = no effect.

1 = enable this bit to automatically validate the current packet and switch to the next bank for both IN and OUT transfers.

- **INTDIS_DMA: Interrupts Disable DMA**

0 = no effect.

1 = If set, when an enabled endpoint-originated interrupt is triggered, the DMA request is disabled.

- **NYET_DIS: NYET Disable (Only for High Speed Bulk OUT endpoints)**

0 = no effect.

1 = forces an ACK response to the next High Speed Bulk OUT transfer instead of a NYET response.

- **DATAX_RX: DATAx Interrupt Enable (Only for high bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = enable DATAx Interrupt.

- **MDATA_RX: MDATA Interrupt Enable (Only for high bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = enable MDATA Interrupt.

- **ERR_OVFLW: Overflow Error Interrupt Enable**

0 = no effect.

1 = enable Overflow Error Interrupt.

- **RX_BK_RDY: Received OUT Data Interrupt Enable**

0 = no effect.

1 = enable Received OUT Data Interrupt.

- **TX_COMPLT: Transmitted IN Data Complete Interrupt Enable**

0 = no effect.

1 = enable Transmitted IN Data Complete Interrupt.

- **TX_PK_RDY/ERR_TRANS: TX Packet Ready/Transaction Error Interrupt Enable**

0 = no effect.

1 = enable TX Packet Ready/Transaction Error Interrupt.

- **RX_SETUP/ERR_FL_ISO: Received SETUP/Error Flow Interrupt Enable**

0 = no effect.

1 = enable RX_SETUP/Error Flow ISO Interrupt.

- **STALL_SNT/ERR_CRISO/ERR_NBTRA: Stall Sent /ISO CRC Error/Number of Transaction Error Interrupt Enable**

0 = no effect.

1 = enable Stall Sent/Error CRC ISO/Error Number of Transaction Interrupt.

- **NAK_IN/ERR_FLUSH: NAKIN/Bank Flush Error Interrupt Enable**

0 = no effect.

1 = enable NAKIN/Bank Flush Error Interrupt.

- **NAK_OUT: NAKOUT Interrupt Enable**

0 = no effect.

1 = enable NAKOUT Interrupt.

- **BUSY_BANK: Busy Bank Interrupt Enable**

0 = no effect.

1 = enable Busy Bank Interrupt.

- **SHRT_PCKT: Short Packet Send/Short Packet Interrupt Enable**

For OUT endpoints:

0 = no effect.

1 = enable Short Packet Interrupt.

For IN endpoints:

Guarantees short packet at end of DMA Transfer if the UDPHS_DMACONTROLx register END_B_EN and UDPHS_EPTCTLx register AUTOVALID bits are also set.

38.7.13 UDPHS Endpoint Control Disable Register

Name: UDPHS_EPTCTLDISx [x=0..6]

Address: 0x400A4108 [0], 0x400A4128 [1], 0x400A4148 [2], 0x400A4168 [3], 0x400A4188 [4], 0x400A41A8 [5], 0x400A41C8 [6]

Access: Write-only

31	30	29	28	27	26	25	24
SHRT_PCKT	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	BUSY_BANK	–	–

15	14	13	12	11	10	9	8
NAK_OUT	NAK_IN/ ERR_FLUSH	STALL_SNT/ ERR_CRISO/ ERR_NBTRA	RX_SETUP/ ERR_FL_ISO	TX_PK_RDY/ ERR_TRANS	TX_COMPLT	RX_BK_RDY	ERR_OVFLW

7	6	5	4	3	2	1	0
MDATA_RX	DATAX_RX	–	NYET_DIS	INTDIS_DMA	–	AUTO_VALID	EPT_DISABL

For additional Information, see “UDPHS Endpoint Control Register” on page 987.

- **EPT_DISABL: Endpoint Disable**

0 = no effect.

1 = disable endpoint.

- **AUTO_VALID: Packet Auto-Valid Disable**

0 = no effect.

1 = disable this bit to not automatically validate the current packet.

- **INTDIS_DMA: Interrupts Disable DMA**

0 = no effect.

1 = disable the “Interrupts Disable DMA”.

- **NYET_DIS: NYET Enable (Only for High Speed Bulk OUT endpoints)**

0 = no effect.

1 = let the hardware handle the handshake response for the High Speed Bulk OUT transfer.

- **DATAX_RX: DATAx Interrupt Disable (Only for High Bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = disable DATAx Interrupt.

- **MDATA_RX: MDATA Interrupt Disable (Only for High Bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = disable MDATA Interrupt.

- **ERR_OVFLW: Overflow Error Interrupt Disable**

0 = no effect.

1 = disable Overflow Error Interrupt.

- **RX_BK_RDY: Received OUT Data Interrupt Disable**

0 = no effect.

1 = disable Received OUT Data Interrupt.

- **TX_COMPLT: Transmitted IN Data Complete Interrupt Disable**

0 = no effect.

1 = disable Transmitted IN Data Complete Interrupt.

- **TX_PK_RDY/ERR_TRANS: TX Packet Ready/Transaction Error Interrupt Disable**

0 = no effect.

1 = disable TX Packet Ready/Transaction Error Interrupt.

- **RX_SETUP/ERR_FL_ISO: Received SETUP/Error Flow Interrupt Disable**

0 = no effect.

1 = disable RX_SETUP/Error Flow ISO Interrupt.

- **STALL_SNT/ERR_CRISO/ERR_NBTRA: Stall Sent/ISO CRC Error/Number of Transaction Error Interrupt Disable**

0 = no effect.

1 = disable Stall Sent/Error CRC ISO/Error Number of Transaction Interrupt.

- **NAK_IN/ERR_FLUSH: NAKIN/bank flush error Interrupt Disable**

0 = no effect.

1 = disable NAKIN/ Bank Flush Error Interrupt.

- **NAK_OUT: NAKOUT Interrupt Disable**

0 = no effect.

1 = disable NAKOUT Interrupt.

- **BUSY_BANK: Busy Bank Interrupt Disable**

0 = no effect.

1 = disable Busy Bank Interrupt.

- **SHRT_PCKT: Short Packet Interrupt Disable**

For OUT endpoints:

0 = no effect.

1 = disable Short Packet Interrupt.

For IN endpoints:

Never automatically add a zero length packet at end of DMA transfer.

38.7.14 UDPHS Endpoint Control Register

Name: UDPHS_EPTCTLx [x=0..6]

Address: 0x400A410C [0], 0x400A412C [1], 0x400A414C [2], 0x400A416C [3], 0x400A418C [4], 0x400A41AC [5], 0x400A41CC [6]

Access: Read-only

31	30	29	28	27	26	25	24
SHRT_PCKT	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	BUSY_BANK	–	–

15	14	13	12	11	10	9	8
NAK_OUT	NAK_IN/ ERR_FLUSH	STALL_SNT/ ERR_CRISO/ ERR_NBTRA	RX_SETUP/ ERR_FL_ISO	TX_PK_RDY/ ERR_TRANS	TX_COMPLT	RX_BK_RDY	ERR_OVFLW

7	6	5	4	3	2	1	0
MDATA_RX	DATAX_RX	–	NYET_DIS	INTDIS_DMA	–	AUTO_VALID	EPT_ENABL

- **EPT_ENABL: Endpoint Enable**

0 = If cleared, the endpoint is disabled according to the device configuration. Endpoint 0 should always be enabled after a hardware or UDPHS bus reset and participate in the device configuration.

1 = If set, the endpoint is enabled according to the device configuration.

- **AUTO_VALID: Packet Auto-Valid Enabled (Not for CONTROL Endpoints)**

Set this bit to automatically validate the current packet and switch to the next bank for both IN and OUT endpoints.

For IN Transfer:

If this bit is set, then the UDPHS_EPTSTAx register TX_PK_RDY bit is set automatically when the current bank is full and at the end of DMA buffer if the UDPHS_DMACONTROLx register END_B_EN bit is set.

The user may still set the UDPHS_EPTSTAx register TX_PK_RDY bit if the current bank is not full, unless the user wants to send a Zero Length Packet by software.

For OUT Transfer:

If this bit is set, then the UDPHS_EPTSTAx register RX_BK_RDY bit is automatically reset for the current bank when the last packet byte has been read from the bank FIFO or at the end of DMA buffer if the UDPHS_DMACONTROLx register END_B_EN bit is set. For example, to truncate a padded data packet when the actual data transfer size is reached.

The user may still clear the UDPHS_EPTSTAx register RX_BK_RDY bit, for example, after completing a DMA buffer by software if UDPHS_DMACONTROLx register END_B_EN bit was disabled or in order to cancel the read of the remaining data bank(s).

- **INTDIS_DMA: Interrupt Disables DMA**

If set, when an enabled endpoint-originated interrupt is triggered, the DMA request is disabled regardless of the UDPHS_IEN register EPT_x bit for this endpoint. Then, the firmware will have to clear or disable the interrupt source or clear this bit if transfer completion is needed.

If the exception raised is associated with the new system bank packet, then the previous DMA packet transfer is normally completed, but the new DMA packet transfer is not started (not requested).

If the exception raised is not associated to a new system bank packet (NAK_IN, NAK_OUT, ERR_FL_ISO...), then the request cancellation may happen at any time and may immediately stop the current DMA transfer.

This may be used, for example, to identify or prevent an erroneous packet to be transferred into a buffer or to complete a DMA buffer by software after reception of a short packet, or to perform buffer truncation on ERR_FL_ISO interrupt for adaptive rate.

- **NYET_DIS: NYET Disable (Only for High Speed Bulk OUT endpoints)**

0 = If clear, this bit lets the hardware handle the handshake response for the High Speed Bulk OUT transfer.

1 = If set, this bit forces an ACK response to the next High Speed Bulk OUT transfer instead of a NYET response.

Note: According to the *Universal Serial Bus Specification, Rev 2.0* (8.5.1.1 NAK Responses to OUT/DATA During PING Protocol), a NAK response to an HS Bulk OUT transfer is expected to be an unusual occurrence.

- **DATAX_RX: DATAx Interrupt Enabled (Only for High Bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = send an interrupt when a DATA2, DATA1 or DATA0 packet has been received meaning the whole microframe data payload has been received.

- **MDATA_RX: MDATA Interrupt Enabled (Only for High Bandwidth Isochronous OUT endpoints)**

0 = no effect.

1 = send an interrupt when an MDATA packet has been received and so at least one packet of the microframe data payload has been received.

- **ERR_OVFLW: Overflow Error Interrupt Enabled**

0 = Overflow Error Interrupt is masked.

1 = Overflow Error Interrupt is enabled.

- **RX_BK_RDY: Received OUT Data Interrupt Enabled**

0 = Received OUT Data Interrupt is masked.

1 = Received OUT Data Interrupt is enabled.

- **TX_COMPLT: Transmitted IN Data Complete Interrupt Enabled**

0 = Transmitted IN Data Complete Interrupt is masked.

1 = Transmitted IN Data Complete Interrupt is enabled.

- **TX_PK_RDY/ERR_TRANS: TX Packet Ready/Transaction Error Interrupt Enabled**

0 = TX Packet Ready/Transaction Error Interrupt is masked.

1 = TX Packet Ready/Transaction Error Interrupt is enabled.

Caution: Interrupt source is active as long as the corresponding UDPHS_EPTSTAx register TX_PK_RDY flag remains low. If there are no more banks available for transmitting after the software has set UDPHS_EPTSTAx/TX_PK_RDY for the last transmit packet, then the interrupt source remains inactive until the first bank becomes free again to transmit at UDPHS_EPTSTAx/TX_PK_RDY hardware clear.

- **RX_SETUP/ERR_FL_ISO: Received SETUP/Error Flow Interrupt Enabled**

0 = Received SETUP/Error Flow Interrupt is masked.

1 = Received SETUP/Error Flow Interrupt is enabled.

- **STALL_SNT/ERR_CRISO/ERR_NBTRA: Stall Sent/ISO CRC Error/Number of Transaction Error Interrupt Enabled**

0 = Stall Sent/ISO CRC error/number of Transaction Error Interrupt is masked.

1 = Stall Sent /ISO CRC error/number of Transaction Error Interrupt is enabled.

- **NAK_IN/ERR_FLUSH: NAKIN/Bank Flush Error Interrupt Enabled**

0 = NAKIN Interrupt is masked.

1 = NAKIN/Bank Flush Error Interrupt is enabled.

- **NAK_OUT: NAKOUT Interrupt Enabled**

0 = NAKOUT Interrupt is masked.

1 = NAKOUT Interrupt is enabled.

- **BUSY_BANK: Busy Bank Interrupt Enabled**

0 = BUSY_BANK Interrupt is masked.

1 = BUSY_BANK Interrupt is enabled.

For OUT endpoints: an interrupt is sent when all banks are busy.

For IN endpoints: an interrupt is sent when all banks are free.

- **SHRT_PCKT: Short Packet Interrupt Enabled**

For OUT endpoints: send an Interrupt when a Short Packet has been received.

0 = Short Packet Interrupt is masked.

1 = Short Packet Interrupt is enabled.

For IN endpoints: a Short Packet transmission is guaranteed upon end of the DMA Transfer, thus signaling a BULK or INTERRUPT end of transfer or an end of isochronous (micro-)frame data, but only if the UDPHS_DMACONTROLx register END_B_EN and UDPHS_EPTCTLx register AUTO_VALID bits are also set.

38.7.15 UDPHS Endpoint Set Status Register

Name: UDPHS_EPTSETSTAx [x=0..6]

Address: 0x400A4114 [0], 0x400A4134 [1], 0x400A4154 [2], 0x400A4174 [3], 0x400A4194 [4], 0x400A41B4 [5], 0x400A41D4 [6]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	TX_PK_RDY	–	KILL_BANK	–
7	6	5	4	3	2	1	0
–	–	FRCESTALL	–	–	–	–	–

- **FRCESTALL: Stall Handshake Request Set**

0 = no effect.

1 = set this bit to request a STALL answer to the host for the next handshake

Refer to chapters 8.4.5 (Handshake Packets) and 9.4.5 (Get Status) of the *Universal Serial Bus Specification, Rev 2.0* for more information on the STALL handshake.

- **KILL_BANK: KILL Bank Set (for IN Endpoint)**

0 = no effect.

1 = kill the last written bank.

- **TX_PK_RDY: TX Packet Ready Set**

0 = no effect.

1 = set this bit after a packet has been written into the endpoint FIFO for IN data transfers

  – This flag is used to generate a Data IN transaction (device to host).
  – Device firmware checks that it can write a data payload in the FIFO, checking that TX_PK_RDY is cleared.
  – Transfer to the FIFO is done by writing in the “Buffer Address” register.
  – Once the data payload has been transferred to the FIFO, the firmware notifies the UDPHS device setting TX_PK_RDY to one.
  – UDPHS bus transactions can start.
  – TXCOMP is set once the data payload has been received by the host.
  – Data should be written into the endpoint FIFO only after this bit has been cleared.
  – Set this bit without writing data to the endpoint FIFO to send a Zero Length Packet.

38.7.16 UDPHS Endpoint Clear Status Register

Name: UDPHS_EPTCLRSTAx [x=0..6]

Address: 0x400A4118 [0], 0x400A4138 [1], 0x400A4158 [2], 0x400A4178 [3], 0x400A4198 [4], 0x400A41B8 [5], 0x400A41D8 [6]

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
NAK_OUT	NAK_IN/ ERR_FLUSH	STALL_SNT/ ERR_NBTRA	RX_SETUP/ ERR_FL_ISO	–	TX_COMPLT	RX_BK_RDY	–

7	6	5	4	3	2	1	0
–	TOGGLESQ	FRCESTALL	–	–	–	–	–

- **FRCESTALL: Stall Handshake Request Clear**

0 = no effect.

1 = clear the STALL request. The next packets from host will not be STALLed.

- **TOGGLESQ: Data Toggle Clear**

0 = no effect.

1 = clear the PID data of the current bank

For OUT endpoints, the next received packet should be a DATA0.

For IN endpoints, the next packet will be sent with a DATA0 PID.

- **RX_BK_RDY: Received OUT Data Clear**

0 = no effect.

1 = clear the RX_BK_RDY flag of UDPHS_EPTSTAx.

- **TX_COMPLT: Transmitted IN Data Complete Clear**

0 = no effect.

1 = clear the TX_COMPLT flag of UDPHS_EPTSTAx.

- **RX_SETUP/ERR_FL_ISO: Received SETUP/Error Flow Clear**

0 = no effect.

1 = clear the RX_SETUP/ERR_FL_ISO flags of UDPHS_EPTSTAx.

- **STALL_SNT/ERR_NBTRA: Stall Sent/Number of Transaction Error Clear**

0 = no effect.

1 = clear the STALL_SNT/ERR_NBTRA flags of UDPHS_EPTSTAx.

- **NAK_IN/ERR_FLUSH: NAKIN/Bank Flush Error Clear**

0 = no effect.

1 = clear the NAK_IN/ERR_FLUSH flags of UDPHS_EPTSTAx.

- **NAK_OUT: NAKOUT Clear**

0 = no effect.

1 = clear the NAK_OUT flag of UDPHS_EPTSTAx.

38.7.17 UDPHS Endpoint Status Register

Name: UDPHS_EPTSTAx [x=0..6]

Address: 0x400A411C [0], 0x400A413C [1], 0x400A415C [2], 0x400A417C [3], 0x400A419C [4], 0x400A41BC [5], 0x400A41DC [6]

Access: Read-only

31	30	29	28	27	26	25	24
SHRT_PCKT	BYTE_COUNT						

23	22	21	20	19	18	17	16
BYTE_COUNT				BUSY_BANK_STA		CURRENT_BANK/ CONTROL_DIR	

15	14	13	12	11	10	9	8
NAK_OUT	NAK_IN/ ERR_FLUSH	STALL_SNT/ ERR_CRISO/ ERR_NBTRA	RX_SETUP/ ERR_FL_ISO	TX_PK_RDY/ ERR_TRANS	TX_COMPLT	RX_BK_RDY/ KILL_BANK	ERR_OVFLW

7	6	5	4	3	2	1	0
TOGGLESQ_STA		FRCESTALL	–	–	–	–	–

- **FRCESTALL: Stall Handshake Request**

0 = no effect.

1= If set a STALL answer will be done to the host for the next handshake.

This bit is reset by hardware upon received SETUP.

- **TOGGLESQ_STA: Toggle Sequencing**

Toggle Sequencing:

– **IN endpoint:** it indicates the PID Data Toggle that will be used for the next packet sent. This is not relative to the current bank.

– CONTROL and OUT endpoint:

These bits are set by hardware to indicate the PID data of the current bank:

Value	Name	Description
0	DATA0	DATA0
1	DATA1	DATA1
2	DATA2	Data2 (only for High Bandwidth Isochronous Endpoint)
3	MDATA	MData (only for High Bandwidth Isochronous Endpoint)

Notes:
1. In OUT transfer, the Toggle information is meaningful only when the current bank is busy (Received OUT Data = 1).
2. These bits are updated for OUT transfer:
   - a new data has been written into the current bank.
   - the user has just cleared the Received OUT Data bit to switch to the next bank.
3. For High Bandwidth Isochronous Out endpoint, it is recommended to check the UDPHS_EPTSTAx/ERR_TRANS bit to know if the toggle sequencing is correct or not.
4. This field is reset to DATA1 by the UDPHS_EPTCLRSTAx register TOGGLESQ bit, and by UDPHS_EPTCTLDISx (disable endpoint).

- **ERR_OVFLW: Overflow Error**

This bit is set by hardware when a new too-long packet is received.

Example: If the user programs an endpoint 64 bytes wide and the host sends 128 bytes in an OUT transfer, then the Overflow Error bit is set.

This bit is updated at the same time as the BYTE_COUNT field.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

- **RX_BK_RDY/KILL_BANK: Received OUT Data/KILL Bank**
  - **Received OUT Data**: (For OUT endpoint or Control endpoint)

This bit is set by hardware after a new packet has been stored in the endpoint FIFO.

This bit is cleared by the device firmware after reading the OUT data from the endpoint.

For multi-bank endpoints, this bit may remain active even when cleared by the device firmware, this if an other packet has been received meanwhile.

Hardware assertion of this bit may generate an interrupt if enabled by the UDPHS_EPTCTLx register RX_BK_RDY bit.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

  - **KILL Bank**: (For IN endpoint)
  - the bank is really cleared or the bank is sent, BUSY_BANK_STA is decremented.
  - the bank is not cleared but sent on the IN transfer, TX_COMPLT
  - the bank is not cleared because it was empty. The user should wait that this bit is cleared before trying to clear another packet.

Note: “Kill a packet” may be refused if at the same time, an IN token is coming and the current packet is sent on the UDPHS line. In this case, the TX_COMPLT bit is set. Take notice however, that if at least two banks are ready to be sent, there is no problem to kill a packet even if an IN token is coming. In fact, in that case, the current bank is sent (IN transfer) and the last bank is killed.

- **TX_COMPLT: Transmitted IN Data Complete**

This bit is set by hardware after an IN packet has been transmitted for isochronous endpoints and after it has been accepted (ACK’ed) by the host for Control, Bulk and Interrupt endpoints.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint), and by UDPHS_EPTCTLDISx (disable endpoint).

- **TX_PK_RDY/ERR_TRANS: TX Packet Ready/Transaction Error**
  - **TX Packet Ready**:

This bit is cleared by hardware, as soon as the packet has been sent for isochronous endpoints, or after the host has acknowledged the packet for Control, Bulk and Interrupt endpoints.

For Multi-bank endpoints, this bit may remain clear even after software is set if another bank is available to transmit.

Hardware clear of this bit may generate an interrupt if enabled by the UDPHS_EPTCTLx register TX_PK_RDY bit.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint), and by UDPHS_EPTCTLDISx (disable endpoint).

  - **Transaction Error**: (For high bandwidth isochronous OUT endpoints) (Read-Only)

This bit is set by hardware when a transaction error occurs inside one microframe.

If one toggle sequencing problem occurs among the n-transactions (n = 1, 2 or 3) inside a microframe, then this bit is still set as long as the current bank contains one “bad” n-transaction. (see “CURRENT_BANK/CONTROL_DIR: Current Bank/Control Direction” on page 996) As soon as the current bank is relative to a new “good” n-transactions, then this bit is reset.

Notes: 1. A transaction error occurs when the toggle sequencing does not respect the *Universal Serial Bus Specification, Rev 2.0* (5.9.2 High Bandwidth Isochronous endpoints) (Bad PID, missing data....)

2. When a transaction error occurs, the user may empty all the “bad” transactions by clearing the Received OUT Data flag (RX_BK_RDY).

If this bit is reset, then the user should consider that a new n-transaction is coming.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint), and by UDPHS_EPTCTLDISx (disable endpoint).

- **RX_SETUP/ERR_FL_ISO: Received SETUP/Error Flow**
  - **Received SETUP**: (for Control endpoint only)

This bit is set by hardware when a valid SETUP packet has been received from the host.

It is cleared by the device firmware after reading the SETUP data from the endpoint FIFO.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint), and by UDPHS_EPTCTLDISx (disable endpoint).

  - **Error Flow**: (for isochronous endpoint only)

This bit is set by hardware when a transaction error occurs.

  - Isochronous IN transaction is missed, the micro has no time to fill the endpoint (underflow).
  - Isochronous OUT data is dropped because the bank is busy (overflow).

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

- **STALL_SNT/ERR_CRISO/ERR_NBTRA: Stall Sent/CRC ISO Error/Number of Transaction Error**
  - **STALL_SNT**: (for Control, Bulk and Interrupt endpoints)

This bit is set by hardware after a STALL handshake has been sent as requested by the UDPHS_EPTSTAx register FRCESTALL bit.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

  - **ERR_CRISO**: (for Isochronous OUT endpoints) (Read-only)

This bit is set by hardware if the last received data is corrupted (CRC error on data).

This bit is updated by hardware when new data is received (Received OUT Data bit).

  - **ERR_NBTRA**: (for High Bandwidth Isochronous IN endpoints)

This bit is set at the end of a microframe in which at least one data bank has been transmitted, if less than the number of transactions per micro-frame banks (UDPHS_EPTCFGx register NB_TRANS) have been validated for transmission inside this microframe.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

- **NAK_IN/ERR_FLUSH: NAK IN/Bank Flush Error**
  - **NAK_IN**:

This bit is set by hardware when a NAK handshake has been sent in response to an IN request from the Host.

This bit is cleared by software.

  - **ERR_FLUSH**: (for High Bandwidth Isochronous IN endpoints)

This bit is set when flushing unsent banks at the end of a microframe.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by EPT_CTL_DISx (disable endpoint).

- **NAK_OUT: NAK OUT**

This bit is set by hardware when a NAK handshake has been sent in response to an OUT or PING request from the Host.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by EPT_CTL_DISx (disable endpoint).

- **CURRENT_BANK/CONTROL_DIR: Current Bank/Control Direction**
  - **Current Bank**: (all endpoints except Control endpoint)

These bits are set by hardware to indicate the number of the current bank.

Value	Name	Description
0	BANK0	Bank 0 (or single bank)
1	BANK1	Bank 1
2	BANK2	Bank 2

Note: The current bank is updated each time the user:
- Sets the TX Packet Ready bit to prepare the next IN transfer and to switch to the next bank.
- Clears the received OUT data bit to access the next bank.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

  - **Control Direction**: (for Control endpoint only)

0 = a Control Write is requested by the Host.

1 = a Control Read is requested by the Host.

Notes:
1. This bit corresponds with the 7th bit of the bmRequestType (Byte 0 of the Setup Data).
2. This bit is updated after receiving new setup data.

- **BUSY_BANK_STA: Busy Bank Number**

These bits are set by hardware to indicate the number of busy banks.

IN endpoint: it indicates the number of busy banks filled by the user, ready for IN transfer.

OUT endpoint: it indicates the number of busy banks filled by OUT transaction from the Host.

Value	Name	Description
0	1BUSYBANK	1 busy bank
1	2BUSYBANKS	2 busy banks
2	3BUSYBANKS	3 busy banks

- **BYTE_COUNT: UDPHS Byte Count**

Byte count of a received data packet.

This field is incremented after each write into the endpoint (to prepare an IN transfer).

This field is decremented after each reading into the endpoint (OUT transfer).

This field is also updated at RX_BK_RDY flag clear with the next bank.

This field is also updated at TX_PK_RDY flag set with the next bank.

This field is reset by EPT_x of UDPHS_EPTRST register.

- **SHRT_PCKT: Short Packet**

An OUT Short Packet is detected when the receive byte count is less than the configured UDPHS_EPTCFGx register EPT_Size.

This bit is updated at the same time as the BYTE_COUNT field.

This bit is reset by UDPHS_EPTRST register EPT_x (reset endpoint) and by UDPHS_EPTCTLDISx (disable endpoint).

38.7.18 UDPHS DMA Channel Transfer Descriptor

The DMA channel transfer descriptor is loaded from the memory.

Be careful with the alignment of this buffer.

The structure of the DMA channel transfer descriptor is defined by three parameters as described below:

Offset 0:

The address must be aligned: 0xXXXX0

Next Descriptor Address Register: UDPHS_DMANXTDSCx

Offset 4:

The address must be aligned: 0xXXXX4

DMA Channelx Address Register: UDPHS_DMAADDRESSx

Offset 8:

The address must be aligned: 0xXXXX8

DMA Channelx Control Register: UDPHS_DMACONTROLx

To use the DMA channel transfer descriptor, fill the structures with the correct value (as described in the following pages).

Then write directly in UDPHS_DMANXTDSCx the address of the descriptor to be used first.

Then write 1 in the LDNXT_DSC bit of UDPHS_DMACONTROLx (load next channel transfer descriptor). The descriptor is automatically loaded upon Endpointx request for packet transfer.

38.7.19 UDPHS DMA Next Descriptor Address Register

Name: UDPHS_DMANXTDSCx [x = 0..5]

Address: 0x400A4300 [0], 0x400A4310 [1], 0x400A4320 [2], 0x400A4330 [3], 0x400A4340 [4], 0x400A4350 [5]

Access: Read-write

31	30	29	28	27	26	25	24
NXT_DSC_ADD							
23	22	21	20	19	18	17	16
NXT_DSC_ADD							
15	14	13	12	11	10	9	8
NXT_DSC_ADD							
7	6	5	4	3	2	1	0
NXT_DSC_ADD							

Note: Channel 0 is not used.

- **NXT_DSC_ADD**

This field points to the next channel descriptor to be processed. This channel descriptor must be aligned, so bits 0 to 3 of the address must be equal to zero.

38.7.20 UDPHS DMA Channel Address Register

Name: UDPHS_DMAADDRESSx [x = 0..5]

Address: 0x400A4304 [0], 0x400A4314 [1], 0x400A4324 [2], 0x400A4334 [3], 0x400A4344 [4], 0x400A4354 [5]

Access: Read-write

31	30	29	28	27	26	25	24
BUFF_ADD							

23	22	21	20	19	18	17	16
BUFF_ADD							

15	14	13	12	11	10	9	8
BUFF_ADD							

7	6	5	4	3	2	1	0
BUFF_ADD							

Note: Channel 0 is not used.

- **BUFF_ADD**

This field determines the AHB bus starting address of a DMA channel transfer.

Channel start and end addresses may be aligned on any byte boundary.

The firmware may write this field only when the UDPHS_DMASTATUS register CHANN_ENB bit is clear.

This field is updated at the end of the address phase of the current access to the AHB bus. It is incrementing of the access byte width. The access width is 4 bytes (or less) at packet start or end, if the start or end address is not aligned on a word boundary.

The packet start address is either the channel start address or the next channel address to be accessed in the channel buffer.

The packet end address is either the channel end address or the latest channel address accessed in the channel buffer.

The channel start address is written by software or loaded from the descriptor, whereas the channel end address is either determined by the end of buffer or the UDPHS device, USB end of transfer if the UDPHS_DMACONTROLx register END_TR_EN bit is set.

38.7.21 UDPHS DMA Channel Control Register

Name: UDPHS_DMACONTROLx [x = 0..5]

Address: 0x400A4308 [0], 0x400A4318 [1], 0x400A4328 [2], 0x400A4338 [3], 0x400A4348 [4], 0x400A4358 [5]

Access: Read-write

31	30	29	28	27	26	25	24
BUFF_LENGTH							
23	22	21	20	19	18	17	16
BUFF_LENGTH							
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
BURST_LCK	DESC_LD_IT	END_BUFFIT	END_TR_IT	END_B_EN	END_TR_EN	LDNXT_DSC	CHANN_ENB

Note: Channel 0 is not used.

- **CHANN_ENB (Channel Enable Command)**

0 = DMA channel is disabled at and no transfer will occur upon request. This bit is also cleared by hardware when the channel source bus is disabled at end of buffer.

If the UDPHS_DMACONTROL register LDNXT_DSC bit has been cleared by descriptor loading, the firmware will have to set the corresponding CHANN_ENB bit to start the described transfer, if needed.

If the UDPHS_DMACONTROL register LDNXT_DSC bit is cleared, the channel is frozen and the channel registers may then be read and/or written reliably as soon as both UDPHS_DMASTATUS register CHANN_ENB and CHANN_ACT flags read as 0.

If a channel request is currently serviced when this bit is cleared, the DMA FIFO buffer is drained until it is empty, then the UDPHS_DMASTATUS register CHANN_ENB bit is cleared.

If the LDNXT_DSC bit is set at or after this bit clearing, then the currently loaded descriptor is skipped (no data transfer occurs) and the next descriptor is immediately loaded.

1 = UDPHS_DMASTATUS register CHANN_ENB bit will be set, thus enabling DMA channel data transfer. Then any pending request will start the transfer. This may be used to start or resume any requested transfer.

- **LDNXT_DSC: Load Next Channel Transfer Descriptor Enable (Command)**

0 = no channel register is loaded after the end of the channel transfer.

1 = the channel controller loads the next descriptor after the end of the current transfer, i.e. when the UDPHS_DMASTATUS/CHANN_ENB bit is reset.

If the UDPHS_DMA CONTROL/CHANN_ENB bit is cleared, the next descriptor is immediately loaded upon transfer request.

DMA Channel Control Command Summary

LDNXT_DSC	CHANN_ENB	Description
0	0	Stop now
0	1	Run and stop at end of buffer
1	0	Load next descriptor now
1	1	Run and link at end of buffer

- **END_TR_EN: End of Transfer Enable (Control)**

Used for OUT transfers only.

0 = USB end of transfer is ignored.

1 = UDPHS device can put an end to the current buffer transfer.

When set, a BULK or INTERRUPT short packet or the last packet of an ISOCHRONOUS (micro) frame (DATAX) will close the current buffer and the UDPHS_DMASTATUSx register END_TR_ST flag will be raised.

This is intended for UDPHS non-prenegotiated end of transfer (BULK or INTERRUPT) or ISOCHRONOUS microframe data buffer closure.

- **END_B_EN: End of Buffer Enable (Control)**

0 = DMA Buffer End has no impact on USB packet transfer.

1 = endpoint can validate the packet (according to the values programmed in the UDPHS_EPTCTLx register AUTO_VALID and SHRT_PCKT fields) at DMA Buffer End, i.e. when the UDPHS_DMASTATUS register BUFF_COUNT reaches 0.

This is mainly for short packet IN validation initiated by the DMA reaching end of buffer, but could be used for OUT packet truncation (discarding of unwanted packet data) at the end of DMA buffer.

- **END_TR_IT: End of Transfer Interrupt Enable**

0 = UDPHS device initiated buffer transfer completion will not trigger any interrupt at UDPHS_STATUSx/END_TR_ST rising.

1 = an interrupt is sent after the buffer transfer is complete, if the UDPHS device has ended the buffer transfer.

Use when the receive size is unknown.

- **END_BUFFIT: End of Buffer Interrupt Enable**

0 = UDPHS_DMA_STATUSx/END_BF_ST rising will not trigger any interrupt.

1 = an interrupt is generated when the UDPHS_DMASTATUSx register BUFF_COUNT reaches zero.

- **DESC_LD_IT: Descriptor Loaded Interrupt Enable**

0 = UDPHS_DMASTATUSx/DESC_LDST rising will not trigger any interrupt.

1 = an interrupt is generated when a descriptor has been loaded from the bus.

- **BURST_LCK: Burst Lock Enable**

0 = the DMA never locks bus access.

1 = USB packets AHB data bursts are locked for maximum optimization of the bus bandwidth usage and maximization of fly-by AHB burst duration.

- **BUFF_LENGTH: Buffer Byte Length (Write-only)**

This field determines the number of bytes to be transferred until end of buffer. The maximum channel transfer size (64 KBytes) is reached when this field is 0 (default value). If the transfer size is unknown, this field should be set to 0, but the transfer end may occur earlier under UDPHS device control.

When this field is written, The UDPHS_DMASTATUSx register BUFF_COUNT field is updated with the write value.

Notes:
1. Bits [31:2] are only writable when issuing a channel Control Command other than “Stop Now”.
2. For reliability it is highly recommended to wait for both UDPHS_DMASTATUSx register CHAN_ACT and CHAN_ENB flags are at 0, thus ensuring the channel has been stopped before issuing a command other than “Stop Now”.

38.7.22 UDPHS DMA Channel Status Register

Name: UDPHS_DMASTATUSx [x = 0..5]

Address: 0x400A430C [0], 0x400A431C [1], 0x400A432C [2], 0x400A433C [3], 0x400A434C [4], 0x400A435C [5]

Access: Read-write

31	30	29	28	27	26	25	24
BUFF_COUNT							
23	22	21	20	19	18	17	16
BUFF_COUNT							
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	DESC_LDST	END_BF_ST	END_TR_ST	–	–	CHANN_ACT	CHANN_ENB

Note: Channel 0 is not used.

- **CHANN_ENB: Channel Enable Status**

0 = if cleared, the DMA channel no longer transfers data, and may load the next descriptor if the UDPHS_DMACONTROLx register LDNXT_DSC bit is set.

When any transfer is ended either due to an elapsed byte count or a UDPHS device initiated transfer end, this bit is automatically reset.

1 = if set, the DMA channel is currently enabled and transfers data upon request.

This bit is normally set or cleared by writing into the UDPHS_DMACONTROLx register CHANN_ENB bit field either by software or descriptor loading.

If a channel request is currently serviced when the UDPHS_DMACONTROLx register CHANN_ENB bit is cleared, the DMA FIFO buffer is drained until it is empty, then this status bit is cleared.

- **CHANN_ACT: Channel Active Status**

0 = the DMA channel is no longer trying to source the packet data.

When a packet transfer is ended this bit is automatically reset.

1 = the DMA channel is currently trying to source packet data, i.e. selected as the highest-priority requesting channel.

When a packet transfer cannot be completed due to an END_BF_ST, this flag stays set during the next channel descriptor load (if any) and potentially until UDPHS packet transfer completion, if allowed by the new descriptor.

- **END_TR_ST: End of Channel Transfer Status**

0 = cleared automatically when read by software.

1 = set by hardware when the last packet transfer is complete, if the UDPHS device has ended the transfer.

Valid until the CHANN_ENB flag is cleared at the end of the next buffer transfer.

- **END_BF_ST: End of Channel Buffer Status**

0 = cleared automatically when read by software.

1 = set by hardware when the BUFF_COUNT downcount reach zero.

Valid until the CHANN_ENB flag is cleared at the end of the next buffer transfer.

- **DESC_LDST: Descriptor Loaded Status**

0 = cleared automatically when read by software.

1 = set by hardware when a descriptor has been loaded from the system bus.

Valid until the CHANN_ENB flag is cleared at the end of the next buffer transfer.

- **BUFF_COUNT: Buffer Byte Count**

This field determines the current number of bytes still to be transferred for this buffer.

This field is decremented from the AHB source bus access byte width at the end of this bus address phase.

The access byte width is 4 by default, or less, at DMA start or end, if the start or end address is not aligned on a word boundary.

At the end of buffer, the DMA accesses the UDPHS device only for the number of bytes needed to complete it.

This field value is reliable (stable) only if the channel has been stopped or frozen (UDPHS_EPTCTLx register NT_DIS_DMA bit is used to disable the channel request) and the channel is no longer active CHANN_ACT flag is 0.

Note: For OUT endpoints, if the receive buffer byte length (BUFF_LENGTH) has been defaulted to zero because the USB transfer length is unknown, the actual buffer byte length received will be 0x10000-BUFF_COUNT.

39. DMA Controller (DMAC)

39.1 Description

The DMA Controller (DMAC) is an AHB-central DMA controller core that transfers data from a source peripheral to a destination peripheral over one or more AMBA buses. One channel is required for each source/destination pair. In the most basic configuration, the DMAC has one master interface and one channel. The master interface reads the data from a source and writes it to a destination. Two AMBA transfers are required for each DMAC data transfer. This is also known as a dual-access transfer.

The DMAC is programmed via the APB interface.

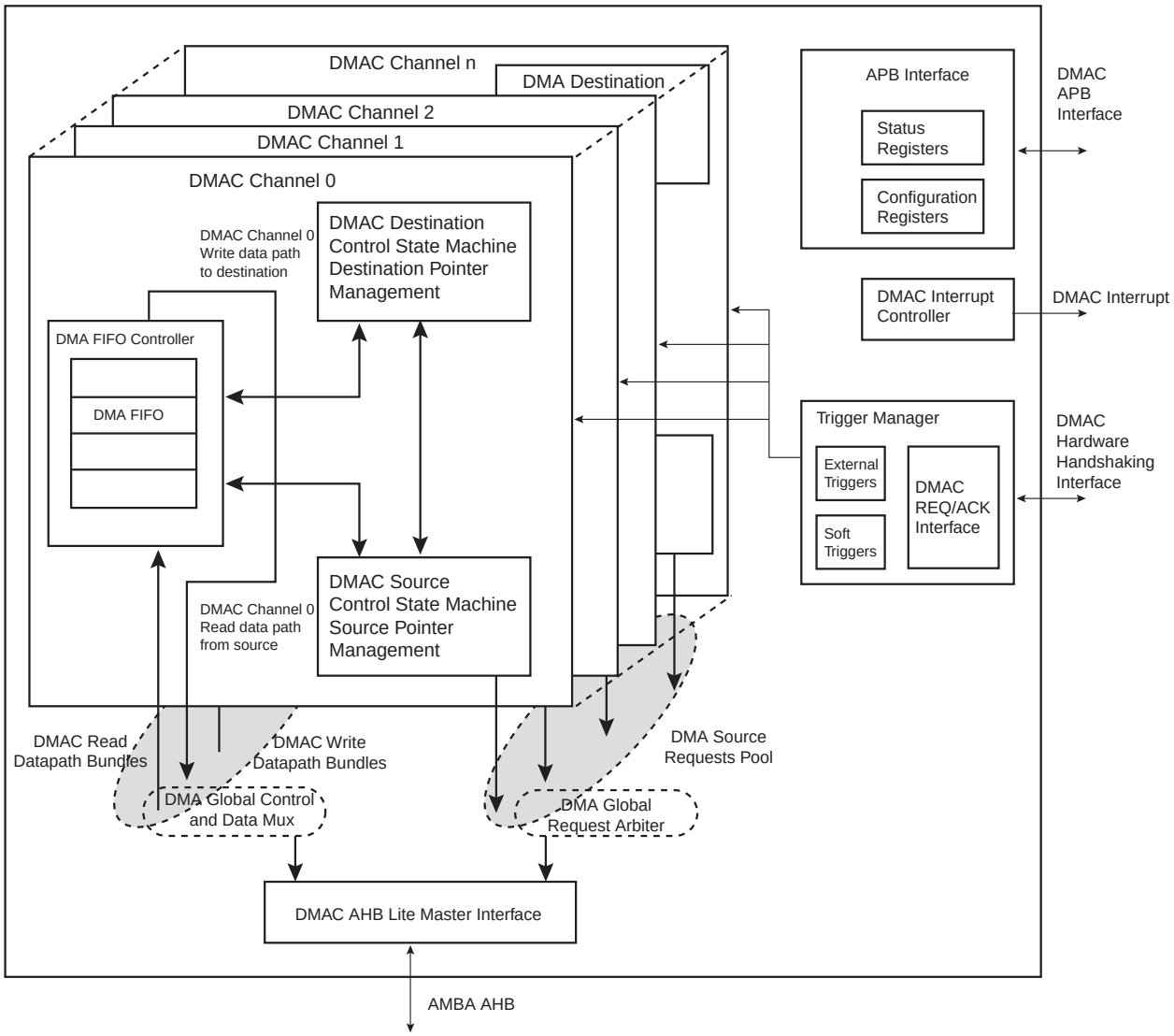
The DMAC embeds four channels:

DMAC Channel Number	FIFO Size
0	8 Bytes
1	8 Bytes
2	8 Bytes
3	32 Bytes

For hardware interface numbers, see Table 39-2, “Register Mapping,” on page 1021.

39.2 Block Diagram

Figure 39-1. DMA Controller (DMAC) Block Diagram



39.3 Functional Description

39.3.1 Basic Definitions

Source peripheral: Device on an AMBA layer from where the DMAC reads data, which is then stored in the channel FIFO. The source peripheral teams up with a destination peripheral to form a channel.

Destination peripheral: Device to which the DMAC writes the stored data from the FIFO (previously read from the source peripheral).

Memory: Source or destination that is always “ready” for a DMAC transfer and does not require a handshaking interface to interact with the DMAC.

Channel: Read/write datapath between a source peripheral on one configured AMBA layer and a destination peripheral on the same or different AMBA layer that occurs through the channel FIFO. If the source peripheral is not memory, then a source handshaking interface is assigned to the channel. If the destination peripheral is not memory, then a destination handshaking interface is assigned to the channel. Source and destination handshaking interfaces can be assigned dynamically by programming the channel registers.

Master interface: DMAC is a master on the AHB bus reading data from the source and writing it to the destination over the AHB bus.

Slave interface: The APB interface over which the DMAC is programmed. The slave interface in practice could be on the same layer as any of the master interfaces or on a separate layer.

Handshaking interface: A set of signal registers that conform to a protocol and *handshake* between the DMAC and source or destination peripheral to control the transfer of a single or chunk transfer between them. This interface is used to request, acknowledge, and control a DMAC transaction. A channel can receive a request through one of two types of handshaking interface: hardware or software.

Hardware handshaking interface: Uses hardware signals to control the transfer of a single or chunk transfer between the DMAC and the source or destination peripheral.

Software handshaking interface: Uses software registers to contr5ol the transfer of a single or chunk transfer between the DMAC and the source or destination peripheral. No special DMAC handshaking signals are needed on the I/O of the peripheral. This mode is useful for interfacing an existing peripheral to the DMAC without modifying it.

Flow controller: The device (either the DMAC or source/destination peripheral) that determines the length of and terminates a DMAC buffer transfer. If the length of a buffer is known before enabling the channel, then the DMAC should be programmed as the flow controller.

Transfer hierarchy: Figure 39-2 on page 1007 illustrates the hierarchy between DMAC transfers, buffer transfers, chunk or single, and AMBA transfers (single or burst) for non-memory peripherals. Figure 39-3 on page 1007 shows the transfer hierarchy for memory.

Figure 39-2. DMAC Transfer Hierarchy for Non-Memory Peripheral

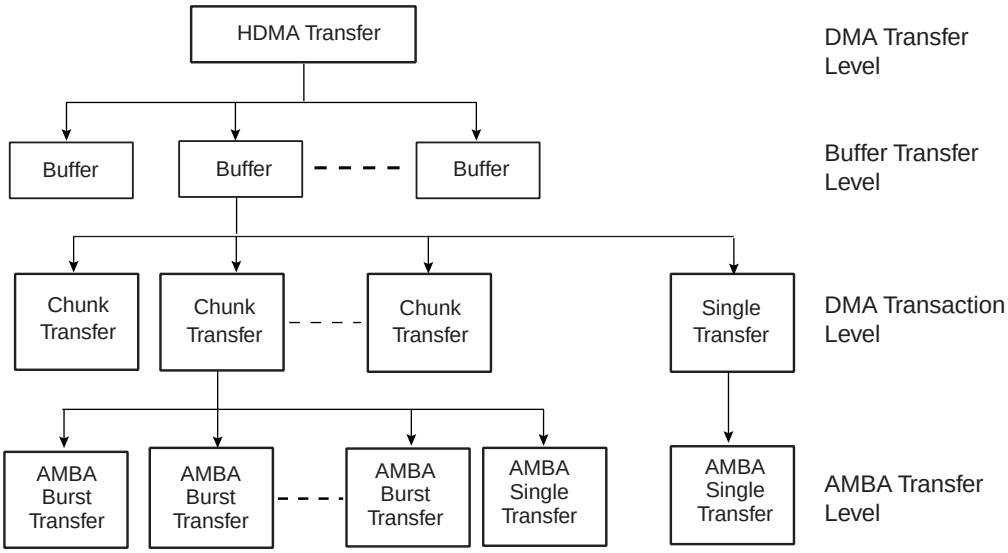
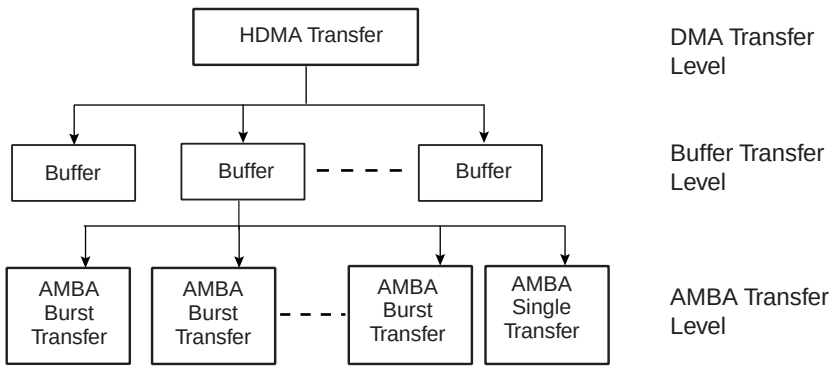


Figure 39-3. DMAC Transfer Hierarchy for Memory



Buffer: A buffer of DMAC data. The amount of data (length) is determined by the flow controller. For transfers between the DMAC and memory, a buffer is broken directly into a sequence of AMBA bursts and AMBA single transfers.

For transfers between the DMAC and a non-memory peripheral, a buffer is broken into a sequence of DMAC transactions (single and chunks). These are in turn broken into a sequence of AMBA transfers.

Transaction: A basic unit of a DMAC transfer as determined by either the hardware or software handshaking interface. A transaction is only relevant for transfers between the DMAC and a source or destination peripheral if the source or destination peripheral is a non-memory device. There are two types of transactions: single transfer and chunk transfer.

- **Single transfer:** The length of a single transaction is always 1 and is converted to a single AMBA access.
- **Chunk transfer:** The length of a chunk is programmed into the DMAC. The chunk is then converted into a sequence of AHB access.DMAC executes each AMBA burst transfer by performing incremental bursts that are no longer than 16 beats.

DMAC transfer: Software controls the number of buffers in a DMAC transfer. Once the DMAC transfer has completed, then hardware within the DMAC disables the channel and can generate an interrupt to signal the completion of the DMAC transfer. You can then re-program the channel for a new DMAC transfer.

Single-buffer DMAC transfer: Consists of a single buffer.

Multi-buffer DMAC transfer: A DMAC transfer may consist of multiple DMAC buffers. Multi-buffer DMAC transfers are supported through buffer chaining (linked list pointers), auto-reloading of channel registers, and contiguous buffers. The source and destination can independently select which method to use.

- **Linked lists (buffer chaining) –** A descriptor pointer (DSCR) points to the location in system memory where the next linked list item (LLI) exists. The LLI is a set of registers that describe the next buffer (buffer descriptor) and a descriptor pointer register. The DMAC fetches the LLI at the beginning of every buffer when buffer chaining is enabled.
- **Contiguous buffers –** Where the address of the next buffer is selected to be a continuation from the end of the previous buffer.

Channel locking: Software can program a channel to keep the AHB master interface by locking the arbitration for the master bus interface for the duration of a DMAC transfer, buffer, or chunk.

Bus locking: Software can program a channel to maintain control of the AMBA bus by asserting hmastlock for the duration of a DMAC transfer, buffer, or transaction (single or chunk). Channel locking is asserted for the duration of bus locking at a minimum.

39.3.2 Memory Peripherals

Figure 39-3 on page 1007 shows the DMAC transfer hierarchy of the DMAC for a memory peripheral. There is no handshaking interface with the DMAC, and therefore the memory peripheral can never be a flow controller. Once the channel is enabled, the transfer proceeds immediately without waiting for a transaction request. The alternative to not having a transaction-level handshaking interface is to allow the DMAC to attempt AMBA transfers to the peripheral once the channel is enabled. If the peripheral slave cannot accept these AMBA transfers, it inserts wait states onto the bus until it is ready; it is not recommended that more than 16 wait states be inserted onto the bus. By using the handshaking interface, the peripheral can signal to the DMAC that it is ready to transmit/receive data, and then the DMAC can access the peripheral without the peripheral inserting wait states onto the bus.

39.3.3 Handshaking Interface

Handshaking interfaces are used at the transaction level to control the flow of single or chunk transfers. The operation of the handshaking interface is different and depends on whether the peripheral or the DMAC is the flow controller.

The peripheral uses the handshaking interface to indicate to the DMAC that it is ready to transfer/accept data over the AMBA bus. A non-memory peripheral can request a DMAC transfer through the DMAC using one of two handshaking interfaces:

- Hardware handshaking
- Software handshaking

Software selects between the hardware or software handshaking interface on a per-channel basis. Software handshaking is accomplished through memory-mapped registers, while hardware handshaking is accomplished using a dedicated handshaking interface.

39.3.3.1 Software Handshaking

When the slave peripheral requires the DMAC to perform a DMAC transaction, it communicates this request by sending an interrupt to the CPU or interrupt controller.

The interrupt service routine then uses the software registers to initiate and control a DMAC transaction. These software registers are used to implement the software handshaking interface.

The SRC_H2SEL/DST_H2SEL bit in the DMAC_CFGx channel configuration register must be set to zero to enable software handshaking.

When the peripheral is not the flow controller, then the last transaction register DMAC_LAST is not used, and the values in these registers are ignored.

39.3.3.2 Chunk Transactions

Writing a 1 to the DMAC_CREQ[2x] register starts a source chunk transaction request, where x is the channel number. Writing a 1 to the DMAC_CREQ[2x+1] register starts a destination chunk transfer request, where x is the channel number.

Upon completion of the chunk transaction, the hardware clears the DMAC_CREQ[2*x*] or DMAC_CREQ[2x+1].

39.3.3.3 Single Transactions

Writing a 1 to the DMAC_SREQ[2x] register starts a source single transaction request, where x is the channel number. Writing a 1 to the DMAC_SREQ[2x+1] register starts a destination single transfer request, where x is the channel number.

Upon completion of the chunk transaction, the hardware clears the DMAC_SREQ[x] or DMAC_SREQ[2x+1].

Software can poll the relevant channel bit in the DMAC_CREQ[2x]/DMAC_CREQ[2x+1] and DMAC_SREQ[x]/DMAC_SREQ[2x+1] registers. When both are 0, then either the requested chunk or single transaction has completed.

39.3.4 DMAC Transfer Types

A DMAC transfer may consist of single or multi-buffers transfers. On successive buffers of a multi-buffer transfer, the DMAC_SADDRx/DMAC_DADDRx registers in the DMAC are reprogrammed using either of the following methods:

- Buffer chaining using linked lists
- Contiguous address between buffers

On successive buffers of a multi-buffer transfer, the DMAC_CTRLAx and DMAC_CTRLBx registers in the DMAC are re-programmed using either of the following methods:

- Buffer chaining using linked lists

When buffer chaining, using linked lists is the multi-buffer method of choice, and on successive buffers, the DMAC_DSCRx register in the DMAC is re-programmed using the following method:

- Buffer chaining using linked lists

A buffer descriptor (LLI) consists of following registers, DMAC_SADDRx, DMAC_DADDRx, DMAC_DSCRx, DMAC_CTRLAx, DMAC_CTRLBx.These registers, along with the DMAC_CFGx register, are used by the DMAC to set up and describe the buffer transfer.

39.3.4.1 Multi-buffer Transfers

39.3.4.2 Buffer Chaining Using Linked Lists

In this case, the DMAC re-programs the channel registers prior to the start of each buffer by fetching the buffer descriptor for that buffer from system memory. This is known as an LLI update.

DMAC buffer chaining is supported by using a Descriptor Pointer register (DMAC_DSCRx) that stores the address in memory of the next buffer descriptor. Each buffer descriptor contains the corresponding buffer descriptor (DMAC_SADDRx, DMAC_DADDRx, DMAC_DSCRx, DMAC_CTRLAx DMAC_CTRLBx).

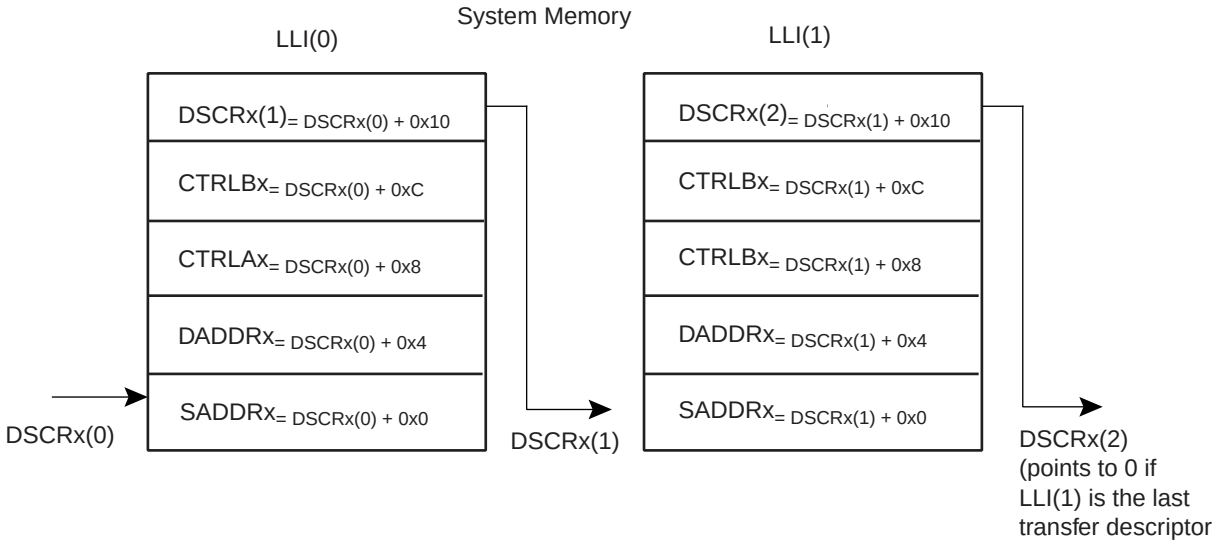
To set up buffer chaining, a sequence of linked lists must be programmed in memory.

The DMAC_SADDRx, DMAC_DADDRx, DMAC_DSCRx, DMAC_CTRLAx and DMAC_CTRLBx registers are fetched from system memory on an LLI update. The updated content of the DMAC_CTRLAx register is written back to memory on buffer completion. Figure 39-4 on page 1010 shows how to use chained linked lists in memory to define multi-buffer transfers using buffer chaining.

The Linked List multi-buffer transfer is initiated by programming DMAC_DSCRx with DSCRx(0) (LLI(0) base address) and DMAC_CTRLBx register with both SRC_DSCR and DST_DSCR set to 0. Other fields and registers are ignored and overwritten when the descriptor is retrieved from memory.

The last transfer descriptor must be written to memory with its next descriptor address set to 0.

Figure 39-4. Multi Buffer Transfer Using Linked List



39.3.4.3 Programming DMAC for Multiple Buffer Transfers

Table 39-1. Multiple Buffers Transfer Management Table

Transfer Type	AUTO	SRC_REP	DST_REP	SRC_DSCR	DST_DSCR	BTSIZE	SADDR	DADDR	Other Fields
1) Single Buffer or Last buffer of a multiple buffer transfer	0	–	–	1	1	USR	USR	USR	USR
2) Multi Buffer transfer with contiguous DADDR	0	–	0	0	1	LLI	LLI	CONT	LLI
3) Multi Buffer transfer with contiguous SADDR	0	0	–	1	0	LLI	CONT	LLI	LLI
4) Multi Buffer transfer with LLI support	0	–	–	0	0	LLI	LLI	LLI	LLI

Notes: 1. USR means that the register field is manually programmed by the user.
2. CONT means that address are contiguous.
3. LLI means that the register field is updated with the content of the linked list item.

39.3.4.4 Contiguous Address Between Buffers

In this case, the address between successive buffers is selected to be a continuation from the end of the previous buffer. Enabling the source or destination address to be contiguous between buffers is a function of DMAC_CTRLAx.SRC_DSCR and DMAC_CTRLAx.DST_DSCR registers.

39.3.4.5 Suspension of Transfers Between buffers

At the end of every buffer transfer, an end of buffer interrupt is asserted if:

- the channel buffer interrupt is unmasked, DMAC_EBCIMR.BTC[n] = ‘1’, where n is the channel number.

Note: The buffer complete interrupt is generated at the completion of the buffer transfer to the destination.

At the end of a chain of multiple buffers, an end of linked list interrupt is asserted if:

- the channel end of chained buffer interrupt is unmasked, DMAC_EBCIMR.CBTC[n] = ‘1’, when n is the channel number.

39.3.4.6 Ending Multi-buffer Transfers

All multi-buffer transfers must end as shown in Row 1 of Table 39-1 on page 1010. At the end of every buffer transfer, the DMAC samples the row number, and if the DMAC is in Row 1 state, then the previous buffer transferred was the last buffer and the DMAC transfer is terminated.

For rows 2, 3, and 4 the user must setup the last buffer descriptor in memory such that both LLI.DMAC_CTRLBx.SRC_DSCR and LLI.DMAC_CTRLBx.DST_DSCR are one and LLI.DMAC_DSCRx is set to 0.

39.3.5 Programming a Channel

Four registers, the DMAC_DSCRx, the DMAC_CTRLAx, the DMAC_CTRLBx and DMAC_CFGx, need to be programmed to set up whether single or multi-buffer transfers take place, and which type of multi-buffer transfer is used. The different transfer types are shown in Table 39-1 on page 1010.

The “BTSIZE, SADDR and DADDR” columns indicate where the values of DMAC_SARx, DMAC_DARx, DMAC_CTLx, and DMAC_LLPx are obtained for the next buffer transfer when multi-buffer DMAC transfers are enabled.

39.3.5.1 Programming Examples

39.3.5.2 Single-buffer Transfer (Row 1)

1. Read the Channel Handler Status Register DMAC_CHSR.ENABLE Field to choose a free (disabled) channel.
2. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the interrupt status register, DMAC_EBCISR.
3. Program the following channel registers:
   a. Write the starting source address in the DMAC_SADDRx register for channel x.
   b. Write the starting destination address in the DMAC_DADDRx register for channel x.
   c. Program DMAC_CTRLAx, DMAC_CTRLBx and DMAC_CFGx according to Row 1 as shown in Table 39-1 on page 1010. Program the DMAC_CTRLBx register with both DST_DSCR and SRC_DSCR fields set to one.
   d. Write the control information for the DMAC transfer in the DMAC_CTRLAx and DMAC_CTRLBx registers for channel x. For example, in the register, you can program the following:
      – i. Set up the transfer type (memory or non-memory peripheral for source and destination) and flow control device by programming the FC of the DMAC_CTRLBx register.
      – ii. Set up the transfer characteristics, such as:
      – Transfer width for the source in the SRC_WIDTH field.
      – Transfer width for the destination in the DST_WIDTH field.
      – Incrementing/decrementing or fixed address for source in SRC_INC field.
      – Incrementing/decrementing or fixed address for destination in DST_INC field.
   e. Write the channel configuration information into the DMAC_CFGx register for channel x.
      – i. Designate the handshaking interface type (hardware or software) for the source and destination peripherals. This is not required for memory. This step requires programming the SRC_H2SEL/DST_H2SEL bits, respectively. Writing a ‘1’ activates the hardware handshaking interface to handle source/destination requests. Writing a ‘0’ activates the software handshaking interface to handle source/destination requests.
      – ii. If the hardware handshaking interface is activated for the source or destination peripheral, assign a handshaking interface to the source and destination peripheral. This requires programming the SRC_PER and DST_PER bits, respectively.

4. After the DMAC selected channel has been programmed, enable the channel by writing a ‘1’ to the DMAC_CHER.ENABLE[n] bit, where n is the channel number. Make sure that bit 0 of DMAC_EN.ENABLE register is enabled.
5. Source and destination request single and chunk DMAC transactions to transfer the buffer of data (assuming non-memory peripherals). The DMAC acknowledges at the completion of every transaction (chunk and single) in the buffer and carry out the buffer transfer.
6. Once the transfer completes, hardware sets the interrupts and disables the channel. At this time you can either respond to the buffer Complete or Transfer Complete interrupts, or poll for the Channel Handler Status Register (DMAC_CHSR.ENABLE[n]) bit until it is cleared by hardware, to detect when the transfer is complete.

39.3.5.3 Multi-buffer Transfer with Linked List for Source and Linked List for Destination (Row 4)

1. Read the Channel Enable register to choose a free (disabled) channel.
2. Set up the chain of Linked List Items (otherwise known as buffer descriptors) in memory. Write the control information in the LLI.DMAC_CTRLAx and LLI.DMAC_CTRLBx registers location of the buffer descriptor for each LLI in memory (see Figure 39-5 on page 1013) for channel x. For example, in the register, you can program the following:
   a. Set up the transfer type (memory or non-memory peripheral for source and destination) and flow control device by programming the FC of the DMAC_CTRLBx register.
   b. Set up the transfer characteristics, such as:
      – i. Transfer width for the source in the SRC_WIDTH field.
      – ii. Transfer width for the destination in the DST_WIDTH field.
      – v. Incrementing/decrementing or fixed address for source in SRC_INCR field.
      – vi. Incrementing/decrementing or fixed address for destination DST_INCR field.
3. Write the channel configuration information into the DMAC_CFGx register for channel x.
   a. Designate the handshaking interface type (hardware or software) for the source and destination peripherals. This is not required for memory. This step requires programming the SRC_H2SEL/DST_H2SEL bits, respectively. Writing a ‘1’ activates the hardware handshaking interface to handle source/destination requests for the specific channel. Writing a ‘0’ activates the software handshaking interface to handle source/destination requests.
   b. If the hardware handshaking interface is activated for the source or destination peripheral, assign the handshaking interface to the source and destination peripheral. This requires programming the SRC_PER and DST_PER bits, respectively.
4. Make sure that the LLI.DMAC_CTRLBx register locations of all LLI entries in memory (except the last) are set as shown in Row 4 of Table 39-1 on page 1010. The LLI.DMAC_CTRLBx register of the last Linked List Item must be set as described in Row 1 of Table 39-1. Figure 39-4 on page 1010 shows a Linked List example with two list items.
5. Make sure that the LLI.DMAC_DSCRx register locations of all LLI entries in memory (except the last) are non-zero and point to the base address of the next Linked List Item.
6. Make sure that the LLI.DMAC_SADDRx/LLI.DMAC_DADDRx register locations of all LLI entries in memory point to the start source/destination buffer address preceding that LLI fetch.
7. Make sure that the LLI.DMAC_CTRLAx.DONE field of the LLI.DMAC_CTRLAx register locations of all LLI entries in memory are cleared.
8. If source picture-picture mode is enabled (DMAC_CTRLBx.SRC_PIP is enabled), program the DMAC_SPIPx register for channel x.
9. If destination picture-in-picture is enabled (DMAC_CTRLBx.DST_PIP is enabled), program the DMAC_DPIPx register for channel x.
10. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the status register: DMAC_EBCISR.

11. Program the DMAC_CTRLBx, DMAC_CFGx registers according to Row 4 as shown in Table 39-1 on page 1010.
12. Program the DMAC_DSCRx register with DMAC_DSCRx(0), the pointer to the first Linked List item.
13. Finally, enable the channel by writing a ‘1’ to the DMAC_CHER.ENABLE[n] bit, where n is the channel number. The transfer is performed.
14. The DMAC fetches the first LLI from the location pointed to by DMAC_DSCRx(0).

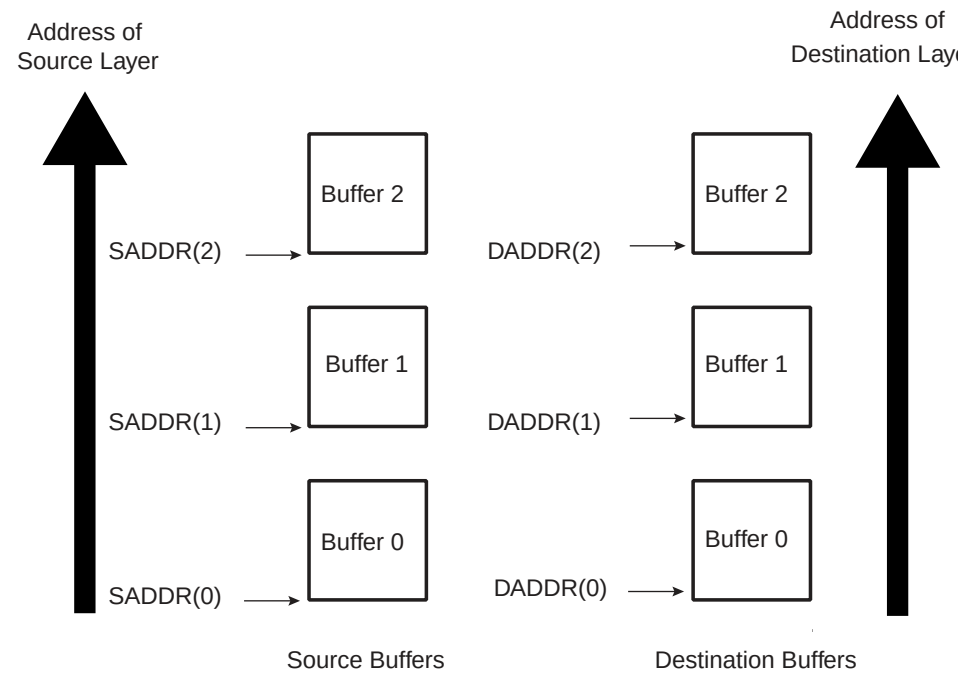
Note: The LLI.DMAC_SADDRx, LLI. DMAC_DADDRx, LLI.DMAC_DSCRx, LLI.DMAC_CTRLAx and LLI.DMAC_CTRLBx registers are fetched. The DMAC automatically reprograms the DMAC_SADDRx, DMAC_DADDRx, DMAC_DSCRx, DMAC_CTRLBx and DMAC_CTRLAx channel registers from the DMAC_DSCRx(0).

15. Source and destination request single and chunk DMAC transactions to transfer the buffer of data (assuming non-memory peripheral). The DMAC acknowledges at the completion of every transaction (chunk and single) in the buffer and carry out the buffer transfer.
16. Once the buffer of data is transferred, the DMAC_CTRLAx register is written out to system memory at the same location and on the same layer where it was originally fetched, that is, the location of the DMAC_CTRLAx register of the linked list item fetched prior to the start of the buffer transfer. Only DMAC_CTRLAx register is written out because only the DMAC_CTRLAx.BTSIZE and DMAC_CTRLAX.DONE bits have been updated by DMAC hardware. Additionally, the DMAC_CTRLAx.DONE bit is asserted when the buffer transfer has completed.

Note: Do not poll the DMAC_CTRLAx.DONE bit in the DMAC memory map. Instead, poll the LLI.DMAC_CTRLAx.DONE bit in the LLI for that buffer. If the poll LLI.DMAC_CTRLAx.DONE bit is asserted, then this buffer transfer has completed. This LLI.DMAC_CTRLAx.DONE bit was cleared at the start of the transfer.

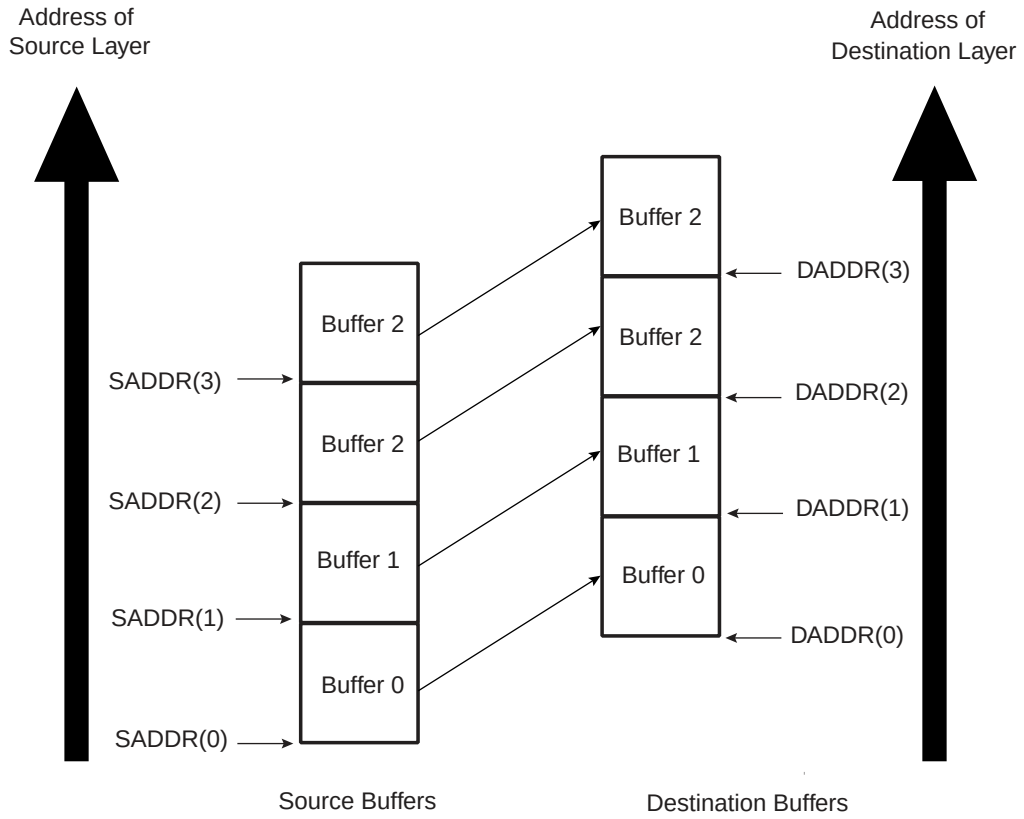
17. The DMAC does not wait for the buffer interrupt to be cleared, but continues fetching the next LLI from the memory location pointed to by current DMAC_DSCRx register and automatically reprograms the DMAC_SADDRx, DMAC_DADDRx, DMAC_DSCRx, DMAC_CTRLAx and DMAC_CTRLBx channel registers. The DMAC transfer continues until the DMAC determines that the DMAC_CTRLBx and DMAC_DSCRx registers at the end of a buffer transfer match described in Row 1 of Table 39-1 on page 1010. The DMAC then knows that the previous buffer transferred was the last buffer in the DMAC transfer. The DMAC transfer might look like that shown in Figure 39-5 on page 1013.

Figure 39-5. Multi-buffer with Linked List Address for Source and Destination



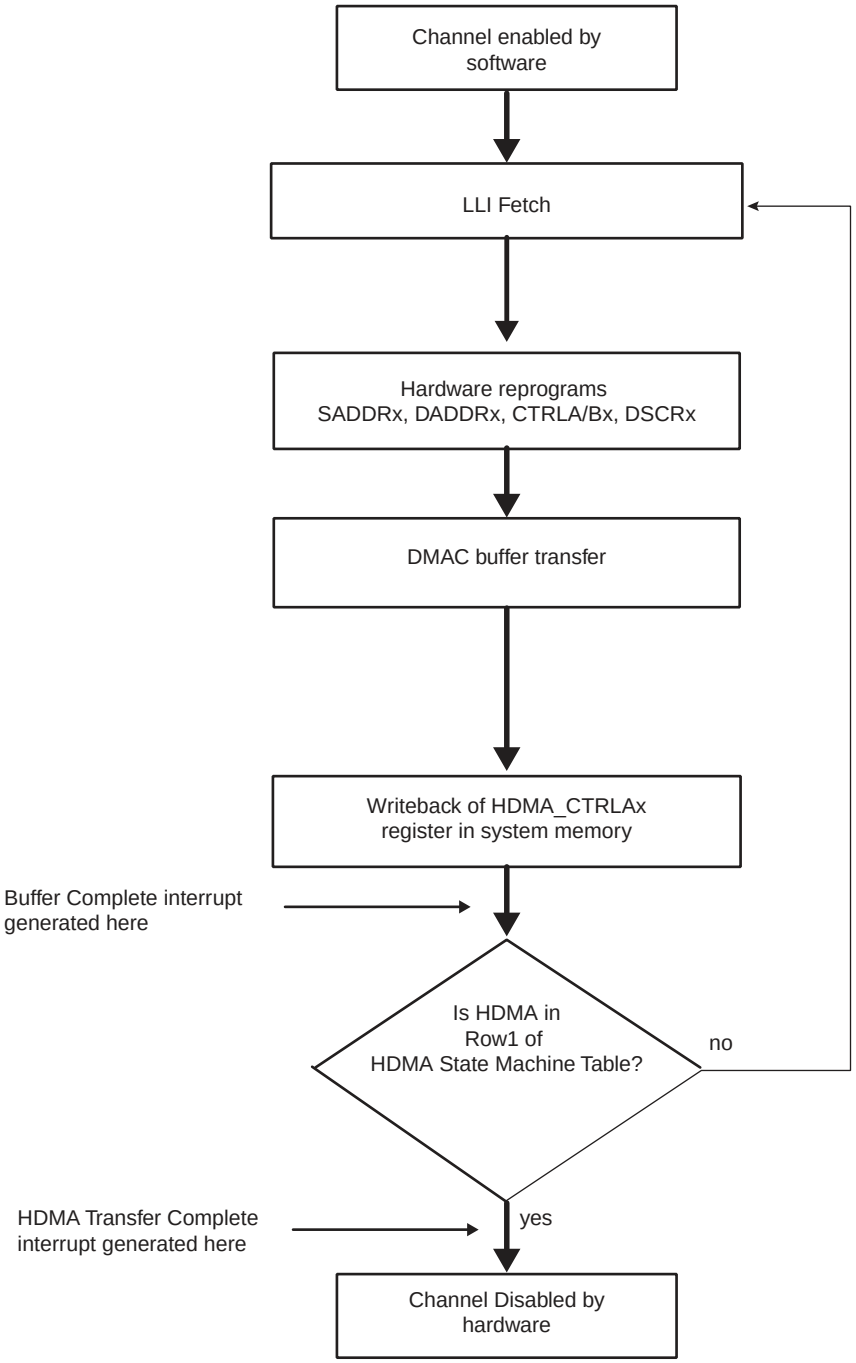
If the user needs to execute a DMAC transfer where the source and destination address are contiguous but the amount of data to be transferred is greater than the maximum buffer size DMAC_CTRLAx.BTSIZE, then this can be achieved using the type of multi-buffer transfer as shown in Figure 39-6 on page 1014.

Figure 39-6. Multi-buffer with Linked Address for Source and Destination Buffers are Contiguous



The DMAC transfer flow is shown in Figure 39-7 on page 1015.

Figure 39-7. DMAC Transfer Flow for Source and Destination Linked List Address



39.3.5.4 Multi-buffer DMAC Transfer with Linked List for Source and Contiguous Destination Address (Row 2)

1. Read the Channel Enable register to choose a free (disabled) channel.
2. Set up the linked list in memory. Write the control information in the LLI.DMAC_CTRLAx and LLI.DMAC_CTRLBx register location of the buffer descriptor for each LLI in memory for channel x. For example, in the register, you can program the following:
   a. Set up the transfer type (memory or non-memory peripheral for source and destination) and flow control device by programming the FC of the DMAC_CTRLBx register.
   b. Set up the transfer characteristics, such as:
   - i. Transfer width for the source in the SRC_WIDTH field.
   - ii. Transfer width for the destination in the DST_WIDTH field.
   - v. Incrementing/decrementing or fixed address for source in SRC_INCR field.
   - vi. Incrementing/decrementing or fixed address for destination DST_INCR field.
3. Write the starting destination address in the DMAC_DADDRx register for channel x.

Note: The values in the LLI.DMAC_DADDRx register location of each Linked List Item (LLI) in memory, although fetched during an LLI fetch, are not used.

4. Write the channel configuration information into the DMAC_CFGx register for channel x.
   a. Designate the handshaking interface type (hardware or software) for the source and destination peripherals. This is not required for memory. This step requires programming the SRC_H2SEL/DST_H2SEL bits, respectively. Writing a '1' activates the hardware handshaking interface to handle source/destination requests for the specific channel. Writing a '0' activates the software handshaking interface to handle source/destination requests.
   b. If the hardware handshaking interface is activated for the source or destination peripheral, assign handshaking interface to the source and destination peripherals. This requires programming the SRC_PER and DST_PER bits, respectively.
5. Make sure that all LLI.DMAC_CTRLBx register locations of the LLI (except the last) are set as shown in Row 2 of Table 39-1 on page 1010, while the LLI.DMAC_CTRLBx register of the last Linked List item must be set as described in Row 1 of Table 39-1. Figure 39-4 on page 1010 shows a Linked List example with two list items.
6. Make sure that the LLI.DMAC_DSCRx register locations of all LLIs in memory (except the last) are non-zero and point to the next Linked List Item.
7. Make sure that the LLI.DMAC_SADDRx register location of all LLIs in memory point to the start source buffer address proceeding that LLI fetch.
8. Make sure that the LLI.DMAC_CTRLAx.DONE field of the LLI.DMAC_CTRLAx register locations of all LLIs in memory is cleared.
9. Clear any pending interrupts on the channel from the previous DMAC transfer by reading the interrupt status register.
10. Program the DMAC_CTRLAx, DMAC_CTRLBx and DMAC_CFGx registers according to Row 2 as shown in Table 39-1 on page 1010
11. Program the DMAC_DSCRx register with DMAC_DSCRx(0), the pointer to the first Linked List item.
12. Finally, enable the channel by writing a '1' to the DMAC_CHER.ENABLE[n] bit. The transfer is performed. Make sure that bit 0 of the DMAC_EN register is enabled.
13. The DMAC fetches the first LLI from the location pointed to by DMAC_DSCRx(0).

Note: The LLI.DMAC_SADDRx, LLI.DMAC_DADDRx, LLI.DMAC_DSCRx and LLI.DMAC_CTRLA/Bx registers are fetched. The LLI.DMAC_DADDRx register location of the LLI although fetched is not used. The DMAC_DADDRx register in the DMAC remains unchanged.

14. Source and destination requests single and chunk DMAC transactions to transfer the buffer of data (assuming non-memory peripherals). The DMAC acknowledges at the completion of every transaction (chunk and single) in the buffer and carry out the buffer transfer

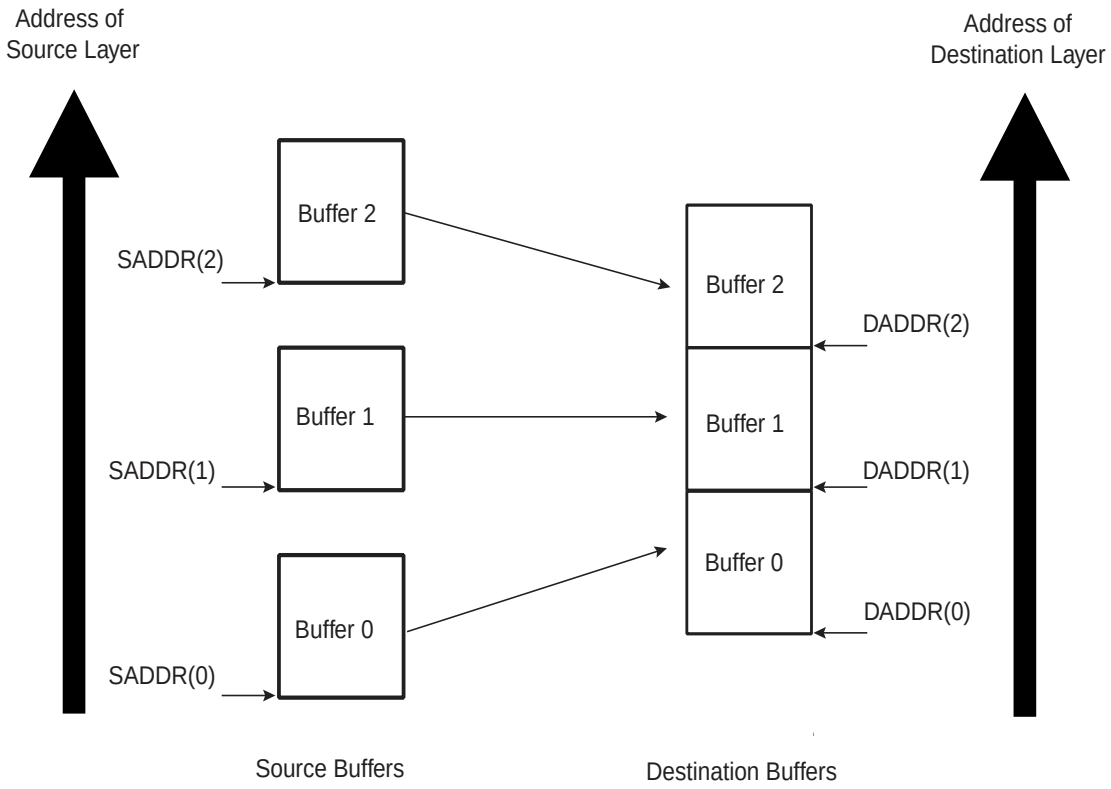
15. Once the buffer of data is transferred, the DMAC_CTRLAx register is written out to system memory at the same location and on the same layer (DMAC_DSCRx.DSCR_IF) where it was originally fetched, that is, the location of the DMAC_CTRLAx register of the linked list item fetched prior to the start of the buffer transfer. Only DMAC_CTRLAx register is written out because only the DMAC_CTRLAx.BTSIZE and DMAC_CTRLAX.DONE fields have been updated by DMAC hardware. Additionally, the DMAC_CTRLAx.DONE bit is asserted when the buffer transfer has completed.

Note: Do not poll the DMAC_CTRLAx.DONE bit in the DMAC memory map. Instead, poll the LLI.DMAC_CTRLAx.DONE bit in the LLI for that buffer. If the poll LLI.DMAC_CTRLAx.DONE bit is asserted, then this buffer transfer has completed. This LLI.DMAC_CTRLAx.DONE bit was cleared at the start of the transfer.

16. The DMAC does not wait for the buffer interrupt to be cleared, but continues and fetches the next LLI from the memory location pointed to by current DMAC_DSCRx register and automatically reprograms the DMAC_SADDRx, DMAC_CTRLAx, DMAC_CTRLBx and DMAC_DSCRx channel registers. The DMAC_DADDRx register is left unchanged. The DMAC transfer continues until the DMAC samples the DMAC_CTRLAx, DMAC_CTRLBx and DMAC_DSCRx registers at the end of a buffer transfer match that described in Row 1 of Table 39-1 on page 1010. The DMAC then knows that the previous buffer transferred was the last buffer in the DMAC transfer.

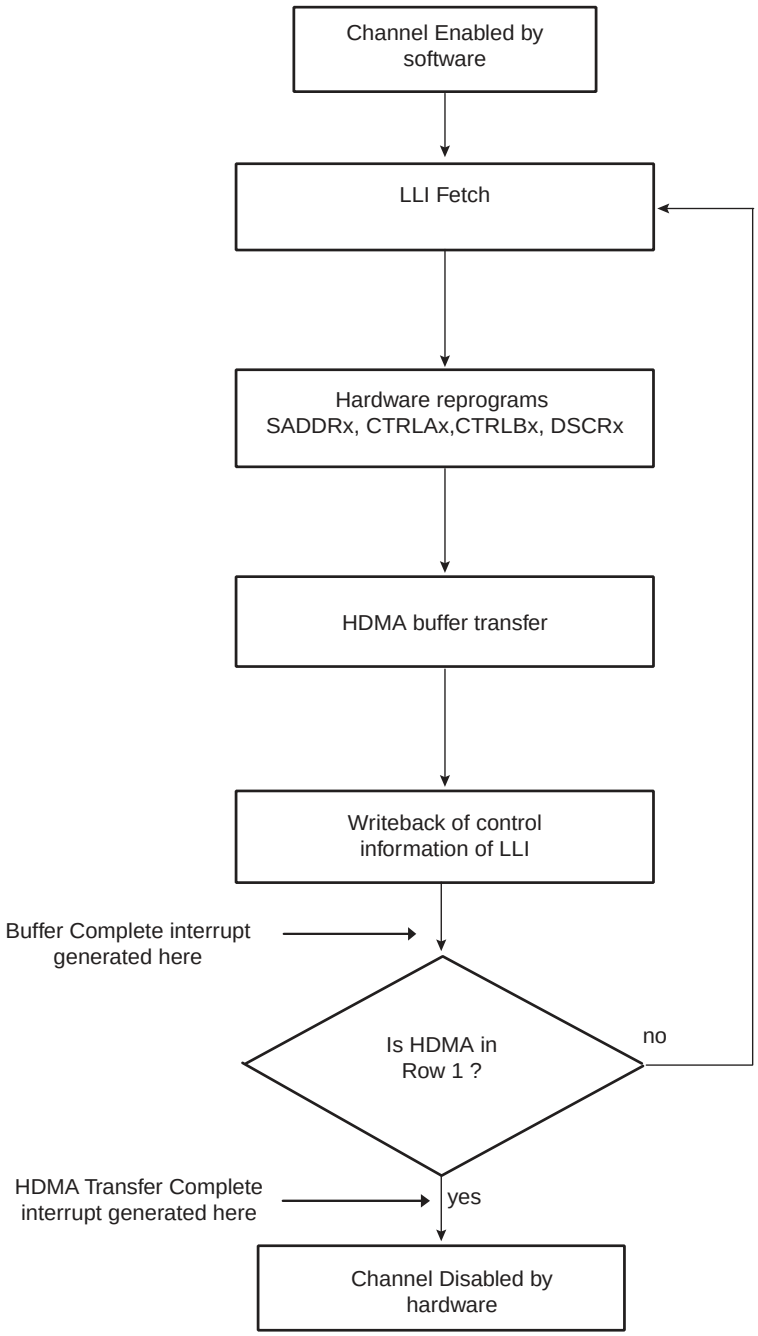
The DMAC transfer might look like that shown in Figure 39-8 on page 1017 Note that the destination address is decrementing.

Figure 39-8. DMAC Transfer with Linked List Source Address and Contiguous Destination Address



The DMAC transfer flow is shown in Figure 39-9 on page 1018.

Figure 39-9. DMAC Transfer Flow for Linked List Source Address and Contiguous Destination Address



39.3.6 Disabling a Channel Prior to Transfer Completion

Under normal operation, software enables a channel by writing a ‘1’ to the Channel Handler Enable Register, DMAC_CHER.ENABLE[n], and hardware disables a channel on transfer completion by clearing the DMAC_CHSR.ENABLE[n] register bit.

The recommended way for software to disable a channel without losing data is to use the SUSPEND[n] bit in conjunction with the EMPTY[n] bit in the Channel Handler Status Register.

1. If software wishes to disable a channel n prior to the DMAC transfer completion, then it can set the DMAC_CHER.SUSPEND[n] bit to tell the DMAC to halt all transfers from the source peripheral. Therefore, the channel FIFO receives no new data.
2. Software can now poll the DMAC_CHSR.EMPTY[n] bit until it indicates that the channel n FIFO is empty, where n is the channel number.
3. The DMAC_CHER.ENABLE[n] bit can then be cleared by software once the channel n FIFO is empty, where n is the channel number.

When DMAC_CTRLAx.SRC_WIDTH is less than DMAC_CTRLAx.DST_WIDTH and the DMAC_CHSRx.SUSPEND[n] bit is high, the DMAC_CHSRx.EMPTY[n] is asserted once the contents of the FIFO do not permit a single word of DMAC_CTRLAx.DST_WIDTH to be formed. However, there may still be data in the channel FIFO but not enough to form a single transfer of DMAC_CTLx.DST_WIDTH width. In this configuration, once the channel is disabled, the remaining data in the channel FIFO are not transferred to the destination peripheral. It is permitted to remove the channel from the suspension state by writing a ‘1’ to the DMAC_CHER.RESUME[n] field register. The DMAC transfer completes in the normal manner. n defines the channel number.

Note: If a channel is disabled by software, an active single or chunk transaction is not guaranteed to receive an acknowledgement.

39.3.6.1 Abnormal Transfer Termination

A DMAC transfer may be terminated abruptly by software by clearing the channel enable bit, DMAC_CHDR.ENABLE[n] where n is the channel number. This does not mean that the channel is disabled immediately after the DMAC_CHSR.ENABLE[n] bit is cleared over the APB interface. Consider this as a request to disable the channel. The DMAC_CHSR.ENABLE[n] must be polled and then it must be confirmed that the channel is disabled by reading back 0.

Software may terminate all channels abruptly by clearing the global enable bit in the DMAC Configuration Register (DMAC_EN.ENABLE bit). Again, this does not mean that all channels are disabled immediately after the DMAC_EN.ENABLE is cleared over the APB slave interface. Consider this as a request to disable all channels. The DMAC_CHSR.ENABLE must be polled and then it must be confirmed that all channels are disabled by reading back ‘0’.

Note: If the channel enable bit is cleared while there is data in the channel FIFO, this data is not sent to the destination peripheral and is not present when the channel is re-enabled. For read sensitive source peripherals, such as a source FIFO, this data is therefore lost. When the source is not a read sensitive device (i.e., memory), disabling a channel without waiting for the channel FIFO to empty may be acceptable as the data is available from the source peripheral upon request and is not lost.

Note: If a channel is disabled by software, an active single or chunk transaction is not guaranteed to receive an acknowledgement.

39.4 DMAC Software Requirements

- There must not be any write operation to Channel registers in an active channel after the channel enable is made HIGH. If any channel parameters must be reprogrammed, this can only be done after disabling the DMAC channel.
- You must program the DMAC_SADDRx and DMAC_DADDRx channel registers with a byte, half-word and word aligned address depending on the source width and destination width.
- After the software disables a channel by writing into the channel disable register, it must re-enable the channel only after it has polled a 0 in the corresponding channel enable status register. This is because the current AHB Burst must terminate properly.
- If you program the BTSIZE field in the DMAC_CTRLA, as zero, and the DMAC is defined as the flow controller, then the channel is automatically disabled.
- When hardware handshaking interface protocol is fully implemented, a peripheral is expected to deassert any sreq or breq signals on receiving the ack signal irrespective of the request the ack was asserted in response to.
- Multiple Transfers involving the same peripheral must not be programmed and enabled on different channel, unless this peripheral integrates several hardware handshaking interface.
- When a Peripheral is flow controller, the targeted DMAC Channel must be enabled before the Peripheral. If you do not ensure this the DMAC Channel might miss a Last Transfer Flag, if the First DMAC request is also the last transfer.

39.5 DMA Controller (DMAC) User Interface

Table 39-2. Register Mapping

Offset	Register	Name	Access	Reset
0x000	DMAC Global Configuration Register	DMAC_GCFG	Read-write	0x10
0x004	DMAC Enable Register	DMAC_EN	Read-write	0x0
0x008	DMAC Software Single Request Register	DMAC_SREQ	Read-write	0x0
0x00C	DMAC Software Chunk Transfer Request Register	DMAC_CREQ	Read-write	0x0
0x010	DMAC Software Last Transfer Flag Register	DMAC_LAST	Read-write	0x0
0x014	Reserved	–	–	–
0x018	DMAC Error, Chained Buffer transfer completed and Buffer transfer completed Interrupt Enable register.	DMAC_EBCIER	Write-only	–
0x01C	DMAC Error, Chained Buffer transfer completed and Buffer transfer completed Interrupt Disable register.	DMAC_EBCIDR	Write-only	–
0x020	DMAC Error, Chained Buffer transfer completed and Buffer transfer completed Mask Register.	DMAC_EBCIMR	Read-only	0x0
0x024	DMAC Error, Chained Buffer transfer completed and Buffer transfer completed Status Register.	DMAC_EBCISR	Read-only	0x0
0x028	DMAC Channel Handler Enable Register	DMAC_CHER	Write-only	–
0x02C	DMAC Channel Handler Disable Register	DMAC_CHDR	Write-only	–
0x030	DMAC Channel Handler Status Register	DMAC_CHSR	Read-only	0x00FF0000
0x034	Reserved	–	–	–
0x038	Reserved	–	–	–
0x03C+ch_num*(0x28)+(0x0)	DMAC Channel Source Address Register	DMAC_SADDR	Read-write	0x0
0x03C+ch_num*(0x28)+(0x4)	DMAC Channel Destination Address Register	DMAC_DADDR	Read-write	0x0
0x03C+ch_num*(0x28)+(0x8)	DMAC Channel Descriptor Address Register	DMAC_DSCR	Read-write	0x0
0x03C+ch_num*(0x28)+(0xC)	DMAC Channel Control A Register	DMAC_CTRLA	Read-write	0x0
0x03C+ch_num*(0x28)+(0x10)	DMAC Channel Control B Register	DMAC_CTRLB	Read-write	0x0
0x03C+ch_num*(0x28)+(0x14)	DMAC Channel Configuration Register	DMAC_CFG	Read-write	0x01000000
0x03C+ch_num*(0x28)+(0x18)	Reserved	–	–	–
0x03C+ch_num*(0x28)+(0x1C)	Reserved	–	–	–
0x03C+ch_num*(0x28)+(0x20)	Reserved	–	–	–
0x03C+ch_num*(0x28)+(0x24)	Reserved	–	–	–
0x064 - 0xC8	DMAC Channel 1 to 3 Register(1)		Read-write	0x0
0x017C- 0x1FC	Reserved	–	–	–

Note: 1. The addresses for the DMAC registers shown here are for DMA Channel 0. This sequence of registers is repeated successively for each DMA channel located between 0x064 and 0xC8.

39.5.1 DMAC Global Configuration Register

Name: DMAC_GCFG

Address: 0x400B0000

Access: Read-write

Reset: 0x00000010

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	ARB_CFG	–	–	–	–

- **ARB_CFG**

0: Fixed priority arbiter.

1: Modified round robin arbiter.

39.5.2 DMAC Enable Register

Name: DMAC_EN

Address: 0x400B0004

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	ENABLE

- **ENABLE**

0: DMA Controller is disabled.

1: DMA Controller is enabled.

39.5.3 DMAC Software Single Request Register

Name: DMAC_SREQ

Address: 0x400B0008

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
DSREQ3	SSREQ3	DSREQ2–	SSREQ2–	DSREQ1	SSREQ1	DSREQ0	SSREQ0

- **DSREQx**

Request a destination single transfer on channel i.

- **SSREQx**

Request a source single transfer on channel i.

39.5.4 DMAC Software Chunk Transfer Request Register

Name: DMAC_CREQ

Address: 0x400B000C

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
DCREQ3	SCREQ3	DCREQ2–	SCREQ2–	DCREQ1	SCREQ1	DCREQ0	SCREQ0

- **DCREQx**

Request a destination chunk transfer on channel i.

- **SCREQx**

Request a source chunk transfer on channel i.

39.5.5 DMAC Software Last Transfer Flag Register

Name: DMAC_LAST

Address: 0x400B0010

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–

23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
DLAST3	SLAST3	DLAST2	SLAST2	DLAST1	SLAST1	DLAST0	SLAST0

- **DLASTx**

Writing one to DLASTx prior to writing one to DSREQx or DCREQx indicates that this destination request is the last transfer of the buffer.

- **SLASTx**

Writing one to SLASTx prior to writing one to SSREQx or SCREQx indicates that this source request is the last transfer of the buffer.

39.5.6 DMAC Error, Buffer Transfer and Chained Buffer Transfer Interrupt Enable Register

Name: DMAC_EBCIER

Address: 0x400B0018

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	ERR3	ERR2	ERR1	ERR0
15	14	13	12	11	10	9	8
–	–	–	–	CBTC3	CBTC2	CBTC1	CBTC0
7	6	5	4	3	2	1	0
–	–	–	–	BTC3	BTC2	BTC1	BTC0

- **BTC[3:0]**

Buffer Transfer Completed Interrupt Enable Register. Set the relevant bit in the BTC field to enable the interrupt for channel i.

- **CBTC[3:0]**

Chained Buffer Transfer Completed Interrupt Enable Register. Set the relevant bit in the CBTC field to enable the interrupt for channel i.

- **ERR[3:0]**

Access Error Interrupt Enable Register. Set the relevant bit in the ERR field to enable the interrupt for channel i.

39.5.7 DMAC Error, Buffer Transfer and Chained Buffer Transfer Interrupt Disable Register

Name: DMAC_EBCIDR

Address: 0x400B001C

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	ERR3	ERR2	ERR1	ERR0
15	14	13	12	11	10	9	8
–	–	–	–	CBTC3	CBTC2	CBTC1	CBTC0
7	6	5	4	3	2	1	0
–	–	–	–	BTC3	BTC2	BTC1	BTC0

- **BTC[3:0]**

Buffer transfer completed Disable Interrupt Register. When set, a bit of the BTC field disables the interrupt from the relevant DMAC channel.

- **CBTC[3:0]**

Chained Buffer transfer completed Disable Register. When set, a bit of the CBTC field disables the interrupt from the relevant DMAC channel.

- **ERR[3:0]**

Access Error Interrupt Disable Register. When set, a bit of the ERR field disables the interrupt from the relevant DMAC channel.

39.5.8 DMAC Error, Buffer Transfer and Chained Buffer Transfer Interrupt Mask Register

Name: DMAC_EBCIMR

Address: 0x400B0020

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	ERR3	ERR2	ERR1	ERR0
15	14	13	12	11	10	9	8
–	–	–	–	CBTC3	CBTC2	CBTC1	CBTC0
7	6	5	4	3	2	1	0
–	–	–	–	BTC3	BTC2	BTC1	BTC0

- **BTC[3:0]**

0: Buffer Transfer completed interrupt is disabled for channel i.

1: Buffer Transfer completed interrupt is enabled for channel i.

- **CBTC[3:0]**

0: Chained Buffer Transfer interrupt is disabled for channel i.

1: Chained Buffer Transfer interrupt is enabled for channel i.

- **ERR[3:0]**

0: Transfer Error Interrupt is disabled for channel i.

1: Transfer Error Interrupt is enabled for channel i.

39.5.9 DMAC Error, Buffer Transfer and Chained Buffer Transfer Status Register

Name: DMAC_EBCISR

Address: 0x400B0024

Access: Read-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	ERR3	ERR2	ERR1	ERR0
15	14	13	12	11	10	9	8
–	–	–	–	CBTC3	CBTC2	CBTC1	CBTC0
7	6	5	4	3	2	1	0
–	–	–	–	BTC3	BTC2	BTC1	BTC0

- **BTC[3:0]**

When BTC[*i*] is set, Channel *i* buffer transfer has terminated.

- **CBTC[3:0]**

When CBTC[*i*] is set, Channel *i* Chained buffer has terminated. LLI Fetch operation is disabled.

- **ERR[3:0]**

When ERR[*i*] is set, Channel *i* has detected an AHB Read or Write Error Access.

39.5.10 DMAC Channel Handler Enable Register

Name: DMAC_CHER

Address: 0x400B0028

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	KEEP3	KEEP2	KEEP1	KEEP0
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	SUSP3	SUSP2	SUSP1	SUSP0
7	6	5	4	3	2	1	0
–	–	–	–	ENA3	ENA2	ENA1	ENA0

- **ENA[3:0]**

When set, a bit of the ENA field enables the relevant channel.

- **SUSP[3:0]**

When set, a bit of the SUSP field freezes the relevant channel and its current context.

- **KEEP[3:0]**

When set, a bit of the KEEP field resumes the current channel from an automatic stall state.

39.5.11 DMAC Channel Handler Disable Register

Name: DMAC_CHDR

Address: 0x400B002C

Access: Write-only

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	RES3	RES2	RES1	RES0
7	6	5	4	3	2	1	0
–	–	–	–	DIS3	DIS2	DIS1	DIS0

- **DIS[3:0]**

Write one to this field to disable the relevant DMAC Channel. The content of the FIFO is lost and the current AHB access is terminated. Software must poll DIS[3:0] field in the DMAC_CHSR register to be sure that the channel is disabled.

- **RES[3:0]**

Write one to this field to resume the channel transfer restoring its context.

39.5.12 DMAC Channel Handler Status Register

Name: DMAC_CHSR

Address: 0x400B0030

Access: Read-only

Reset: 0x00FF0000

31	30	29	28	27	26	25	24
–	–	–	–	STAL3	STAL2	STAL1	STAL0
23	22	21	20	19	18	17	16
–	–	–	–	EMPT3	EMPT2	EMPT1	EMPT0
15	14	13	12	11	10	9	8
–	–	–	–	SUSP3	SUSP2	SUSP1	SUSP0
7	6	5	4	3	2	1	0
–	–	–	–	ENA3	ENA2	ENA1	ENA0

- **ENA[3:0]**

A one in any position of this field indicates that the relevant channel is enabled.

- **SUSP[3:0]**

A one in any position of this field indicates that the channel transfer is suspended.

- **EMPT[3:0]**

A one in any position of this field indicates that the relevant channel is empty.

- **STAL[3:0]**

A one in any position of this field indicates that the relevant channel is stalling.

39.5.13 DMAC Channel x [x = 0..3] Source Address Register

Name: DMAC_SADDRx [x = 0..3]

Addresses: 0x400B003C [0], 0x400B0064 [1], 0x400B008C [2], 0x400B00B4 [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
SADDRx							

23	22	21	20	19	18	17	16
SADDRx							

15	14	13	12	11	10	9	8
SADDRx							

7	6	5	4	3	2	1	0
SADDRx							

- **SADDRx**

Channel x source address. This register must be aligned with the source transfer width.

39.5.14 DMAC Channel x [x = 0..3] Destination Address Register

Name: DMAC_DADDRx [x = 0..3]

Addresses: 0x400B0040 [0], 0x400B0068 [1], 0x400B0090 [2], 0x400B00B8 [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
DADDRx							

23	22	21	20	19	18	17	16
DADDRx							

15	14	13	12	11	10	9	8
DADDRx							

7	6	5	4	3	2	1	0
DADDRx							

- **DADDRx**

Channel x destination address. This register must be aligned with the destination transfer width.

39.5.15 DMAC Channel x [x = 0..3] Descriptor Address Register

Name: DMAC_DSCRx [x = 0..3]

Addresses: 0x400B0044 [0], 0x400B006C [1], 0x400B0094 [2], 0x400B00BC [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
DSCRx							

23	22	21	20	19	18	17	16
DSCRx							

15	14	13	12	11	10	9	8
DSCRx							

7	6	5	4	3	2	1	0
DSCRx						–	

- **DSCRx**

Buffer Transfer descriptor address. This address is word aligned.

39.5.16 DMAC Channel x [x = 0..3] Control A Register

Name: DMAC_CTRLAx [x = 0..3]

Addresses: 0x400B0048 [0], 0x400B0070 [1], 0x400B0098 [2], 0x400B00C0 [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
DONE	–	DST_WIDTH		–	–	SRC_WIDTH	

23	22	21	20	19	18	17	16
–	–	–	DCSIZE	–	–	–	SCSIZE

15	14	13	12	11	10	9	8
				BTSIZE			

7	6	5	4	3	2	1	0
BTSIZE							

- **BTSIZE**

Buffer Transfer Size. The transfer size relates to the number of transfers to be performed, that is, for writes it refers to the number of source width transfers to perform when DMAC is flow controller. For Reads, BTSIZE refers to the number of transfers completed on the Source Interface. When this field is set to 0, the DMAC module is automatically disabled when the relevant channel is enabled.

- **SCSIZE**

Source Chunk Transfer Size.

SCSIZE value	Number of data transferred
0	1
1	4

- **DCSIZE**

Destination Chunk Transfer size.

DCSIZE	Number of data transferred
0	1
1	4

- **SRC_WIDTH**

SRC_WIDTH	Single Transfer Size
00	BYTE
01	HALF-WORD
1X	WORD

- **DST_WIDTH**

DST_WIDTH	Single Transfer Size
00	BYTE
01	HALF-WORD
1X	WORD

- **DONE**

0: The transfer is performed.

1: If SOD field of DMAC_CFG register is set to true, then the DMAC is automatically disabled when an LLI updates the content of this register.

The DONE field is written back to memory at the end of the transfer.

39.5.17 DMAC Channel x [x = 0..3] Control B Register

Name: DMAC_CTRLBx [x = 0..3]

Addresses: 0x400B004C [0], 0x400B0074 [1], 0x400B009C [2], 0x400B00C4 [3]

Access: Read-write

Reset: 0x00000000

31	30	29	28	27	26	25	24
–	IEN	DST_INCR		–	–	SRC_INCR	

23	22	21	20	19	18	17	16
–	FC		DST_DSCR	–	–	–	SRC_DSCR

15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	–

- **SRC_DSCR**

0: Source address is updated when the descriptor is fetched from the memory.

1: Buffer Descriptor Fetch operation is disabled for the source.

- **DST_DSCR**

0: Destination address is updated when the descriptor is fetched from the memory.

1: Buffer Descriptor Fetch operation is disabled for the destination.

- **FC**

This field defines which device controls the size of the buffer transfer, also referred as to the Flow Controller.

FC	Type of transfer	Flow Controller
000	Memory-to-Memory	DMA Controller
001	Memory-to-Peripheral	DMA Controller
010	Peripheral-to-Memory	DMA Controller
011	Peripheral-to-Peripheral	DMA Controller

- **SRC_INCR**

SRC_INCR	Type of addressing mode
00	INCREMENTING
10	FIXED

- **DST_INCR**

DST_INCR	Type of addressing scheme
00	INCREMENTING
10	FIXED

- **IEN**

If this bit is cleared, when the buffer transfer is completed, the BTC[x] flag is set in the EBCISR status register. This bit is active low.

39.5.18 DMAC Channel x [x = 0..3] Configuration Register

Name: DMAC_CFGx [x = 0..3]

Addresses: 0x400B0050 [0], 0x400B0078 [1], 0x400B00A0 [2], 0x400B00C8 [3]

Access: Read-write

Reset: 0x0100000000

31	30	29	28	27	26	25	24
–	–	FIFOCFG		–	AHB_PROT		

23	22	21	20	19	18	17	16
–	LOCK_IF_L	LOCK_B	LOCK_IF	–	–	–	SOD

15	14	13	12	11	10	9	8
–	–	DST_H2SEL	–	–	–	SRC_H2SEL	–

7	6	5	4	3	2	1	0
DST_PER				SRC_PER			

- **SRC_PER**

Channel x Source Request is associated with peripheral identifier coded SRC_PER handshaking interface.

- **DST_PER**

Channel x Destination Request is associated with peripheral identifier coded DST_PER handshaking interface.

- **SRC_H2SEL**

0: Software handshaking interface is used to trigger a transfer request.

1: Hardware handshaking interface is used to trigger a transfer request.

- **DST_H2SEL**

0: Software handshaking interface is used to trigger a transfer request.

1: Hardware handshaking interface is used to trigger a transfer request.

- **SOD**

0: STOP ON DONE disabled, the descriptor fetch operation ignores DONE Field of CTRLA register.

1: STOP ON DONE activated, the DMAC module is automatically disabled if DONE FIELD is set to 1.

- **LOCK_IF**

0: Interface Lock capability is disabled

1: Interface Lock capability is enabled

- **LOCK_B**

0: AHB Bus Locking capability is disabled.

1: AHB Bus Locking capability is enabled.

- **LOCK_IF_L**

0: The Master Interface Arbiter is locked by the channel x for a chunk transfer.

1: The Master Interface Arbiter is locked by the channel x for a buffer transfer.

- **AHB_PROT**

AHB_PROT field provides additional information about a bus access and is primarily used to implement some level of protection.

HPROT[3]	HPROT[2]	HPROT[1]	HPROT[0]	Description
			1	Data access
		AHB_PROT[0]		0: User Access 1: Privileged Access
	AHB_PROT[1]			0: Not Bufferable 1: Bufferable
AHB_PROT[2]				0: Not cacheable 1: Cacheable

- **FIFOCFG**

FIFOCFG	FIFO request
00	The largest defined length AHB burst is performed on the destination AHB interface.
01	When half FIFO size is available/filled, a source/destination request is serviced.
10	When there is enough space/data available to perform a single AHB access, then the request is serviced.

40. 12-bit Analog-to-Digital Converter (ADC12B)

40.1 Description

The ADC12B is based on a Cyclic Pipeline 12-bit Analog-to-Digital Converter (ADC12B).

It also integrates an 8-to-1 analog multiplexer, making possible the analog-to-digital conversions of 8 analog lines. The conversions extend from 0V to AD12BVREF.

The ADC12B supports a 10-bit or 12-bit resolution mode, and conversion results are reported in a common register for all channels, as well as in a channel-dedicated register. Software trigger, external trigger on rising edge of the AD12BTRG pin, internal triggers from Timer Counter output(s) or PWM Event lines are configurable.

The ADC12B also integrates a Sleep Mode and a conversion sequencer and connects with a PDC channel. These features reduce both power consumption and processor intervention.

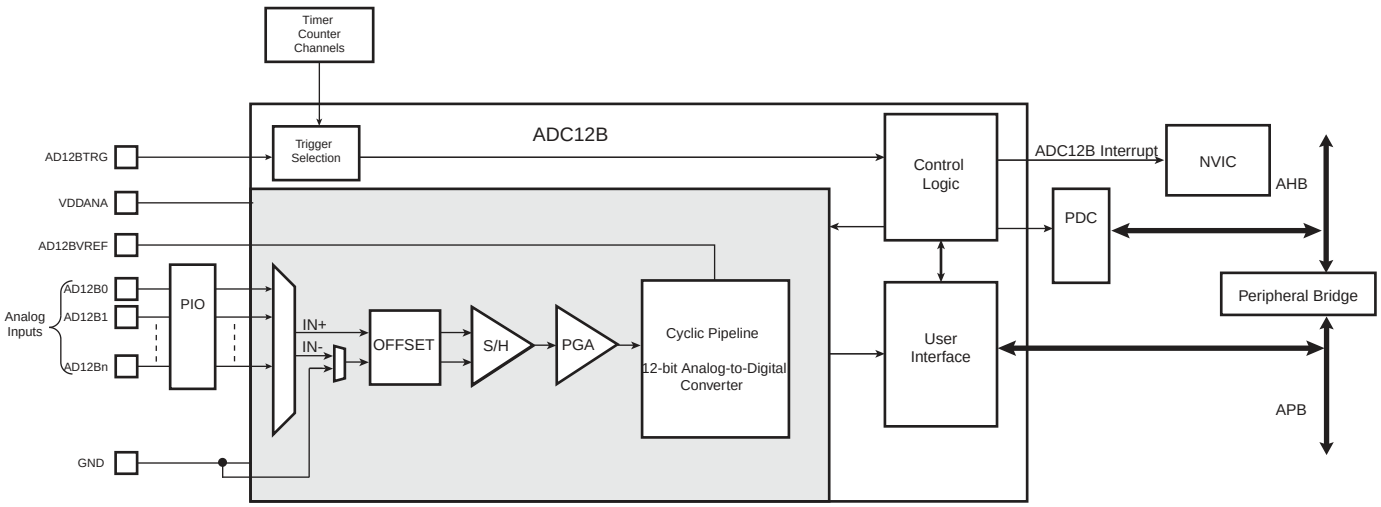
This ADC12B has a selectable single-ended or fully differential input and benefits from a 2-bit programmable gain. A whole set of reference voltage is generated internally from a single external reference voltage node that may be equal to the analog supply voltage. An external decoupling capacitance is required for noise filtering.

A digital error correction circuit based on the multi-bit redundant signed digit (RSD) algorithm is employed in order to reduce INL and DNL errors.

Finally, the user can configure ADC12B timings, such as Startup Time and Sample & Hold Time.

40.2 Block Diagram

Figure 40-1. Analog-to-Digital Converter Block Diagram



40.3 Signal Description

Table 40-1. ADC12B Pin Description

Pin Name	Description
AD12B0 - AD12B7	Analog input channels
AD12BTRG	External trigger

40.4 Product Dependencies

40.4.1 Power Management

The ADC12B Controller is not continuously clocked. The programmer must first enable the ADC12B Controller clock in the Power Management Controller (PMC) before using the ADC12B Controller. However, if the application does not require ADC12B operations, the ADC12B Controller clock can be stopped when not needed and restarted when necessary.

Configuring the ADC12B Controller does not require the ADC12B Controller clock to be enabled.

40.4.2 Interrupt Sources

The ADC12B interrupt line is connected on one of the sources of the Nested Vectored Interrupt Controller (NVIC). Using the ADC12B interrupt requires the NVIC to be programmed first.

Table 40-2. Peripheral IDs

Instance	ID
ADC12B	26

40.4.3 Analog Inputs

The analog input pins are multiplexed with PIO lines. The assignment of the ADC12B input is automatically done as soon as the corresponding channel is enabled by writing the register ADC12B_CHER. By default, after reset, the PIO line is configured as an input with its pull-up enabled and the ADC12B input is connected to the GND.

40.4.4 I/O Lines

The AD12BTRG pin is shared with other peripheral functions through the PIO Controller. In this case, the PIO Controller needs to be set accordingly to assign the AD12BTRG pin to the ADC12B function.

Table 40-3. I/O Lines

Instance	Signal	I/O Line	Peripheral
ADC12B	AD12BTRG	PA2	B

40.4.5 Timer Triggers

Timer Counters may or may not be used as hardware triggers depending on user requirements. Thus, some or all of the timer counters may be non-connected.

40.4.6 PWM Event Lines

PWM Event Lines may or may not be used as hardware triggers depending on user requirements.

40.4.7 Conversion Performances

For performance and electrical characteristics of the ADC12B, see the DC Characteristics section of the product datasheet.

40.5 Functional Description

40.5.1 Analog-to-digital Conversion

The ADC12B uses the ADC12B Clock to perform conversions. Converting a single analog value to 12-bit digital data requires Sample and Hold Clock cycles as defined in the SHTIM field of the “ADC12B Mode Register” on page 1054 and 10 ADC12B Clock cycles. The ADC12B Clock frequency is selected in the PRESCAL field of the Mode Register (ADC12B_MR).

The ADC12B clock range is between MCK/2, if PRESCAL is 0, and MCK/128, if PRESCAL is set to 63 (0x3F). PRESCAL must be programmed in order to provide an ADC12B clock frequency according to the parameters given in the Electrical Characteristics section of the product datasheet.

40.5.2 Conversion Reference

The conversion is performed on a full range between 0V and the reference voltage pin AD12BVREF Analog inputs between these voltages convert to values based on a linear conversion.

40.5.3 Conversion Resolution

The ADC12B supports 10-bit or 12-bit resolution. The 10-bit selection is performed by setting the LOWRES bit in the ADC12B Mode Register (ADC12B_MR). By default, after a reset, the resolution is the highest and the DATA field in the data registers is fully used. By setting the LOWRES bit, the ADC12B switches in the lowest resolution and the conversion results can be read in the eight lowest significant bits of the data registers. The two highest bits of the DATA field in the corresponding ADC12B_CDR register and of the LDATA field in the ADC12B_LCDR register read 0.

Moreover, when a PDC channel is connected to the ADC12B, 12-bit or 10-bit resolution sets the transfer request size to 16 bits.

40.5.4 Differential Inputs

The ADC12B can be used either as a single ended ADC12B (DIFF bit equal to 0) or as a fully differential ADC12B (DIFF bit equal to 1) as shown in Figure 40-2. By default, after a reset, the ADC12B is in single ended mode.

The same inputs are used in single ended or differential mode.

In single ended mode, inputs are managed by an 8:1 channels analog multiplexer. In the fully differential mode, inputs are managed by a 4:1 channels analog multiplexer. See Table 40-4 and Table 40-5.

Table 40-4. Input Pins and Channel Number in Single Ended Mode

Input Pins	Channel Number
AD12B0	CH0
AD12B1	CH1
AD12B2	CH2
AD12B3	CH3
AD12B4	CH4
AD12B5	CH5
AD12B6	CH6
AD12B7	CH7

Table 40-5. Input Pins and Channel Number In Differential Mode

Input Pins	Channel Number
AD12B0-AD12B1	CH0
AD12B2-AD12B3	CH2
AD12B4-AD125B	CH4
AD12B6-AD12B7	CH6

40.5.5 Input Gain and Offset

The ADC12B has a built in Programmable Gain Amplifier (PGA) and Programmable Offset.

The Programmable Gain Amplifier can be set to gains of 1/2, 1, 2 and 4. The Programmable Gain Amplifier can be used either for single ended applications or for fully differential applications.

The gain is configurable through the GAIN bit as shown in Table 40-6.

Table 40-6. Gain of the Sample and Hold Unit: GAIN Bits and DIFF Bit.

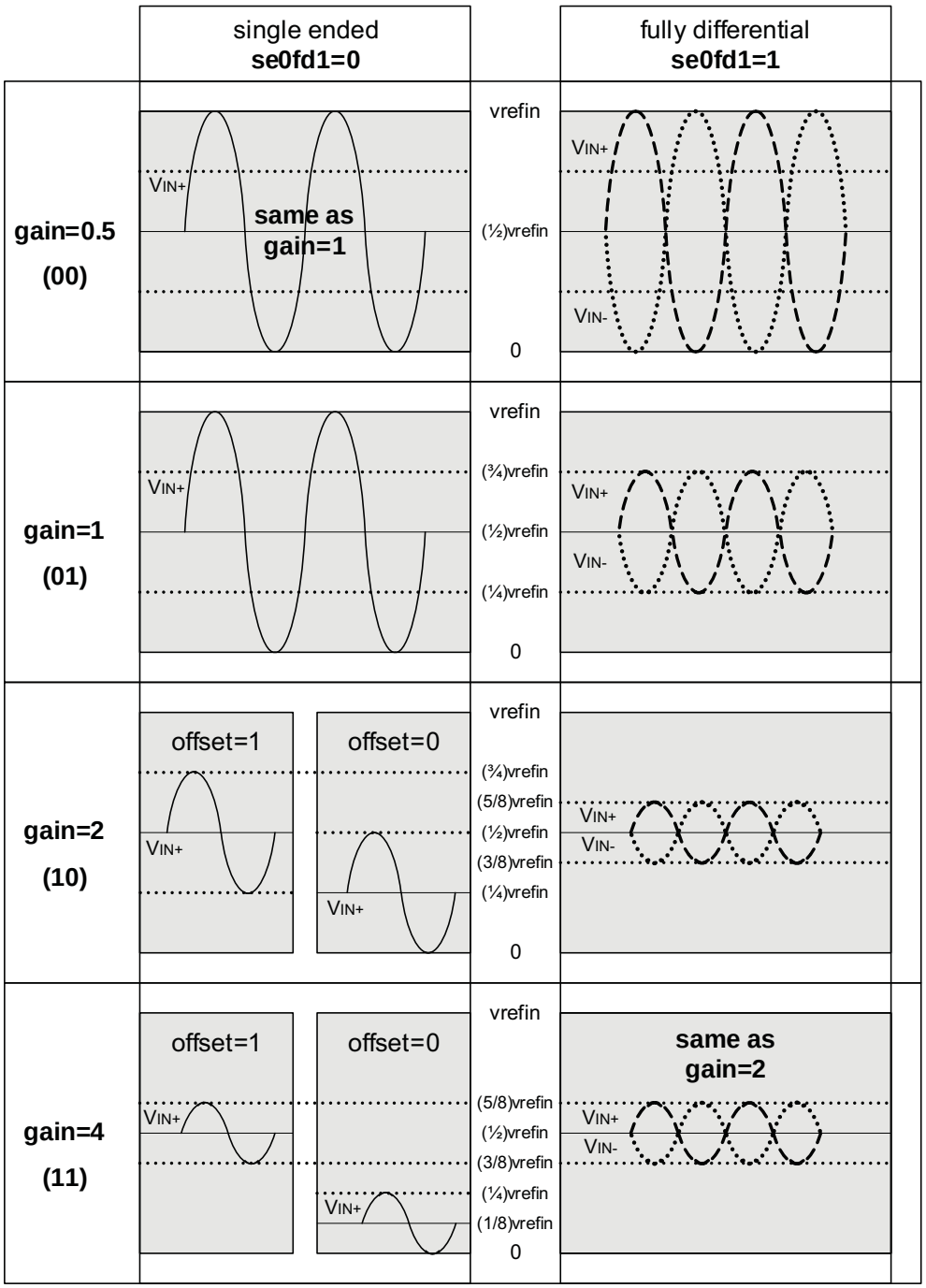
GAIN<0:1>	GAIN (DIFF = 0)	GAIN (DIFF = 1)
00	1	0.5
01	1	1
10	2	2
11	4	2

To allow full range, analog offset of the ADC12B can be configured by the OFFSET bit. The Offset can only be changed in single ended mode. In fully differential mode the offset is always set to Vrefin/2.

Table 40-7. Offset of the Sample and Hold Unit: OFFSET DIFF and Gain (G)

OFFSET Bit	OFFSET (DIFF = 0)	OFFSET (DIFF = 1)
0	Vrefin/2G	Vrefin/2
1	Vrefin/2	

Figure 40-2. Analog Full Scale Ranges in Single Ended/Differential Applications Versus Gain and Offset



40.5.6 Power Consumption Adjustment

The power consumption of the ADC12B can be adjusted through a 2-bit bias control (IBCTL bit in ADC12B_ACR register) providing possibilities for smart optimization of power and effective resolution relative to the application speed request.

Please refer to the Electrical Characteristics of the product datasheet for further details.

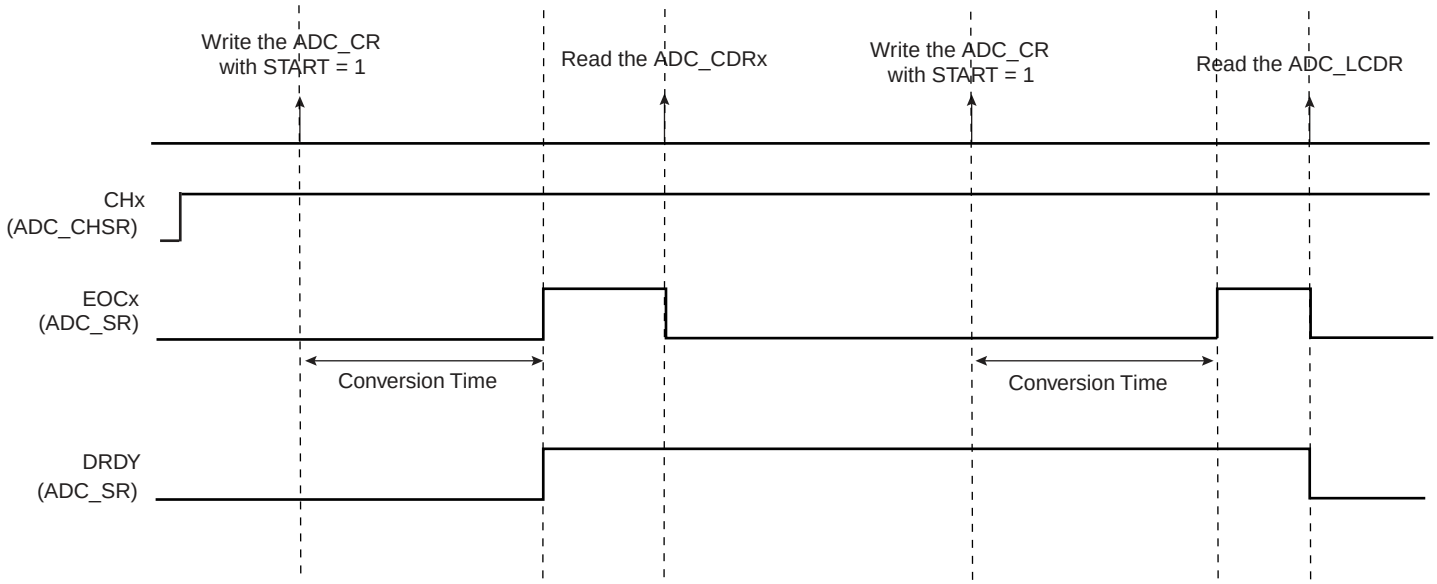
40.5.7 Conversion Results

When a conversion is completed, the resulting 12-bit digital value is stored in the Channel Data Register (ADC12B_CDR) of the current channel and in the ADC12B Last Converted Data Register (ADC12B_LCDR).

The channel EOC bit in the Status Register (ADC12B_SR) is set and the DRDY bit is set. In the case of a connected PDC channel, DRDY rising triggers a data transfer request. In any case, either EOC and DRDY can trigger an interrupt.

Reading one of the ADC12B_CDR registers clears the corresponding EOC bit. Reading ADC12B_LCDR clears the DRDY bit and the EOC bit corresponding to the last converted channel.

Figure 40-3. EOCx and DRDY Flag Behavior

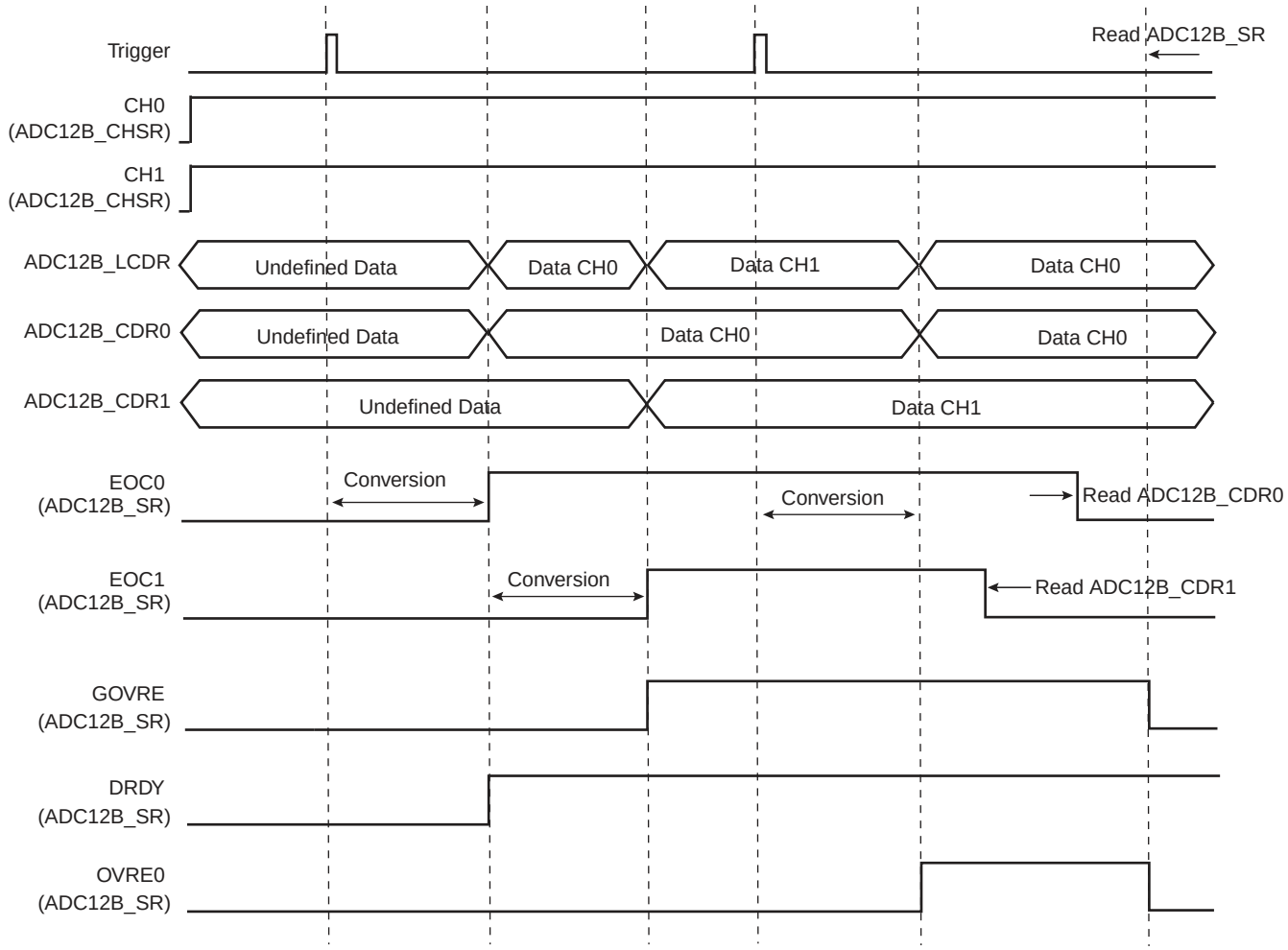


If the ADC12B_CDR is not read before further incoming data is converted, the corresponding Overrun Error (OVRE) flag is set in the Status Register (ADC12B_SR).

Likewise, new data converted when DRDY is high sets the GOVRE bit (General Overrun Error) in ADC12B_SR.

The OVRE and GOVRE flags are automatically cleared when ADC12B_SR is read.

Figure 40-4. GOVRE and OVREx Flag Behavior



Warning: If the corresponding channel is disabled during a conversion or if it is disabled and then reenabled during a conversion, its associated data and its corresponding EOC and OVRE flags in ADC12B_SR are unpredictable.

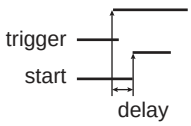
The ADC12B can be triggered externally by software or internally from the Timer Counter or PWM.

40.5.8 Conversion Triggers

Conversions of the active analog channels are started with a software or a hardware trigger. The software trigger is provided by writing the Control Register (ADC12B_CR) with the START bit at 1.

The hardware trigger can be one of the TIOA outputs of the Timer Counter channels, PWM Event lines or the external trigger input of the ADC12B (AD12BTRG). The hardware trigger is selected with the field TRGSEL in the Mode Register (ADC12B_MR). The selected hardware trigger is enabled with the TRGEN bit in the Mode Register (ADC12B_MR).

If a hardware trigger is selected, the start of a conversion is triggered after a delay starting at each rising edge of the selected signal. Due to asynchronous handling, the delay may vary in a range of 2 MCK clock periods to 1 ADC12B clock period.



If one of the TIOA outputs is selected, the corresponding Timer Counter channel must be programmed in Waveform Mode.

Only one start command is necessary to initiate a conversion sequence on all the channels. The ADC12B hardware logic automatically performs the conversions on the active channels, then waits for a new request. The Channel Enable (ADC12B_CHER) and Channel Disable (ADC12B_CHDR) Registers enable the analog channels to be enabled or disabled independently.

If the ADC12B is used with a PDC, only the transfers of converted data from enabled channels are performed and the resulting data buffers should be interpreted accordingly.

Warning: Enabling hardware triggers does not disable the software trigger functionality. Thus, if a hardware trigger is selected, the start of a conversion can be initiated either by the hardware or the software trigger.

40.5.9 Sleep Mode and Conversion Sequencer

The ADC12B Sleep Mode maximizes power saving by automatically deactivating the ADC12B when it is not being used for conversions. Sleep Mode is selected by setting the SLEEP bit in the Mode Register ADC12B_MR.

Two sleep Mode are selectable (OFFMODES): STANDBY Mode and OFF Mode. In Standby Mode, the ADC12B is powered off except voltage reference to allow fast startup. In OFF Mode the ADC12B is totally powered off.

Table 40-8. Low Power Modes According SLEEP Bit and OFFMODES Bit.

SLEEP Bit	OFFMODES Bit	Low Power Mode
0	_	Normal Mode
1	0	Standby Mode
1	1	Off Mode

The SLEEP mode is automatically managed by a conversion sequencer, which can automatically process the conversions of all channels at lowest power consumption.

When a start conversion request occurs, the ADC12B is automatically activated. As the analog cell requires a start-up time, the logic waits during this time and starts the conversion on the enabled channels. When all conversions are complete, the ADC12B is deactivated until the next trigger. Triggers occurring during the sequence are not taken into account.

The conversion sequencer allows automatic processing with minimum processor intervention and optimized power consumption. Conversion sequences can be performed periodically using a Timer/Counter output or a PWM Event line. The periodic acquisition of several samples can be processed automatically without any intervention of the processor thanks to the PDC.

The conversion sequencer can only be used if all ADC12B inputs have the same input configuration, e.g. same PGA gain, same input type (differential or single ended) and same input offset. If input have different configurations, sequencer can’t be used because PGA gain, input type and input offset can’t be changed.

Note: The reference voltage pins always remain connected in normal mode as in sleep mode.

40.5.10 ADC12B Timings

Each ADC12B has its own minimal Startup Time that is programmed through the field STARTUP in the Mode Register (ADC12B_MR).

In the same way, a minimal Sample and Hold Time is necessary for the ADC12B to guarantee the best converted final value between the two channels selection. This time has to be programmed through the SHTIM bitfield in the Mode Register (ADC12B_MR).

Warning: No input buffer amplifier to isolate the source is included in the ADC12B. This must be taken into consideration to program a precise value in the SHTIM field. See the section, ADC12B Characteristics in the product datasheet.

40.6 12-bit Analog-to-Digital Converter (ADC12B) User Interface

Table 40-9. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	ADC12B_CR	Write-only	–
0x04	Mode Register	ADC12B_MR	Read-write	0x00000000
0x08	Reserved	–	–	–
0x0C	Reserved	–	–	–
0x10	Channel Enable Register	ADC12B_CHER	Write-only	–
0x14	Channel Disable Register	ADC12B_CHDR	Write-only	–
0x18	Channel Status Register	ADC12B_CHSR	Read-only	0x00000000
0x1C	Status Register	ADC12B_SR	Read-only	0x000C0000
0x20	Last Converted Data Register	ADC12B_LCDR	Read-only	0x00000000
0x24	Interrupt Enable Register	ADC12B_IER	Write-only	–
0x28	Interrupt Disable Register	ADC12B_IDR	Write-only	–
0x2C	Interrupt Mask Register	ADC12B_IMR	Read-only	0x00000000
0x30	Channel Data Register 0	ADC12B_CDR0	Read-only	0x00000000
0x34	Channel Data Register 1	ADC12B_CDR1	Read-only	0x00000000
...	...	...	...	...
0x4C	Channel Data Register 7	ADC12B_CDR7	Read-only	0x00000000
0x64	Analog Control Register	ADC12B_ACR	Read-write	0x00000000
0x68	Extended Mode Register	ADC12B_EMR	Read-write	0x00000000
0x50 - 0xFC	Reserved	–	–	–

40.6.1 ADC12B Control Register

Name: ADC12B_CR

Address: 0x400A8000

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	START	SWRST

- **SWRST: Software Reset**

0 = No effect.

1 = Resets the ADC12B simulating a hardware reset.

- **START: Start Conversion**

0 = No effect.

1 = Begins analog-to-digital conversion.

40.6.2 ADC12B Mode Register

Name: ADC12B_MR

Address: 0x400A8004

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	SHTIM			
23	22	21	20	19	18	17	16
STARTUP							
15	14	13	12	11	10	9	8
PRESCAL							
7	6	5	4	3	2	1	0
–	–	SLEEP	LOWRES	TRGSEL			TRGEN

- **TRGEN: Trigger Enable**

TRGEN	Selected TRGEN
0	Hardware triggers are disabled. Starting a conversion is only possible by software.
1	Hardware trigger selected by TRGSEL field is enabled.

- **TRGSEL: Trigger Selection**

TRGSEL			Selected TRGSEL
0	0	0	External trigger
0	0	1	TIO Output of the Timer Counter Channel 0
0	1	0	TIO Output of the Timer Counter Channel 1
0	1	1	TIO Output of the Timer Counter Channel 2
1	0	0	PWM Event Line 0
1	0	1	PWM Event Line 1
1	1	0	Reserved
1	1	1	Reserved

- **LOWRES: Resolution**

LOWRES	Selected Resolution
0	12-bit resolution
1	10-bit resolution

- **SLEEP: Sleep Mode**

SLEEP	Selected Mode
0	Normal Mode
1	Sleep Modes (see OFFMODES register)

- **PRESCAL: Prescaler Rate Selection**
  ADC12BClock = MCK/((PRESCAL+1) * 2)

- **STARTUP: Start Up Time**
  Startup Time = (STARTUP+1) * 8/ADC12BClock

- **SHTIM: Sample & Hold Time**

Sample and Hold Time = SHTIM/ADC12BClock

40.6.3 ADC12B Channel Enable Register

Name: ADC12B_CHER

Address: 0x400A8010

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **CHx: Channel x Enable**

0 = No effect.

1 = Enables the corresponding channel.

40.6.4 ADC12B Channel Disable Register

Name: ADC12B_CHDR

Address: 0x400A8014

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **x: Channel x Disable**

0 = No effect.

1 = Disables the corresponding channel.

Warning: If the corresponding channel is disabled during a conversion or if it is disabled then reenabled during a conversion, its associated data and its corresponding EOC and OVRE flags in ADC12B_SR are unpredictable.

40.6.5 ADC12B Channel Status Register

Name: ADC12B_CHSR

Address: 0x400A8018

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **CHx: Channel x Status**

0 = Corresponding channel is disabled.

1 = Corresponding channel is enabled.

40.6.6 ADC12B Analog Control Register

Name: ADC12B_ACR

Address: 0x400A8064

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	OFFSET	DIFF
15	14	13	12	11	10	9	8
–	–	–	–	–	–	IBCTL	
7	6	5	4	3	2	1	0
–	–	–	–	–	–	GAIN	

- **GAIN: Input Gain**

Gain of the sample and hold unit according to GAIN bits and DIFF bit

GAIN<0:1>	GAIN (DIFFx = 0)	GAIN (DIFF = 1)
00	1	0.5
01	1	1
10	2	2
11	4	2

- **IBCTL: Bias Current Control**

Bias Current Control

IBCTL<0:1>	Current
00	typ - 20%
01	typ
10	typ + 20%
11	typ + 40%

- **DIFF: Differential Mode**

0 = Single Ended Mode

1 = Fully Differential Mode

- **OFFSET: Input OFFSET**

Offset of the sample and hold unit according to OFFSET bit, DIFF bit and Gain (G).

OFFSET	OFFSET (DIFF = 0)	OFFSET (DIFF = 1)
0	Vrefin/2G	Vrefin/2
1	Vrefin/2	

40.6.7 ADC12B Extended Mode Register

Name: ADC12B_EMR

Address: 0x400A8068

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
OFF_MODE_STARTUP_TIME							
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	OFFMODES

- **OFFMODES: Off Mode if Sleep Bit (ADC12B_MR) = 1**

0 = Standby Mode

1 = Off Mode

- **OFF_MODE_STARTUP_TIME: Startup Time**

Off Mode Startup Time = (OFF_MODE_STARTUP_TIME+1) * 8/ADC12BClock

40.6.8 ADC12B Status Register

Name: ADC12B_SR

Address: 0x400A801C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion x**

0 = Corresponding analog channel is disabled, or the conversion is not finished.

1 = Corresponding analog channel is enabled and conversion is complete.

- **OVREx: Overrun Error x**

0 = No overrun error on the corresponding channel since the last read of ADC12B_SR.

1 = There has been an overrun error on the corresponding channel since the last read of ADC12B_SR.

- **DRDY: Data Ready**

0 = No data has been converted since the last read of ADC12B_LCDR.

1 = At least one data has been converted and is available in ADC12B_LCDR.

- **GOVRE: General Overrun Error**

0 = No General Overrun Error occurred since the last read of ADC12B_SR.

1 = At least one General Overrun Error has occurred since the last read of ADC12B_SR.

- **ENDRX: End of RX Buffer**

0 = The Receive Counter Register has not reached 0 since the last write in ADC12B_RCR or ADC12B_RNCR.

1 = The Receive Counter Register has reached 0 since the last write in ADC12B_RCR or ADC12B_RNCR.

- **RXBUFF: RX Buffer Full**

0 = ADC12B_RCR or ADC12B_RNCR have a value other than 0.

1 = Both ADC12B_RCR and ADC12B_RNCR have a value of 0.

40.6.9 ADC12B Last Converted Data Register

Name: ADC12B_LCDR

Address: 0x400A8020

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	LDATA			
7	6	5	4	3	2	1	0
LDATA							

- **LDATA: Last Data Converted**

The analog-to-digital conversion data is placed into this register at the end of a conversion and remains until a new conversion is completed.

40.6.10 ADC12B Interrupt Enable Register

Name: ADC12B_IER

Address: 0x400A8024

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Enable x**
- **OVREx: Overrun Error Interrupt Enable x**
- **DRDY: Data Ready Interrupt Enable**
- **GOVRE: General Overrun Error Interrupt Enable**
- **ENDRX: End of Receive Buffer Interrupt Enable**
- **RXBUFF: Receive Buffer Full Interrupt Enable**

0 = No effect.

1 = Enables the corresponding interrupt.

40.6.11 ADC12B Interrupt Disable Register

Name: ADC12B_IDR

Address: 0x400A8028

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Disable x**
- **OVREx: Overrun Error Interrupt Disable x**
- **DRDY: Data Ready Interrupt Disable**
- **GOVRE: General Overrun Error Interrupt Disable**
- **ENDRX: End of Receive Buffer Interrupt Disable**
- **RXBUFF: Receive Buffer Full Interrupt Disable**

0 = No effect.

1 = Disables the corresponding interrupt.

40.6.12 ADC12B Interrupt Mask Register

Name: ADC12B_IMR

Address: 0x400A802C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Mask x**
- **OVREx: Overrun Error Interrupt Mask x**
- **DRDY: Data Ready Interrupt Mask**
- **GOVRE: General Overrun Error Interrupt Mask**
- **ENDRX: End of Receive Buffer Interrupt Mask**
- **RXBUFF: Receive Buffer Full Interrupt Mask**

0 = The corresponding interrupt is disabled.

1 = The corresponding interrupt is enabled.

40.6.13 ADC12B Channel Data Register

Name: ADC12B_CDRx

Address: 0x400A8030

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	DATA			
7	6	5	4	3	2	1	0
DATA							

- **DATA: Converted Data**

The analog-to-digital conversion data is placed into this register at the end of a conversion and remains until a new conversion is completed. The Convert Data Register (CDR) is only loaded if the corresponding analog channel is enabled.

41. Analog-to-Digital Converter (ADC)

41.1 Description

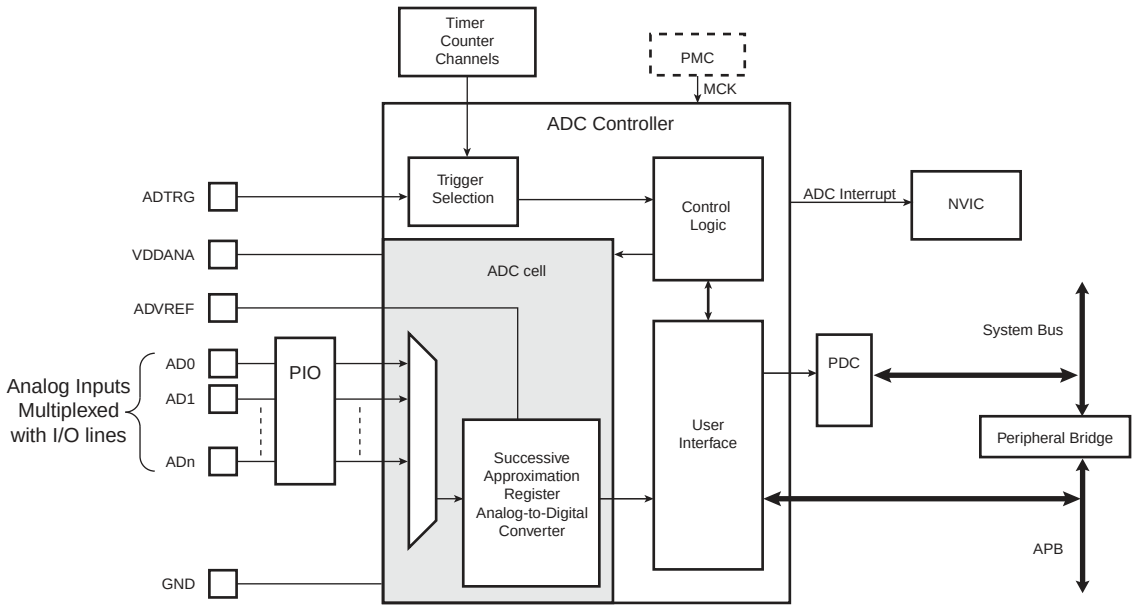
The ADC is based on a Successive Approximation Register (SAR) 10-bit Analog-to-Digital Converter (ADC). It also integrates an 8-to-1 analog multiplexer, making possible the analog-to-digital conversions of 8 analog lines. The conversions extend from 0V to ADVREF. The ADC supports an 8-bit or 10-bit resolution mode, and conversion results are reported in a common register for all channels, as well as in a channel-dedicated register. Software trigger, external trigger on rising edge of the ADTRG pin or internal triggers from Timer Counter output(s) or PWM Event lines are configurable.

The ADC also integrates a Sleep Mode and a conversion sequencer and connects with a PDC channel. These features reduce both power consumption and processor intervention.

Finally, the user can configure ADC timings, such as Startup Time and Sample & Hold Time.

41.2 Block Diagram

Figure 41-1. Analog-to-Digital Converter Block Diagram



41.3 Signal Description

Table 41-1. ADC Pin Description

Pin Name	Description
AD0 - AD7	Analog input channels
ADTRG	External trigger

41.4 Product Dependencies

41.4.1 Power Management

The MCK of the ADC Controller is not continuously clocked. The programmer must first enable the ADC Controller MCK in the Power Management Controller (PMC) before using the ADC Controller. However, if the application does not require ADC operations, the ADC Controller clock can be stopped when not needed and restarted when necessary. Configuring the ADC Controller does not require the ADC Controller clock to be enabled.

41.4.2 Interrupt Sources

The ADC interrupt line is connected on one of the internal sources of the Advanced Interrupt Controller. Using the ADC interrupt requires the NVIC to be programmed first.

Table 41-2. Peripheral IDs

Instance	ID
ADC	27

41.4.3 Analog Inputs

The analog input pins can be multiplexed with PIO lines. In this case, the assignment of the ADC input is automatically done as soon as the corresponding channel is enabled by writing the register ADC_CHER. By default, after reset, the PIO line is configured as input with its pull-up enabled and the ADC input is connected to the GND.

41.4.4 I/O Lines

The pin ADTRG may be shared with other peripheral functions through the PIO Controller. In this case, the PIO Controller should be set accordingly to assign the pin ADTRG to the ADC function.

41.4.5 Timer Triggers

Timer Counters may or may not be used as hardware triggers depending on user requirements. Thus, some or all of the timer counters may be non-connected.

41.4.6 PWM Event Lines

PWM Event Lines may or may not be used as hardware triggers depending on user requirements.

41.4.7 Conversion Performances

For performance and electrical characteristics of the ADC, see the DC Characteristics section.

41.5 Functional Description

41.5.1 Analog-to-digital Conversion

The ADC uses the ADC Clock to perform conversions. Converting a single analog value to a 10-bit digital data requires Sample and Hold Clock cycles as defined in the field SHTIM of the “ADC Mode Register” on page 1075 and 10 ADC Clock cycles. The ADC Clock frequency is selected in the PRESCAL field of the Mode Register (ADC_MR).

The ADC clock range is between MCK/2, if PRESCAL is 0, and MCK/128, if PRESCAL is set to 63 (0x3F). PRESCAL must be programmed in order to provide an ADC clock frequency according to the parameters given in the Product definition section.

41.5.2 Conversion Reference

The conversion is performed on a full range between 0V and the reference voltage pin ADVREF Analog inputs between these voltages convert to values based on a linear conversion.

41.5.3 Conversion Resolution

The ADC supports 8-bit or 10-bit resolutions. The 8-bit selection is performed by setting the bit LOWRES in the ADC Mode Register (ADC_MR). By default, after a reset, the resolution is the highest and the DATA field in the data registers is fully used. By setting the bit LOWRES, the ADC switches in the lowest resolution and the conversion results can be read in the eight lowest significant bits of the data registers. The two highest bits of the DATA field in the corresponding ADC_CDR register and of the LDATA field in the ADC_LCDR register read 0.

Moreover, when a PDC channel is connected to the ADC, 10-bit resolution sets the transfer request sizes to 16-bit. Setting the bit LOWRES automatically switches to 8-bit data transfers. In this case, the destination buffers are optimized.

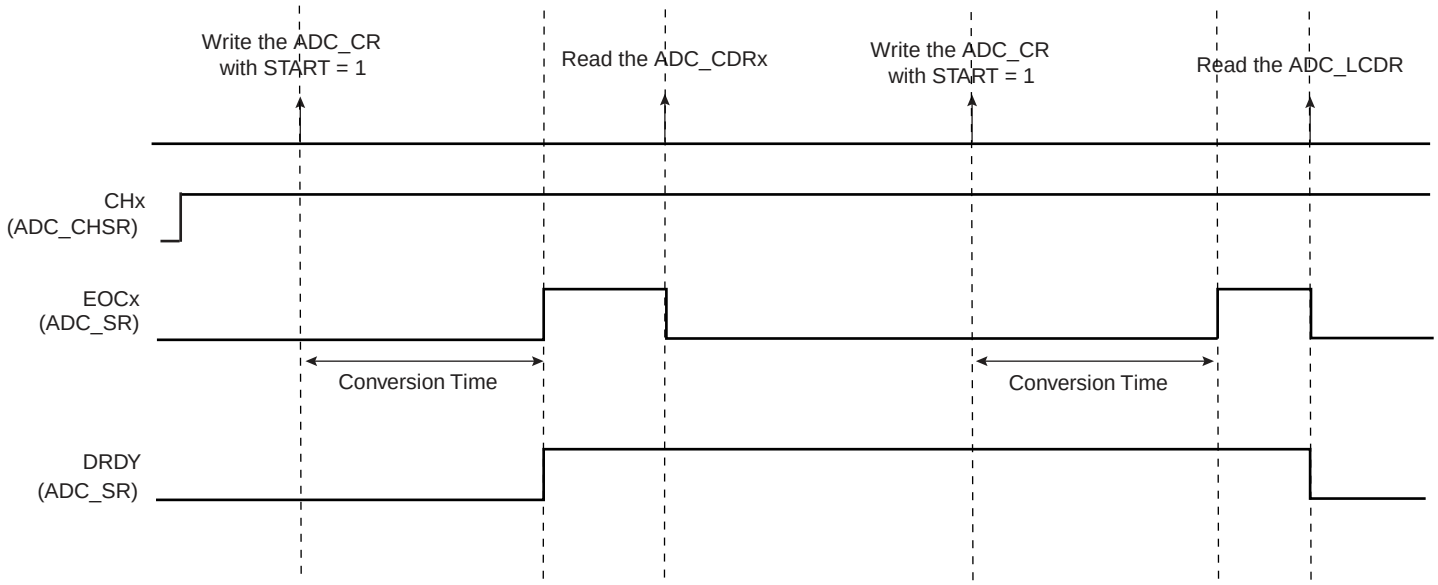
41.5.4 Conversion Results

When a conversion is completed, the resulting 10-bit digital value is stored in the Channel Data Register (ADC_CDR) of the current channel and in the ADC Last Converted Data Register (ADC_LCDR).

The channel EOC bit in the Status Register (ADC_SR) is set and the DRDY is set. In the case of a connected PDC channel, DRDY rising triggers a data transfer request. In any case, either EOC and DRDY can trigger an interrupt.

Reading one of the ADC_CDR registers clears the corresponding EOC bit. Reading ADC_LCDR clears the DRDY bit and the EOC bit corresponding to the last converted channel.

Figure 41-2. EOCx and DRDY Flag Behavior

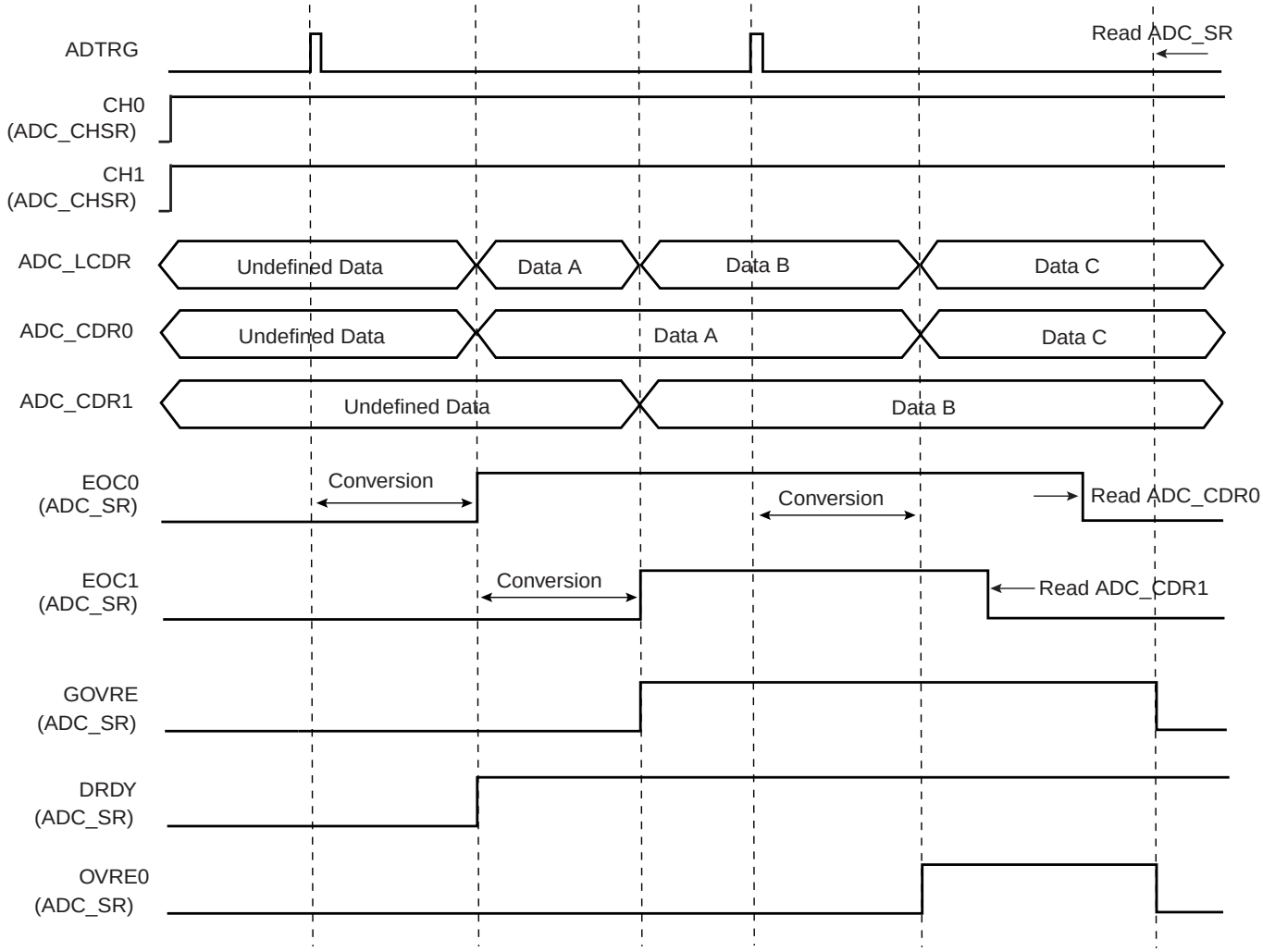


If the ADC_CDR is not read before further incoming data is converted, the corresponding Overrun Error (OVRE) flag is set in the Status Register (ADC_SR).

In the same way, new data converted when DRDY is high sets the bit GOVRE (General Overrun Error) in ADC_SR.

The OVRE and GOVRE flags are automatically cleared when ADC_SR is read.

Figure 41-3. GOVRE and OVREx Flag Behavior



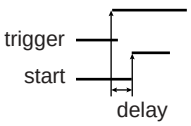
Warning: If the corresponding channel is disabled during a conversion or if it is disabled and then reenabled during a conversion, its associated data and its corresponding EOC and OVRE flags in ADC_SR are unpredictable.

41.5.5 Conversion Triggers

Conversions of the active analog channels are started with a software or a hardware trigger. The software trigger is provided by writing the Control Register (ADC_CR) with the bit START at 1.

The hardware trigger can be one of the TIOA outputs of the Timer Counter channels, PWM Event lines or the external trigger input of the ADC (ADTRG). The hardware trigger is selected with the field TRGSEL in the Mode Register (ADC_MR). The selected hardware trigger is enabled with the bit TRGEN in the Mode Register (ADC_MR).

If a hardware trigger is selected, the start of a conversion is triggered after a delay starting at each rising edge of the selected signal.Due to asynchronism handling, the delay may vary in a range of 2 MCK clock periods to 1 ADC clock period.



If one of the TIOA outputs is selected, the corresponding Timer Counter channel must be programmed in Waveform Mode.

Only one start command is necessary to initiate a conversion sequence on all the channels. The ADC hardware logic automatically performs the conversions on the active channels, then waits for a new request. The Channel Enable (ADC_CHER) and Channel Disable (ADC_CHDR) Registers enable the analog channels to be enabled or disabled independently.

If the ADC is used with a PDC, only the transfers of converted data from enabled channels are performed and the resulting data buffers should be interpreted accordingly.

Warning: Enabling hardware triggers does not disable the software trigger functionality. Thus, if a hardware trigger is selected, the start of a conversion can be initiated either by the hardware or the software trigger.

41.5.6 Sleep Mode and Conversion Sequencer

The ADC Sleep Mode maximizes power saving by automatically deactivating the ADC when it is not being used for conversions. Sleep Mode is selected by setting the bit SLEEP in the Mode Register ADC_MR.

The SLEEP mode is automatically managed by a conversion sequencer, which can automatically process the conversions of all channels at lowest power consumption.

When a start conversion request occurs, the ADC is automatically activated. As the analog cell requires a start-up time, the logic waits during this time and starts the conversion on the enabled channels. When all conversions are complete, the ADC is deactivated until the next trigger. Triggers occurring during the sequence are not taken into account.

The conversion sequencer allows automatic processing with minimum processor intervention and optimized power consumption. Conversion sequences can be performed periodically using a Timer/Counter output or a PWM Event line. The periodic acquisition of several samples can be processed automatically without any intervention of the processor thanks to the PDC.

Note: The reference voltage pins always remain connected in normal mode as in sleep mode.

41.5.7 ADC Timings

Each ADC has its own minimal Startup Time that is programmed through the field STARTUP in the Mode Register ADC_MR.

In the same way, a minimal Sample and Hold Time is necessary for the ADC to guarantee the best converted final value between two channels selection. This time has to be programmed through the bitfield SHTIM in the Mode Register ADC_MR.

Warning: No input buffer amplifier to isolate the source is included in the ADC. This must be taken into consideration to program a precise value in the SHTIM field. See the section, ADC Characteristics in the product datasheet.

41.6 Analog-to-Digital Converter (ADC) User Interface

Table 41-3. Register Mapping

Offset	Register	Name	Access	Reset
0x00	Control Register	ADC_CR	Write-only	–
0x04	Mode Register	ADC_MR	Read-write	0x00000000
0x08	Reserved	–	–	–
0x0C	Reserved	–	–	–
0x10	Channel Enable Register	ADC_CHER	Write-only	–
0x14	Channel Disable Register	ADC_CHDR	Write-only	–
0x18	Channel Status Register	ADC_CHSR	Read-only	0x00000000
0x1C	Status Register	ADC_SR	Read-only	0x000C0000
0x20	Last Converted Data Register	ADC_LCDR	Read-only	0x00000000
0x24	Interrupt Enable Register	ADC_IER	Write-only	–
0x28	Interrupt Disable Register	ADC_IDR	Write-only	–
0x2C	Interrupt Mask Register	ADC_IMR	Read-only	0x00000000
0x30	Channel Data Register 0	ADC_CDR0	Read-only	0x00000000
0x34	Channel Data Register 1	ADC_CDR1	Read-only	0x00000000
...	...	...	...	...
0x4C	Channel Data Register 7	ADC_CDR7	Read-only	0x00000000
0x50 - 0xFC	Reserved	–	–	–

41.6.1 ADC Control Register

Name: ADC_CR

Address: 0x400AC000

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
–	–	–	–	–	–	START	SWRST

- **SWRST: Software Reset**

0 = No effect.

1 = Resets the ADC simulating a hardware reset.

- **START: Start Conversion**

0 = No effect.

1 = Begins analog-to-digital conversion.

41.6.2 ADC Mode Register

Name: ADC_MR

Address: 0x400AC004

Access: Read-write

31	30	29	28	27	26	25	24
–	–	–	–	SHTIM			
23	22	21	20	19	18	17	16
–	STARTUP						
15	14	13	12	11	10	9	8
PRESCAL							
7	6	5	4	3	2	1	0
–	–	SLEEP	LOWRES	TRGSEL			TRGEN

- **TRGEN: Trigger Enable**

TRGEN	Selected TRGEN
0	Hardware triggers are disabled. Starting a conversion is only possible by software.
1	Hardware trigger selected by TRGSEL field is enabled.

- **TRGSEL: Trigger Selection**

TRGSEL			Selected TRGSEL
0	0	0	TIO Output of the Timer Counter Channel 0
0	0	1	TIO Output of the Timer Counter Channel 1
0	1	0	TIO Output of the Timer Counter Channel 2
0	1	1	PWM Event Line 0
1	0	0	PWM Event Line 1
1	0	1	Reserved
1	1	0	External trigger
1	1	1	Reserved

- **LOWRES: Resolution**

LOWRES	Selected Resolution
0	10-bit resolution
1	8-bit resolution

- **SLEEP: Sleep Mode**

SLEEP	Selected Mode
0	Normal Mode
1	Sleep Mode

- **PRESCAL: Prescaler Rate Selection**

  ADCClock = MCK / ((PRESCAL+1) * 2)

- **STARTUP: Start Up Time**
  Startup Time = (STARTUP+1) * 8 / ADCClock

- **SHTIM: Sample & Hold Time**
  Sample & Hold Time = SHTIM/ADCClock

41.6.3 ADC Channel Enable Register

Name: ADC_CHER

Address: 0x400AC010

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **CHx: Channel x Enable**

0 = No effect.

1 = Enables the corresponding channel.

41.6.4 ADC Channel Disable Register

Name: ADC_CHDR

Address: 0x400AC014

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **CHx: Channel x Disable**

0 = No effect.

1 = Disables the corresponding channel.

Warning: If the corresponding channel is disabled during a conversion or if it is disabled then reenabled during a conversion, its associated data and its corresponding EOC and OVRE flags in ADC_SR are unpredictable.

41.6.5 ADC Channel Status Register

Name: ADC_CHSR

Address: 0x400AC018

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	–	–
7	6	5	4	3	2	1	0
CH7	CH6	CH5	CH4	CH3	CH2	CH1	CH0

- **CHx: Channel x Status**

0 = Corresponding channel is disabled.

1 = Corresponding channel is enabled.

41.6.6 ADC Status Register

Name: ADC_SR

Address: 0x400AC01C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion x**

0 = Corresponding analog channel is disabled, or the conversion is not finished.

1 = Corresponding analog channel is enabled and conversion is complete.

- **OVREx: Overrun Error x**

0 = No overrun error on the corresponding channel since the last read of ADC_SR.

1 = There has been an overrun error on the corresponding channel since the last read of ADC_SR.

- **DRDY: Data Ready**

0 = No data has been converted since the last read of ADC_LCDR.

1 = At least one data has been converted and is available in ADC_LCDR.

- **GOVRE: General Overrun Error**

0 = No General Overrun Error occurred since the last read of ADC_SR.

1 = At least one General Overrun Error has occurred since the last read of ADC_SR.

- **ENDRX: End of RX Buffer**

0 = The Receive Counter Register has not reached 0 since the last write in ADC_RCR or ADC_RNCR.

1 = The Receive Counter Register has reached 0 since the last write in ADC_RCR or ADC_RNCR.

- **RXBUFF: RX Buffer Full**

0 = ADC_RCR or ADC_RNCR have a value other than 0.

1 = Both ADC_RCR and ADC_RNCR have a value of 0.

41.6.7 ADC Last Converted Data Register

Name: ADC_LCDR

Address: 0x400AC020

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	LDATA	
7	6	5	4	3	2	1	0
LDATA							

- **LDATA: Last Data Converted**

The analog-to-digital conversion data is placed into this register at the end of a conversion and remains until a new conversion is completed.

41.6.8 ADC Interrupt Enable Register

Name: ADC_IER

Address: 0x400AC024

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Enable x**
- **OVREx: Overrun Error Interrupt Enable x**
- **DRDY: Data Ready Interrupt Enable**
- **GOVRE: General Overrun Error Interrupt Enable**
- **ENDRX: End of Receive Buffer Interrupt Enable**
- **RXBUFF: Receive Buffer Full Interrupt Enable**

0 = No effect.

1 = Enables the corresponding interrupt.

41.6.9 ADC Interrupt Disable Register

Name: ADC_IDR

Address: 0x400AC028

Access: Write-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Disable x**
- **OVREx: Overrun Error Interrupt Disable x**
- **DRDY: Data Ready Interrupt Disable**
- **GOVRE: General Overrun Error Interrupt Disable**
- **ENDRX: End of Receive Buffer Interrupt Disable**
- **RXBUFF: Receive Buffer Full Interrupt Disable**

0 = No effect.

1 = Disables the corresponding interrupt.

41.6.10 ADC Interrupt Mask Register

Name: ADC_IMR

Address: 0x400AC02C

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	RXBUFF	ENDRX	GOVRE	DRDY
15	14	13	12	11	10	9	8
OVRE7	OVRE6	OVRE5	OVRE4	OVRE3	OVRE2	OVRE1	OVRE0
7	6	5	4	3	2	1	0
EOC7	EOC6	EOC5	EOC4	EOC3	EOC2	EOC1	EOC0

- **EOCx: End of Conversion Interrupt Mask x**
- **OVREx: Overrun Error Interrupt Mask x**
- **DRDY: Data Ready Interrupt Mask**
- **GOVRE: General Overrun Error Interrupt Mask**
- **ENDRX: End of Receive Buffer Interrupt Mask**
- **RXBUFF: Receive Buffer Full Interrupt Mask**

0 = The corresponding interrupt is disabled.

1 = The corresponding interrupt is enabled.

41.6.11 ADC Channel Data Register

Name: ADC_CDRx

Address: 0x400AC030

Access: Read-only

31	30	29	28	27	26	25	24
–	–	–	–	–	–	–	–
23	22	21	20	19	18	17	16
–	–	–	–	–	–	–	–
15	14	13	12	11	10	9	8
–	–	–	–	–	–	DATA	
7	6	5	4	3	2	1	0
DATA							

- **DATA: Converted Data**

The analog-to-digital conversion data is placed into this register at the end of a conversion and remains until a new conversion is completed. The Convert Data Register (CDR) is only loaded if the corresponding analog channel is enabled.

42. Electrical Characteristics

42.1 Absolute Maximum Ratings

Table 42-1. Absolute Maximum Ratings*

Operating Temperature (Industrial).....-40°C to + 85°C
Storage Temperature.....-60°C to + 150°C
Voltage on Input Pins with Respect to Ground.....-0.3V to + 4.0V
Maximum Operating Voltage (VDDCORE) 2.0V
Maximum Operating Voltage (VDDIO) 4.0V
Total DC Output Current on all I/O lines 100-lead LQFP.....100 mA 144-lead LQFP .....130 mA 100-ball TFBGA .....100 mA 144-ball LFBGA .....130 mA

*NOTICE: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or other conditions beyond those indicated in the operational sections of this specification is not implied. **Exposure to absolute maximum rating conditions for extended periods may affect device reliability.**

42.2 DC Characteristics

The following characteristics are applicable to the operating temperature range: T_A = -40°C to 85°C, unless otherwise specified.

Table 42-2. DC Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDCORE}	DC Supply Core		1.62	1.8	1.95	V
V_{DDIO}	DC Supply I/Os		1.62	3.3	3.6	V
V_{DDBU}	Backup I/O Lines Power Supply		1.62		3.6	V
V_{DDUTMI}	USB UTMI+ Interface Power Supply		3.0		3.6	V
V_{DDPLL}	PLL A, UPLL and Main Oscillator Supply		1.62		1.95	V
V_{DDANA}	ADC Analog Power Supply		(1)		(1)	V
V_{IL}	Input Low-level Voltage	PIOA/B/C[0–31]	-0.3		$0.3 \times V_{DDIO}$	V
V_{IH}	Input High-level Voltage	PIOA/B/C[0–31]	$0.7 \times V_{DDIO}$		V_{DDIO} + 0.3V	V
V_{OH}	Output High-level Voltage	PIOA/B/C[0–31] I_{OH} ~ 0 I_{OH} > 0 (See I_{OH} characteristics in this table)	 V_{DDIO} - 0.2V V_{DDIO} - 0.4V			V
V_{OL}	Output Low-level Voltage	PIOA/B/C[0–31] I_{OH} ~ 0 I_{OH} > 0 (See I_{OL} characteristics in this table)			 0.2 0.4	V
V_{Hys}	Hysteresis Voltage	PIOA/B/C[0–31] except PIOA[14], PB[9–16], PB[25–PB31] and PC[20–27]	150		500	mV
		ERASE, TST, FWUP, JTAGSEL	230		700	mV
I_{OH}	Source Current	1.62V < VDDIO < 1.95V; V_{OH} = V_{DDIO} - 0.4V - PA3 (SPCK), PA15 (MCCK) pins - Other pins(2)			 -8 -3	mA
		3.0V < VDDIO < 3.6V; V_{OH} = V_{DDIO} - 0.4V - PA3 (SPCK), PA15 (MCCK) pins - Other pins(2)			 -15 -3	
		1.62V < VDDIO < 3.6V; V_{OH} = V_{DDIO} - 0.4V - NRST, TDO			 -2	
		Relaxed Mode: 3.0V < VDDIO < 3.6V; V_{OH} = 2.2V - PA3 (SPCK), PA15 (MCCK) pins - Other pins(2)			 -24 -9	

Table 42-2. DC Characteristics (Continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I_{OL}	Sink Current	1.62V < VDDIO < 1.95V; V_{OL} = 0.4V - PA3 (SPCK), PA15 (MCCK) pins - Other pins[2]			 8 4	mA
		3.0V < VDDIO < 3.6V; V_{OL} = 0.4V - PA3 (SPCK), PA15 (MCCK) pins - Other pins[2]			 9 6	
		1.62V < VDDIO < 3.6V; V_{OL} = 0.4V - NRST, TDO			2	
		Relaxed Mode: 3.0V < VDDIO < 3.6V; V_{OL} = 0.6V - PA3 (SPCK), PA15 (MCCK) pins - Other pins[2]			 14 9	
I_{IL}	Input Low Leakage Current	V_{DDIO} powered pins[3] No pull-up or pull-down; V_{IN} = GND; V_{DDIO} Max. (Typ: T_A = 25°C, Max: T_A = 85°C)		5	30	nA
		V_{DDBU} powered pins[4] No pull-up or pull-down; V_{IN} = GND; V_{DDBU} Max. (Typ: T_A = 25°C, Max: T_A = 85°C)			1	µA
I_{IH}	Input High Leakage Current	V_{DDIO} powered pins[3] No pull-up or pull-down; V_{IN} = VDD; V_{DDIO} Max. (Typ: T_A = 25°C, Max: T_A = 85°C)		2	18	nA
		V_{DDBU} powered pins[4] No pull-up or pull-down; V_{IN} = VDD; V_{DDBU} Max. (Typ: T_A = 25°C, Max: T_A = 85°C)			1	µA
R_{PULLUP}	Pull-up Resistor	PA0–PA31, PB0–PB31, PC0–PC31	50	100	150	kΩ
		NRSTB	10		20	kΩ
$R_{PULLDOWN}$	Pull-down Resistor	TST, ERASE, JTAGSEL	10		20	kΩ
R_{ODT}	On-die Series Termination Resistor	PA0–PA31, PB0–PB31, PC0–PC31	28	36	43	Ω

Notes:
1. Refer to Section 42.7 “12-bit ADC Characteristics” and Section 42.9 “AC Characteristics”
2. PA[0–2], PA[4–14], PA[16–31]; PB[0–31]; PC[0–31]
3. PA[0–31], PB[0–31], PC[0–31]
4. FWUP, JTAGSEL, NRSTB, ERASE, TST

Table 42-3. 1.8V Voltage Regulator Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDIN}	DC Input Voltage Range		1.8	3.3	3.6	V
V_{DDOUT}	DC Output Voltage	Normal Mode		1.8		V
		Standby Mode		0		
$V_{O(accuracy)}$	Output Voltage Accuracy	I_{LOAD} = 0.5–150 mA	-3		3	%
I_{LOAD}	Maximum DC Output Current	V_{DDIN} > 2.2V			150	mA
		$V_{DDIN} \leq$ 2.2V			60	
$I_{LOAD-START}$	Maximum Peak Current during startup(3)	(3)			300	mA
$V_{DROPOUT}$	Dropout Voltage	V_{DDIN} = 1.8V I_{LOAD} = 60 mA			150	mV
V_{LINE}	Line Regulation	V_{DDIN} 2.7–3.6 V I_{LOAD} MAX		20	50	mV
$V_{LINE-TR}$	Transient Line regulation	V_{DDIN} 2.7–3.6 V $t_r = t_f$ = 5 µs I_{LOAD} Max CD_{OUT} = 4.7µF		50	100	mV
V_{LOAD}	Load Regulation	$V_{DDIN} \geq$ 2.2V I_{LOAD} = 10% to 90% MAX		20	50	mV
$V_{LOAD-TR}$	Transient Load Regulation	$V_{DDIN} \geq$ 2.2V I_{LOAD} = 10% to 90% MAX $t_r = t_f$ = 5 µs CD_{OUT} = 4.7 µF		50	100	mV
I_Q	Quiescent Current	Normal Mode @ I_{LOAD} = 0 mA		7	10	µA
		Normal Mode @ I_{LOAD} = 150 mA		700	1200	
		Standby Mode			1	
CD_{IN}	Input Decoupling Capacitor	(1)		10		µF
CD_{OUT}	Output Decoupling Capacitor	(2)		4.7		µF
		ESR	0.5		10	Ω
t_{on}	Turn on Time	CD_{OUT} = 4.7 µF, V_{DDOUT} reaches V_{T+} (core power brownout detector supply rising threshold)		120	250	µs
		CD_{OUT} = 4.7 µF, V_{DDOUT} reaches 1.8V (± 3%)		200	400	µs

Notes:
1. A 10 µF or higher ceramic capacitor must be connected between VDDIN and the closest GND pin of the device. This large decoupling capacitor is mandatory to reduce startup current, improving transient response and noise rejection.
2. To ensure stability, an external 4.7µF output capacitor, CD_{OUT} must be connected between the VDDOUT and the closest GND pin of the device. The ESR (Equivalent Series Resistance) of the capacitor must be in the range 0.5 to 10 Ω. Solid tantalum, and multilayer ceramic capacitors are all suitable as output capacitor. A 100 nF bypass capacitor between VDDOUT and the closest GND pin of the device decreases output noise and improves the load transient response.
3. Defined as the current needed to charge external bypass/decoupling capacitor network.

Table 42-4. Core Power Supply Brownout Detector Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{T-}	Supply Falling Threshold(1)		1.52	1.55	1.58	V
V_{hys-}	Hysteresis V_{T-}			25	38	mV
V_{T+}	Supply Rising Threshold		1.35	1.50	1.62	V
t_{RST}	Reset Period		100	–	350	µs
V_{hys+}	Hysteresis V_{T+}		100		250	mV
I_{DDON}	Current Consumption on VDDCORE	Brownout Detector enabled		18		µA
I_{DDOFF}		Brownout Detector disabled			200	nA
t_{d-}	V_{T-} Detection Propagation Time	VDDCORE = V_{T+} to (V_{T-} - 100mV)			200	ns
t_{d+}	V_{T+} Detection Propagation Time		100	200	350	µs
t_{START}	Startup Time	From disabled state to enabled state		100	200	µs

Note: 1. The product is guaranteed to be functional at V_{T-}.

Figure 42-1. Core Brownout Output Waveform

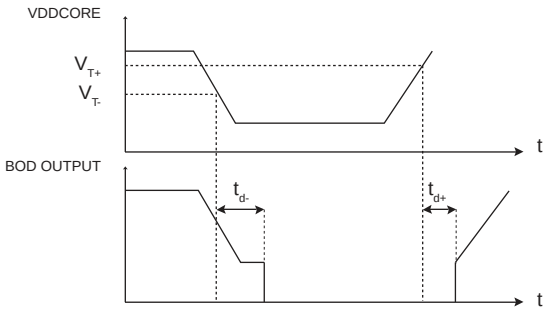


Table 42-5. VDDUTMI Supply Monitor

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_T	Supply Monitor Threshold	16 selectable steps of 100mV	1.9		3.4	V
$V_{T(accuracy)}$	Threshold Level Accuracy		-1.5		+1.5	%
V_{hys}	Hysteresis Voltage			20	30	mV
I_{DDON}	Current Consumption on VDDCORE	Enabled		18	28	µA
I_{DDOFF}		Disabled			1	
t_{START}	Startup Time	From disabled state to enabled state			140	µs

Figure 42-2. VDDUTMI Supply Monitor

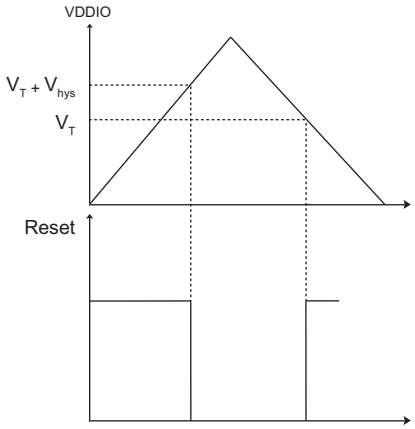


Table 42-6. Backup Power Supply Zero-Power-on Reset Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{T+}	Threshold Voltage Rising	At startup	1.50	1.55	1.60	V
V_{T-}	Threshold Voltage Falling		1.40	1.45	1.50	V
t_{RST}	Reset Period		40	90	150	µs

Figure 42-3. Zero-Power-on Reset Characteristics

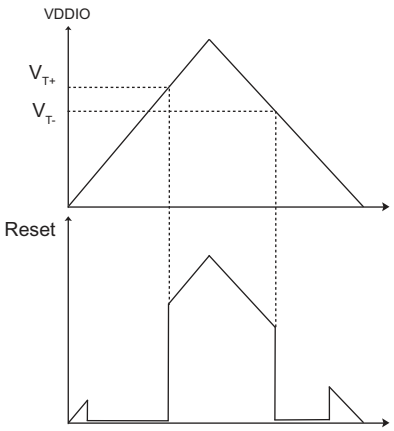


Table 42-7. DC Flash Characteristics

Symbol	Parameter	Conditions	Typ	Max	Unit
$I_{DD(standby)}$	Standby Current	@ 25°C onto VDDCORE = 1.8V	<1	1.5	µA
		@ 85°C onto VDDCORE = 1.8V	14	40	
		@ 25°C onto VDDCORE = 1.95V	<1	1.8	
		@ 85°C onto VDDCORE = 1.95V	15	50	
I_{CC}	Active Current	128-bit Mode Read Access:			mA
		Maximum Read Frequency onto VDDCORE = 1.8V @ 25°C	15	20	
		Maximum Read Frequency onto VDDCORE = 1.95V @ 25°C	20	25	
		64-bit Mode Read Access:			
		Maximum Read Frequency onto VDDCORE = 1.8V @ 25°C	7.5	10	
		Maximum Read Frequency onto VDDCORE = 1.95V @ 25°C	10	12.5	
		Write onto VDDCORE = 1.8V @ 25°C	3.6	4.5	
		Write onto VDDCORE = 1.95V @ 25°C	5.0	6.0	

42.3 Power Consumption

- Power consumption of the device according to the different Low Power Mode capabilities (Backup, Wait, Sleep) and Active mode
- Power consumption on power supply in different modes: Backup, Wait, Sleep and Active
- Power consumption by peripheral: calculated as the difference in current measurement after having enabled then disabled the corresponding clock

42.3.1 Backup Mode Current Consumption

The Backup mode configuration and measurements are defined as follows.

42.3.1.1 Configuration A

- All Power supplies OFF, except VDDBU
- Supply Monitor on VDDUTMI is disabled
- RTT and RTC not used
- Embedded RC Oscillator used
- Wake-up pin FWUP = VDDBU
- Current measurement on AMP1

Figure 42-4. Measurement Setup

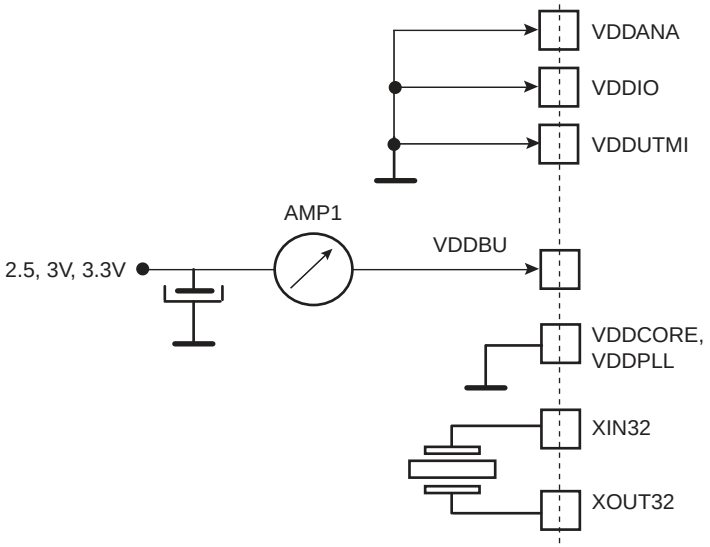


Table 42-8. Power Consumption for Backup Mode Configuration A

Conditions	VDDBU Consumption (AMP1)	Unit
VDDBU = 3.3V @ 25°C	3.0	µA
VDDBU = 3.0V @ 25°C	2.7	
VDDBU = 2.5V @ 25°C	2.2	
VDDBU = 1.8V @ 25°C	1.6	

42.3.1.2 Configuration B

- All power supplies OFF, except VDDBU and VDDIO
- Supply Monitor on VDDUTMI is disabled
- RTC ON, RTT ON
- 32 kHz Crystal Oscillator used
- FWUP pin = VDDBU
- Wake-up pins WKUP0–15 = VDDIO
- Current measurement on AMP1 and on AMP2

Figure 42-5. Measurement Setup

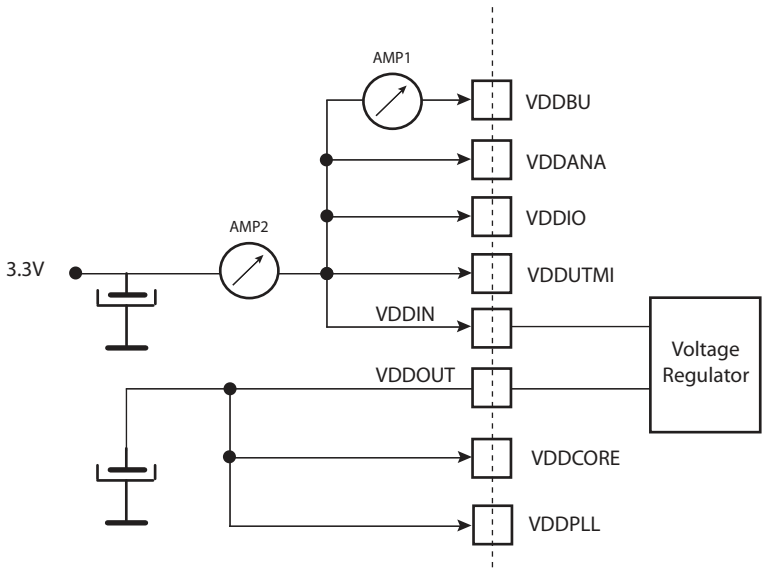


Table 42-9. Power Consumption for Backup Mode Configuration B

Conditions	VDDBU Consumption (AMP1)	Total Consumption (AMP2)	Unit
VDDBU = 3.3V @ 25°C	3.0	3.06	µA
VDDBU = 3.0V @ 25°C	2.7	2.75	
VDDBU = 2.5V @ 25°C	2.2	2.25	
VDDBU = 1.8V @ 25°C	1.6	1.64	

42.3.2 Wait and Sleep Mode Current Consumption

The Wait mode and Sleep mode configuration and measurements are defined below.

42.3.2.1 Sleep Mode

- All power supplies are powered
- Core Clock OFF
- Master Clock (MCK) running at various frequencies with PLLA or the fast RC oscillator
- Fast startup through pins WKUP0–15
- Current measurement on AMP1 (VDDOUT = VDDCORE + VDDPLL)
- All peripheral clocks deactivated

Figure 42-6. Measurement Setup for Sleep Mode

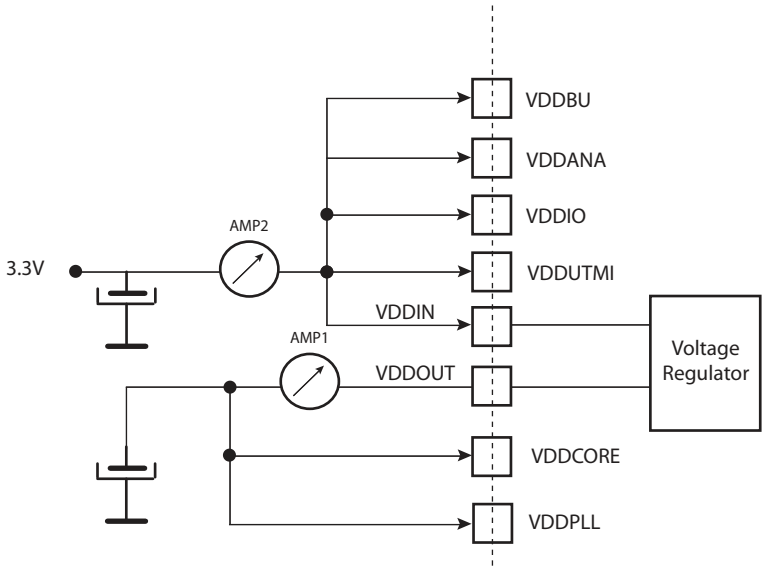


Table 42-10 gives current consumption in typical conditions.

Table 42-10. Typical Current Consumption for Sleep Mode

Conditions	VDDOUT Consumption (AMP1)	Total Consumption (AMP2)	Unit
Figure 42-6 on page 1095 @ 25°C MCK = 48 MHz There is no activity on the I/Os of the device.	11.8	11.9	mA

Figure 42-7. Current Consumption in Sleep Mode (AMP1) versus Master Clock Ranges (refer to Table 42-10)

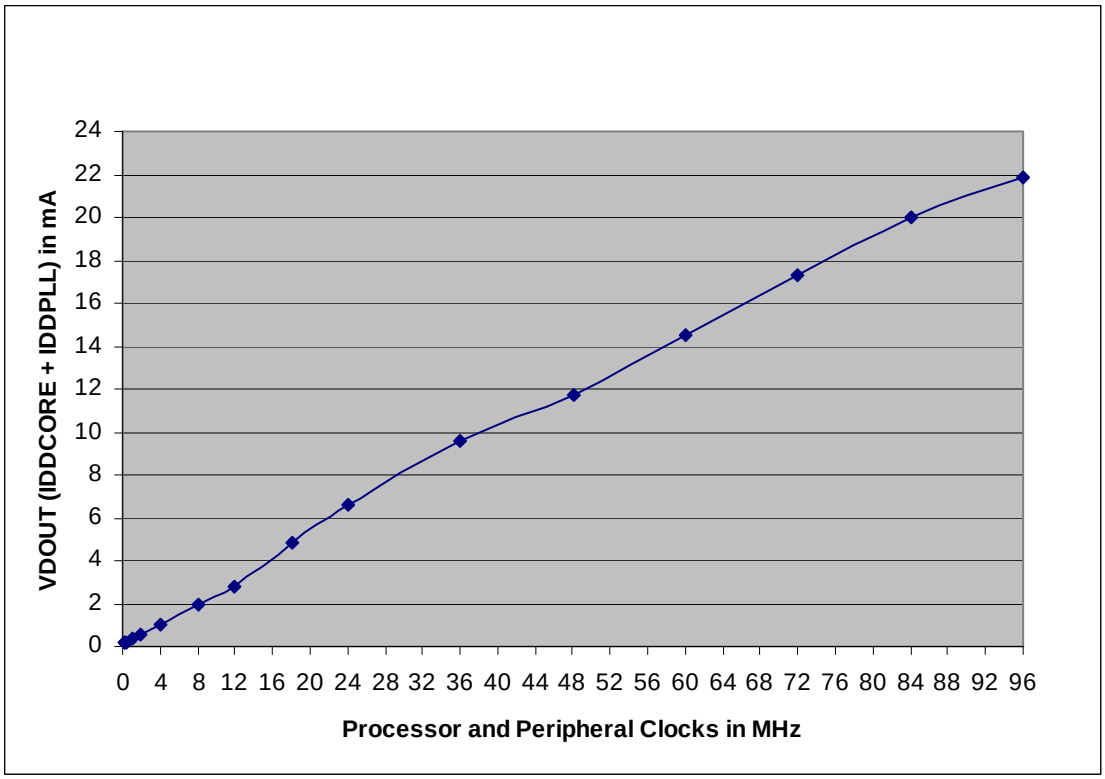


Table 42-11. Sleep Mode Current Consumption Versus Master Clock (MCK) Variation

Core Clock/MCK (MHz)	AMP1 (VDDOUT) Consumption	Unit
96	21.9	mA
84	20	
72	17.3	
60	14.5	
48	11.72	
36	9.6	
24	6.56	
18	4.8	
12	2.835	
8	1.937	
4	1.013	
2	0.567	
1	0.343	
0.5	0.23	
0.25	0.174	
0.125	0.146	

42.3.2.2 Wait Mode

- All power supplies are powered
- Core clock and master clock stopped
- Current measurement on AMP1, AMP2 and AMP3
- All peripheral clocks deactivated

Figure 42-8. Measurement Setup for Wait Mode

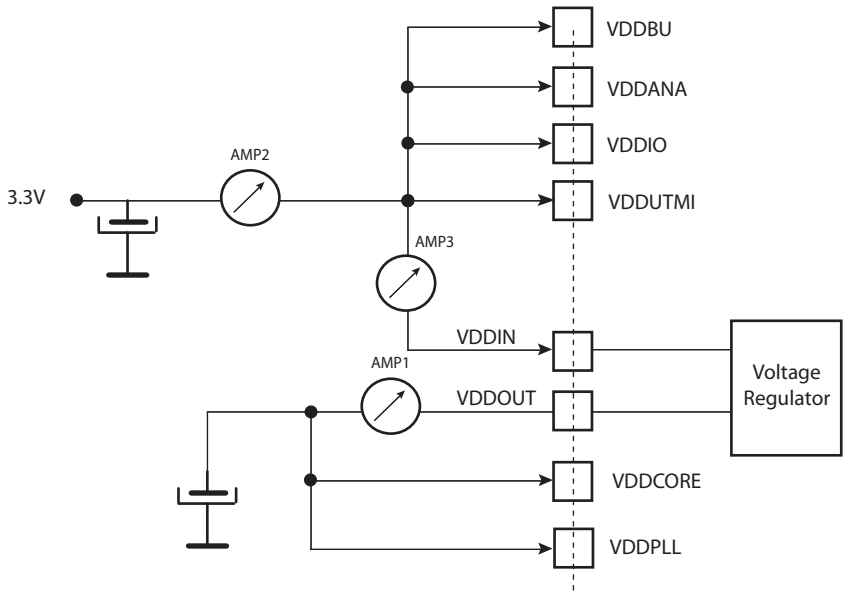


Table 42-12 gives current consumption in typical conditions.

Table 42-12. Typical Current Consumption in Wait Mode

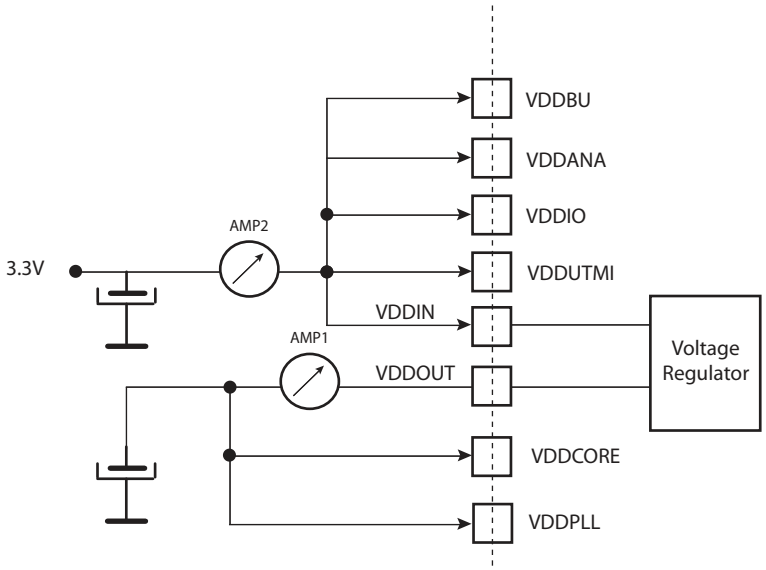
Conditions	VDDOUT Consumption (AMP1)	Total Consumption (AMP2)	Regulator and Core Consumption (AMP3)	Unit
See Figure 42-8 on page 1097 @ 25°C There is no activity on the I/Os of the device.	15.4	27.3	23.4	µA

42.3.3 Active Mode Power Consumption

The Active Mode configuration and measurements are defined as follows:

- VDDIO = 3.3V
- VDDCORE = 1.8V (internal voltage regulator used)
- T_A = 25 °C
- Application running from Flash memory with 128-bit access mode
- All peripheral clocks are deactivated.
- Master Clock (MCK) running at various frequencies with PLLA or the fast RC oscillator
- Current measurement on AMP1 (VDDOUT = VDDCORE + VDDPLL) and total current on AMP2

Figure 42-9. Active Mode Measurement Setup



The following tables give Active mode current consumption in typical conditions.

- VDDCORE at 1.8V
- Temperature = 25°C

Table 42-13. Master Clock (MCK) Variation with PLLA

Core Clock/MCK (MHz)	AMP1 (VDDOUT) Consumption	AMP2 (Total) Consumption	Unit
96	48	48.3	mA
84	44	44.3	
72	39.4	39.7	
60	35.2	35.4	
48	30.2	30.5	
36	25.8	26.1	
24	20.4	20.6	
18	18.3	18.5	

Table 42-14. Master Clock (MCK) Variation with Fast RC Oscillator

Core Clock/MCK (MHz)	AMP1 (VDDOUT) Consumption	AMP2 (Total) Consumption	Unit
12	10	10.08	mA
8	7.5	7.54	
4	5	5.03	
2	2.68	2.70	
1	1.4	1.42	
0.5	0.77	0.78	
0.25	0.44	0.45	
0.125	0.28	0.29	
0.032	0.046	0.061	

42.3.4 Peripheral Power Consumption in Active Mode

Table 42-15. Power Consumption on VDDCORE(1)

Peripheral	Consumption (Typ)	Unit
PIO Controller	11	µA/MHz
USART	31.3	
PWM	53.8	
TWI	16	
SPI	2.55	
Timer Counter Channels	9.3	
ADC12B	17.45	
ADC	15.7	
HSMCI	33	
SMC	78.8	
SSC	16.3	
UDPHS	96	

Note: 1. V_{DDIO} = 3.3V, V_{DDCORE} = 1.80V, T_A = 25°C

42.4 Crystal Oscillators Characteristics

42.4.1 32 kHz RC Oscillator Characteristics

Table 42-16. 32 kHz RC Oscillator Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{OSC}	RC Oscillator Frequency		20	32	44	kHz
	Frequency Supply Dependency		-3		3	%/V
	Frequency Temperature Dependency	Over temperature range -40 to 85 °C versus 25°C T_A	-11		11	%
Duty	Duty Cycle		45	50	55	%
t_{START}	Startup Time				100	µs
I_{DDON}	Current Consumption	After Startup Time T_A = -40 to 85 °C Typical consumption at 2.2V supply and 25°C T_A		540	870	nA

42.4.2 4/8/12 MHz RC Oscillators Characteristics

Table 42-17. 4/8/12 MHz RC Oscillators Characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
f_{OSC}	RC Oscillator Frequency Range			4		12	MHz
f_{OUT}	Output Frequency[1]	1.62V < VDDPLL < 1.95V, -40°C < Temp < +85°C	4 MHz[2]	2.6	4	5.4	MHz
			8 MHz[3]	7.6	8	8.4	
			12 MHz[3]	11.4	12	12.6	
Duty	Duty Cycle			45	50	55	%
t_{START}	Startup Time					10	µs
I_{DDON}	Active Current Consumption	4 MHz			80	120	µA
		8 MHz			105	160	
		12 MHz			145	210	
I_{DDOFF}	Off Mode Current Consumption					0.2	µA

Note: 1. Frequency range can be configured in the Supply Controller registers.
2. Not trimmed from factory
3. After trimming from factory

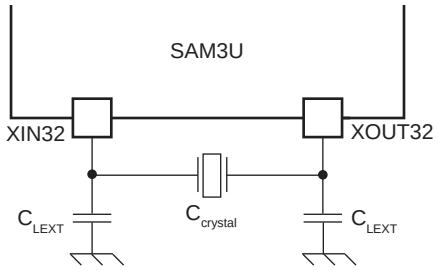
42.4.3 32.768 kHz Crystal Oscillator Characteristics

Table 42-18. 32.768 kHz Crystal Oscillator Characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
f_{OSC}	Operating Frequency	Normal mode with crystal				32.768	kHz
$V_{rip(VDDBU)}$	Supply Ripple Voltage (on VDDBU)	RMS value, 10 kHz to 10 MHz				30	mV
	Duty Cycle			40	50	60	%
t_{START}	Startup Time	R_S < 50 KΩ(1)	$C_{crystal}$ = 12.5pF			900	ms
			$C_{crystal}$ = 6pF			300	
		R_S < 100 KΩ(1)	$C_{crystal}$ = 12.5pF			1200	
			$C_{crystal}$ = 6pF			500	
I_{DDON}	Current consumption	R_S < 50 KΩ(1)	$C_{crystal}$ = 12.5pF		650	1400	nA
			$C_{crystal}$ = 6pF		450	1200	
		R_S < 100 KΩ(1)	$C_{crystal}$ = 12.5pF		900	1600	
			$C_{crystal}$ = 6pF		650	1400	
I_{DDST}	Standby Current Consumption	Standby mode @ 3.6V				5	nA
P_{ON}	Drive level					0.1	µW
R_f	Internal resistor	Between XIN32 and XOUT32			10		MΩ
C_{LEXT}	Maximum external capacitor on XIN32 and XOUT32					22	pF
$C_{crystal}$	Allowed Crystal Capacitance Load	From crystal specification		6		12.5	pF
C_{para}	Internal Parasitic Capacitance			1.2	1.4	1.6	pF

Notes: 1. R_S is the series resistor.

Figure 42-10. 32.768 kHz Crystal Oscillator Schematic



$C_{LEXT} = 2 \times (C_{crystal} - C_{para} - C_{PCB})$

where:

C_{PCB} is the capacitance of the printed circuit board (PCB) track layout from the crystal to the SAM3U pin.

42.4.4 32.768 kHz Crystal Characteristics

Table 42-19. Crystal Characteristics

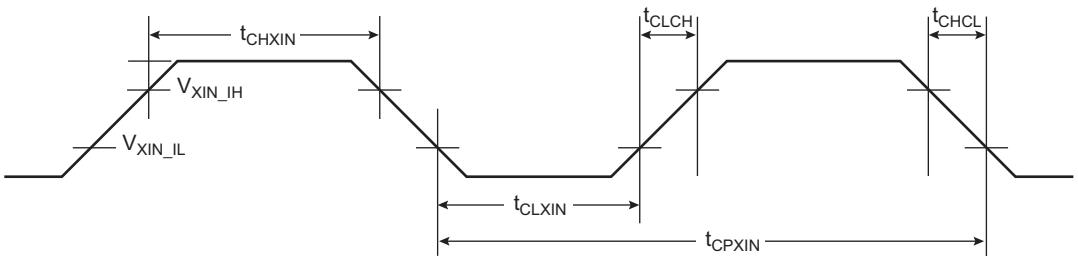
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
ESR	Equivalent Series Resistor (R_S)	Crystal @ 32.768 kHz		50	100	kΩ
C_m	Motional capacitance		0.6		3	fF
C_{SHUNT}	Shunt capacitance		0.6		2	pF

42.4.5 32.768 kHz XIN32 Clock Input Characteristics in Bypass Mode

Table 42-20. XIN32 Clock Electrical Characteristics (In Bypass Mode)

Symbol	Parameter	Conditions	Min	Max	Unit
$1/(t_{CPXIN32})$	XIN32 Clock Frequency	32.768 kHz crystal oscillator is in Bypass mode: SUPC_MR.OSCBYPASS = 1 SUPC_CR.XTALSEL = 1		44	kHz
$t_{CPXIN32}$	XIN32 Clock Period		22		µs
$t_{CHXIN32}$	XIN32 Clock High Half-period		11		µs
$t_{CLXIN32}$	XIN32 Clock Low Half-period		11		µs
t_{CLCH}	Rise Time	—	400		ns
t_{CHCL}	Fall Time	—	400		ns
C_i	XIN32 Input Capacitance	—		6	pF
R_{IN}	XIN32 Pull-down Resistor	—	3	5	MΩ
V_{XIN32_IL}	V_{XIN32} Input Low-level Voltage	—	-0.3	$0.3 \times V_{DDBU}$	V
V_{XIN32_IH}	V_{XIN32} Input High-level Voltage	—	$0.7 \times V_{DDBU}$	V_{DDBU} + 0.3	V

Figure 42-11. XIN32 Clock Timing

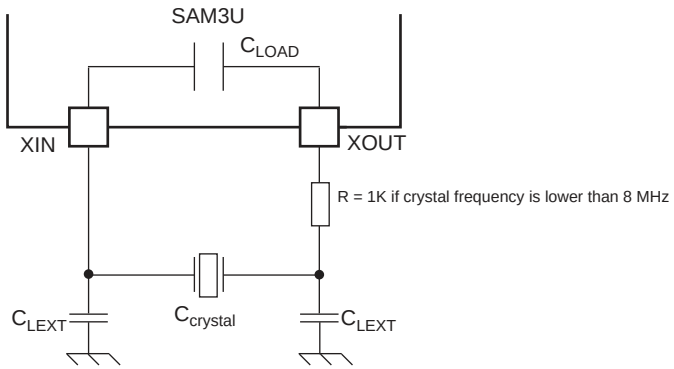


42.4.6 3 to 20 MHz Crystal Oscillator Characteristics

Table 42-21. 3 to 20 MHz Crystal Oscillator Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{OSC}	Operating Frequency	Normal mode with crystal	3	16	20	MHz
$f_{OSC(Bypass)}$	Operating Frequency In Bypass Mode	External Clock on XIN			50	MHz
$V_{rip(VDDPLL)}$	Supply Ripple Voltage (on VDDPLL)	RMS value, 10 kHz to 10 MHz			30	mV
	Duty Cycle		40	50	60	%
t_{START}	Startup Time	3 MHz, C_{SHUNT} = 3pF 8 MHz, C_{SHUNT} = 7pF 12 to 16 MHz, C_{SHUNT} = 7pF 20 MHz, C_{SHUNT} = 7pF			14.5 4 1.4 1	ms
I_{DD_ON}	Current Consumption	3 MHz 8 MHz 12 to 16 MHz 20 MHz		150 150 300 400	250 250 450 550	µA
$I_{DD(Standby)}$	Standby Current Consumption	Standby mode @ 3.6V			5	nA
P_{ON}	Drive Level	3 MHz 8 MHz 1 2MHz, 16 MHz, 20 MHz			15 30 50	µW
R_f	Internal resistor	Between XIN and XOUT		1		MΩ
C_{LEXT}	External capacitor on XIN and XOUT				10	pF
$C_{crystal}$	Allowed Crystal Capacitance Load	From crystal specification	12.5		17.5	pF
C_{LOAD}	Internal Equivalent Load Capacitance	Integrated Load Capacitance (XIN and XOUT in series)	7.5	9.5	11.5	pF

Figure 42-12. 3 to 20 MHz Crystal Oscillator Schematic



$C_{LEXT} = 2 \times (C_{crystal} - C_{LOAD} - C_{PCB})$

where:

C_{PCB} is the capacitance of the printed circuit board (PCB) track layout from the crystal to the SAM3U pin.

42.4.7 3 to 20 MHz Crystal Characteristics

Table 42-22. Crystal Characteristics

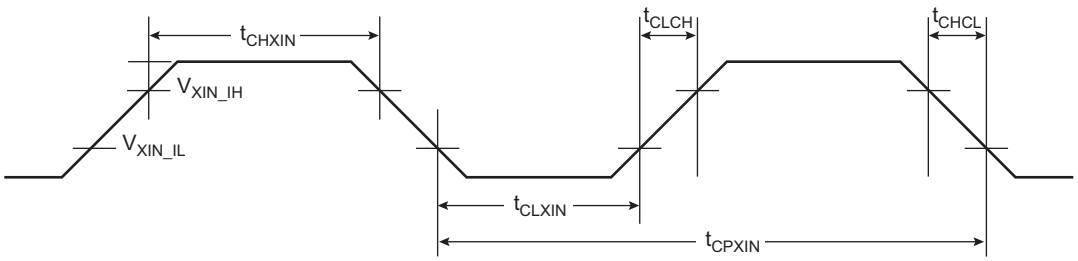
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
ESR	Equivalent Series Resistor (R_S)	Fundamental @ 3 MHz Fundamental @ 8 MHz Fundamental @ 12 MHz Fundamental @ 16 MHz Fundamental @ 20 MHz			200 100 80 80 50	W
C_m	Motional capacitance				8	fF
C_{SHUNT}	Shunt capacitance				7	pF

42.4.8 3 to 20 MHz XIN Clock Input Characteristics in Bypass Mode

Table 42-23. XIN Clock Electrical Characteristics (In Bypass Mode)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$1/(t_{CPXIN})$	XIN Clock Frequency	3–20 MHz crystal oscillator is in Bypass mode			50	MHz
t_{CPXIN}	XIN Clock Period		20			ns
t_{CHXIN}	XIN Clock High Half-period		8			ns
t_{CLXIN}	XIN Clock Low Half-period		8			ns
t_{CLCH}	Rise Time		400			ns
t_{CHCL}	Fall Time		400			ns
C_i	XIN Input Capacitance				6	pF
R_{IN}	XIN Pull-down Resistor			1		MΩ
V_{XIN_IL}	V_{XIN} Input Low-level Voltage		-0.3		$0.3 \times V_{DDPLL}$	V
V_{XIN_IH}	V_{XIN} Input High-level Voltage		$0.7 \times V_{DDPLL}$		$V_{DDPLL} + 0.3$	V

Figure 42-13. XIN Clock Timing



42.4.9 Crystal Oscillators Design Consideration Information

SAM3U oscillators are low power oscillators requiring particular attention when designing PCB systems.

When choosing a crystal for the 32.768 kHz Slow Clock Oscillator or for the 3–20 MHz oscillator, several parameters must be taken into account. Important parameters between crystal and SAM3U specifications are as follows:

- Load Capacitance

  $C_{crystal}$ is the equivalent capacitor value the oscillator must “show” to the crystal in order to oscillate at the target frequency. Crystal must be chosen according to the internal load capacitance (C_{LOAD})of the on-chip oscillator. Having a mismatch for the load capacitance will result in a frequency drift.

- Drive Level

  Crystal drive level ≥ Oscillator Drive Level. Having a crystal drive level number lower than the oscillator specification may damage the crystal.

- Equivalent Series Resistor (ESR)

  Crystal ESR ≤ Oscillator ESR Max. Having a crystal with ESR value higher than the oscillator may cause the oscillator to not start.

- Shunt Capacitance

  Max. crystal Shunt capacitance ≤ Oscillator Shunt Capacitance (C_{SHUNT}). Having a crystal with ESR value higher than the oscillator may cause the oscillator to not start.

42.5 UPLL, PLLA Characteristics

Table 42-24. Supply Voltage Phase Lock Loop Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDPLLR}	Supply Voltage Range		1.6	1.8	2	V
$V_{rip(VDDPLL)}$	Allowable Voltage Ripple	RMS value 10 kHz to 10 MHz RMS value > 10 MHz			30 10	mV

Table 42-25. PLLA Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{IN}	Input Frequency		1		40	MHz
f_{OUT}	Output Frequency		80		240	MHz
I_{PLL}	Current Consumption	Active mode @ 96 MHz @ 1.8V Active mode @ 160 MHz @ 1.8V Active mode @ 192 MHz @ 1.8V		1 1.6 2.4	1.3 2 3	mA
		Standby mode			1	µA
t_s	Settling Time				200	µs

Table 42-26. UPLL Characteristics for USB High Speed Device Port

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{IN}	Input Frequency			12		MHz
Δf_{IN}	Input Frequency Accuracy	(1)	-0.05		+0.05	%
f_{OUT}	Output Frequency			480		MHz
I_{PLL}	Current Consumption	Active mode @ 480 MHz @ 1.8V		2.5	5	mA
		Standby mode			2	µA

Note: 1. Required for 12 MHz Clock Signal injection on XIN pin (oscillator in Bypass mode)

42.6 USB High Speed Port

42.6.1 Typical Connection

For typical connection please refer to Section 38. “USB High Speed Device Port (UDPHS)”.

42.6.2 USB Electrical Characteristics

Table 42-27. Electrical Parameters

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
R_{PUI}	Bus Pull-up Resistor on Upstream Port (idle bus)	In FS or HS Mode		1.5		kΩ
R_{PUA}	Bus Pull-up Resistor on Upstream Port (upstream port receiving)	In FS or HS Mode		15		kΩ

42.6.2.1 USB Transceiver

USB 2.0 Compliant in full-speed and high-speed modes. Refer to Chapter 7 of the USB 2.0, Revision 2.0 April 27, 2000.

42.6.3 Static Power Consumption

Table 42-28. Static Power Consumption

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I_{BIAS}	Bias current consumption on VBG				1	µA
$I_{VDDUTMI}$	HS Transceiver & I/O current consumption				8	µA
	FS / HS Transceiver & I/O current consumption	No connection(1)			3	µA

Note: 1. If cable is connected add 200 µA (Typical) due to Pull-up/Pull-down current consumption.

42.6.4 Dynamic Power Consumption

Table 42-29. Dynamic Power Consumption

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I_{BIAS}	Bias current consumption on VBG			0.7	0.8	mA
$I_{VDDUTMI}$	HS Transceiver current consumption	HS transmission		47	60	mA
	HS Transceiver current consumption	HS reception		18	27	mA
	FS/HS Transceiver current consumption	FS transmission 0m cable(1)		4	6	mA
	FS/HS Transceiver current consumption	FS transmission 5m cable(1)		26	30	mA
	FS/HS Transceiver current consumption	FS reception(1)		3	4.5	mA

Note: 1. Including 1 mA due to Pull-up/Pull-down current consumption.

42.7 12-bit ADC Characteristics

Table 42-30. Analog Power Supply Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDANA}	ADC Analog Supply	12-bit or 10-bit resolution	2.4	3.0	3.6	V
		10-bit resolution	2.0		3.6	V
$V_{rip(max)}$	Max. Voltage Ripple	RMS value, 10 kHz to 20 MHz			20	mV
I_{VDDANA}	Current Consumption	Sleep Mode		0.1	1	µA
		Fast Wake Up Mode		1.8	2.6	mA
		Normal Mode (ADC12B_ACR.IBCTL = 00)(1)		4.7	7.1	mA
		Normal Mode (ADC12B_ACR.IBCTL = 01)(2)		6	9	mA

Notes: 1. Use ADC12B_ACR.IBCTL = 00 for sampling frequency below 500 kHz.
2. Use ADC12B_ACR.IBCTL = 01 for sampling frequency between 500 kHz and 1 MHz.

Table 42-31. Channel Conversion Time and ADC Clock

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{ADC}	ADC Clock Frequency		1		20	MHz
t_{CP_ADC}	ADC Clock Period		50		1000	ns
f_S	Sampling Frequency		0.05		1	MHz
t_{START}	ADC Startup Time	From OFF Mode to Normal Mode: - Voltage Reference OFF - Analog Circuitry OFF	20	30	40	µs
		From Standby Mode to Normal Mode: - Voltage Reference ON - Analog Circuitry OFF	4	8	12	
t_{TRACK}	Track and Hold Time	See Section 42.7.2.1 “Sample and Hold Time versus Source Output Impedance” for more details	160			ns
t_{CONV}	Conversion Time			20		t_{CP_ADC}
t_s	Settling Time	Settling time to change offset and gain	200			ns

Table 42-32. External Voltage Reference Input

Parameter	Conditions	Min	Typ	Max	Unit
ADVREF Input Voltage Range, 12-bit	2.4V < V_{DDANA} < 3.6V	2.4		V_{DDANA}	V
ADVREF Input Voltage Range, 10-bit	2.0V < V_{DDANA} < 3.6V	2.0		V_{DDANA}	V
ADVREF Current				250	µA
ADVREF Input DC impedance			14		kΩ

42.7.1 Static Performance Characteristics

Minimal code = 0

Maximal code = 4095

ADC resolution = 12 bits (4096)

Temperature range -40 to 100 °C

f_{ADC} = 2 MHz

ADC12B_ACR.IBCTL = 01

In Table 42-33 and Table 42-34, the LSB is relative to analog scale for 12-bit ADC:

- Single Ended (ex: ADVREF = 3.0V),
  - Gain = 1, LSB = (3.0V / 4096) = 732 µV
  - Gain = 2, LSB = (1.5V / 4096) = 366 µV
  - Gain = 4, LSB = (750mV / 4096) = 183 µV
- Differential (ex: ADVREF = 3.0V),
  - Gain = 0.5, LSB = (6.0V / 4096) = 1465 µV
  - Gain = 1, LSB = (3.0V / 4096) = 732 µV
  - Gain = 2, LSB = (750mV / 4096) = 366 µV

In Table 42-35, the LSB is relative to analog scale for 10-bit ADC: LSB = 3.0V/1024.

Table 42-33. INL, DNL, 12-bit mode, VDDANA Supply Voltage Conditions

Symbol	Parameter	Conditions[1]	Min	Typ	Max	Unit
INL	Integral Non-linearity	VDDANA 2.4V to < 3.0V Differential, DIFF = 1, OFF = x, GAIN = xx	-2.2	±1	+2.2	LSB
		VDDANA 2.4V to < 3.0V Single-ended, DIFF = 0, OFF = x, GAIN = xx	-6	±1	+6	
		VDDANA 3.0V to < 3.6V Differential, DIFF = 1, OFF = x, GAIN = xx	-1.5	±1	+1.5	
		VDDANA 3.0V to < 3.6V Single-ended, DIFF = 0, OFF = x, GAIN = xx	-5	±1	+5	
DNL	Differential Non-linearity	VDDANA 2.4V to < 3.0V Differential, DIFF = 1, OFF = x, GAIN = xx	-1.5	±0.5	+1.5	
		VDDANA 2.4V to < 3.0V Single-ended, DIFF = 0, OFF = x, GAIN = xx	-2.2	±0.5	+2.2	
		VDDANA 3.0V to < 3.6V Differential, DIFF = 1, OFF = x, GAIN = xx	-1.5	±0.5	+1.5	
		VDDANA 3.0V to < 3.6V Single-ended, DIFF = 0, OFF = x, GAIN = xx	-2.2	±0.5	+2.2	

Note: 1. 'x' in conditions represents digital 0 or 1

Table 42-34. Gain Error, Offset Error, 12-bit Mode, VDDANA Supply Voltage Conditions[1]

Symbol	Parameter	Conditions[2]	Min	Typ	Max	Unit
E_G	Gain error	VDDANA 2.4V to < 3.6V Differential, DIFF = 1, OFF = x, GAIN = xx	-1.56 -64	-0.56 -23	+0.29 +12	% LSB
		VDDANA 2.4V to < 3.6V Single ended, DIFF = 0, OFF = x, GAIN = xx	-1.56 -64	-0.56 -23	+0.78 +32	% LSB
E_O	Offset error	VDDANA 2.4V to < 3.6V Differential, DIFF = 1, OFF = x, GAIN = xx	-30		+64	LSB
		VDDANA 2.4V to < 3.6V Single ended, DIFF = 0, OFF = x, GAIN = xx	-60		+80	LSB

Notes: 1. Offset and Gain errors are given without calibration. A software calibration can be done to reduce Gain and offset errors.
2. 'x' in conditions represents digital 0 or 1

Figure 42-14. Offset and Gain Definitions

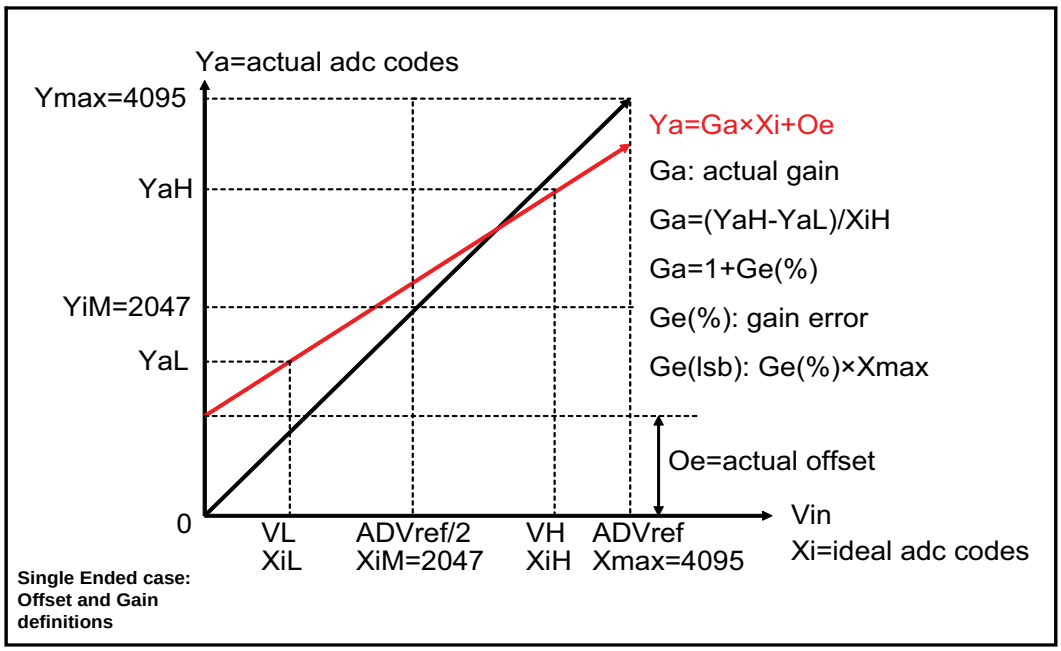


Table 42-35. Static Performance Characteristics - 10-bit mode [1]

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
	Resolution			10		bit
INL	Integral Non-linearity		-1	±0.5	+1	LSB
DNL	Differential Non-linearity	No missing code	-1	±0.5	+1	LSB
E_O	Offset Error	All gain, Differential or Single-ended, no calibration	-8	+3	+20	LSB
E_G	Gain Error	All gain, Differential or Single-ended, no calibration	-16	-6	+3	LSB

Note: 1. Single-ended or differential mode, any gain values.

42.7.2 Dynamic Performance Characteristics

The following conditions apply for the characteristics provided in Table 42-36 and Table 42-37:

- ADC resolution = 12 bits
- Temperature range -40 to 100 °C
- f_{ADC} = 20 MHz
- ADC12B_ACR.IBCTL = 01
- f_S = 1 MHz
- f_{IN} = 127 kHz
- FFT using 1024 points or more
- Frequency band = [1–500 kHz]
- Nyquist conditions fulfilled

Table 42-36. Dynamic Performance Characteristics in Single-ended and 12-bit Mode

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
SNR	Signal to Noise Ratio	Single-ended, DIFF = 0, OFF = x, GAIN = xx	57	58		dB
THD	Total Harmonic Distortion	Single-ended, DIFF = 0, OFF = x, GAIN = xx	-66	-72		dB
SINAD	Signal to Noise and Distortion	Single-ended, DIFF = 0, OFF = x, GAIN = xx	54	57		dB
ENOB	Effective Number of Bits	Single-ended, DIFF = 0, OFF = x, GAIN = xx	9.0	10.0		bits

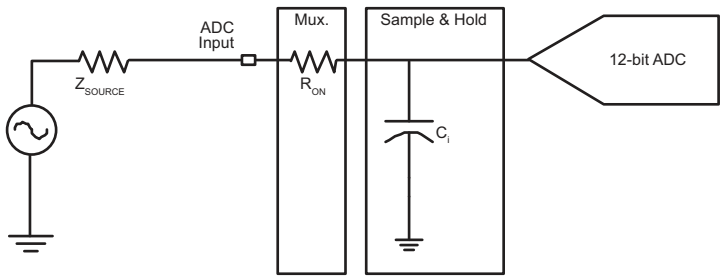
Table 42-37. Dynamic Performance Characteristics in Differential and 12-bit Mode

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
SNR	Signal to Noise Ratio	Differential, DIFF = 1, OFF = x, GAIN = xx	59	64		dB
THD	Total Harmonic Distortion	Differential, DIFF = 1, OFF = x, GAIN = xx	-69	-80		dB
SINAD	Signal to Noise and Distortion	Differential, DIFF = 1, OFF = x, GAIN = xx	59	64		dB
ENOB	Effective Number of Bits	Differential, DIFF = 1, OFF = x, GAIN = xx	9.5	10.3		bits

42.7.2.1 Sample and Hold Time versus Source Output Impedance

The following figure gives a simplified acquisition path.

Figure 42-15. Simplified Acquisition Path



During the tracking phase the ADC needs to track the input signal during the tracking time shown below:

- 10-bit mode: $t_{TRACK} = 0.042 \times Z_{SOURCE} + 160$
- 12-bit mode: $t_{TRACK} = 0.054 \times Z_{SOURCE} + 205$

With t_{TRACK} expressed in ns and Z_{SOURCE} expressed in ohms.

Two cases must be considered:

1. The calculated tracking time (t_{TRACK}) is lower than 15 t_{CP_ADC}.

   Set ADC12B_MR.SHTIM = 0.

   In this case, the allowed Z_{SOURCE} can be computed versus the ADC frequency with the hypothesis of $t_{TRACK} = 15 \times t_{CP_ADC}$

   where $t_{CP_ADC} = 1/f_{ADC}$. See Table 42-38.

2. The calculated tracking time (t_{TRACK}) is higher than 15 t_{CP_ADC}.

   Set ADC12B_MR.SHTIM = 0.

   In this case, a timer will trigger the ADC in order to set the correct sampling rate according to the Track time.

   The maximum possible sampling frequency will be defined by t_{TRACK} in nanoseconds, computed by the previous formula but with minus $15 \times t_{CP_ADC}$.

   10-bit mode: $1/f_S = t_{TRACK} - 15 \times t_{CP_ADC} + 5\ t_{CP_ADC}$

   12-bit mode: $1/f_S = t_{TRACK} - 15 \times t_{CP_ADC} + 5\ t_{CP_ADC}$

Note: C_{sample} and R_{ON} are taken into account in the formulas.

Table 42-38. Source Impedance Values

f_{ADC} = ADC clock (MHz)	Z_{SOURCE} (kΩ) for 12 bits	Z_{SOURCE} (kΩ) for 10 bits
20.00	10	14
16.00	14	19
10.67	22	30
8.00	31	41
6.40	40	52
5.33	48	63
4.57	57	74
4.00	66	85
3.56	74	97
3.20	83	108
2.91	92	119
2.67	100	130
2.46	109	141
2.29	118	152
2.13	126	164
2.00	135	175
1.00	274	353

Table 42-39. Analog Inputs

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IR}	Input Voltage Range[1]		0		V_{ADVREF}	V
I_{lkg}	Input Leakage Current				±0.5	µA
C_i	Input Capacitance				8	pF

Note: 1. Input voltage range can be up to VDDANA without destruction or over-consumption.
If VDDIO < V_{ADVREF} max input voltage is VDDIO.

42.7.3 ADC Application Information

For more information on data converter terminology, please refer to the application note *Data Converter Terminology* (Atmel literature No. 6022) available on www.atmel.com.

42.8 10-bit Successive Approximation Register (SAR) ADC Characteristics

Table 42-40. Channel Conversion Time and ADC Clock

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{ADC}	ADC Clock Frequency	10-bit resolution mode			5	MHz
		8-bit resolution mode			8	MHz
t_{START}	Startup Time				20	µs
t_{TRACK}	Track and Hold Acquisition Time		600			ns
t_{CONV}	Conversion Time	ADC Clock = 5 MHz			2	µs
		ADC Clock = 8 MHz			1.25	
	Throughput Rate	ADC Clock = 5 MHz			384(1)	ksps
		ADC Clock = 8 MHz			533(2)	

Notes: 1. Corresponds to 13 clock cycles at 5 MHz: 3 clock cycles for track and hold acquisition time and 10 clock cycles for conversion.
2. Corresponds to 15 clock cycles at 8 MHz: 5 clock cycles for track and hold acquisition time and 10 clock cycles for conversion

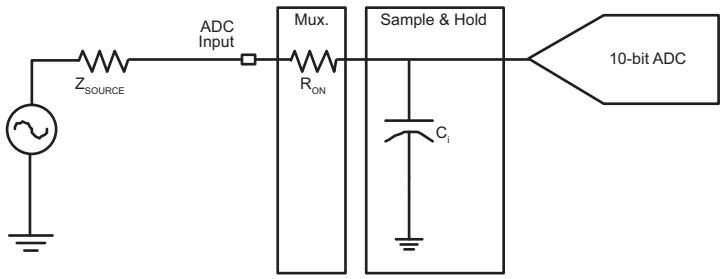
Table 42-41. External Voltage Reference Input

Parameter	Conditions	Min	Typ	Max	Unit
ADVREF Input Voltage Range		2.4		V_{DDANA} + 0.2	V
ADVREF Average Current	13 samples at ADC Clock = 5 MHz		200	250	µA
Current Consumption on VDDCORE			0.55	1	mA

42.8.1 Sample and Hold Time versus Source Output Impedance

Figures 42-16 and gives a simplified acquisition path.

Figure 42-16. Figure 43-11. Simplified Acquisition Path



The user can drive ADC input with impedance up to:

- $Z_{SOURCE} \leq (SHTIM - 470) \times 10$ in 8-bit resolution mode
- $Z_{SOURCE} \leq (SHTIM - 589) \times 7.69$ in 10-bit resolution mode

with SHTIM (in Sample and Hold Time register) expressed in ns and Z_{SOURCE} expressed in ohms.

Note: C_{sample} and R_{ON} are taken into account in the formulas

Table 42-42. Analog Inputs

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IR}	Input Voltage Range		0		V_{ADVREF}	V
I_{lkg}	Input Leakage Current				±0.5	µA
C_i	Input Capacitance				8	pF

Table 42-43. Analog Power Supply Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DDANA}	ADC Analog Supply		3.0		3.6	V
$V_{rip(max)}$	Maximum Voltage Ripple	RMS value, 10 kHz to 20 MHz			20	mV

Table 42-44. Transfer Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
	Resolution			10		bit
INL	Integral Non-linearity				±2	LSB
DNL	Differential Non-linearity	No missing code			±1	LSB
E_O	Offset Error				±2	LSB
E_G	Gain Error				±2	LSB
	Absolute accuracy				±4	LSB

42.8.2 ADC Application Information

For more information on data converter terminology, please refer to the application note *Data Converter Terminology* (Atmel literature No. 6022) available on www.atmel.com.

42.9 AC Characteristics

42.9.1 Master Clock Characteristics

Table 42-45. Master Clock Waveform Parameters

Symbol	Parameter	Conditions	Min	Max	Unit
$1/(t_{CPMCK})$	Master Clock Frequency	VDDCORE @ 1.62V VDDCORE @ 1.8V		84 96	MHz

42.9.2 I/O Characteristics

Criteria used to define the maximum frequency of the I/Os:

- Output duty cycle (40%–60%)
- Minimum output swing: 100 mV to VDDIO - 100 mV
- Minimum output swing: 100 mV to VDDIO - 100 mV
- Addition of rising and falling time inferior to 75% of the period

Table 42-46. I/O Characteristics

Symbol	Parameter	Conditions		Min	Max	Unit
FreqMax1	Pin Group 1 (1) Maximum output frequency	30 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V		45 65	MHz
		45 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V		34 45	
$PulseminH_1$	Pin Group 1 (1) High Level Pulse Width	30 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V	11 7.7		ns
		45 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V	14.7 11		
$PulseminL_1$	Pin Group 1 (1) Low Level Pulse Width	30 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V	11 7.7		ns
		45 pF	V_{DDIO} = 1.62V V_{DDIO} = 3.0V	14.7 11		
FreqMax2	Pin Group 2 (2) Maximum output frequency	25 pF	1.62V < V_{DDIO} < 3.6V		35	MHz
$PulseminH_2$	Pin Group 2 (2) High Level Pulse Width	25 pF	1.62V < V_{DDIO} < 3.6V	14.5		ns
$PulseminL_2$	Pin Group 2 (2) Low Level Pulse Width	25 pF	1.62V < V_{DDIO} < 3.6V	14.5		ns

Notes: 1. Pin Group 1 = PA3, PA15
2. Pin Group 2 = PA[0–2], PA[4–14], PA[16–31], PB[0–31], PC[0–31]

Table 42-47. NRSTB Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{NRSTB(filtered)}$	Filtered Pulse Width				1	µs
$t_{NRSTB(unfiltered)}$	Unfiltered Pulse Width		100			µs

42.9.3 SPI Characteristics

Figure 42-17. SPI Master Mode with (CPOL = NCPHA = 0) or (CPOL = NCPHA = 1)

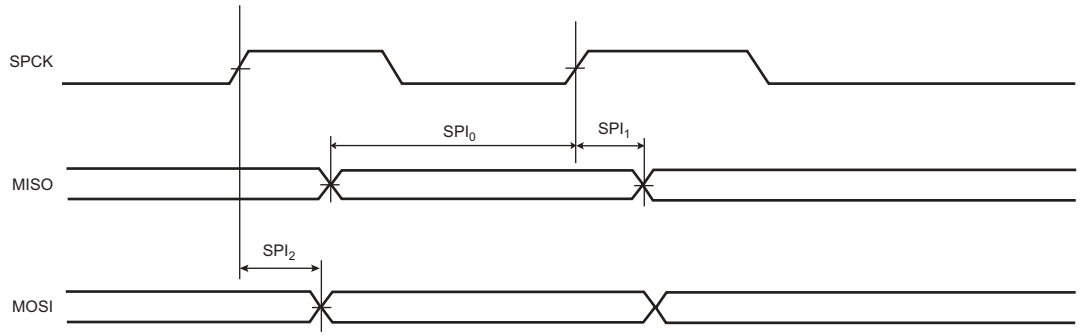


Figure 42-18. SPI Master Mode with (CPOL = 0 and NCPHA = 1) or (CPOL = 1 and NCPHA = 0)

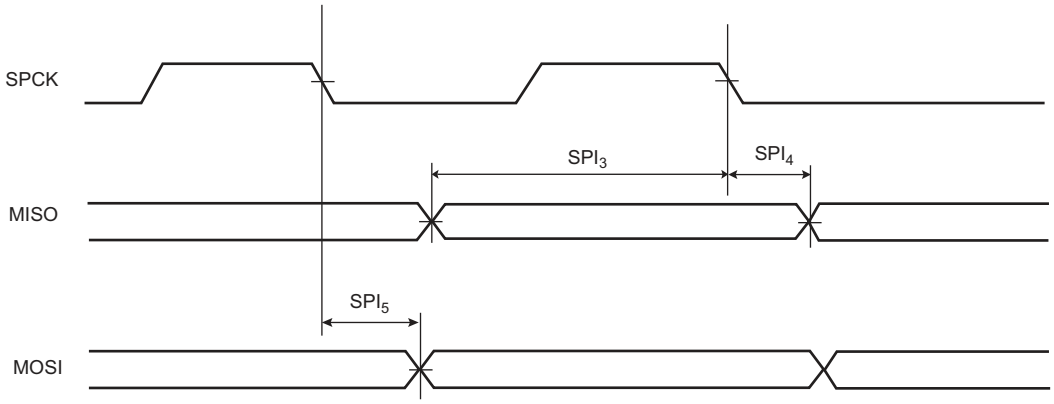


Figure 42-19. SPI Slave Mode with (CPOL = 0 and NCPHA = 1) or (CPOL = 1 and NCPHA = 0)

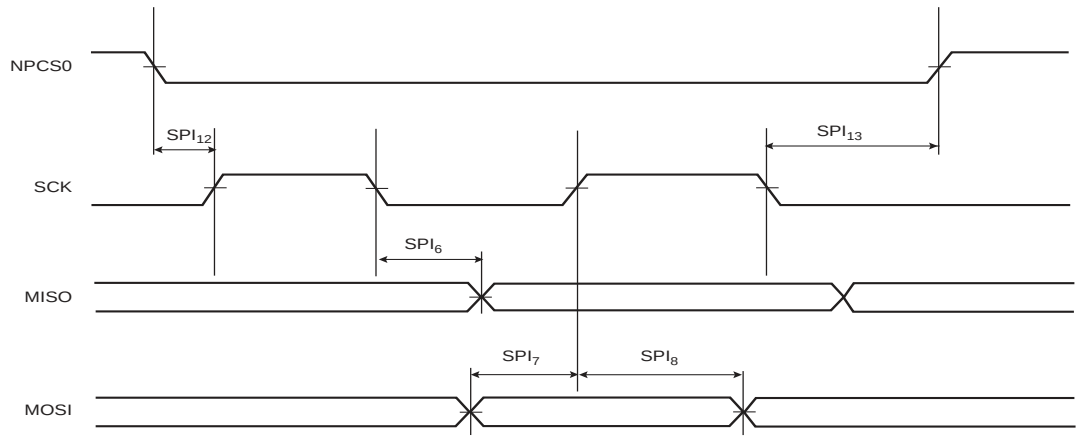
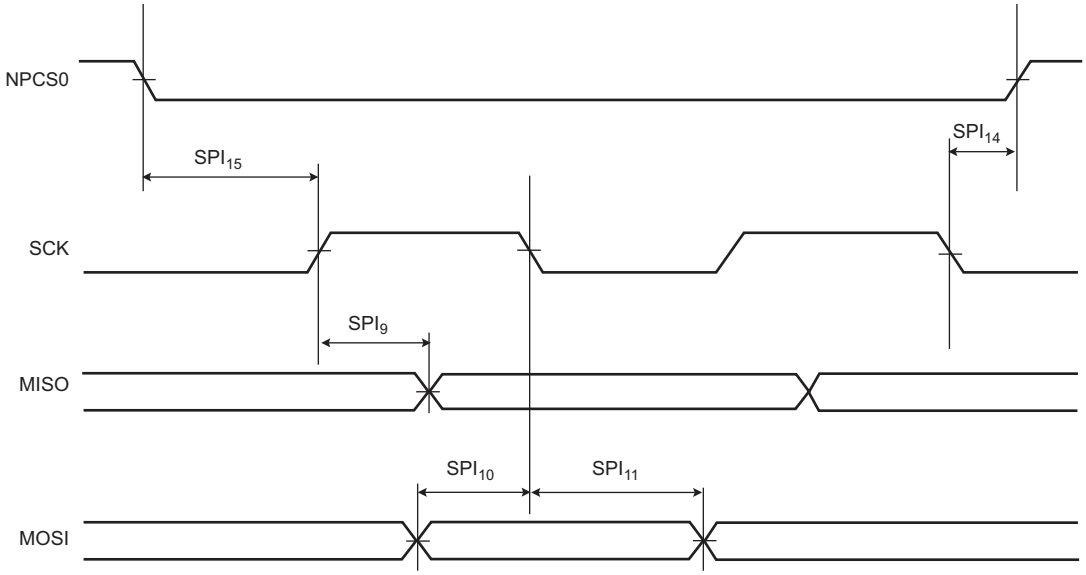


Figure 42-20. SPI Slave Mode with (CPOL = NCPHA = 0) or (CPOL = NCPHA = 1)



42.9.3.1 Maximum SPI Frequency

The following formulas give maximum SPI frequency in Master read and write modes and in Slave read and write modes.

Master Write Mode

The SPI only sends data to a slave device such as an LCD, for example. The limit is given by SPI_2 (or SPI_5) timing. Since it gives a maximum frequency above the maximum pad speed (see Section 42.9.2 “I/O Characteristics”), the max SPI frequency is defined by the pin FreqMax value.

Master Read Mode

$$f_{SPCK}Max = \frac{1}{SPI_0(orSPI_3) + t_{valid}}$$

t_{valid} is the slave time response to output data after detecting an SPCK edge. For a non-volatile memory with t_{valid} (or t_v) = 12 ns, f_{SPCK}Max = 38.5 MHz at V_{DDIO} = 3.3V.

Slave Read Mode

In slave mode, SPCK is the input clock for the SPI. The max SPCK frequency is given by setup and hold timings SPI_7/SPI_8(or SPI_{10}/SPI_{11}). Since this gives a frequency well above the pad limit, the limit in slave read mode is given by SPCK pad.

Slave Write Mode

$$f_{SPCK}Max = \frac{1}{SPI_6(orSPI_9) + t_{su}}$$

For 3.3V I/O domain and SPI6, f_{SPCK}Max = 33 MHz. t_{su} is the setup time from the master before sampling data.

42.9.3.2 SPI Timings

SPI timings are given for the following domains:

- 3.3V domain: VDDIO from 3.0V to 3.6V, maximum external capacitor = 30 pF
- 1.8V domain: VDDIO from 1.65V to 1.95V, maximum external capacitor = 30 pF

Table 42-48. SPI Timings

Symbol	Parameter	Conditions	Min	Max	Unit
SPI_0	MISO Setup time before SPCK rises (master)	3.3V domain	14		ns
		1.8V domain	17		
SPI_1	MISO Hold time after SPCK rises (master)	3.3V domain	0		ns
		1.8V domain	0		
SPI_2	SPCK rising to MOSI Delay (master)	3.3V domain		3	ns
		1.8V domain		3.5	
SPI_3	MISO Setup time before SPCK falls (master)	3.3V domain	14		ns
		1.8V domain	17		
SPI_4	MISO Hold time after SPCK falls (master)	3.3V domain	0		ns
		1.8V domain	0		
SPI_5	SPCK falling to MOSI Delay (master)	3.3V domain		3	ns
		1.8V domain		3.5	
SPI_6	SPCK falling to MISO Delay (slave)	3.3V domain		14	ns
		1.8V domain		17	
SPI_7	MOSI Setup time before SPCK rises (slave)	3.3V domain	0.5		ns
		1.8V domain	1		
SPI_8	MOSI Hold time after SPCK rises (slave)	3.3V domain	0.5		ns
		1.8V domain	1		
SPI_9	SPCK rising to MISO Delay (slave)	3.3V domain		14	ns
		1.8V domain		17	
SPI_{10}	MOSI Setup time before SPCK falls (slave)	3.3V domain	0		ns
		1.8V domain	0		
SPI_{11}	MOSI Hold time after SPCK falls (slave)	3.3V domain	1.5		ns
		1.8V domain	1.5		
SPI_{12}	NPCS Setup time to SPCK (slave)	3.3V domain	5.2		ns
		1.8V domain	5		
SPI_{13}	NPCS Hold time after SPCK (slave)	3.3V domain	0		ns
		1.8V domain	0		
SPI_{14}	NPCS Setup time to SPCK (slave)	3.3V domain	4.2		ns
		1.8V domain	4		
SPI_{15}	NPCS Hold time after SPCK (slave)	3.3V domain	0		ns
		1.8V domain	0		

Note that in SPI master mode the SAM3U does not sample the data (MISO) on the opposite edge where data clocks out (MOSI) but the same edge is used as shown in Figure 42-17 and Figure 42-18.

42.9.4 MCI Timings

The High Speed MultiMedia Card Interface (HSMCI) supports the MultiMedia Card (MMC) Specification V4.3, the SD Memory Card Specification V2.0, the SDIO V2.0 specification and CE-ATA V1.1.

42.9.5 SSC Timings

SSC timings are given for the following domains:

- 1.8V domain: V_{DDIO} from 1.65V to 1.95V, maximum external capacitor = 25 pF
- 3.3V domain: V_{DDIO} from 3.0V to 3.6V, maximum external capacitor = 25 pF

Figure 42-21. SSC Transmitter, TK and TF as Output

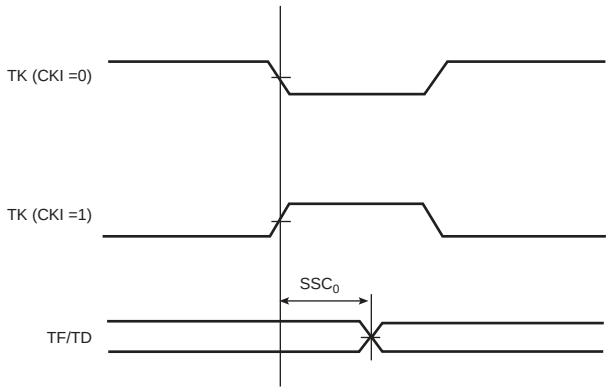


Figure 42-22. SSC Transmitter, TK as Input and TF as Output

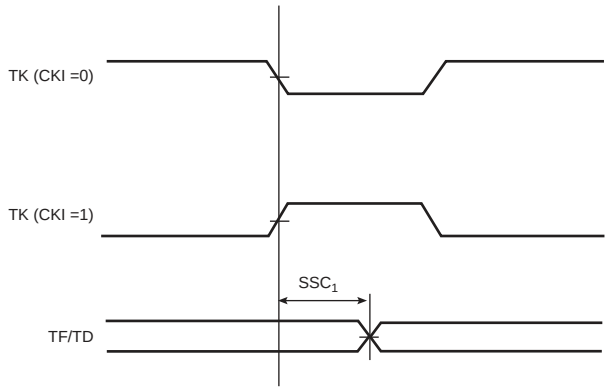


Figure 42-23. SSC Transmitter, TK as Output and TF as Input

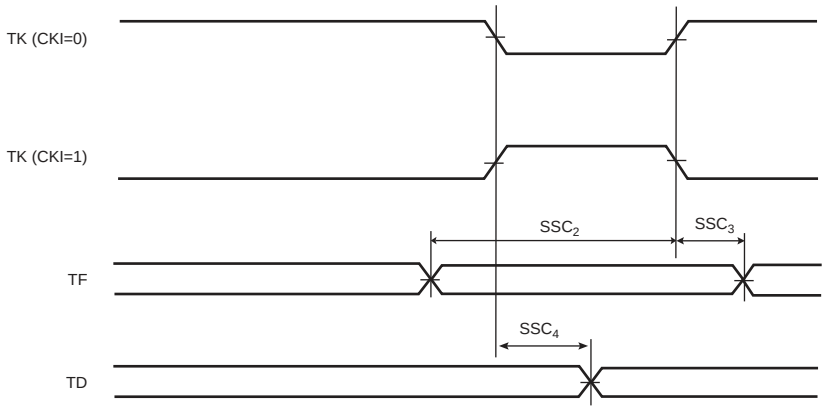


Figure 42-24. SSC Transmitter, TK and TF as Input

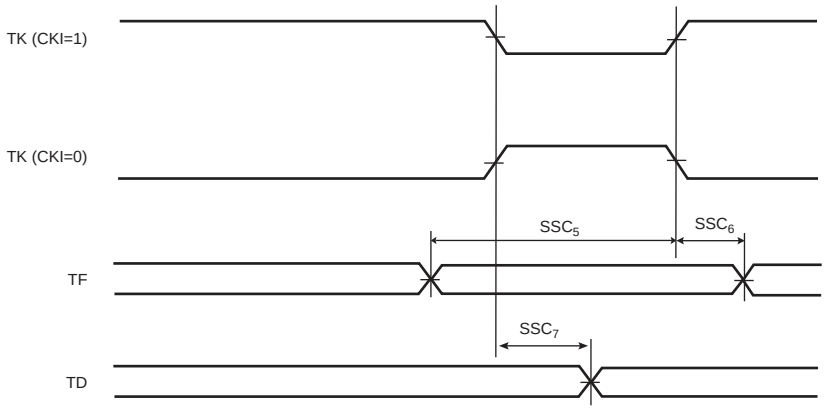


Figure 42-25. SSC Receiver RK and RF as Input

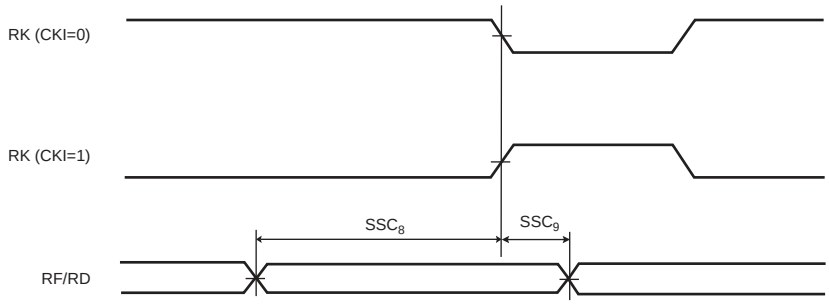


Figure 42-26. SSC Receiver, RK as Input and RF as Output

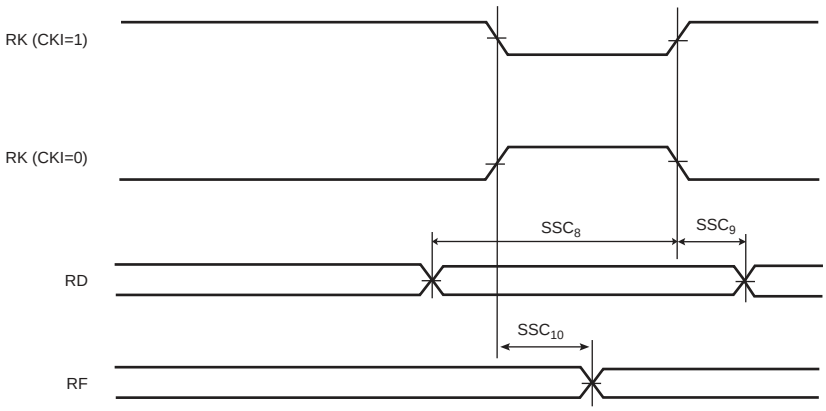


Figure 42-27. SSC Receiver, RK and RF as Output

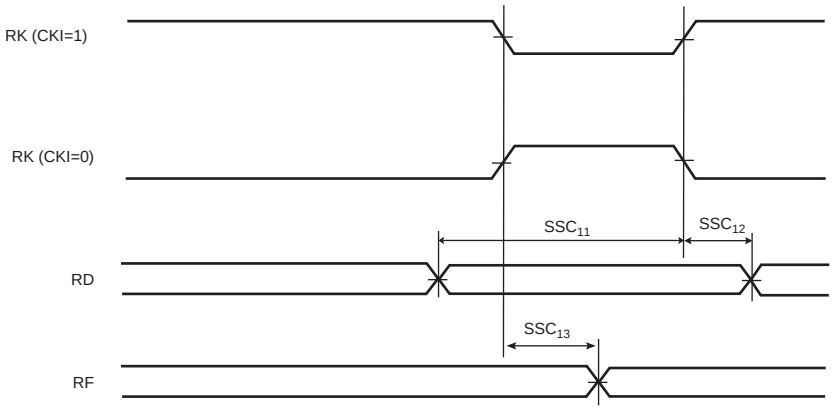


Figure 42-28. SSC Receiver, RK as Output and RF as Input

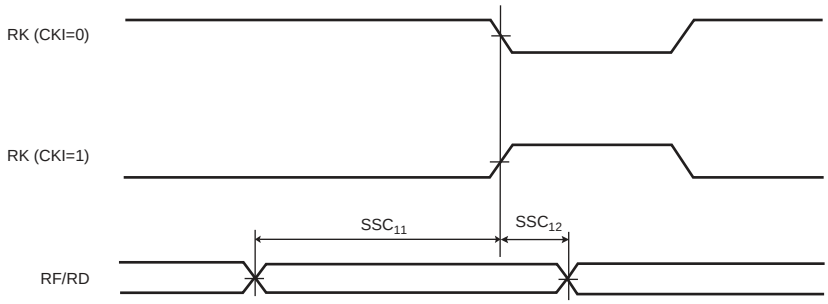
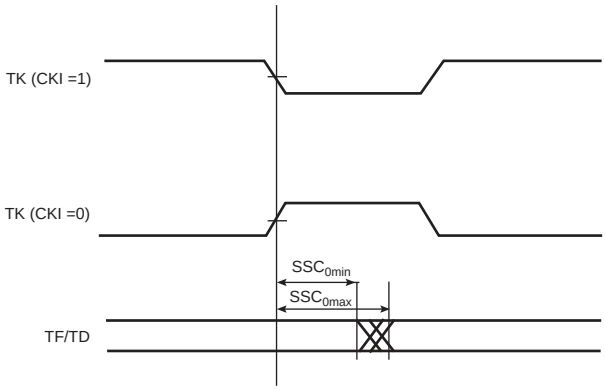


Table 42-49. SSC Timings

Symbol	Parameter	Domain	Conditions	Min	Max	Unit
Transmitter						
SSC_0	TK edge to TF/TD (TK output, TF output)	1.8V 3.3V		0[1] 0[1]	2 [1] 1.5[1]	ns
SSC_1	TK edge to TF/TD (TK input, TF output)	1.8V 3.3V		5[1] 5[1]	17.5 [1] 14.5[1]	ns
SSC_2	TF setup time before TK edge (TK output)	1.8V 3.3V		17 - t_{CPMCK} 15 - t_{CPMCK}		ns
SSC_3	TF hold time after TK edge (TK output)	1.8V 3.3V		t_{CPMCK} - 5 t_{CPMCK} - 5		ns
SSC_4	TK edge to TF/TD (TK output, TF input)	1.8V	–	0	2	ns
			STTDLY = 0 START = 4, 5 or 7	$2 \times t_{CPMCK}$[1]	$2 + (2 \times t_{CPMCK})$[1]	
		3.3V	–	0	30.5	
			STTDLY = 0 START = 4, 5 or 7	$2 \times t_{CPMCK}$[1]	$2 + (2 \times t_{CPMCK})$[1]	
SSC_5	TF setup time before TK edge (TK input)	1.8V 3.3V		0 0		ns
SSC_6	TF hold time after TK edge (TK input)	1.8V 3.3V		t_{CPMCK} t_{CPMCK}		ns
SSC_7	TK edge to TF/TD (TK input, TF input)	1.8V	–	5	18	ns
			STTDLY = 0 START = 4, 5 or 7	$5 + (3 \times t_{CPMCK})$[1]	$18 + (3 \times t_{CPMCK})$[1]	
		3.3V	–	5	15	
			STTDLY = 0 START = 4, 5 or 7	$5 + (3 \times t_{CPMCK})$[1]	$15 + (3 \times t_{CPMCK})$[1]	
Receiver						
SSC_8	RF/RD setup time before RK edge (RK input)	1.8V 3.3V		0 0		ns
SSC_9	RF/RD hold time after RK edge (RK input)	1.8V 3.3V		t_{CPMCK} t_{CPMCK}		ns
SSC_{10}	RK edge to RF (RK input)	1.8V 3.3V		5[1] 5[1]	18[1] 15[1]	ns
SSC_{11}	RF/RD setup time before RK edge (RK output)	1.8V 3.3V		17 - t_{CPMCK} 15 - t_{CPMCK}		ns
SSC_{12}	RF/RD hold time after RK edge (RK output)	1.8V 3.3V		t_{CPMCK} - 5 t_{CPMCK} - 5		ns
SSC_{13}	RK edge to RF (RK output)	1.8V 3.3V		0[1] 0[1]	3[1] 2[1]	ns

Note: 1. For output signals (TF, TD, RF), min and max access times are defined. The min access time is the time between the TK (or RK) edge and the signal change. The max access timing is the time between the TK edge and the signal stabilization. Figure 42-29 illustrates min and max accesses for SSC_0. This also applies to SSC_1, SSC_4, and SSC_7, SSC_{10} and SSC_{13}.

Figure 42-29. Min and Max Access Time of Output Signals



42.9.6 SMC Timings

Timings are given in the following domains:

- 1.8V domain: VDDIO from 1.65V to 1.95V, maximum external capacitor = 25 pF
- 3.3V domain: VDDIO from 3.0V to 3.6V, maximum external capacitor = 25 pF

Timings are given assuming a capacitance load on data, control and address pads. In the following tables t_{CPMCK} is MCK period.

42.9.6.1 Read Timings

Table 42-50. SMC Read Signals - NRD Controlled (READ_MODE = 1)

Symbol	Parameter	Min		Max		Unit
	VDDIO Supply	1.8V Domain	3.3V Domain	1.8V Domain	3.3V Domain	
NO HOLD Settings (NRD_HOLD = 0)						
SMC_1	Data Setup before NRD High	17.5	16			ns
SMC_2	Data Hold after NRD High	0	0			ns
HOLD Settings (NRD_HOLD ≠ 0)						
SMC_3	Data Setup before NRD High	17	15			ns
SMC_4	Data Hold after NRD High	0	0			ns
HOLD or NO HOLD Settings (NRD_HOLD ≠ 0, NRD_HOLD = 0)						
SMC_5	NBS0/A0, NBS1, NBS2/A1, NBS3, A2–A25 valid before NRD High	(NRD_SETUP + NRD_PULSE) × t_{CPMCK} + 7	(NRD_SETUP + NRD_PULSE) × t_{CPMCK} + 6.5			ns
SMC_6	NCS low before NRD High	(NRD_SETUP + NRD_PULSE - NCS_RD_SETUP) × t_{CPMCK} + 8	(NRD_SETUP + NRD_PULSE - NCS_RD_SETUP) × t_{CPMCK} + 7			ns
SMC_7	NRD Pulse Width	NRD_PULSE × t_{CPMCK} - 5	NRD_PULSE × t_{CPMCK} - 5			ns

Table 42-51. SMC Read Signals - NCS Controlled (READ_MODE = 0)

Symbol	Parameter	Min		Max		Unit
	VDDIO supply	1.8V Domain	3.3V Domain	1.8V Domain	3.3V Domain	
NO HOLD Settings (NCS_RD_HOLD = 0)						
SMC_8	Data Setup before NCS High	20	16			ns
SMC_9	Data Hold after NCS High	0	0			ns
HOLD SETTINGS (NCS_RD_HOLD ≠ 0)						
SMC_{10}	Data Setup before NCS High	18	15			ns
SMC_{11}	Data Hold after NCS High	0	0			ns
HOLD or NO HOLD Settings (NCS_RD HOLD ≠ 0, NCS_RD_HOLD = 0)						
SMC_{12}	NBS0/A0, NBS1, NBS2/A1, NBS3, A2–A25 valid before NCS High	(NCS_RD_SETUP + NCS_RD_PULSE) × t_{CPMCK} - 3.5	(NCS_RD_SETUP + NCS_RD_PULSE) × t_{CPMCK} - 3			ns
SMC_{13}	NRD low before NCS High	(NCS_RD_SETUP + NCS_RD_PULSE - NRD_SETUP) × t_{CPMCK} - 2	(NCS_RD_SETUP + NCS_RD_PULSE - NRD_SETUP) × t_{CPMCK} - 2			ns
SMC_{14}	NCS Pulse Width	NCS_RD_PULSE length × t_{CPMCK} - 5	NCS_RD_PULSE length × t_{CPMCK} - 5			ns

42.9.6.2 Write Timings

Table 42-52. SMC Write Signals - NWE Controlled (WRITE_MODE = 1)

Symbol	Parameter	Min		Max		Unit
	VDDIO supply	1.8V Domain	3.3V Domain	1.8V Domain	3.3V Domain	
HOLD or NO HOLD Settings (NWE_HOLD ≠ 0, NWE_HOLD = 0)						
SMC_{15}	Data Out Valid before NWE High	NWE_PULSE × t_{CPMCK} - 4	NWE_PULSE × t_{CPMCK} - 3.5			ns
SMC_{16}	NWE Pulse Width	NWE_PULSE × t_{CPMCK} - 5	NWE_PULSE × t_{CPMCK} - 5			ns
SMC_{17}	NBS0/A0 NBS1, NBS2/A1, NBS3, A2–A25 valid before NWE low	NWE_SETUP × t_{CPMCK} + 8	NWE_SETUP × t_{CPMCK} + 7			ns
SMC_{18}	NCS low before NWE high	(NWE_SETUP - NCS_RD_SETUP + NWE_PULSE) × t_{CPMCK} + 2	(NWE_SETUP - NCS_RD_SETUP + NWE_PULSE) × t_{CPMCK} + 3			ns
HOLD Settings (NWE_HOLD ≠ 0)						
SMC_{19}	NWE High to Data OUT, NBS0/A0 NBS1, NBS2/A1, NBS3, A2–A25 change	NWE_HOLD × t_{CPMCK} - 5.5	NWE_HOLD × t_{CPMCK} - 5.5			ns
SMC_{20}	NWE High to NCS Inactive (1)	(NWE_HOLD - NCS_WR_HOLD) × t_{CPMCK} - 3	(NWE_HOLD - NCS_WR_HOLD) × t_{CPMCK} - 3			ns
NO HOLD Settings (NWE_HOLD = 0)						
SMC_{21}	NWE High to Data OUT, NBS0/A0 NBS1, NBS2/A1, NBS3, A2–A25, NCS change(1)	4	4			ns

Note: 1. Hold length = total cycle duration - setup duration - pulse duration. “hold length” is for “NCS_WR_HOLD length” or “NWE_HOLD length”.

Table 42-53. SMC Write NCS Controlled (WRITE_MODE = 0)

Symbol	Parameter	Min		Max		Unit
	VDDIO supply	1.8V Domain	3.3V Domain	1.8V Domain	3.3V Domain	
SMC_{22}	Data Out Valid before NCS High	NCS_WR_PULSE × t_{CPMCK} - 3	NCS_WR_PULSE × t_{CPMCK} - 2			ns
SMC_{23}	NCS Pulse Width	NCS_WR_PULSE × t_{CPMCK} - 5	NCS_WR_PULSE × t_{CPMCK} - 5			ns
SMC_{24}	NBS0/A0 NBS1, NBS2/A1, NBS3, A2–A25 valid before NCS low	NCS_WR_SETUP × t_{CPMCK} - 3	NCS_WR_SETUP × t_{CPMCK} - 2.5			ns
SMC_{25}	NWE low before NCS high	(NCS_WR_SETUP - NWE_SETUP + NCS_PULSE) × t_{CPMCK} - 2.5	(NCS_WR_SETUP - NWE_SETUP + NCS_PULSE) × t_{CPMCK} - 2			ns
SMC_{26}	NCS High to Data Out, NBS0/A0, NBS1, NBS2/A1, NBS3, A2–A25, change	NCS_WR_HOLD × t_{CPMCK} - 6.5	NCS_WR_HOLD × t_{CPMCK} - 5.5			ns
SMC_{27}	NCS High to NWE Inactive	(NCS_WR_HOLD - NWE_HOLD) × t_{CPMCK} - 5	(NCS_WR_HOLD - NWE_HOLD) × t_{CPMCK} - 4.5			ns

Figure 42-30. SMC Timings - NCS Controlled Read and Write

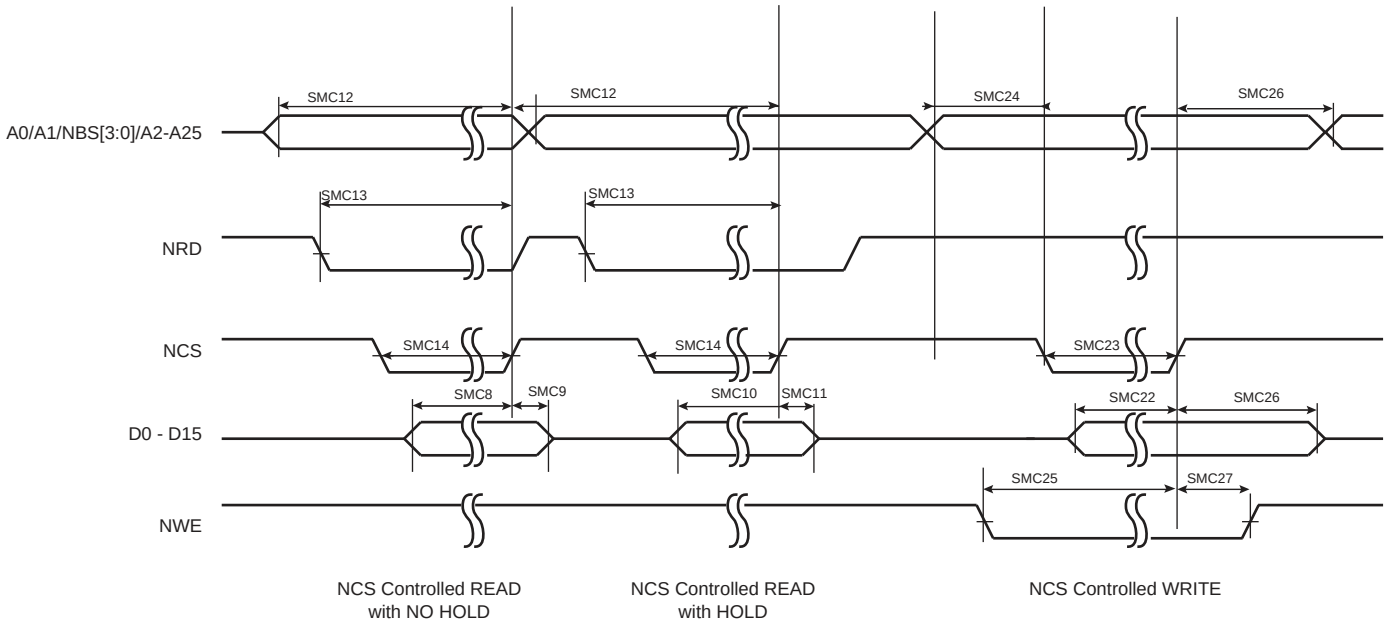
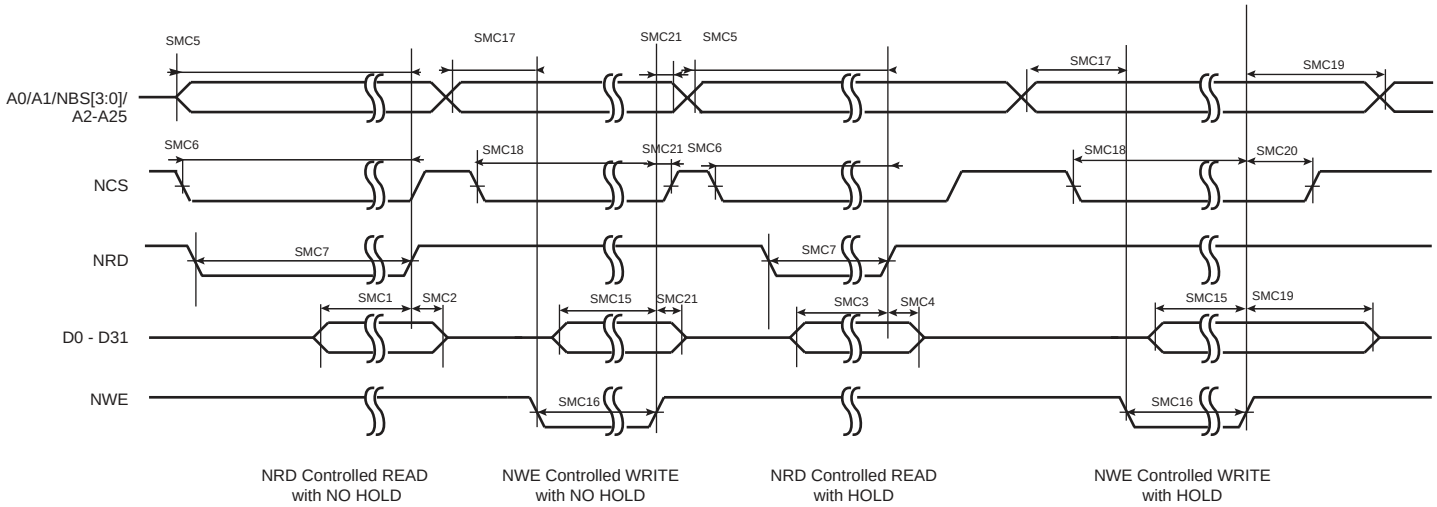


Figure 42-31. SMC Timings - NRD Controlled Read and NWE Controlled Write



42.9.7 Two-wire Serial Interface Characteristics

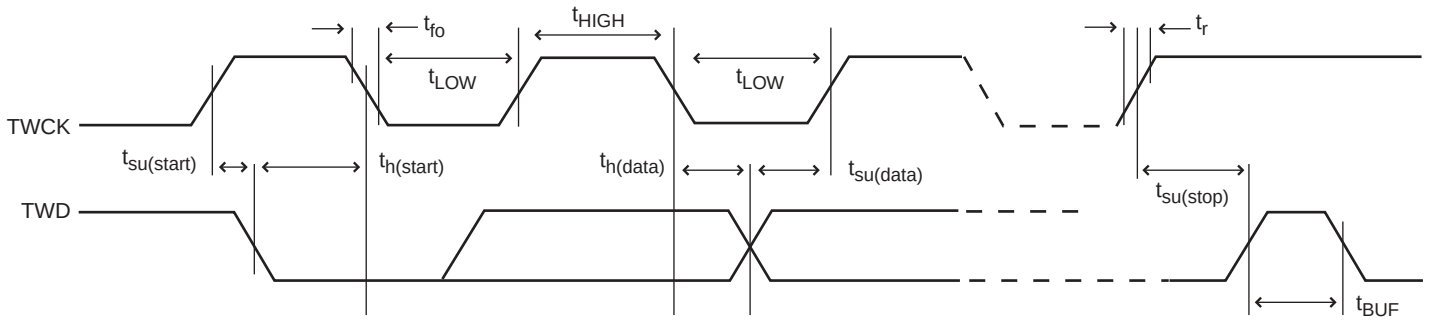
Table 42-54 describes the requirements for devices connected to the Two-wire Serial Bus. For timing symbols refer to Figure 42-32.

Table 42-54. Two-wire Serial Bus Requirements

Symbol	Parameter	Conditions	Min	Max	Unit
V_{IL}	Input Low-voltage		-0.3	$0.3 \times V_{DDIO}$	V
V_{IH}	Input High-voltage		$0.7 \times V_{DDIO}$	V_{CC} + 0.3	V
V_{hys}	Hysteresis of Schmitt Trigger Inputs		0.150	–	V
V_{OL}	Output Low-voltage	3 mA sink current	-	0.4	V
t_r	Rise Time for both TWD and TWCK		$20 + 0.1C_b$ (1)(2)	300	ns
t_{fo}	Output Fall Time from V_{IHmin} to V_{ILmax}	10 pF < C_b < 400 pF Figure 42-32	$20 + 0.1C_b$ (1)(2)	250	ns
C_i (1)	Capacitance for each I/O Pin		–	10	pF
f_{TWCK}	TWCK Clock Frequency		0	400	kHz
Rp	Value of Pull-up resistor	$f_{TWCK} \le 100$ kHz	$(V_{DDIO}$ - 0.4V) ÷ 3mA	1000ns ÷ C_b	Ω
		$f_{TWCK} > 100$ kHz		300ns ÷ C_b	
t_{LOW}	Low Period of the TWCK clock	$f_{TWCK} \le 100$ kHz	(3)	–	µs
		$f_{TWCK} > 100$ kHz	(3)	–	µs
t_{HIGH}	High period of the TWCK clock	$f_{TWCK} \le 100$ kHz	(4)	–	µs
		$f_{TWCK} > 100$ kHz	(4)	–	µs
$t_{h(start)}$	Hold Time (repeated) START Condition	$f_{TWCK} \le 100$ kHz	t_{HIGH}	–	µs
		$f_{TWCK} > 100$ kHz	t_{HIGH}	–	µs
$t_{su(start)}$	Setup time for a repeated START condition	$f_{TWCK} \le 100$ kHz	t_{HIGH}	–	µs
		$f_{TWCK} > 100$ kHz	t_{HIGH}	–	µs
$t_{h(data)}$	Data hold time	$f_{TWCK} \le 100$ kHz	0	$3 \times t_{CPMCK}$	µs
		$f_{TWCK} > 100$ kHz	0	$3 \times t_{CPMCK}$	µs
$t_{su(data)}$	Data setup time	$f_{TWCK} \le 100$ kHz	$t_{LOW} - 3 \times t_{CPMCK}$	–	ns
		$f_{TWCK} > 100$ kHz	$t_{LOW} - 3 \times t_{CPMCK}$	–	ns
$t_{su(stop)}$	Setup time for STOP condition	$f_{TWCK} \le 100$ kHz	t_{HIGH}	–	µs
		$f_{TWCK} > 100$ kHz	t_{HIGH}	–	µs
t_{BUF}	Bus free time between a STOP and START condition	$f_{TWCK} \le 100$ kHz	t_{LOW}	–	µs
		$f_{TWCK} > 100$ kHz	t_{LOW}	–	µs

Notes:
1. Required only for $f_{TWCK} > 100$ kHz
2. C_b = capacitance of one bus line in pF. Per I2C Standard compatibility, C_b Max = 400 pF
3. The TWCK low period is defined as follows: $t_{LOW} = ((CLDIV \times 2^{CKDIV}) + 4) \times t_{MCK}$
4. The TWCK high period is defined as follows: $t_{HIGH} = ((CHDIV \times 2^{CKDIV}) + 4) \times t_{MCK}$
5. t_{CPMCK} = MCK bus period

Figure 42-32. Two-wire Serial Bus Timing



42.9.8 Embedded Flash Characteristics

The maximum operating frequency given in Table 42-55 is limited by the Embedded Flash access time when the processor is fetching code out of it. The table provides the device maximum operating frequency defined by the value of field FWS of the EEFC_FMR. This field defines the number of wait states required to access the Embedded Flash Memory.

Note: The embedded flash is fully tested during production test, the flash contents is not set to a known state prior to shipment. Therefore, the flash contents should be erased prior to programming an application.

Table 42-55. Embedded Flash Wait State - VDDCORE 1.62V/1.80V

EEFC_FMR.FWS	Read Operations	Maximum Operating Frequency (MHz)	
		VDDCORE 1.62V	VDDCORE 1.80V
0	1 cycle	24	27
1	2 cycles	40	47
2	3 cycles	72	84
3	4 cycles	84	96

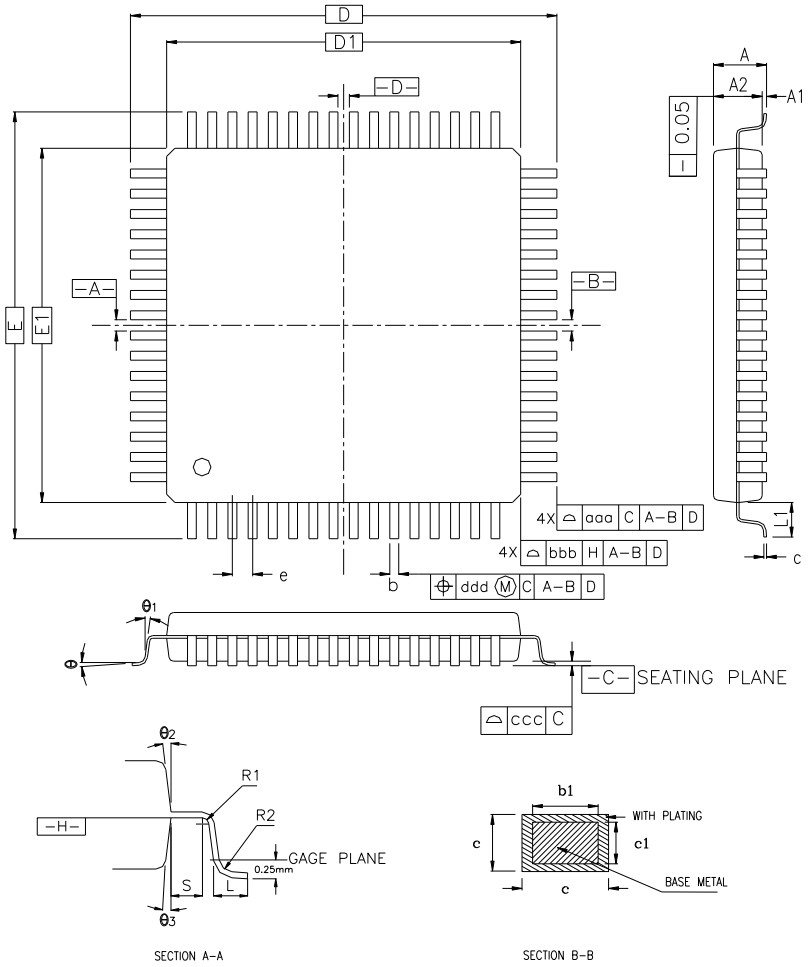
Table 42-56. AC Flash Characteristics

Parameter	Conditions	Min	Typ	Max	Unit
Program Cycle Time	Per page including auto-erase			4.6	ms
	Per page without auto-erase			2.3	ms
Full Chip Erase			10	11.5	ms
Data Retention	Not Powered or Powered	10			years
Endurance	Write/Erase cycles @ 25°C		30K		cycles
	Write/Erase cycles @ 85°C	10K			

43. Mechanical Characteristics

43.1 100-lead LQFP Package

Figure 43-1. 100-lead LQFP Package Drawing



CONTROL DIMENSIONS ARE IN MILLIMETERS.

SYMBOL	MILLIMETER			INCH		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	—	—	1.60	—	—	0.063
A1	0.05	—	0.15	0.002	—	0.006
A2	1.35	1.40	1.45	0.053	0.055	0.057
D	16.00 BSC.			0.630 BSC.		
D1	14.00 BSC.			0.551 BSC.		
E	16.00 BSC.			0.630 BSC.		
E1	14.00 BSC.			0.551 BSC.		
R2	0.08	—	0.20	0.003	—	0.008
R1	0.08	—	—	0.003	—	—
θ	0°	3.5°	7°	0°	3.5°	7°
θ1	0°	—	—	0°	—	—
θ2	11°	12°	13°	11°	12°	13°
θ3	11°	12°	13°	11°	12°	13°
c	0.09	—	0.20	0.004	—	0.008
c1	0.09	0.127	0.16	0.004	0.005	0.006
L1	1.00 REF			0.039 REF		
L	0.45	0.60	0.75	0.018	0.024	0.030
S	0.20	—	—	0.008	—	—
b	0.17	—	0.27	0.007	—	0.011
b1	0.17	0.20	0.23	0.007	0.008	0.009
e	0.50 BSC.			0.020 BSC.		
TOLERANCES OF FORM AND POSITION						
aaa	0.20			0.008		
bbb	0.20			0.008		
ccc	0.08			0.003		
ddd	0.08			0.003		

NOTES :

1. DIMENSIONS D1 AND E1 DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25mm PER SIDE. D1 AND E1 DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE H
2. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08MM TOTAL IN EXESS OF THE b DIMENSION AT MAXIMUM MATERIAL CONDITION. DAMBAR CAN NOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT

Table 43-1. Device and 100-lead LQFP Package Maximum Weight

SAM3UE4/2/1	800	mg

Table 43-2. 100-lead LQFP Package Reference

JEDEC Drawing Reference	MS-026
JESD97 Classification	e3

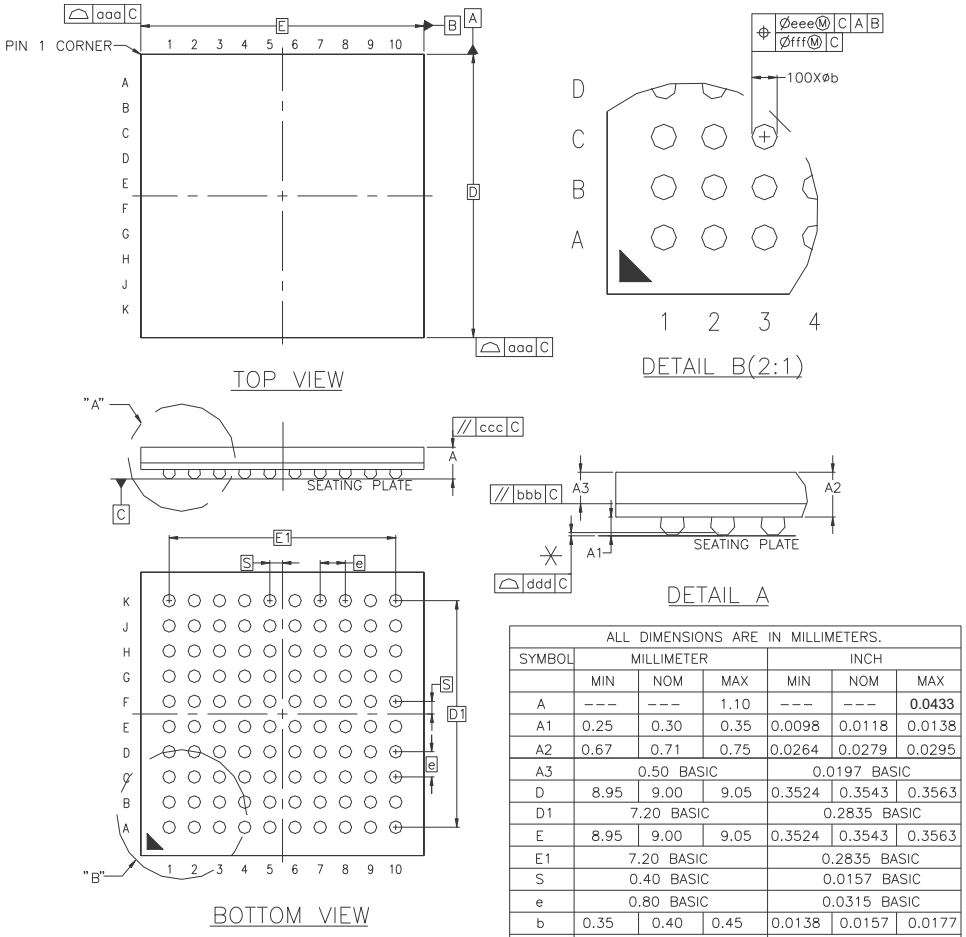
Table 43-3. 100-lead LQFP Package Characteristics

Moisture Sensitivity Level	3

This package respects the recommendations of the NEMI User Group.

43.2 100-ball TFBGA Package

Figure 43-2. 100-ball TFBGA Package Drawing



ALL DIMENSIONS ARE IN MILLIMETERS.						
SYMBOL	MILLIMETER			INCH		
	MIN	NOM	MAX	MIN	NOM	MAX
A	---	---	1.10	---	---	0.0433
A1	0.25	0.30	0.35	0.0098	0.0118	0.0138
A2	0.67	0.71	0.75	0.0264	0.0279	0.0295
A3	0.50 BASIC			0.0197 BASIC		
D	8.95	9.00	9.05	0.3524	0.3543	0.3563
D1	7.20 BASIC			0.2835 BASIC		
E	8.95	9.00	9.05	0.3524	0.3543	0.3563
E1	7.20 BASIC			0.2835 BASIC		
S	0.40 BASIC			0.0157 BASIC		
e	0.80 BASIC			0.0315 BASIC		
b	0.35	0.40	0.45	0.0138	0.0157	0.0177
aaa	0.15			0.0059		
bbb	0.20			0.0079		
ccc	0.20			0.0079		
ddd	0.12			0.0047		
eee	0.15			0.0059		
fff	0.08			0.0031		

Table 43-4. 100-ball TFBGA Soldering Information (Substrate Level)

Ball Land	0.45 mm
Soldering Mask Opening	0.35 mm

Table 43-5. 100-ball TFBGA Device Maximum Weight

141	mg

Table 43-6. 100-ball TFBGA Package Characteristics

Moisture Sensitivity Level	3

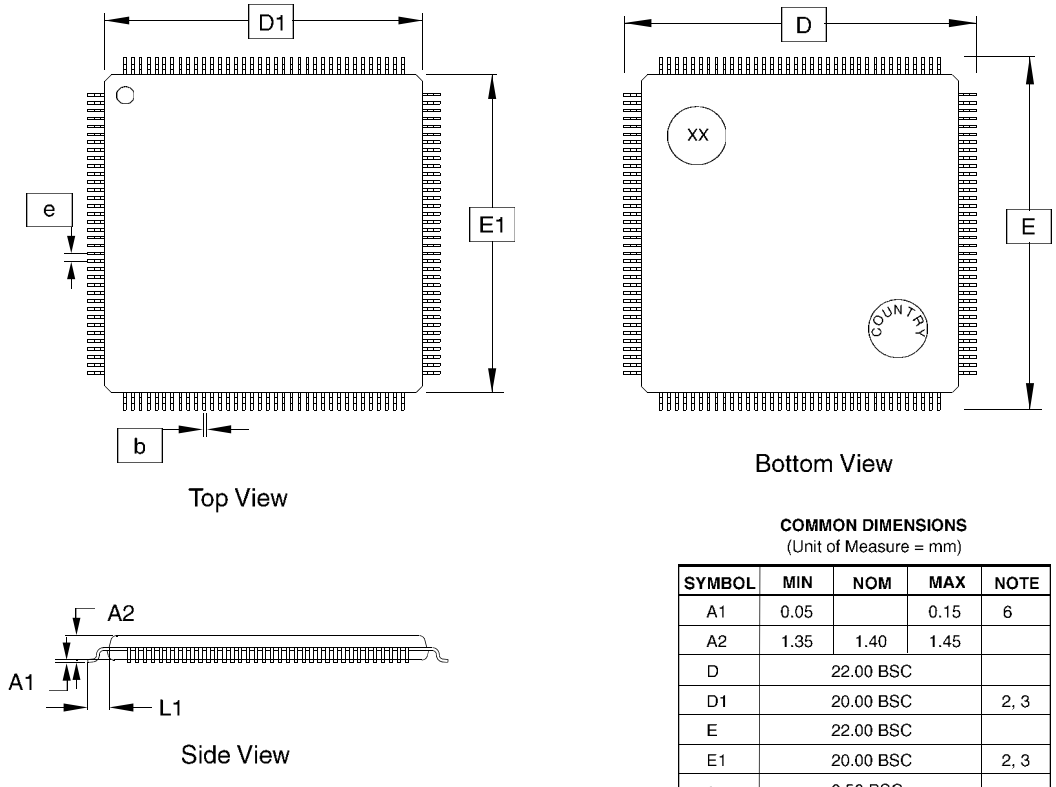
Table 43-7. 100-ball TFBGA Package Reference

JEDEC Drawing Reference	MO-275-DDAC-1
JESD97 Classification	e8

This package respects the recommendations of the NEMI User Group.

43.3 144-lead LQFP Package

Figure 43-3. 144-lead LQFP Package Drawing



COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A1	0.05		0.15	6
A2	1.35	1.40	1.45	
D		22.00 BSC		
D1		20.00 BSC		2, 3
E		22.00 BSC		
E1		20.00 BSC		2, 3
e		0.50 BSC		
b	0.17	0.22	0.27	4, 5
L1		1.00 REF		

Notes:
1. This drawing is for general information only; refer to JEDEe Drawing MS-026 for additional information.
2. The top package body size may be smaller than the bottom package size by as much as 0.15 mm.
3. Dimensions D1 and E1 do not include mold protrusions. Allowable protrusion is 0.25 mm per side. D1 and E1 are maximum plastic body size dimensions including mold mismatch.
4. b dimension by more than 0.08 mm. Dambar cannot be located on the lower radius or the foot. Minimum space between protrusion and an adjacent lead is 0.07 mm for 0.4 and 0.5 mm pitch packages.
5. These dimensions apply to the flat section of the lead between 0.10 mm and 0.25 mm from the lead tip.
6. A1 is defined as the distance from the seating place to the lowest point on the package body.

Table 43-8. 144-lead LQFP Device Maximum Weight

1400	mg

Table 43-9. 144-lead LQFP Package Characteristics

Moisture Sensitivity Level	3

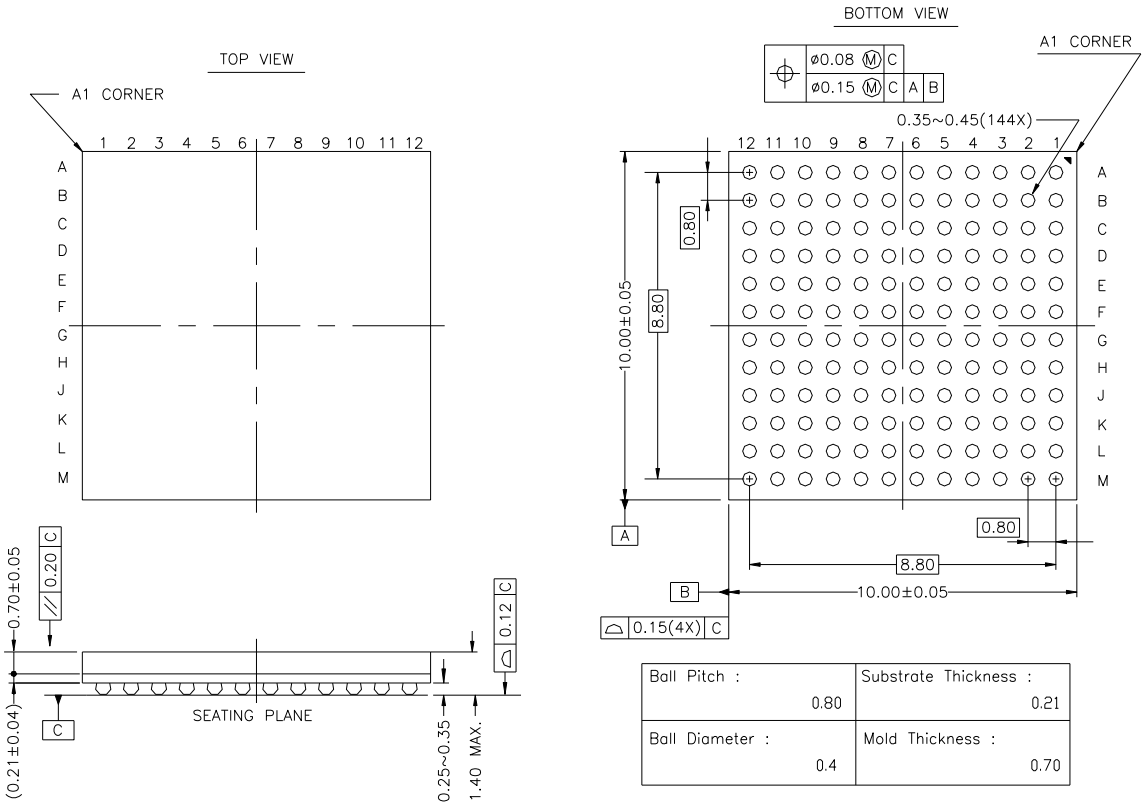
Table 43-10. 144-lead LQFP Package Reference

JEDEC Drawing Reference	MS-026
JESD97 Classification	e3

This package respects the recommendations of the NEMI User Group.

43.4 144-ball LFBGA Package

Figure 43-4. 144-ball LFBGA Package Drawing



All dimensions are in mm.

Table 43-11. 144-ball LFBGA Soldering Information (Substrate Level)

Ball Land	0.380 mm
Soldering Mask Opening	0.280 mm

Table 43-12. Device and 144-ball LFBGA Package Maximum Weight

300	mg

Table 43-13. 144-ball LFBGA Package Characteristics

Moisture Sensitivity Level	3

Table 43-14. 144-ball LFBGA Package Reference

JEDEC Drawing Reference	none
JESD97 Classification	e1

This package respects the recommendations of the NEMI User Group.

43.5 Soldering Profile

Table 43-15 gives the recommended soldering profile from J-STD-020C.

Table 43-15. Soldering Profile

Profile Feature	Green Package
Average Ramp-up Rate (217°C to Peak)	3°C/sec. max.
Preheat Temperature 175°C ±25°C	180 sec. max.
Temperature Maintained Above 217°C	60 sec. to 150 sec.
Time within 5°C of Actual Peak Temperature	20 sec. to 40 sec.
Peak Temperature Range	260°C
Ramp-down Rate	6°C/sec. max.
Time 25°C to Peak Temperature	8 min. max.

Note: The package is certified to be backward compatible with Pb/Sn soldering profile.

A maximum of three reflow passes is allowed per component.

43.6 Packaging Resources

Land Pattern Definition.

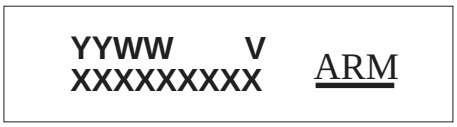
Refer to the following IPC Standards:

- IPC-7351A and IPC-782 (*Generic Requirements for Surface Mount Design and Land Pattern Standards*) http://landpatterns.ipc.org/default.asp
- Atmel Green and RoHS Policy and Package Material Declaration Data Sheet available on www.atmel.com

44. Marking

All devices are marked with the Atmel logo and the ordering code.

Additional marking is as follows:



where

- “YY”: manufactory year
- “WW”: manufactory week
- “V”: revision
- “XXXXXXXXX”: lot number

45. Ordering Information

Table 45-1. SAM3U Ordering Information

Ordering Code	MRL	Flash (Kbytes)	Package	Operating Temperature Range
ATSAM3U4EA-AU	A	256	LQFP144	Industrial -40°C to 85°C
ATSAM3U4EA-CU	A	256	LFBGA 144	Industrial -40°C to 85°C
ATSAM3U4CA-AU	A	256	LQFP 100	Industrial -40°C to 85°C
ATSAM3U4CA-CU	A	256	TFBGA100	Industrial -40°C to 85°C
ATSAM3U2EA-AU	A	128	LQFP144	Industrial -40°C to 85°C
ATSAM3U2EA-CU	A	128	LFBGA144	Industrial -40°C to 85°C
ATSAM3U2CA-AU	A	128	LQFP100	Industrial -40°C to 85°C
ATSAM3U2CA-CU	A	128	TFBGA100	Industrial -40°C to 85°C
ATSAM3U1EA-AU	A	64	LQFP144	Industrial -40°C to 85°C
ATSAM3U1EA-CU	A	64	LFBGA144	Industrial -40°C to 85°C
ATSAM3U1CA-AU	A	64	LQFP100	Industrial -40°C to 85°C
ATSAM3U1CA-CU	A	64	TFBGA100	Industrial -40°C to 85°C
ATSAM3U1EB-AU	B	64	LQFP144	Industrial -40°C to 85°C
ATSAM3U1EB-CU	B	64	LFBGA144	Industrial -40°C to 85°C
ATSAM3U1CB-AU	B	64	LQFP100	Industrial -40°C to 85°C
ATSAM3U1CB-CU	B	64	TFBGA100	Industrial -40°C to 85°C

46. SAM3U Series Errata

46.1 SAM3U Errata - Rev. A Parts

Revision A parts Chip IDs are as follows:

SAM3U4C (Rev A)	0x28000961
SAM3U2C (Rev A)	0x280A0761
SAM3U1C (Rev A)	0x28090561
SAM3U4E (Rev A)	0x28100961
SAM3U2E (Rev A)	0x281A0761
SAM3U1E (Rev A)	0x28190561

46.1.1 Flash

46.1.1.1 Flash: Issue Running at Frequency Lower than 5 MHz

When the system clock (MCK) is lower than 5 MHz with two Wait States (WS) programmed in the EEFC Flash Mode Register (EEFC_FMR), the Cortex fetches erroneous instructions.

Problem Fix/Workaround

Do not use two WS when running at a frequency lower than 5 MHz.

46.1.1.2 Flash: Read Flash in 64-bit Mode

Higher than expected power consumption can be seen when reading Flash in 64-bit mode.

Problem Fix/Workaround

Use 128-bit mode instead.

46.1.1.3 Flash: Flash Programming

When writing data into the Flash memory plane (either through the EEFC, using the IAP function, or FFPI), the data may not be correctly written (i.e., the data written is not the one expected).

Problem Fix/Workaround

Set the number of Wait States (WS) to 6 (FWS = 6) during the programming.

46.1.1.4 Flash: Fetching Error after Reading the Unique Identifier

After reading the Unique Identifier (or using the STUI/SPUI command), the processor may fetch wrong instructions. It depends on the code and on the region of the code.

Problem Fix/Workaround

In order to avoid this problem, follow the steps below:

1. Set bit 16 of EEFC_FMR to 1
2. Send the Start Read Unique Identifier command (STUI) by writing the EEFC Flash Command Register (EEFC_FCR) with the STUI command.
3. Wait for the FRDY bit to fall
4. Read the Unique ID (and next bits if required)
5. Send the Stop Read Unique Identifier command (SPUI) by writing the EEFC_FCR with the SPUI command.
6. Wait for the FRDY bit to rise
7. Clear bit 16 of EEFC_FMR

Note: During the sequence, the software cannot run out of Flash (so needs to run out of SRAM).

46.1.2 12-bit Analog-to-Digital Converter (ADC12B)

46.1.2.1 ADC12B: Current Consumption in Backup Mode on VDDANA

In Backup mode, the current consumption on VDDANA is around 1.0 mA instead of 0.1 µA

Problem Fix/Workaround

Four workarounds are possible:

1. Do not supply VDDANA and VDDIO in Backup mode using an external switch managed by SHDN pin.
2. Do not supply VDDANA in Backup mode using an external switch managed by the SHDN and set all PIOs with ADC inputs (PA22, PA30, PB3–PB8, PC15–PC18, PC28–C21) at low level (either externally or by software).
3. Do not supply VDDANA in Backup mode using an external switch managed by any PIO and set all PIOs with ADC inputs (PA22, PA30, PB3–PB8, PC15–PC18, PC28–C21) at low level (either externally or by software). Since the PIO state is preserved when in backup mode, any free PIO line can be used to switch off the external switch by driving the PIO line at low level (PIO is input, pull-up enabled after backup reset).
4. Use Wait mode instead of Backup mode.

46.1.2.2 ADC: Trigger Launches only One Conversion

A start command initiates a conversion sequence of one channel but not all activated channels as expected.

Problem Fix/Workaround

Send as many start commands as the number of activated channels, or use free run mode.

46.1.2.3 ADC12B: Saturation

When the ADC12B works in saturation (measurements below 0V or above AD12BVREF) the results may be erratic, the value deviation can be around 30 LSB to the expected data.

Problem Fix/Workaround

None.

46.1.2.4 ADC: Wrong First Conversions

The first conversions done by the ADC may be erroneous if the maximum gain (x4 in single ended or x2 in differential mode) is not used. The issue appears after the power-up or if a conversion has not occured for 1 minute.

Problem Fix/Workaround

Three workarounds are possible:

1. Perform 16 dummy conversions on one channel (whatever conditions used in term of setup of gain, single/differential, offset, and channel selected). The next conversions will be correct for any channels and any settings. Note that these dummy conversions need to be performed if no conversion has occured for 1 minute or for a new chip startup.
2. Perform a dummy conversion on a single ended channel on which an external voltage of ADVREF/2 (±10%) is applied. Use the following conditions for this conversion: gain at 4, offset set at 1. The next conversions will be correct for any channels and any settings. Note that this dummy conversion needs to be performed if no conversion has occured for 1 minute or for a new chip startup.
3. Perform a dummy conversion on a differential channel on which the two inputs are connected together and connected to any voltage (from 0 to ADVREF). Use the following conditions for this conversion: gain at 4, offset set at 1. The next conversions will be correct for any channels and any settings. Note that this dummy conversion needs to be performed if no conversion has occured for 1 minute or for a new chip startup.

46.1.3 Power Management Controller (PMC)

46.1.3.1 PMC: Main Oscillator Frequency selection if the Main On-chip RC Oscillator is OFF

When the 4/8/12 MHz RC Oscillator is off, the frequency selection (MOSCRCF field in CKGR_MOR) can not be changed. The register can be written but the modification to MOSCRCF will not be taken into account.

Problem Fix/Workaround

Modify MOSCRCF while 4/8/12 MHz RC Oscillator is on (MOSCREN = 1).

46.2 SAM3U Errata - Rev. B Parts

Revision B parts Chip IDs are as follows:

SAM3U1C (Rev B) 0x28090562

SAM3U1E (Rev B) 0x28190562

46.2.1 Flash

46.2.1.1 Flash: Issue Running at Frequency Lower than 5 MHz

When the system clock (MCK) is lower than 5 MHz with two Wait States (WS) programmed in the EEFC Flash Mode Register (EEFC_FMR), the Cortex fetches erroneous instructions.

Problem Fix/Workaround

Do not use two WS when running at a frequency lower than 5 MHz.

46.2.1.2 Flash: Flash Programming

When writing data into the Flash memory plane (either through the EEFC, using the IAP function, or FFPI), the data may not be correctly written (i.e., the data written is not the one expected).

Problem Fix/Workaround

Set the number of Wait States (WS) to 6 (FWS = 6) during the programming.

46.2.1.3 Flash: Fetching Error after Reading the Unique Identifier

After reading the Unique Identifier (or using the STUI/SPUI command), the processor may fetch wrong instructions. It depends on the code and on the region of the code.

Problem Fix/Workaround

In order to avoid this problem, follow the steps below:

1. Set bit 16 of EEFC_FMR to 1
2. Send the Start Read Unique Identifier command (STUI) by writing the EEFC Flash Command Register (EEFC_FCR) with the STUI command.
3. Wait for the FRDY bit to fall
4. Read the Unique ID (and next bits if required)
5. Send the Stop Read Unique Identifier command (SPUI) by writing the EEFC_FCR with the SPUI command.
6. Wait for the FRDY bit to rise
7. Clear bit 16 of EEFC_FMR

Note: During the sequence, the software cannot run out of Flash (so needs to run out of SRAM).

46.2.2 12-bit Analog-to-Digital Converter (ADC12B)

46.2.2.1 ADC12B: Current Consumption in Backup Mode on VDDANA

In Backup mode, the current consumption on VDDANA is around 1.0 mA instead of 0.1 µA

Problem Fix/Workaround

Four workarounds are possible:

1. Do not supply VDDANA and VDDIO in Backup mode using an external switch managed by SHDN pin.
2. Do not supply VDDANA in Backup mode using an external switch managed by the SHDN and set all PIOs with ADC inputs (PA22, PA30, PB3–PB8, PC15–PC18, PC28–C21) at low level (either externally or by software).
3. Do not supply VDDANA in Backup mode using an external switch managed by any PIO and set all PIOs with ADC inputs (PA22, PA30, PB3–PB8, PC15–PC18, PC28–C21) at low level (either externally or by software). Since the PIO state is preserved when in backup mode, any free PIO line can be used to switch off the external switch by driving the PIO line at low level (PIO is input, pull-up enabled after backup reset).
4. Use Wait mode instead of Backup mode.

46.2.2.2 ADC: Trigger Launches only One Conversion

A start command initiates a conversion sequence of one channel but not all activated channels as expected.

Problem Fix/Workaround

Send as many start commands as the number of activated channels, or use free run mode.

46.2.2.3 ADC: Wrong First Conversions

The first conversions done by the ADC may be erroneous if the maximum gain (x4 in single ended or x2 in differential mode) is not used. The issue appears after the power-up or if a conversion has not occured for 1 minute.

Problem Fix/Workaround

Three workarounds are possible:

1. Perform 16 dummy conversions on one channel (whatever conditions used in term of setup of gain, single/differential, offset, and channel selected). The next conversions will be correct for any channels and any settings. Note that these dummy conversions need to be performed if no conversion has occured for 1 minute or for a new chip startup.
2. Perform a dummy conversion on a single ended channel on which an external voltage of ADVREF/2 (±10%) is applied. Use the following conditions for this conversion: gain at 4, offset set at 1. The next conversions will be correct for any channels and any settings. Note that this dummy conversion needs to be performed if no conversion has occured for 1 minute or for a new chip startup.
3. Perform a dummy conversion on a differential channel on which the two inputs are connected together and connected to any voltage (from 0 to ADVREF). Use the following conditions for this conversion: gain at 4, offset set at 1. The next conversions will be correct for any channels and any settings. Note that this dummy conversion needs to be performed if no conversion has occured for 1 minute or for a new chip startup.

46.2.3 Power Management Controller (PMC)

46.2.3.1 PMC: Main Oscillator Frequency selection if the Main On-chip RC Oscillator is OFF

When the 4/8/12 MHz RC Oscillator is off, the frequency selection (MOSCRCF field in CKGR_MOR) can not be changed. The register can be written but the modification to MOSCRCF will not be taken into account.

Problem Fix/Workaround

Modify MOSCRCF while 4/8/12 MHz RC Oscillator is on (MOSCREN = 1).

47. Revision History

In the tables that follow, the most recent version of the document appears first.

Table 47-1. SAM3U Datasheet Rev. 6430G Revision History

Doc. Date	Changes
31-Mar-15	Reformatted document General editorial changes throughout
	"Description" on page 1: - in first paragraph, replaced "an RTC" with "a low-power RTC" - added paragraph relating to low-power modes - added paragraph relating to Real-time Event Management
	Section 1. "Features" Updated description of "Low Power Modes" Table 1-1, "Configuration Summary": reorganized contents; added SPI feature; provided details specific to 12-bit and 10-bit ADCs
	Section 2. "Block Diagram" Figure 2-1 "144-pin SAM3U4/2/1E Block Diagram": corrected "VDDUTMII" to "VDDUTMI"; deleted TC1 and TC2 to reflect single 3-channel timer counter block TC0 Figure 2-2 "100-pin SAM3U4/2/1C Block Diagram": corrected "VDDUTMII" to "VDDUTMI"; deleted TC1 and TC2 to reflect single 3-channel timer counter block TC0 Table 3-1, "Signal Description List": corrected two instances of "VDDUTMII" to "VDDUTMI"
	Section 3. "Signal Description" Section 3.1 "Design Considerations": updated to provide title and number of referenced application note
	Updated Section 4. "Package and Pinout"
	Section 5. "Power Considerations" Added Section 5.2 "Power-up Considerations" Section 5.4 "Typical Powering Schematics": in first sentence and in Figure 5-2 "Single Supply", corrected supply voltage range "1.8V-3.6V" to "1.62–3.6 V" Table 5-1, "Low Power Mode Configuration Summary": replaced "BOD alarm" with "SM alarm" in potential wake-up sources for Backup mode Updated Section 5.7 "Wake-up Sources" Updated Section 5.8 "Fast Startup"
	Section 6. "Input/Output Lines" Section 6.7 "ERASE Pin": in first paragraph, added details relative to reprogamming Flash content
	Section 7. "Architecture" (changed title—was previously "Processor and Architecture") Removed section 7.1 "ARM Cortex-M3 Processor" Removed section 7.8 "Debug and Test Features"
	Section 8. "Memories" Inserted Section 8.1 "Memory Mapping" (was previously section 8. "Product Mapping") Updated Section 8.2.1 "Internal SRAM", Section 8.2.3.4 "Lock Regions", and Section 8.2.3.10 "GPNVM Bits" Section 8.2.4 "Boot Strategies": deleted sentence "The GPNVM bit can be cleared or set respectively through the commands "Clear General-purpose NVM Bit" and "Set General-purpose NVM Bit" of the EEFC User Interface" (this information is already provided in Section 8.2.3.10 "GPNVM Bits")
	Added Section 9. "Real-time Event Management"

Table 47-1. SAM3U Datasheet Rev. 6430G Revision History (Continued)

Doc. Date	Changes
31-Mar-15	Revised Section 10. ”System Controller”
	Section 11. ”Peripherals” Table 11-2, “Multiplexing on PIO Controller A (PIOA)”: added two footnotes on selecting extra functions Table 11-3, “Multiplexing on PIO Controller B (PIOB)”: added three footnotes on selecting extra functions Table 11-4, “Multiplexing on PIO Controller C (PIOC)”: replaced footnotes with two footnotes on selecting extra functions
	Removed section 12. Embedded Peripherals Overview
	Section 13. ”Debug and Test Features” Added Section 13.2 ”Embedded Characteristics” Section 13.5.7 ”IEEE 1149.1 JTAG Boundary Scan”: in second paragraph, changed “enabled when FWUP, NRSTB and JTAGSEL are high” to “enabled when FWUP, NRST, NRSTB and JTAGSEL are high” Section 13.5.2 ”Debug Architecture”: in first sentence, corrected “embeds four functional units” to “embeds five functional units”
	Section 19. ”General Purpose Backup Registers (GPBR)” Updated to correct number of registers from 4 to 8
	Section 22. ”SAM3U4/2/1 Boot Program” Updated Section 22.4.3 ”USB Device Port” Section 22.4.4 ”In Application Programming (IAP) Feature”: replaced two instances of “MC_FSR register” with “EEFC_FSR”
	Section 25. ”Peripheral DMA Controller (PDC)” Deleted sentence “This document describes the AHB Peripheral DMA Controller (AHB PDC) version 1.0.0.”
	Section 27. ”Power Management Controller (PMC)” Section 27.14.15 ”PMC Status Register”: in FOS bit description, corrected second value to ‘1’ (was ‘0’) Updated Section 27.13 ”Register Write Protection” Section 27.14.10 ”PMC Clock Generator PLLA Register”: updated DIVA field description Updated Section 27.14.20 ”PMC Write Protection Mode Register” Updated Section 27.14.21 ”PMC Write Protection Status Register”
	Section 35. ”Timer Counter (TC)” Replaced instances of “Master clock” or “MCK” with “peripheral clock” throughout Replaced instances of ‘quadrature decoder logic’ with ‘quadrature decoder’ or ‘QDEC’ throughout Section 35.1 ”Description”: replaced “driven by TIOA0, TIOB0 and TIOA1 inputs” with “driven by TIOA0, TIOB0 and TIOB1 inputs” Section 35.2 ”Embedded Characteristics”: changed “Two multi-purpose input/output signals” to “Two multi-purpose input/output signals acting as trigger event”; deleted last bullet “Two global registers that act on all TC channels” Moved Table 35-1, “Timer Counter Clock Assignment” from Section 35.1 ”Description” to Section 35.3 ”Block Diagram” and updated table footnote Section 35.5.2 ”Power Management”: specified “clock of each channel” at end of paragraph Section 35.5.3 ”Interrupt Sources”: changed title (was “Interrupt”); specified “an interrupt line per channel” in first sentence Added Table 35-5, “Peripheral IDs” Updated Section 35.6.2 ”16-bit Counter” Section 35.6.3 ”Clock Selection”: updated names of internal clock signals Section 35.6.11.1 ”WAVSEL = 00”: replaced “0xFFFF” with “2^{16}-1” in first paragraph

Table 47-1. SAM3U Datasheet Rev. 6430G Revision History (Continued)

Doc. Date	Changes
31-Mar-15	Section 35. "Timer Counter (TC)" (cont'd) In Figure 35-9 "WAVSEL = 10 without Trigger" and Figure 35-10 "WAVSEL = 10 with Trigger", replaced "0xFFFF" with "2^n-1" (with "n" representing counter size) Section 35.6.11.3 "WAVSEL = 01": replaced "0xFFFF" with "2^{16}-1" in first paragraph In Figure 35-13 "WAVSEL = 11 without Trigger" and Figure 35-14 "WAVSEL = 11 with Trigger", replaced "0xFFFF" with "2^n-1" (with "n" representing counter size) Section 35.6.14.1 "Description": in first paragraph, changed TIOA1 into TIOB1 and corrected link to Figure 35-15 Section 35.6.14.2 "Input Pre-processing": deleted sentence "Filters can be disabled using the FILTER bit in the TC_BMR" Figure 35-16 "Input Stage": replaced "FILTER" with "MAXFILTER > 0" Section 35.6.14.3 "Direction Status and Change Detection": rewrote sixth paragraph for clarity Section 35.6.14.4 "Position and Rotation Measurement": rewrote first paragraph for clarity and changed TIOA1 into TIOB1; at end of second paragraph, defined External Trigger Edge and External Trigger configuration in TC_CMR Section 35.6.14.5 "Speed Measurement": in fifth paragraph, replaced "EDGTRG can be set to 0x01" with "ETRGEDG must be set to 0x01"; in seventh paragraph, replaced sentence "The speed can be read on TC_RA0 register in TC_CMR0" with "The speed can be read on field RA in register TC_RA0" Table 35-6, "Register Mapping": defined offset range 0xE8–0xFC as reserved Section 35.7.2 "TC Channel Mode Register: Capture Mode": in 'Name' line, replaced "(WAVE = 0)" with "(CAPTURE_MODE)"; updated TCCLKS field values 0–4 Section 35.7.3 "TC Channel Mode Register: Waveform Mode": in 'Name' line, replaced "(WAVE = 1)" with "(WAVEFORM_MODE)"; updated TCCLKS field values 0–4; added note to ENETRG bit description description Section 35.7.4 "TC Counter Value Register": in CV field description, added notation "IMPORTANT: For 16-bit channels, CV field size is limited to register bits 15:0" Section 35.7.5 "TC Register A": in RA field description, added notation "IMPORTANT: For 16-bit channels, RA field size is limited to register bits 15:0" Section 35.7.6 "TC Register B": in RB field description, added notation "IMPORTANT: For 16-bit channels, RB field size is limited to register bits 15:0" Section 35.7.7 "TC Register C": in RC field description, added notation "IMPORTANT: For 16-bit channels, RC field size is limited to register bits 15:0" Section 35.7.8 "TC Status Register": updated bit descriptions Section 35.7.13 "TC Block Mode Register": - removed FILTER bit (register bit 19 now reserved) - corrected TC2XC2S field configuration values: value 2 is TIOA0 (was TIOA1); value 3 is TIOA1 (was TIOA2)
	Section 42. "Electrical Characteristics" Updated and harmonized parameter symbols throughout Table 42-2, "DC Characteristics": corrected VDDUTMII to VDDUTMI; updated values for parameter "On-die Series Termination Resistor"; removed parameter "Input Capacitance" Table 42-4, "Core Power Supply Brownout Detector Characteristics": added parameter "Reset Period" Table 42-6, "Backup Power Supply Zero-Power-on Reset Characteristics": renamed parameter "Reset Time-out Period" to "Reset Period" Table 42-17, "4/8/12 MHz RC Oscillators Characteristics": removed parameter "Frequency Temperature Dependency" Table 42-18, "32.768 kHz Crystal Oscillator Characteristics": updated conditions for parameters "Startup Time" and "Current Consumption"; added parameter "Allowed Crystal Capacitance Load" Figure 42-10 "32.768 kHz Crystal Oscillator Schematic": added "$C_{crystal}$" label Table 42-20, "XIN32 Clock Electrical Characteristics (In Bypass Mode)": in footnote, corrected "32768 kHz" to "32.768 kHz"

Table 47-1. SAM3U Datasheet Rev. 6430G Revision History (Continued)

Doc. Date	Changes
31-Mar-15	Section 42. "Electrical Characteristics" (cont'd) Updated Figure 42-11 "XIN32 Clock Timing" Table 42-21, "3 to 20 MHz Crystal Oscillator Characteristics": updated values for parameter "External capacitor on XIN and XOUT"; added parameter "Allowed Crystal Capacitance Load"; deleted all footnotes Updated Figure 42-13 "XIN Clock Timing" Updated Section 42.4.9 "Crystal Oscillators Design Consideration Information" Table 42-25, "PLLA Characteristics": updated min/max values for parameters "Input Frequency" and "Output Frequency" Table 42-25, "PLLA Characteristics": added max value for Current Consumption (Standby mode) Table 42-28, "Static Power Consumption": corrected VDDUTMII to VDDUTMI Table 42-29, "Dynamic Power Consumption": corrected VDDUTMII to VDDUTMI Deleted section 43.6.5 "USB High Speed Design Guidelines" Table 42-30, "Analog Power Supply Characteristics": changed VDDIN to VDDANA Table 42-32, "External Voltage Reference Input": changed VDDIN to VDDANA Updated Section 42.7.1 "Static Performance Characteristics" Table 42-33, "INL, DNL, 12-bit mode, VDDANA Supply Voltage Conditions": changed VDDIN to VDDANA Table 42-34, "Gain Error, Offset Error, 12-bit Mode, VDDANA Supply Voltage Conditions(1)": changed VDDIN to VDDANA Inserted heading Section 42.7.2 "Dynamic Performance Characteristics" and updated content Replaced section "Track and Hold Time versus Source Output Impedance" with Section 42.7.2.1 "Sample and Hold Time versus Source Output Impedance" Table 42-39, "Analog Inputs": in footnote, changed VDDIN to VDDANA Restored Section 42.8 "10-bit Successive Approximation Register (SAR) ADC Characteristics" (content was inadvertently removed in version 6430F of this datasheet) Section 42.9.3.1 "Maximum SPI Frequency": updated content under "Master Write Mode" and "Master Read Mode" Table 42-49, "SSC Timings": updated parameters SSC_4 and SSC_7; deleted footnote "Timings SSC4 and SSC7 depend on..." Section 42.9 "AC Characteristics": removed Figure 43-27. "USART SPI Master Mode", Figure 43-28. "USART SPI Slave mode (Mode 1 or 2)", Figure 43-29. "USART SPI Slave mode (Mode 0 or 3)", and Table 43-49. "USART SPI Timings" Table 42-54, "Two-wire Serial Bus Requirements": in bottom row, replaced duplicated parameter "Hold Time (repeated) START Condition" with new parameter "Bus free time between a STOP and START condition" Section 42.9.8 "Embedded Flash Characteristics": in first paragraph, corrected "field FWS of the MC_FMR register" to "field FWS of the EEFC_FMR"; updated text and replaced two wait state tables with single Table 42-55, "Embedded Flash Wait State - VDDCORE 1.62V/1.80V"
	Section 43. "Mechanical Characteristics" Figure 43-1 "100-lead LQFP Package Drawing": added notes 1 and 2 Section 43.2 "100-ball TFBGA Package": at end of section, added sentence "This package respects the recommendations of the NEMI User Group." Figure 43-2 "100-ball TFBGA Package Drawing": corrected 'A' maximum dimension in inches from 0.0575 to 0.0433 Updated Table 43-4, "100-ball TFBGA Soldering Information (Substrate Level)" Updated Table 43-5, "100-ball TFBGA Device Maximum Weight" Updated Table 43-7, "100-ball TFBGA Package Reference" Section 43.3 "144-lead LQFP Package": at end of section, added sentence "This package respects the recommendations of the NEMI User Group." Updated Table 43-8, "144-lead LQFP Device Maximum Weight"

Table 47-1. SAM3U Datasheet Rev. 6430G Revision History (Continued)

Doc. Date	Changes
31-Mar-15	Inserted Section 44. ”Marking” (was previously in Section 46. ”SAM3U Series Errata”)
	Section 45. ”Ordering Information” Table 45-1, “SAM3U Ordering Information”: removed “Package Type” column (this information is provided on the Atmel website)
	Section 46. ”SAM3U Series Errata” Deleted sentence referencing application note “Errata on SAM3U Engineering Sample Devices” Section 46.1.1.1 ”Flash: Issue Running at Frequency Lower than 5 MHz”: changed lower frequency limit from 2.5 MHz to 5 MHz Section 46.2.1.1 ”Flash: Issue Running at Frequency Lower than 5 MHz”: changed lower frequency limit from 2.5 MHz to 5 MHz Section 46.1.2.3 ”ADC12B: Saturation”: corrected instance of “ADREF” to “AD12BVREF”

Doc. Rev. 6430F	Comments	Change Request Ref.(1)
	PMC:	
	Section 27.9 ”Fast Startup”, SUPC_FSMR --> PMC_FSMR and SUPC_FSPR --> PMC_FSPR	8010
	Section 27.3 ”Master Clock Controller”, removed bogus sentence about Master Clock divider functionality	rfo
	Section 27.1 ”Description”, changed sentence “Processor Clock (HCLK), must be switched off...”	8217
	Memories:	
	Section 8.2.3.1 ”Flash Overview”, Flash size should be 64KBytes instead of 256KBytes	8029
	Electrical Characteristics:	
	Section 43.7, 43.7.1 Gain and Offset Calibration removed	8031
	Section 42.4 ”Crystal Oscillators Characteristics”:	8174
	Table 42-16, “32 kHz RC Oscillator Characteristics”, changed parameter ‘Frequency Temperature Dependency’	
	Table 42-4, “Core Power Supply Brownout Detector Characteristics”, changed MAX value of VTH+	8223
	Section 42.9.8 ”Embedded Flash Characteristics”, added note regarding erasing Flash contents	
	Errata:	
	Section 46.2 ”SAM3U Errata - Rev. B Parts”, added errata section for rev. B	8131
	Section 46.1 ”SAM3U Errata - Rev. A Parts”: Section 46.1.2.2 ”ADC: Trigger Launches only One Conversion”, added errata	rfo
	Section 46.2 ”SAM3U Errata - Rev. B Parts”: Section 46.2.2.2 ”ADC: Trigger Launches only One Conversion”, added errata	rfo
	Section 46.1 ”SAM3U Errata - Rev. A Parts”: Section 46.1.2.4 ”ADC: Wrong First Conversions”, added errata	8164
	Section 46.2 ”SAM3U Errata - Rev. B Parts”: Section 46.2.2.3 ”ADC: Wrong First Conversions”, added errata	
	Overview & Mechanical Characteristics:	
	Replaced all occurrences of '100-ball LFBGA' into '100-ball TFBGA'	8044
	Ordering Information:	
	Table 45-1, “SAM3U Ordering Information”, updated with MRL B devices	8130

Doc. Rev. 6430F	Comments (Continued)	Change Request Ref.[1]
	SPI:	
	Section 32.8.11 "SPI Write Protection Status Register", description of register simplified	8136
	Section 32.8.10 "SPI Write Protection Mode Register", removed 'SPI' from register description names	rfo
	Section 32. "Serial Peripheral Interface (SPI) Programmer Datasheet", SPI version updated to version 'R'	rfo
	TC:	
	Section 34.1 "Description": Table 34-1, "Timer Counter Clock Assignment", footnote for table updated	8159

Doc. Rev. 6430E	Comments	Change Request Ref.[1]
	Overview:	
	Comment in front of rows PA24 and PA25 removed, and put as a footnote[4] for TWD1 and TWCK1.	
	Table 11-2, "Multiplexing on PIO Controller A (PIOA)", "Peripheral B" column, PA2 and PA17 texts exchanged.	7724
	Figure "The fast restart circuitry (shown in Figure 27-3 "Fast Startup Circuitry" on page 454) is fully asynchronous and provides a fast startup signal to the Power Management Controller. As soon as the fast startup signal is asserted, the PMC automatically restarts the embedded 4/8/12 MHz fast RC oscillator, switches the master clock on this 4 MHz clock by default and reenables the processor clock.", 'Falling/Rising Edge Detector' changed to 'High/Low Level Detector' in 3 blocks.	7954 7922 rfo
	Wait mode consumption updated in Table 5-1, "Low Power Mode Configuration Summary"	
	Clock Generator:	
	Last sentence removed from Section 26.5.1 "Divider and Phase Lock Loop Programming", as PLLADIV2 does not exist.	7751
	Third bullet edited in Section 26.1 "Description".	7908
	Electrical Characteristics:	
	3 values updated in Table 42-12, "Typical Current Consumption in Wait Mode".	rfo
	Section 43.7.1 "Sample and Hold Time versus Source Output Impedance" created.	
	SUPC:	
	Section 19.3.2 "Slow Clock Generator", variable VDD_SUPPLY_MONITOR changed to VDD_Backup, in order to get VDDBU instead of VDDUTMI.	7743
	PMC:	
	Section 27.8 "Programmable Clock Output Controller", UPLLCK --> UPLLCK/2.	7898
	Figure 27-1, "General Clock Block Diagram" edited (UPLLCK --> UPLLCK/2, and UPLLDIV /1/2 --> Divider /2)	7912
	USART:	
	Section 35. "Universal Synchronous Asynchronous Receiver Transmitter (USART)", PDC condition shown instead of DMA.	7804
	Errata:	
	Section 46.1.1.4 "Flash: Fetching Error after Reading the Unique Identifier" added.	7978

Doc. Rev. 6430D	Comments	Change Request Ref.[1]
	Overview:	
	Section 5.6.2 ”Wait Mode”, sentence starting with ‘By configuring...’ --> ‘This is done by configuring...’	7492
	Section 11. ”Peripherals”, (Rev A) was removed from Table 10-1.	7642
	TWD1 and TWCK1 removed from Figure 2-2, “100-pin SAM3U4/2/1C Block Diagram”.	7624
	Table 3-1, “Signal Description List”, Note (4) added to TDO Output.	7635
	A typo fixed in Section 8.2.1 ”Internal SRAM”: 4224 Kbytes --> 4224 bytes.	7305
	Debug and Test Features:	
	Table 13-1, “Debug and Test Signal List”, Note (1) added to TDO Output.	7635
	Section 13.5.8 ”ID Code Register”, Chip ID and JTAG ID Code edited.	7543
	Section 13.5.7 ”IEEE 1149.1 JTAG Boundary Scan”, second paragraph updated.	7485
	Chip ID:	
	CHIPID_CIDR column in Table 29-1, “ATSAM3U Chip IDs Register” updated as in Table 9-1	7642
	Clock Generator:	
	Section 26.6 ”UTMI Phase Lock Loop Programming”, first sentence edited, together with Table 26-5, “UTMI PLL Block Diagram”.	7484
	PMC:	
	Section 27.9 ”Fast Startup”, a sentence starting with ‘Important’ added as a second paragraph. In the first paragraph, ‘LPM bit is at 0’ replaced by ‘LPM bit is at 1’.	7539
	Section 27.14.15 ”PMC Status Register”, MOSCSELS bit descriptions reversed.	7389
	Electrical Characteristics:	
	In Table 42-18, “32.768 kHz Crystal Oscillator Characteristics”, C_{LEXT} Maximum value is 22 instead of 20.	7589
	Section 42.9.7 ”Two-wire Serial Interface Characteristics” updated: UART --> USART, SPCK --> SCK, Figures and titles updated.	7320
	Errata:	
	Section 46.1.2.1 ”ADC12B: Current Consumption in Backup Mode on VDDANA” edited.	7420
	Section 46.1.1.3 ”Flash: Flash Programming” added.	7205
	Backpage:	
	A typo fixed: ‘tehincal’ --> ‘technical’	7536

Doc. Rev. 6430C	Comments	Change Request Ref.[1]
	Overview:	
	Section 2. ”SAM3U Block Diagram”, changed orientation of block diagrams.	rfo
	Section 5. ”Power Considerations”, fixed grammar in Voltage ranges.	
	Section 3. ”Signal Description”, USART signal DCD0 is an Input	6681
	Figure 5-1, “Single Supply”, Main supply range is 1.8V-3.6V.	6698
	Figure 5-1, Figure 5-2, Figure 5-3, updated “Note” below figures, “With Main Supply <2.0V USB and ADC are not usable.	
	Section 5.6 ”Low-power Modes”, stray references to WUPx pins, renamed WKUPx	6711
	Table 5-1 ”Low Power Mode Configuration Summary”, updated footnote “5”.	6964
	Table 11-2 ”Multiplexing on PIO Controller A (PIOA)”, TWD1 and TWCK1 only available on 144-pin version.	6686
	Section 10.13 ”Chip Identification”	
	Table 10-2, “SAM3U Chip IDs Register - Revision A Parts”, added to datasheet.	6951
	Section 12.4 ”Universal Synchronous Asynchronous Receiver Transmitter (USART)”...”SCK up to MCK/6”	rfo→7097
	CHIP ID:	
	”ARCH: Architecture Identifier” bit field updated with SAM3S, SAM3N identifiers. Bitfield tables reorganized.	6967
	CORTEX:	
	Section 12.19 ”Nested Vectored Interrupt Controller”, text on 3rd bullet updated: “Level detection of interrupt signals.”	6823
	EFC:	
	Section 21.3.3.7 ”Unique Identifier”, Unique Identifier is located ... 0x80000-0x8000F.	rfo
	Figure 21-6, “Example of Partial Page Programming” text added below figure,..”works only with 128-bit (or higher) boundaries...”	6827
	HSMCI:	
	Section 37.10 ”HSMCI Boot Operation Mode”, added precision on boot from internal Flash.	6745
	”SDCBUS: SDCard/SDIO Bus Width”, bitfield table updated.	7125
	Values, Names, Descriptions updated in bitfield description tables. (global)	rfo
	Section 37.13.18 ”HSMCI Write Protect Mode Register”, ASCI code is for MCI.	
	MATRIX:	6718
	Section 23.6.6 ”Write Protect Status Register”, WPVS identified in bitfield description.	
	PMC:	
	“PMC Fast Startup Polarity Register”, FSTPx: bitfield typo fixed.	6688
	“PMC Clock Generator PLLA Register”, removed STMODE bitfield.	6706
	Section 27.11 ”Programming Sequence” Step 5 “Selection of Programmable Clocks”, updated: “Four clock options are available: main clock, slow clock, PLLACK and UPLLCK. By default, the clock source selected is main clock.”	
	Section 27.10 ”Clock Failure Detector”, updated with new information.	7128

Doc. Rev. 6430C	Comments (Continued)	Change Request Ref.[1]
	PWM: Section 38.6.23 "PWM Fault Mode Register", Section 38.6.24 "PWM Fault Status Register", Section 38.6.25 "PWM Fault Clear Register", Section 38.6.27 "PWM Fault Protection Enable Register", bitfield descriptions updated. Table 38-2, "I/O Lines", new to datasheet.	6824 rfo
	RTC: Section 17.3.2 "Interrupt", updated. Section 17.5 "Real Time Clock (RTC) User Interface", the reset for RTC_CALR is 0x01210720. TIMEVSEL, CALEVSEL bitfield descriptions reorganized.	7071 7046/7087 6796
	SSC: Redundant letter C removed from title.	6949
	SUPC: Section 19.4 "Supply Controller (SUPC) User Interface", offset updated for GPBR: 0x90-0xDC. FWUPDBC, WUPDBC bitfield descriptions reorganized. Backup supply is VDDBU	6950 6796 6714
	TC: Figure 36-2 "Clock Chaining Selection", channel 1 updated. updated bitfields: TC0XC0S, TC1XC1S, TC2XC2S, TCCLKS, BURST, ETRGEDG, LDRA, LDRB, TCCLKS, BURST, EEVTEDG, EEVT, WAVSEL, ACPA, ACPC, AEEVT, ASWTRG, BCPB, BCPC, BEEVT, BSWTRG	6687 6796
	UDHP: Figure 39-4 "Logical Address Space for DPR Access", EP0 has but 1 bank Figure 39-1 "Block Diagram", 1 PMC to UTMI signal line. Notes removed. Figure 39.4 "Product Dependencies", added to datasheet. Figure 39-6 "Register Mapping", DMA offset updated to 0x300 + channel *...	6750 6792 rfo 6822
	USART: Section 35.6.7 "Modem Mode", is available. Section 35.6 "Functional Description", ...SCK up to MCK/6 Section 35.6.8.2 "Baud Rate" SPI Master Mode: ..."the value programmed in CD must be superior or equal to 6." SPI Slave Mode:..."the external clock (SCK) frequency must be at least 6 times lower than the system clock." Section 35.6.1 "Baud Rate Generator","...signal provided on SCK must be at least 3 times lower than MCK in USART mode, or 6 in SPI mode." Section 35.6.1.3 "Baud Rate in Synchronous Mode or SPI Mode", ..."limits the SCK maximum frequency to MCK/3 in USART mode, or MCK/6 in SPI mode."	6791 rfo→7097

Doc. Rev. 6430C	Comments (Continued)	Change Request Ref.[1]
	Electrical Characteristics: Table 42-18, “32.768 kHz Crystal Oscillator Characteristics”, last row of the table changed from C_L to C_{PARA} “Internal Parasitic Capacitance”. Schematic and Crystal formula updated Table 42-21, “3 to 20 MHz Crystal Oscillator Characteristics”, C_{LEXT} row, Parameter cell updated. Added 1K resistor to Schematic and Crystal formula updated. Table 42-16, “32 kHz RC Oscillator Characteristics”, table updated. Table 42-17, “4/8/12 MHz RC Oscillators Characteristics”, updated “Frequency Temperature Dependency” Table 43-31, “Channel Conversion Time and ADC Clock”, $T_{START-UP}$ “From OFF mode...” startup times updated. Table 43-32, “External Voltage Reference Input”, ADVREF changed to AD12BVREF. Table 43-37, “Analog Inputs”, V_{ADVREF} changed to $V_{AD12BVREF}$	6701 6951 7098
	Errata: Section 46.1 ”SAM3U Errata - Rev. A Parts”, added to Errata.	6951

Doc Rev 6430B	Comments	Change Request Ref.[1]
	Introduction: Section 1. ”SAM3U Description”, Updated: 52 Kbytes of SRAM. 4x USARTs (SAM3U1C/2C/4C have 3), up to 2x TWIs (SAM3U1C/2C/4C have 1), up to 5x SPIs SAM3U1C/2C/4C have 4), Table 1-1, “Configuration Summary” EBI column updated, 8 bits for SAM3U1C/2C/4C SAM3U4/3/2C rows FWUP replaces NO in FWUP,SHDN pins column.	6400 6642
	Figure 2-1 ”144-pin SAM3U4/2/1E Block Diagram” and Figure 2-2 ”100-pin SAM3U4/2/1C Block Diagram” updated, SM cell removed; UART moved to peripheral area, added Flash Unique block, removed 12B from ADC block, added SysTick counter and Fmax 96MHz to M3 block. FWUP replaces WKUP in fig 2-1, FWUP added to fig 2-2. Figure 2-2 ”100-pin SAM3U4/2/1C Block Diagram”, NWR1/NBS1, NXRP0, A0 removed from block diagram,	6482/6642 rfo/
	Table 3-1, “Signal Description List”, Schmit Trigger added ”PIO Controller - PIOA - PIOB - PIOC”. exception details given in footnote. VDDIN, VDDOUT added to table. ”Serial Wire/JTAG Debug Port (SWJ-DP)” replaced ICE and JTAG. This section of the table updated status of pulldowns and pullups specified.	6480 rfo
	Section 4. ”Package and Pinout”; reorganized according to product. Section 4.1 ”SAM3U4/2/1E Package and Pinout”, Section 4.2 ”SAM3U4/2/1C Package and Pinout”, pinouts finalized in datasheet.	6471/rfo 6607
	Section 5.5.1 ”Backup Mode”, BOD replaced by Supply Monitor/SM. Figure 5-4 ”Wake-up Source”, BODEN replaced by SMEN. FWUP → Falling Edge Detector. Table 5-1, “Low Power Mode Configuration Summary”, PIO state in Low Power Mode, backup mode is; “Previous state saved.” Figure 5-3 ”Backup Batteries Used”, FWUP replaces FWKUP.	rfo 6645 6642

Doc Rev 6430B	Comments (Continued)	Change Request Ref.(1)
	Section 6.6 ”NRSTB Pin”, VDDIO changed to VDDBU Section 6. ”Input/Output Lines” replaces Section 5.8 “Programmable I/O Lines”. Section 6.1 ”General Purpose I/O Lines (GPIO)” and Section 6.2 ”System I/O Lines” replace Section 6. “I/O Line Considerations”. Figure 6-1 ”On-Die Termination schematic”, added. Section 6.8 “PIO Controllers”, removed. Section 8. ”Product Mapping”, title changed from “Memories”. Section 9. ”Memories”; now comprises Section 9.1 ”Embedded Memories” and Section 9.2 ”External Memories” Section 9.1.3.5 ”Security Bit Feature”, updated	6646 6481/rfo
	Table 7-3, “SAM3U Master to Slave Access”, Slave 9, High Speed Peripheral Bridge line added. Section 7.2 ”APB/AHB Bridges”, reference to ADC updated “10-bit ADC, 12-bit ADC (ADC12B)”. Table 11-3, “Multiplexing on PIO Controller B (PIOB)” ADC12B2, ADC12B3 properly listed. Section 12.10.1 ”12-bit High Speed ADC”, Section 12.10.2 ”10-bit Low Power ADC”, titles changed. “Quadrature Decoder Logic” on page 51 properly stated in list of TC functions.	6663 6397
	Section 12.10.1 ”12-bit High Speed ADC”, 2nd item on list updated. Section 12.10.2 ”10-bit Low Power ADC”, Ksample values updated on 2nd item of list.	rfo
	ADC12B: Section 40.6.6 ”ADC12B Analog Control Register”,IBCTL reasigned to fields 8 and 9	6649
	CORTEX-M3: Table 12-31, “Priority grouping”updated. Section 13.19.7.1 ”IP27”, title changed to IP27, value in bitfields 0 to 7 changed to IP28. Section 12.20.6 ”Application Interrupt and Reset Control Register”read/write values to VECTKEY changed Section 12.5.2.2 ”Non Maskable Interrupt (NMI)” added to datasheet. Section 12.6.2 ”Fault escalation and hard faults”, last sentence updated with NMI function. Section 12.3.5 ”Data types” Condition tags sorted out. Table 12-11, “Faults”updated footnote 1 Table 12-29, “CMSIS functions for NVIC control”Description in 4th row updated. on page 44, “...copyright ARM Ltd., 2008 - 2009.” precise years given. Table 12-4, “Memory access behavior”last row assinged to Reserved in Memory Map. Big Endien not used in this product.	6394: 6436 6483 rfo
	Debug and Test: Section 13.1 ”Overview”, SWJ-DP...also embeds a serial trace. Table 13-1, “Debug and Test Signal List”, reorganized.	rfo
	FFPI: Section 21.2.5.4 ”Flash Lock Commands”, last sentence removed from 2nd paragraph (ref to EA command).	6677
	HSMCI: Section 37.12 ”Write Protection Registers”, Section 37.13.18 ”HSMCI Write Protect Mode Register” and Section 37.13.19 ”HSMCI Write Protect Status Register”,added.	6432
	MATRIX: Table 23-1, “Register Mapping”, added offsets for Write Protection Registers	6431

Doc Rev 6430B	Comments (Continued)	Change Request Ref.(1)
	PDC: Section 26. "Peripheral DMA Controller (PDC)" Section replaced.	6468
	PIO: Section 30.5.1 "Write Protection Registers", Section 30.6.42 "PIO Write Protect Mode Register" and Section 30.6.43 "PIO Write Protect Status Register" added with links to protected registers.	6430
	PMC: Section 27.14.16 "PMC Interrupt Mask Register", Section 27.14.13 "PMC Interrupt Enable Register", Section 27.14.14 "PMC Interrupt Disable Register", 0 and 1read or write values described. Section 27.13 "Register Write Protection", Section 27.14.20 "PMC Write Protection Mode Register" and Section 27.14.20 "PMC Write Protection Mode Register" added with links to protected registers. Section 27.10 "Clock Failure Detector", added sentence on Fast RC Section 27.11 "Programming Sequence", added step 1 and reordered subsequent numbering sequence. removed code example, bitfield names updated.	6311/rfo 6432 6469 6591 rfo
	PWM: Table 38-4, "Fault Inputs", "PWM Fault Input Number" column, typos fixed	6397
	RSTC: Section 15.2 "Block Diagram", "backup_nreset" replaces "core_backup_reset". Section 15.3.1 "Reset Controller Overview", RSTC_MR..."is powered with VDDBU..." Section 15.3.4.2 "Backup Reset", "The vddcore_nreset signal is asserted by the SUPC..." and "backup_nreset" replaces "core_backup_reset".	rfo
	SMC: Table 25-4, "External Memory Mapping", restored rows for chip selects 0, 1, 2 to the table.	6397
	SPI: Section 32.7.10 "SPI Write Protection Control Register" and Section 32.7.11 "SPI Write Protection Status Register", added.	6432
	SSC: Section 31.7.1 "Write Protection Registers", Section 31.8.17 "SSC Write Protect Mode Register" and Section 31.8.18 "SSC Write Protect Status Register"	6429
	SUPC: Figure 19-5 "Raising the VDDUTMI Power Supply", updated, i.e., shutdown polarity changed, Fast RC Oscillator, NRST, periph_nreset, proc_nreset signals added, detailed startup time added up to instruction fetch. Figure 19-6 "NRSTB Reset", updated SHDN / vr_standby waveform. Section 19.4.8 "Supply Controller Status Register", added note concerning "status register flag reset". Figure 19-2 "Separated Backup Supply Powering Scheme"	6604 rfo 6653 6642
	USART: Section 35.7.2 "USART Mode Register", VAR_SYNC bitfield description updated. Section 35.7.1 "USART Control Register" RSTSTA description updated with UNRE bit. Section "Receive NACK Inhibit", updated. Section 35.7.1 "USART Control Register", NACK description, grammar fixed. Section 35.6.10 "Write Protection Registers", Section 35.7.16 "USART Write Protect Mode Register" and Section 35.7.17 "USART Write Protect Status Register", added.	6282 6283 6422 6432

Doc Rev 6430B	Comments (Continued)	Change Request Ref.[1]
	Electrical Characteristics:	
	Section 42. ”Electrical Characteristics”, updated	rfo
	Section 42.9.3.1 ”Maximum SPI Frequency”, added	
	Figure 42-5 ”Measurement Setup”, updated.	6663
	Table 42-46, “I/O Characteristics”, in the Conditions column: V_{DDIO} = 1.62V	
	Mechanical Characteristics:	
	Section 43.5 ”Soldering Profile”, added.	rfo

Doc. Rev.	Date	Comments	Change Request Ref.
	24-Mar-09	First Issue - advance information	
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