

MC68HC08LN56 MC68HC708LN56

General Release Specification

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Microcontrollers**

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MC68HC08LN56

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General Release Specification

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The following revision history table summarizes changes contained in this document. For your convenience, the page number designators have been linked to the appropriate location.

Revision History

Date	Revision Level	Description	Page Number(s)
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Chapter 1

General Description

1.1 Introduction

The MC68HC08LN56/708LN56 is a member of the low-cost, high-performance M68HC08 Family of 8-bit microcontroller units (MCUs). The M68HC08 Family is based on the customer-specified integrated circuit (CSIC) design strategy. All MCUs in the family use the enhanced M68HC08 central processor unit (CPU08) and are available with a variety of modules, memory sizes and types, and package types.

1.2 Features

Features of the MC68HC08LN56/708LN56 include:

- High-Performance M68HC08 Architecture
- Fully Upward-Compatible Object Code with M6805, M146805, and M68HC05 Families
- 8-MHz Internal Bus Frequency at 5.0 V/4 MHz Internal Bus Frequency at 3.0 V
- 56 Kbytes of EPROM/OTPROM
- On-Chip Monitor ROM Firmware for Use with Host Personal Computer
- 1280 Bytes of On-Chip RAM
- LCD Controller and Drivers (40 × 32)
 - On-Chip Voltage Generator
 - Contrast Control
 - 1/32 Multiplex Dynamic Display
 - Total of 2 Lines × 16 Characters (5 × 8 Characters)
 - 160-Byte, Fully Bit Mapped LCD RAM
- 4-Channel 8-Bit Successive Approximation A/D Converter
- Dual Serial Peripheral Interface (SPI) Modules
- Serial Communications Interface (SCI) Module
- 16-Bit, 4-Channel Timer Interface Module (TIM)
 - Each Channel Selectable as Input Capture, Output Compare, or PWM
- System Protection Features
 - Optional Computer Operating Properly (COP) Reset
 - Low-Voltage Inhibit
 - Illegal Opcode Detection
 - Illegal Address Detection
- Clock Generator Module (CGMB)
- Time Base Module Periodic Interrupt
 - 1, 4, 16, or 256 Hz with 32.768-kHz Crystal
- 144-Pin Plastic Quad Flat Pack (QFP)

General Description

- Low-Power Design (Fully Static with Stop and Wait Modes)
- Master Reset Pin and Power-On Reset
- 42 General-Purpose I/O pins, Including
 - 19 Shared Function I/O Pins
 - 8-Bit Keyboard Wakeup Port

Features of the CPU08 include:

- Enhanced HC05 Programming Model
- Extensive Loop Control Functions
- 16 Addressing Modes (Eight More Than the HC05)
- 16-Bit Index Register and Stack Pointer
- Memory-to-Memory Data Transfers
- Fast 8×8 Multiply Instruction
- Fast 16/8 Divide Instruction
- Binary-Coded Decimal (BCD) Instructions
- Optimization for Controller Applications
- Third Party C Language Support

1.3 Block Diagram

Figure 1-1 shows the structure of the MC68HC08LN56/708LN56 block diagram.

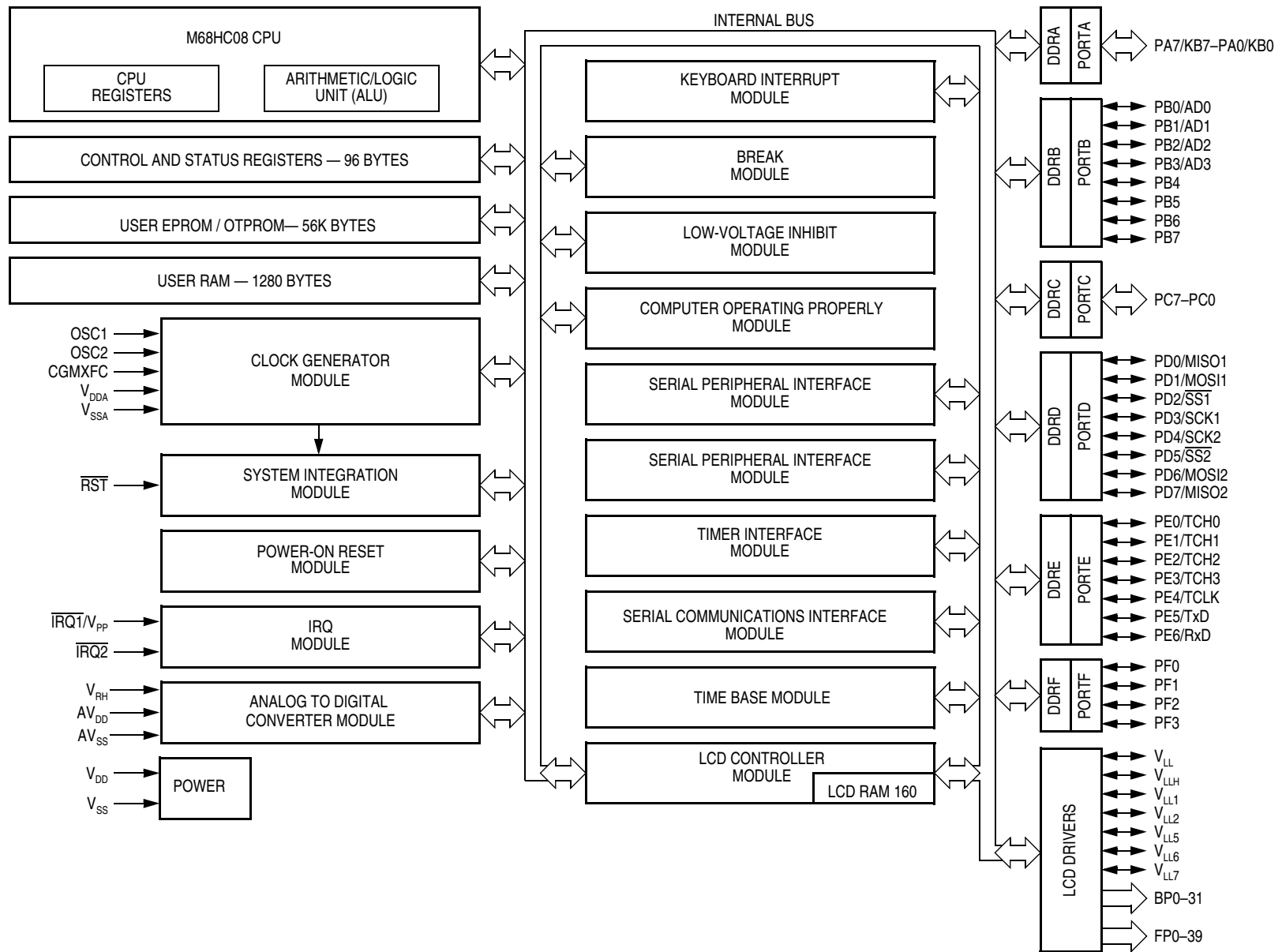


Figure 1-1. MC68HC08LN56/708LN56 Block Diagram

1.4 Pin Assignment

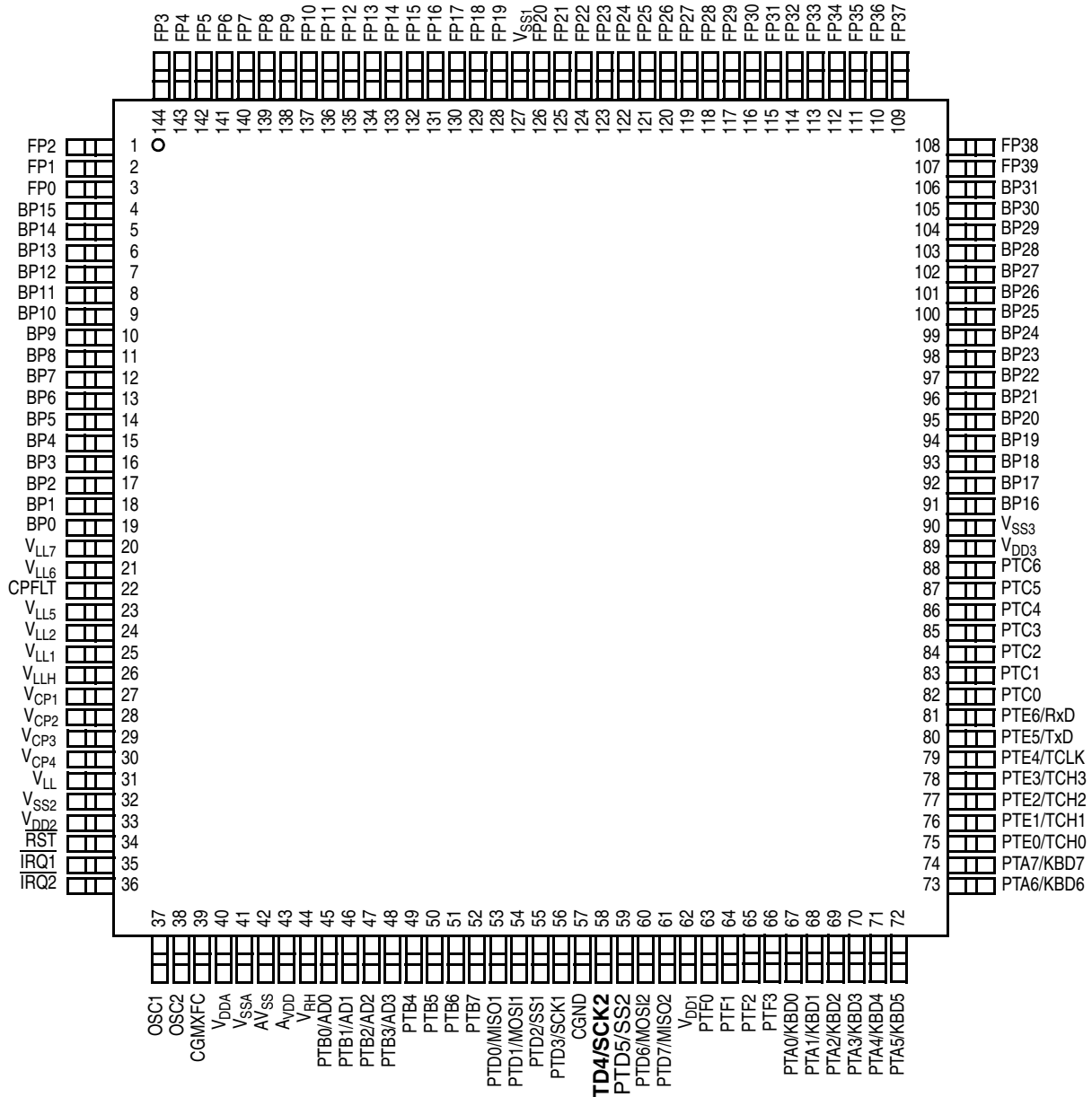
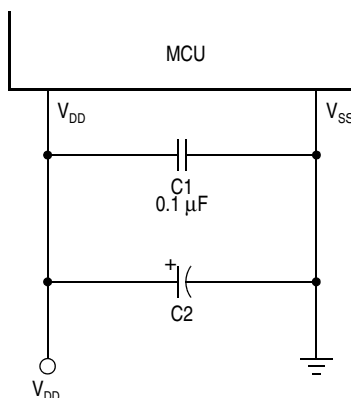


Figure 1-2. MC68HC08LN56/708LN56 Pin Assignment

1.4.1 Power Supply Pins (V_{DD3} : V_{DD1} - V_{SS3} : V_{SS1})

V_{DD} and V_{SS} are the power supply and ground pins. The MCU operates from a single power supply.

Fast signal transitions on MCU pins place high, short-duration current demands on the power supply. To prevent noise problems, take special care to provide power supply bypassing at the MCU as [Figure 1-3](#) shows. Place the C1 bypass capacitor as close to the MCU as possible. Use a high-frequency-response ceramic capacitor for C1. C2 is an optional bulk current bypass capacitor for use in applications that require the port pins to source high-current levels.



NOTE: Component values shown represent typical applications

Figure 1-3. Power Supply Bypassing

1.4.2 Oscillator Pins (OSC1 and OSC2)

The OSC1 and OSC2 pins are the connections for the on-chip oscillator circuit. See [Chapter 4 Clock Generator Module \(CGMB\)](#) for more information.

1.4.3 External Reset Pin (\overline{RST})

A logic zero on the \overline{RST} pin forces the MCU to a known startup state. \overline{RST} is bidirectional, allowing a reset of the entire system. It is driven low when any internal reset source is asserted, therefore use open drain outputs with resistive pullups on this pin. See [Chapter 5 System Integration Module \(SIM\)](#) for more information.

1.4.4 External Interrupt Pins ($\overline{IRQ1}/V_{PP}$ and $\overline{IRQ2}$)

$\overline{IRQ1}/V_{PP}$ is the asynchronous external interrupt pin. $\overline{IRQ1}/V_{PP}$ is also the EPROM/OTPROM programming power pin. $\overline{IRQ2}$ is a second asynchronous external interrupt. See [Chapter 5 System Integration Module \(SIM\)](#) and [Chapter 8 External Interrupt Module \(IRQ\)](#) for more information.

1.4.5 Clock Ground Pin (CGND)

CGND is the ground for the port output buffers and the ground return for the serial clock in the serial peripheral interface module (SPI). See [Chapter 11 Serial Peripheral Interface Module \(SPI\)](#) for more information.

NOTE

CGND must be grounded for proper MCU operation.

1.4.6 CGM Power Supply Pin (V_{DDA})

V_{DDA} is the power supply pin for the analog portion of the clock generator module (CGM). See [Chapter 4 Clock Generator Module \(CGMB\)](#) for more information.

1.4.7 External Filter Capacitor Pin (CGMXFC)

CGMXFC is an external filter capacitor connection for the CGM. See [Chapter 4 Clock Generator Module \(CGMB\)](#) for more information.

1.4.8 Port A Input/Output (I/O) Pins (PTA7/KBD7:PTA0/KBD0)

Port A is an 8-bit bidirectional I/O port. Any or all of the port pins can be programmed to serve as external interrupt pins. See [Chapter 13 I/O Ports](#) and [Chapter 9 Keyboard Module \(KB\)](#) for more information.

1.4.9 Port B I/O Pins (PTB7:PTB4, PTB3/AD3:PTB0/AD0)

Port B is an 8-bit bidirectional I/O port that shares four of its pins with the analog-to-digital converter. See [Chapter 14 Analog-to-Digital Converter \(ADC\)](#) for more information.

1.4.10 Port C I/O Pins (PTC6:PTC0)

Port C is a 7-bit bidirectional I/O port. See [Chapter 13 I/O Ports](#).

1.4.11 Port D I/O Pins (PTD7/MISO2:PTD0/MISO1)

Port D is an 8-bit bidirectional I/O port that shares its pins with the serial peripheral interface modules (SPI). See [Chapter 11 Serial Peripheral Interface Module \(SPI\)](#) for more information.

1.4.12 A/D Converter Power Supply Pins and Reference (AV_{DD} , AV_{SS} , V_{RH})

AV_{DD} and AV_{SS} are the A/D converter power supply pins. See [Chapter 14 Analog-to-Digital Converter \(ADC\)](#) for more information.

1.4.13 Port E I/O Pins (PTE6/RxD:PTE0/TCH0)

Port E is a 7-bit special function port that shares its pins with the SCI and the timer channels. See [Chapter 12 Serial Communications Interface Module \(SCI\)](#) and [Chapter 10 Timer Interface Module \(TIM\)](#) for more information.

1.4.14 Port F I/O Pins (PTF3:PTF0)

Port F is a 4-bit general-purpose port. PTF3:PTF0 are capable of driving LEDs. See [Chapter 13 I/O Ports](#) for more information.

1.4.15 LCD Back Planes (BP31:BP0)

BP31:BP0 are the LCD backplane drivers. See [Chapter 15 Liquid Crystal Display Driver \(LCD\)](#) for more information.

1.4.16 LCD Driver Pins (FP39:FP0)

FP39:FP0 are the LCD frontplane drivers. See [Chapter 15 Liquid Crystal Display Driver \(LCD\)](#) for more information.

1.5 LCD Driver Power Supply Pins (CPFLT, V_{LL7}:V_{LL1}, V_{LL}, V_{LLH}, and V_{CP4}:V_{CP1})

The LCD module requires multiple voltage levels, which are generated internally with a charge pump. CPFLT and V_{LLH} are pins for filter capacitors used by the charge pump. CPFLT should be tied to ground through a 0.01 μ F capacitor and V_{LLH} through a 0.22 μ F capacitor. V_{LL7}:V_{LL1} are the power supply pins for the LCD drivers which are used to generate the LCD charge pump voltage levels. Each should be tied to ground through a 0.1 μ F capacitor, with the exception of V_{LL7}, which should use a 0.22 μ F capacitor. V_{LL} is the supply input for the LCD digital logic and should be tied to the same potential as V_{DD}, as well as to a 0.1 μ F capacitor to ground for noise filtering. V_{CP4}:V_{CP1} are the pins used to connect the charge pump to 0.1 μ F switched capacitors. See [Chapter 15 Liquid Crystal Display Driver \(LCD\)](#) for more information.

1.6 Clock Distribution

Each module in the MC68HC08LN56/708LN56 that requires a clock uses either a buffered raw oscillator clock CGMXCLK or the system bus clock CGMOUT. CGMOUT is a divide-by-2 of either the PLL (if engaged) or CGMXCLK. The internal bus clock is a divide-by-2 of CGMOUT.

General Description

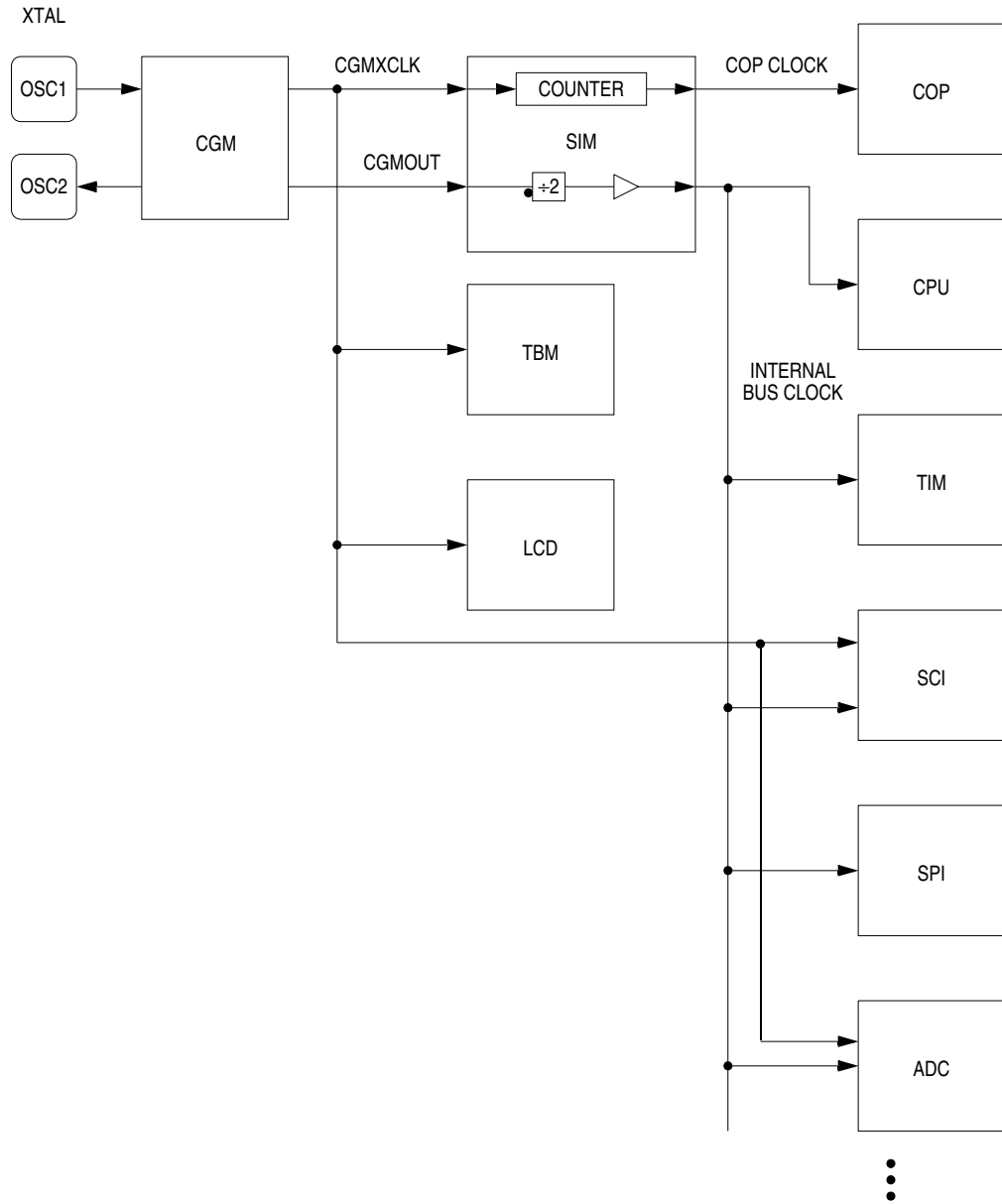


Figure 1-4. Clock Distribution Block Diagram

Chapter 2

Memory

2.1 Introduction

The CPU08 can address 64 Kbytes of memory space. The memory map, shown in [Figure 2-1](#), includes:

- 57,384 bytes of EPROM or OTPROM
- 1280 bytes of RAM
- 40 bytes of user-defined vectors
- 240 bytes of monitor ROM
- 160 bytes of LCD RAM

2.2 I/O Section

Addresses \$0000:\$004F, shown in [Figure 2-2](#), contain most of the control, status, and data registers. Additional I/O registers have the following addresses:

- \$FE00 (SIM break status register, SBSR)
- \$FE01 (SIM reset status register, SRSR)
- \$FE03 (SIM break flag control register, SBFCR)
- \$FE07 (EPROM control register, EPMCR)
- \$FE0C and \$FE0D (break address registers, BRKH and BRKL)
- \$FE0E (break status and control register, BRKSCR)
- \$FE0F (LVI status register, LVISR)
- \$FFFF (COP control register, COPCTL)

[Table 2-1](#) lists vector locations.

Memory

\$0000	I/O REGISTERS 80 BYTES	\$FE00	SIM BREAK STATUS REGISTER (SBSR)
↓		\$FE01	SIM RESET STATUS REGISTER (SRSR)
\$004F	RAM 1280 BYTES	\$FE02	RESERVED
↓		\$FE03	SIM BREAK FLAG CONTROL REGISTER (SBFCR)
\$0050	RESERVED 2224 BYTES	\$FE04	INTERRUPT STATUS REGISTER 1 (INT1)
↓		\$FE05	INTERRUPT STATUS REGISTER 2 (INT2)
\$054F	LCD RAM 160 BYTES (WITH 352 BYTES RESERVED)	\$FE06	INTERRUPT STATUS REGISTER 3 (INT3)
↓		\$FE07	EPROM CONTROL REGISTER (EPMCR) LOWER
\$0550	RESERVED 3584 BYTES	\$FE08	EPROM CONTROL REGISTER (EPMCR) UPPER
↓		↓	RESERVED
\$0DFF	EPROM 57,344 BYTES	\$FE0B	BREAK ADDRESS REGISTER HIGH (BRKH)
↓		\$FE0C	BREAK ADDRESS REGISTER LOW (BRKL)
\$0E00	MONITOR ROM 240 BYTES	\$FE0D	BREAK STATUS AND CONTROL REGISTER (BRKSCR)
↓		\$FE0E	LVI STATUS REGISTER (LVISR)
\$0FFF	UNIMPLEMENTED 192 BYTES	\$FE0F	
↓		\$FE10	
\$1000	RESERVED 24 BYTES	↓	
↓		\$FEFF	
\$1DFF	VECTORS 40 BYTES	\$FF00	
↓		↓	
\$1E00		\$FFBF	
↓		↓	
\$FDFF		\$FFC0	
		↓	
		\$FFD7	
		↓	
		\$FFD8	
		↓	
		\$FFFF	

Figure 2-1. Memory Map

Addr.	Name		Bit 7	6	5	4	3	2	1	Bit 0
\$0000	Port A Data Register (PTA)	R:	PTA7	PTA6	PTA5	PTA4	PTA3	PTA2	PTA1	PTA0
		W:								
\$0001	Port B Data Register (PTB)	R:	PTB7	PTB6	PTB5	PTB4	PTB3	PTB2	PTB1	PTB0
		W:								
\$0002	Port C Data Register (PTC)	R:	0	PTC6	PTC5	PTC4	PTC3	PTC2	PTC1	PTC0
		W:								
\$0003	Port D Data Register (PTD)	R:	PTD7	PTD6	PTD5	PTD4	PTD3	PTD2	PTD1	PTD0
		W:								
\$0004	Data Direction Register A (DDRA)	R:	DDRA7	DDRA6	DDRA5	DDRA4	DDRA3	DDRA2	DDRA1	DDRA0
		W:								
\$0005	Data Direction Register B (DDRB)	R:	DDRB7	DDRB6	DDRB5	DDRB4	DDRB3	DDRB2	DDRB1	DDRB0
		W:								
\$0006	Data Direction Register C (DDRC)	R:	0	DDRC6	DDRC5	DDRC4	DDRC3	DDRC2	DDRC1	DDRC0
		W:								
\$0007	Data Direction Register D (DDRD)	R:	DDRD7	DDRD6	DDRD5	DDRD4	DDRD3	DDRD2	DDRD1	DDRD0
		W:								
\$0008	Port E Data Register (PTE)	R:	0	PTE6	PTE5	PTE4	PTE3	PTE2	PTE1	PTE0
		W:								
\$0009	Port F Data Register (PTF)	R:	0	0	0	0	PTF3	PTF2	PTF1	PTF0
		W:								
\$000A	Reserved	R:								
		W:								
\$000B	Reserved	R:								
		W:								
\$000C	Data Direction Register E (DDRE)	R:	0	DDRE6	DDRE5	DDRE4	DDRE3	DDRE2	DDRE1	DDRE0
		W:								
\$000D	Data Direction Register F (DDRF)	R:	0	0	0	0	DDRF3	DDRF2	DDRF1	DDRF0
		W:								
\$000E	Reserved	R:								
		W:								
\$000F	Reserved	R:								
		W:								
\$0010	SPI 1 Control Register (SP1CR)	R:	SPRIE	DMAS	SPMSTR	CPOL	CPHA	SPWOM	SPE	SPTIE
		W:								
\$0011	SPI 1 Status and Control Register (SP1SCR)	R:	SPRF	OVRIE	OVRF	MODF	SPTIE	MODIE	SPR1	SPR0
		W:								

= Unimplemented

R = Reserved

Figure 2-2. Control, Status, and Data Registers (Sheet 1 of 5)

Memory

Addr.	Name		Bit 7	6	5	4	3	2	1	Bit 0
\$0012	SPI 1 Data Register (SP1DR)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0013	SCI Control Register 1 (SCC1)	R:	LOOPS	ENSCI	TXINV	M	WAKE	ILTY	PEN	PTY
		W:								
\$0014	SCI Control Register 2 (SCC2)	R:	SCTIE	TCIE	SCRIE	ILIE	TE	RE	RWU	SBK
		W:								
\$0015	SCI Control Register 3 (SCC3)	R:	R8	T8	DMARE	DMATE	ORIE	NEIE	FEIE	PEIE
		W:								
\$0016	SCI Status Register 1 (SCS1)	R:	SCTE	TC	SCRf	IDLE	OR	NF	FE	PE
		W:								
\$0017	SCI Status Register 2 (SCS2)	R:	0	0	0	0	0	0	BKF	RPF
		W:								
\$0018	SCI Data Register (SCDR)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0019	SCI Baud Rate Register (SCBR)	R:	0	0	SCP1	SCP0	0	SCR2	SCR1	SCR0
		W:								
\$001A	Keyboard Status/Control Register (KBSCR)	R:	0	0	0	0	KEYF	0	IMASKK	MODEK
		W:						ACKK		
\$001B	Keyboard Interrupt Control Register (KBICR)	R:	KB7IE	KB6IE	KB5IE	KB4IE	KB3IE	KB2IE	KB1IE	KBOIE
		W:								
\$001C	SPI 2 Control Register (SP2CR)	R:	SPRIE	DMAS	SP-MSTR	CPOL	CPHA	SPWOM	SPE	SPTIE
		W:								
\$001D	SPI 2 Status and Control Register (SP2SCR)	R:	SPRF	OVRIE	OVRf	MODF	SPTe	MODIE	SPR1	SPR0
		W:								
\$001E	SPI 2 Data Register (SP2DR)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$001F	Configuration Register (CONFIG)	R:	0	LVISTOP	LVIRST	LVIPWR	SSREC		STOP	COPD
		W:								
\$0020	Timer Status and Control Register (TSC)	R:	TOF	TOIE	TSTOP	0	0	PS2	PS1	PS0
		W:	0			TRST				
\$0021	Timer DMA Select Register (TDMA)	R:	0	0	0	0	DMA3S	DMA2S	DMA1S	DMA0S
		W:								
\$0022	Timer Counter Register High (TCNTH)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$0023	Timer Counter Register Low (TCNTL)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0024	Timer Modulo Register High (TMODH)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								

= Unimplemented

R = Reserved

Figure 2-2. Control, Status, and Data Registers (Sheet 2 of 5)

Addr.	Name		Bit 7	6	5	4	3	2	1	Bit 0
\$0025	Timer Modulo Register Low (TMODL)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0026	Timer Channel 0 Status and Control Register (TSC0)	R:	CH0F	CH0IE	MS0B	MS0A	ELS0B	ELS0A	TOV0	CH0MAX
		W:	0							
\$0027	Timer Channel 0 Register High (TCH0H)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$0028	Timer Channel 0 Register Low (TCH0L)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0029	Timer Channel 1 Status and Control Register (TSC1)	R:	CH1F	CH1IE	0	MS1A	ELS1B	ELS1A	TOV1	CH1MAX
		W:	0							
\$002A	Timer Channel 1 Register High (TCH1H)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$002B	Timer Channel 1 Register Low (TCH1L)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$002C	Timer Channel 2 Status and Control Register (TSC2)	R:	CH2F	CH2IE	MS2B	MS2A	ELS2B	ELS2A	TOV2	CH2MAX
		W:	0							
\$002D	Timer Channel 2 Register High (TCH2H)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$002E	Timer Channel 2 Register Low (TCH2L)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$002F	Timer Channel 3 Status and Control Register (TSC3)	R:	CH3F	CH3IE	0	MS3A	ELS3B	ELS3A	TOV3	CH3MAX
		W:	0							
\$0030	Timer Channel 3 Register High (TCH3H)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$0031	Timer Channel 3 Register Low (TCH3L)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$0032	IRQ Status/Control Register (ISCR)	R:	IRQ2F	0	IMASK2	MODE2	IRQ1F	0	IMASK1	MODE1
		W:		ACK2				ACK1		
\$0033	LCD FrontPlane Latch 0 (LCDFL0)	R:	FP7	FP6	FP5	FP4	FP3	FP2	FP1	FP0
		W:								
\$0034	LCD FrontPlane Latch 1 (LCDFL1)	R:	FP15	FP14	FP13	FP12	FP11	FP10	FP9	FP8
		W:								
\$0035	LCD FrontPlane Latch 2 (LCDFL2)	R:	FP23	FP22	FP21	FP20	FP19	FP18	FP17	FP16
		W:								
\$0036	LCD FrontPlane Latch 3 (LCDFL3)	R:	FP31	FP30	FP29	FP28	FP27	FP26	FP25	FP24
		W:								
\$0037	LCD FrontPlane Latch 4 (LCDFL4)	R:	FP39	FP38	FP37	FP36	FP35	FP34	FP33	FP32
		W:								

□ = Unimplemented

□ R = Reserved

Figure 2-2. Control, Status, and Data Registers (Sheet 3 of 5)

Memory

Addr.	Name		Bit 7	6	5	4	3	2	1	Bit 0
\$0038	LCD Control Register (LCDCR)	R:	DISON	SUPV	R	R	R	R	R	R
		W:								
\$0039	LCD Contrast Control Register (LCDCCR)	R:	CTCL7	CTCL6	CTCL5	CTCL4	CTCL3	CTCL2	CTCL1	CTCL0
		W:								
\$003A	LCD Prescale Divider Register (LCDDIV)	R:	PE	DIV6	DIV5	DIV4	DIV3	DIV2	DIV1	DIV0
		W:								
\$003B	LCD Frame Rate Register (LCDFR)	R:	0	0	0	0	FR3	FR2	FR1	FR0
		W:								
\$003F	Time Base Control Register (TBCR)	R:	TBIF	TBIE	TBR1	TBR0	0	0	TBON	0
		W:					TACK			
\$0040	A/D Control Register (ADSCR)	R:	COCO/ IDMAS	AIEN	ADC0	ADCH4	ADCH3	ADCH2	ADCH1	ADCH0
		W:								
\$0041	A/D Data Register (ADR)	R:	AD7	AD6	AD5	AD4	AD3	AD2	AD1	AD0
		W:								
\$0042	A/D Clock Register (ADCL)	R:	ADIV2	ADIV1	ADIV0	ADICLK	0	0	0	0
		W:								
\$004A	PLL Control Register (PCTL)	R:	PLLIE	PLLF	PLLON	BCS	PRE1	PRE0	VPR1	VPR0
		W:								
\$004B	PLL Bandwidth Control Register (PBWC)	R:	AUTO	LOCK	ACQ	0	0	0	0	0
		W:								
\$004C	PLL Multiplier Select High Register (PMSH)	R:	0	0	0	0	MUL11	MUL10	MUL9	MUL8
		W:								
\$004D	PLL Multiplier Select Low Register (PMSL)	R:	MUL7	MUL6	MUL5	MUL4	MUL3	MUL2	MUL1	MUL0
		W:								
\$004E	PLL VCO Select Range (PVRS)	R:	VRS7	VRS6	VRS5	VRS4	VRS3	VRS2	VRS1	VRS0
		W:								
\$004F	PLL Reference Divider Select Register (PRDS)	R:	0	0	0	0	RDS3	RDX2	RDX1	RDX0
		W:								
\$FE00	SIM Break Status Register (SBSR)	R:	R	R	R	R	R	R	SBSW	R
		W:								
\$FE01	SIM Reset Status Register (SRSR)	R:	POR	PIN	COP	ILOP	ILAD	0	LVI	0
		W:								
\$FE03	SIM Break Flag Control Register (SBFCR)	R:	BCFE	R	R	R	R	R	R	R
		W:								
\$FE04	Interrupt Status Register 1 (INT1)	R:	I6	I5	I4	I3	I2	I1	0	0
		W:	R	R	R	R	R	R	R	R
\$FE05	Interrupt Status Register 2 (INT2)	R:	I14	I13	I12	I11	I10	I9	I8	I7
		W:	R	R	R	R	R	R	R	R

= Unimplemented

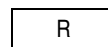
R = Reserved

Figure 2-2. Control, Status, and Data Registers (Sheet 4 of 5)

Addr.	Name		Bit 7	6	5	4	3	2	1	Bit 0
\$FE06	Interrupt Status Register 3 (INT3)	R:	0	0	0	0	I18	I17	I16	I15
		W:	R	R	R	R	R	R	R	R
\$FE07	EPROM Control Register 1 (EPMCR1)	R:	EPMCR1	0	0	0	0	ELAT1	0	EPGM1
		W:								
\$FE08	EPROM Control Register 2 (EPMCR2)	R:	EPMCR2	0	0	0	0	ELAT2	0	EPGM2
		W:								
\$FE0C	Break Address Register High (BRKH)	R:	Bit 15	14	13	12	11	10	9	Bit 8
		W:								
\$FE0D	Break Address Register Low (BRKL)	R:	Bit 7	6	5	4	3	2	1	Bit 0
		W:								
\$FE0E	Break Status and Control Register (BRKSCR)	R:	BRKE	BRKA	0	0	0	0	0	0
		W:								
\$FE0F	LVI Status Register (LVISR)	R:	LVIOUT	0	0	0	0	0	0	0
		W:								
\$FFFF	COP Control Register (COPCTL)	R:	LOW BYTE OF RESET VECTOR							
		W:	WRITING TO \$FFFF CLEARS COP COUNTER							



= Unimplemented



= Reserved

Figure 2-2. Control, Status, and Data Registers (Sheet 5 of 5)

Table 2-1. Vector Addresses

	Address	Vector
Low ↑ Priority ↓ High	\$FFD8:\$FFD9	Time Base Module Vector (High:Low)
	\$FFDA:\$FFDB	A/D Vector (High:Low)
	\$FFDC:\$FFDD	Keyboard Vector (High:Low)
	\$FFDE:\$FFDF	IRQ2 Vector (High:Low)
	\$FFE0:\$FFE1	SCI Transmit Vector (High:Low)
	\$FFE2:\$FFE3	SCI Receive Vector (High:Low)
	\$FFE4:\$FFE5	SCI Error Vector (High:Low)
	\$FFE6:\$FFE7	SPI 2 Transmit Vector (High:Low)
	\$FFE8:\$FFE9	SPI 2 Receive Vector (High:Low)
	\$FFEA:\$FFEB	SPI 1 Transmit Vector (High:Low)
	\$FFEC:\$FFED	SPI 1 Receive Vector (High:Low)
	\$FFEE:\$FFEF	TIM Overflow Vector (High:Low)
	\$FFF0:\$FFF1	TIM Channel 3 Vector (High:Low)
	\$FFF2:\$FFF3	TIM Channel 2 Vector (High:Low)
	\$FFF4:\$FFF5	TIM Channel 1 Vector (High:Low)
	\$FFF6:\$FFF7	TIM Channel 0 Vector (High:Low)
	\$FFF8:\$FFF9	PLL Vector (High:Low)
	\$FFFA:\$FFFB	IRQ1 Vector (High:Low)
	\$FFFC:\$FFFD	SWI Vector (High:Low)
	\$FFFE:\$FFFF	Reset Vector (High:Low)

Chapter 3

Central Processing Unit (CPU)

3.1 Introduction

This section describes the central processor unit (CPU08, Version A). The M68HC08 CPU is an enhanced and fully object-code-compatible version of the M68HC05 CPU. The *CPU08 Reference Manual* (Freescale document number CPU08RM/AD) contains a description of the CPU instruction set, addressing modes, and architecture.

3.2 Features

Features of the CPU include:

- Fully Upward, Object-Code Compatibility with M68HC05 Family
- 16-Bit Stack Pointer with Stack Manipulation Instructions
- 16-Bit Index Register with X-Register Manipulation Instructions
- 8-MHz CPU Internal Bus Frequency
- 64-Kbyte Program/Data Memory Space
- 16 Addressing Modes
- Memory-to-Memory Data Moves without Using Accumulator
- Fast 8-Bit by 8-Bit Multiply and 16-Bit by 8-Bit Divide Instructions
- Enhanced Binary-Coded Decimal (BCD) Data Handling
- Modular Architecture with Expandable Internal Bus Definition for Extension of Addressing Range beyond 64 Kbytes
- Low-Power Stop and Wait Modes

3.3 CPU Registers

Figure 3-1 shows the five CPU registers. CPU registers are not part of the memory map.

Central Processing Unit (CPU)

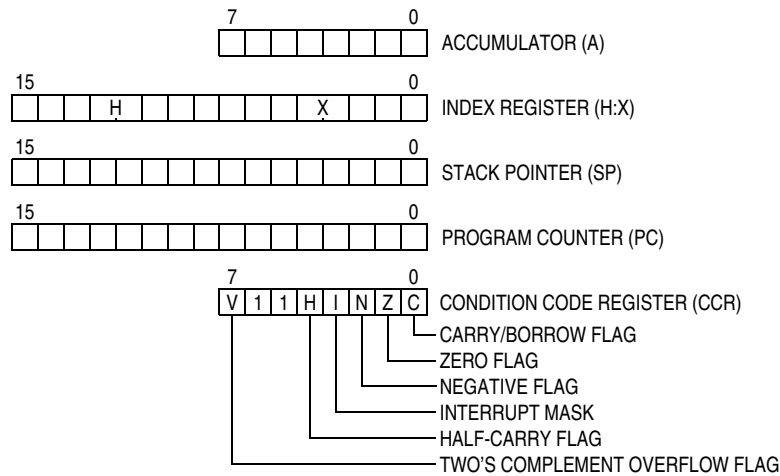


Figure 3-1. CPU Registers

3.3.1 Accumulator

The accumulator (A) is a general-purpose 8-bit register. The CPU uses the accumulator to hold operands and the results of arithmetic/logic operations.

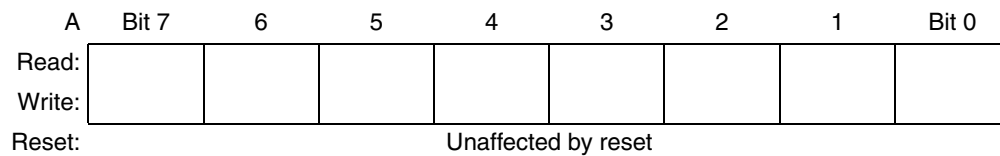


Figure 3-2. Accumulator (A)

3.3.2 Index Register

The 16-bit index register (H:X) allows indexed addressing of a 64-Kbyte memory space. H is the upper byte of the index register, and X is the lower byte. H:X is the concatenated 16-bit index register.

In the indexed addressing modes, the CPU uses the contents of the index register to determine the conditional address of the operand.

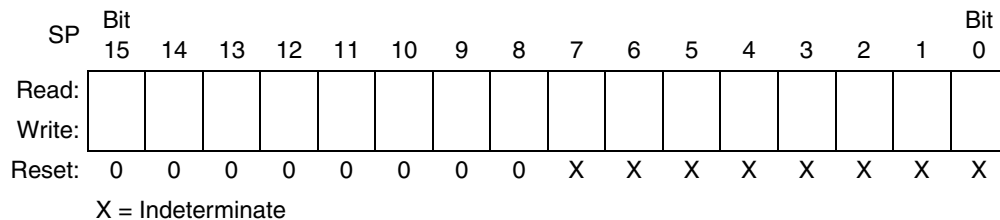


Figure 3-3. Index Register (H:X)

The index register can serve also as a temporary data storage location.

3.3.3 Stack Pointer

The stack pointer (SP) is a 16-bit register that contains the address of the next location on the stack. During a reset, the stack pointer is preset to \$00FF. The reset stack pointer (RSP) instruction sets the least significant byte to \$FF and does not affect the most significant byte. The stack pointer decrements as data is pushed onto the stack and increments as data is pulled from the stack.

In the stack pointer 8-bit offset and 16-bit offset addressing modes, the stack pointer can function as an index register to access data on the stack. The CPU uses the contents of the stack pointer to determine the conditional address of the operand.

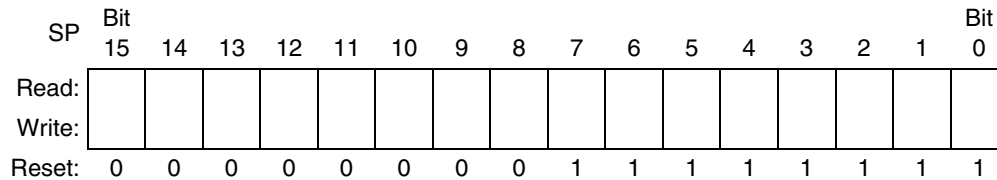


Figure 3-4. Stack Pointer (SP)

NOTE

The location of the stack is arbitrary and may be relocated anywhere in RAM. Moving the SP out of page zero (\$0000 to \$00FF) frees direct address (page zero) space. For correct operation, the stack pointer must point only to RAM locations.

3.3.4 Program Counter

The program counter (PC) is a 16-bit register that contains the address of the next instruction or operand to be fetched.

Normally, the program counter automatically increments to the next sequential memory location every time an instruction or operand is fetched. Jump, branch, and interrupt operations load the program counter with an address other than that of the next sequential location.

During reset, the program counter is loaded with the reset vector address located at \$FFFE and \$FFFF. The vector address is the address of the first instruction to be executed after exiting the reset state.

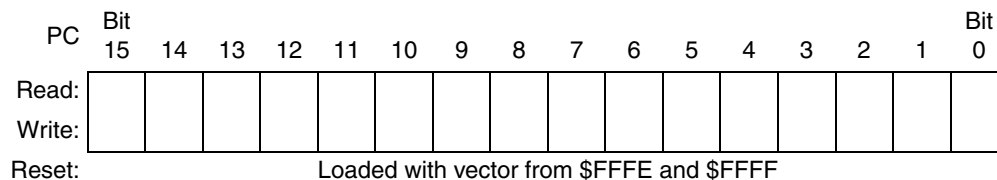


Figure 3-5. Program Counter (PC)

3.3.5 Condition Code Register

The 8-bit condition code register (CCR) contains the interrupt mask and five flags that indicate the results of the instruction just executed. Bits 6 and 5 are set permanently to logic one. The following paragraphs describe the functions of the condition code register.

CCR	Bit 7	6	5	4	3	2	1	Bit 0
Read:	V	1	1	H	I	N	Z	C
Write:								
Reset:	X	1	1	X	1	X	X	X

X = Indeterminate

Figure 3-6. Condition Code Register (CCR)

V — Overflow Flag

The CPU sets the overflow flag when a two's complement overflow occurs. The signed branch instructions BGT, BGE, BLE, and BLT use the overflow flag.

- 1 = Overflow
- 0 = No overflow

H — Half-Carry Flag

The CPU sets the half-carry flag when a carry occurs between accumulator bits 3 and 4 during an ADD or ADC operation. The half-carry flag is required for binary-coded decimal (BCD) arithmetic operations. The DAA instruction uses the states of the H and C flags to determine the appropriate correction factor.

- 1 = Carry between bits 3 and 4
- 0 = No carry between bits 3 and 4

I — Interrupt Mask

When the interrupt mask is set, all maskable CPU interrupts are disabled. CPU interrupts are enabled when the interrupt mask is cleared. When a CPU interrupt occurs, the interrupt mask is set automatically after the CPU registers are saved on the stack, but before the interrupt vector is fetched.

- 1 = Interrupts disabled
- 0 = Interrupts enabled

NOTE

To maintain M6805 compatibility, the upper byte of the index register (H) is not stacked automatically. If the interrupt service routine modifies H, then the user must stack and unstack H using the PSHH and PULH instructions.

After the I bit is cleared, the highest-priority interrupt request is serviced first.

A return from interrupt (RTI) instruction pulls the CPU registers from the stack and restores the interrupt mask from the stack. After any reset, the interrupt mask is set and can only be cleared by the clear interrupt mask software instruction (CLI).

N — Negative flag

The CPU sets the negative flag when an arithmetic operation, logic operation, or data manipulation produces a negative result, setting bit 7 of the result.

- 1 = Negative result
- 0 = Non-negative result

Z — Zero flag

The CPU sets the zero flag when an arithmetic operation, logic operation, or data manipulation produces a result of \$00.

1 = Zero result

0 = Non-zero result

C — Carry/Borrow Flag

The CPU sets the carry/borrow flag when an addition operation produces a carry out of bit 7 of the accumulator or when a subtraction operation requires a borrow. Some instructions — such as bit test and branch, shift, and rotate — also clear or set the carry/borrow flag.

1 = Carry out of bit 7

0 = No carry out of bit 7

3.4 Arithmetic/Logic Unit

The arithmetic/logic unit (ALU) performs the arithmetic and logic operations defined by the instruction set.

Refer to the *CPU08 Reference Manual* (Freescale document number CPU08RM/AD) for a description of the instructions and addressing modes and more detail about CPU architecture.

3.5 CPU During Break Interrupts

If the break module is enabled, a break interrupt causes the CPU to execute the software interrupt instruction (SWI) at the completion of the current CPU instruction. See [Chapter 17 Break Module \(BREAK\)](#). The program counter vectors to \$FFFC:\$FFFD (\$FEFC:\$FEFD in monitor mode).

A return from interrupt instruction (RTI) in the break routine ends the break interrupt and returns the MCU to normal operation if the break interrupt has been deasserted.

Chapter 4

Clock Generator Module (CGMB)

4.1 Introduction

This section describes the clock generator module (CGM, Version B). The CGM generates the crystal clock signal, CGMXCLK, which operates at the frequency of the crystal. The CGM also generates the base clock signal, CGMOUT, which is based on either the crystal clock divided by two or the phase-locked loop (PLL) clock, CGMVCLK, divided by two. This is the clock from which the SIM derives the system clocks, including the bus clock, which is at a frequency of CGMOUT/2. The PLL is a fully functional frequency generator designed for use with crystals or ceramic resonators. The PLL can generate an 8-MHz bus frequency using a 32-kHz crystal.

4.2 Features

Features of the CGMB include:

- Phase-Locked Loop with Output Frequency in Integer Multiples of an Integer Dividend of the Crystal Reference
- Low-Frequency Crystal Operation with Low-Power Operation and High-Output Frequency Resolution
- Programmable Reference Divider for Even Greater Resolution
- Programmable Prescaler for Power-of-Two Increases in Frequency
- Programmable Hardware Voltage-Controlled Oscillator (VCO) for Low-Jitter Operation
- Automatic Bandwidth Control Mode for Low-Jitter Operation
- Automatic Frequency Lock Detector
- CPU Interrupt on Entry or Exit from Locked Condition

4.3 Functional Description

The CGMB consists of three major submodules:

- Crystal oscillator circuit — The crystal oscillator circuit generates the constant crystal frequency clock, CGMXCLK.
- Phase-locked loop (PLL) — The PLL generates the programmable VCO frequency clock, CGMVCLK.
- Base clock selector circuit — This software-controlled circuit selects either CGMXCLK divided by two or the VCO clock, CGMVCLK, divided by two as the base clock, CGMOUT. The SIM derives the system clocks from CGMOUT.

Figure 4-1 shows the structure of the CGM.

Clock Generator Module (CGMB)

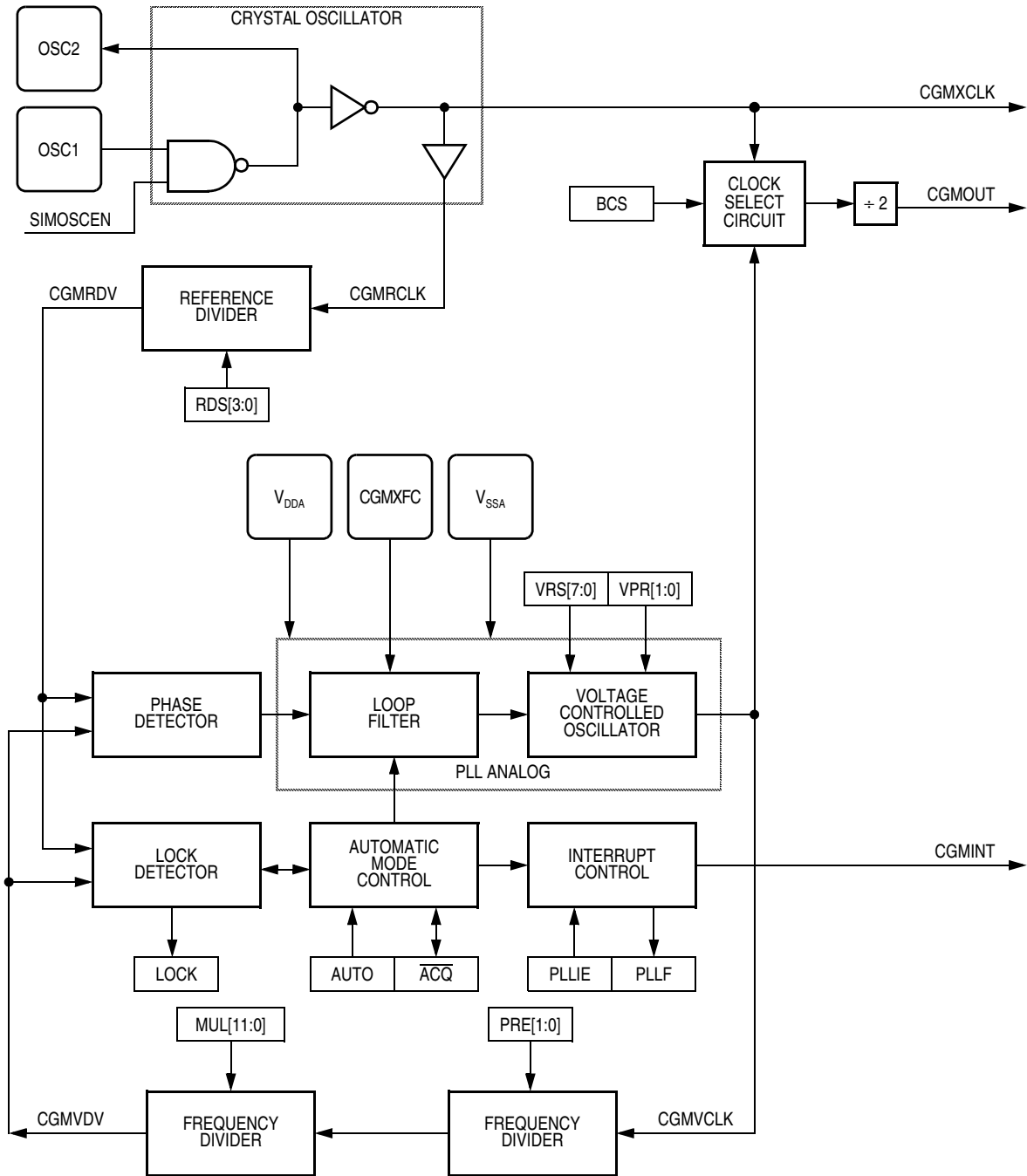


Figure 4-1. CGMB Block Diagram

4.3.1 Crystal Oscillator Circuit

The crystal oscillator circuit consists of an inverting amplifier and an external crystal. The OSC1 pin is the input to the amplifier and the OSC2 pin is the output. The SIMOSCEN signal from the system integration module (SIM) enables the crystal oscillator circuit.

The CGMXCLK signal is the output of the crystal oscillator circuit and runs at a rate equal to the crystal frequency. CGMXCLK is then buffered to produce CGMRCLK, the PLL reference clock.

CGMXCLK can be used by other modules which require precise timing for operation. The duty cycle of CGMXCLK is not guaranteed to be 50% and depends on external factors, including the crystal and related external components. An externally generated clock also can feed the OSC1 pin of the crystal oscillator circuit. Connect the external clock to the OSC1 pin and let the OSC2 pin float.

4.3.2 Phase-Locked Loop Circuit (PLL)

The PLL is a frequency generator that can operate in either acquisition mode or tracking mode, depending on the accuracy of the output frequency. The PLL can change between acquisition and tracking modes either automatically or manually.

4.3.3 PLL Circuits

The PLL consists of these circuits:

- Voltage-controlled oscillator (VCO)
- Reference divider
- Frequency prescaler
- Modulo VCO frequency divider
- Phase detector
- Loop filter
- Lock detector

The operating range of the VCO is programmable for a wide range of frequencies and for maximum immunity to external noise, including supply and CGM/XFC noise. The VCO frequency is bound to a range from roughly one-half to twice the center-of-range frequency, f_{VRS} . Modulating the voltage on the CGM/XFC pin changes the frequency within this range. By design, f_{VRS} is equal to the nominal center-of-range frequency, f_{NOM} , (38.4 kHz) times a linear factor L and a power-of-two factor E, or $(L \times 2^E)f_{NOM}$.

CGMRCLK is the PLL reference clock, a buffered version of CGMXCLK. CGMRCLK runs at a frequency, f_{RCLK} , and is fed to the PLL through a programmable modulo reference divider, which divides f_{RCLK} by a factor R. This feature allows frequency steps of higher resolution. The divider's output is the final reference clock, CGMRDV, running at a frequency $f_{RDV} = f_{RCLK}/R$.

The VCO's output clock, CGMVCLK, running at a frequency f_{VCLK} is fed back through a programmable prescale divider and a programmable modulo divider. The prescaler divides the VCO clock by a power-of-two factor P and the modulo divider reduces the VCO clock by a factor, N. The dividers' output is the VCO feedback clock, CGMVDV, running at a frequency $f_{VDV} = f_{VCLK}/(N \times 2^P)$. (See [4.3.6 Programming the PLL](#) for more information.)

The phase detector then compares the VCO feedback clock, CGMVDV, with the final reference clock, CGMRDV. A correction pulse is generated based on the phase difference between the two signals. The loop filter then slightly alters the DC voltage on the external capacitor connected to CGM/XFC based on the width and direction of the correction pulse. The filter can make fast or slow corrections depending on its mode, described in [4.3.4 Acquisition and Tracking Modes](#). The value of the external capacitor and the reference frequency determines the speed of the corrections and the stability of the PLL.

The lock detector compares the frequencies of the VCO feedback clock, CGMVDV, and the final reference clock, CGMRDV. Therefore, the speed of the lock detector is directly proportional to the final reference frequency, f_{RDV} . The circuit determines the mode of the PLL and the lock condition based on this comparison.

4.3.4 Acquisition and Tracking Modes

The PLL filter is manually or automatically configurable into one of two operating modes:

- Acquisition mode — In acquisition mode, the filter can make large frequency corrections to the VCO. This mode is used at PLL startup or when the PLL has suffered a severe noise hit and the VCO frequency is far off the desired frequency. When in acquisition mode, the \overline{ACQ} bit is clear in the PLL bandwidth control register. (See [4.5.2 PLL Bandwidth Control Register](#).)
- Tracking mode — In tracking mode, the filter makes only small corrections to the frequency of the VCO. PLL jitter is much lower in tracking mode, but the response to noise is also slower. The PLL enters tracking mode when the VCO frequency is nearly correct, such as when the PLL is selected as the base clock source. (See [4.3.8 Base Clock Selector Circuit](#).) The PLL is automatically in tracking mode when not in acquisition mode or when the \overline{ACQ} bit is set.

4.3.5 Manual and Automatic PLL Bandwidth Modes

The PLL can change the bandwidth or operational mode of the loop filter manually or automatically. Automatic mode is recommended for most users.

In automatic bandwidth control mode (AUTO = 1), the lock detector automatically switches between acquisition and tracking modes. Automatic bandwidth control mode also is used to determine when the VCO clock, CGMVCLK, is safe to use as the source for the base clock, CGMOUT. (See [4.5.2 PLL Bandwidth Control Register](#).) If PLL interrupts are enabled, the software can wait for a PLL interrupt request and then check the LOCK bit. If interrupts are disabled, software can poll the LOCK bit continuously (during PLL startup, usually) or at periodic intervals. In either case, when the LOCK bit is set, the VCO clock is safe to use as the source for the base clock. (See [4.3.8 Base Clock Selector Circuit](#).) If the VCO is selected as the source for the base clock and the LOCK bit is clear, the PLL has suffered a severe noise hit and the software must take appropriate action, depending on the application. (See [4.6 Interrupts](#) for information and precautions on using interrupts.) The following conditions apply when the PLL is in automatic bandwidth control mode:

- The \overline{ACQ} bit (See [4.5.2 PLL Bandwidth Control Register](#).) is a read-only indicator of the mode of the filter. (See [4.3.4 Acquisition and Tracking Modes](#).)
- The \overline{ACQ} bit is set when the VCO frequency is within a certain tolerance, Δ_{TRK} , and is cleared when the VCO frequency is out of a certain tolerance, Δ_{UNT} . (See [4.8 Acquisition/Lock Time Specifications](#) for more information.)
- The LOCK bit is a read-only indicator of the locked state of the PLL.

- The LOCK bit is set when the VCO frequency is within a certain tolerance, Δ_{LOCK} , and is cleared when the VCO frequency is out of a certain tolerance Δ_{UNL} . (See [4.8 Acquisition/Lock Time Specifications](#) for more information.)
- CPU interrupts can occur if enabled ($\text{PLLIE} = 1$) when the PLL's lock condition changes, toggling the LOCK bit. (See [4.5.1 PLL Control Register](#).)

The PLL also may operate in manual mode ($\text{AUTO} = 0$). Manual mode is used by systems that do not require an indicator of the lock condition for proper operation. Such systems typically operate well below f_{BUSMAX} . The following conditions apply when in manual mode:

- $\overline{\text{ACQ}}$ is a writable control bit that controls the mode of the filter. Before turning on the PLL in manual mode, the $\overline{\text{ACQ}}$ bit must be clear.
- Before entering tracking mode ($\overline{\text{ACQ}} = 1$), software must wait a given time, t_{ACQ} (See [4.8 Acquisition/Lock Time Specifications](#).), after turning on the PLL by setting PLLON in the PLL control register (PCTL).
- Software must wait a given time, t_{AL} , after entering tracking mode before selecting the PLL as the clock source to CGMOUT ($\text{BCS} = 1$).
- The LOCK bit is disabled.
- CPU interrupts from the CGMB are disabled.

4.3.6 Programming the PLL

The following procedure shows how to program the PLL.

NOTE

The round function in the following equations means that the real number should be rounded to the nearest integer number.

1. Choose the desired bus frequency, f_{BUSDES} .
2. Calculate the desired VCO frequency (four times the desired bus frequency).

$$f_{\text{VCLKDES}} = 4 \times f_{\text{BUSDES}}$$

3. Choose a practical PLL (crystal) reference frequency, f_{RCLK} , and the reference clock divider, R.

Frequency errors to the PLL are corrected at a rate of f_{RCLK}/R . For stability and lock time reduction, this rate must be as fast as possible. The VCO frequency must be an integer multiple of this rate. The relationship between the VCO frequency f_{VCLK} and the reference frequency f_{RCLK} is

$$f_{\text{VCLK}} = \frac{2^P N}{R} (f_{\text{RCLK}})$$

P, the power of two multiplier, and N, the range multiplier, are integers.

In cases where desired bus frequency has some tolerance, choose f_{RCLK} to a value determined either by other module requirements (such as modules which are clocked by CGMXCLK), cost requirements, or ideally, as high as the specified range allows. See [Chapter 22 Preliminary Electrical Specifications](#). Choose the reference divider $R = 1$. After choosing N and P (as shown below), the actual bus frequency can be determined using equation in 2 above.

Clock Generator Module (CGMB)

When the tolerance on the bus frequency is tight, choose f_{RCLK} to an integer divisor of f_{BUSDES} , and $R = 1$. If f_{RCLK} cannot meet this requirement, use the following equation to solve for R with practical choices of f_{RCLK} , and choose the f_{RCLK} that gives the lowest R .

$$R = \text{round} \left[R_{MAX} \times \left\{ \left(\frac{f_{VCLKDES}}{f_{RCLK}} \right) - \text{integer} \left(\frac{f_{VCLKDES}}{f_{RCLK}} \right) \right\} \right]$$

4. Select a VCO frequency multiplier, N .

$$N = \text{round} \left(\frac{R \times f_{VCLKDES}}{f_{RCLK}} \right)$$

Reduce N/R to the lowest possible R .

5. If N is $< N_{max}$, use $P = 0$. If $N > N_{max}$, choose P using the table below:

Current N value	P
$0 < N \leq N_{max}$	0
$N_{max} < N \leq N_{max} \times 2$	1
$N_{max} \times 2 < N \leq N_{max} \times 4$	2
$N_{max} \times 4 < N \leq N_{max} \times 8$	3

Then recalculate N :

$$N = \text{round} \left(\frac{R \times f_{VCLKDES}}{f_{RCLK} \times 2^P} \right)$$

6. Calculate and verify the adequacy of the VCO and bus frequencies f_{VCLK} and f_{BUS} :

$$f_{VCLK} = (2^P \times N/R) \times f_{RCLK}$$

$$f_{BUS} = (f_{VCLK})/4$$

7. Select the VCO's power-of-two range multiplier E , according to the following table:

Frequency Range	E
$0 < f_{VCLK} \leq f_{VRSMAX}/4$	0
$f_{VRSMAX}/4 < f_{VCLK} \leq f_{VRSMAX}/2$	1
$f_{VRSMAX}/2 < f_{VCLK} \leq f_{VRSMAX}$	2

NOTE: Do not program E to a value of 3.

8. Select a VCO linear range multiplier, L, where $f_{\text{NOM}} = 38.4 \text{ KHz}$

$$L = \text{round}\left(\frac{f_{\text{VCLK}}}{2^E \times f_{\text{NOM}}}\right)$$

9. Calculate and verify the adequacy of the VCO programmed center-of-range frequency, f_{VRS} . The center-of-range frequency is the midpoint between the minimum and maximum frequencies attainable by the PLL.

$$f_{\text{VRS}} = (L \times 2^E) f_{\text{NOM}}$$

For proper operation,

$$|f_{\text{VRS}} - f_{\text{VCLK}}| \leq \frac{f_{\text{NOM}} \times 2^E}{2}$$

10. Verify the choice of P, R, N, E, and L by comparing f_{VCLK} to f_{VRS} and f_{VCLKDES} . For proper operation, f_{VCLK} must be within the application's tolerance of f_{VCLKDES} , and f_{VRS} must be as close as possible to f_{VCLK} .

NOTE

Exceeding the recommended maximum bus frequency or VCO frequency can crash the MCU.

11. Program the PLL registers accordingly:
- In the PRE bits of the PLL control register (PCTL), program the binary equivalent of P.
 - In the VPR bits of the PLL control register (PCTL), program the binary equivalent of E.
 - In the PLL multiplier select register low (PMSL) and the PLL multiplier select register high (PMSH), program the binary equivalent of N.
 - In the PLL VCO range select register (PVRS), program the binary coded equivalent of L.
 - In the PLL reference divider select register (PRDS), program the binary coded equivalent of R.

Table 4-1 provides a numeric example (numbers are in hexadecimal notation):

Table 4-1. Numeric Example

f_{BUS}	f_{RCLK}	E	P	N	L	R
8 MHz	32.768 kHz	2	0	3d1	d0	1

4.3.7 Special Programming Exceptions

The programming method described in [4.3.6 Programming the PLL](#) does not account for three possible exceptions. A value of zero for R, N, or L is meaningless when used in the equations given. To account for these exceptions:

A zero value for R or N is interpreted exactly the same as a value of one. A zero value for L disables the PLL and prevents its selection as the source for the base clock. (See [4.3.8 Base Clock Selector Circuit](#).)

4.3.8 Base Clock Selector Circuit

This circuit is used to select either the crystal clock, CGMXCLK, or the VCO clock, CGMVCLK, as the source of the base clock, CGMOUT. The two input clocks go through a transition control circuit that waits up to three CGMXCLK cycles and three CGMVCLK cycles to change from one clock source to the other. During this time, CGMOUT is held in stasis. The output of the transition control circuit is then divided by two to correct the duty cycle. Therefore, the bus clock frequency, which is one-half of the base clock frequency, is one-fourth the frequency of the selected clock (CGMXCLK or CGMVCLK).

The BCS bit in the PLL control register (PCTL) selects which clock drives CGMOUT. The VCO clock cannot be selected as the base clock source if the PLL is not turned on. The PLL cannot be turned off if the VCO clock is selected. The PLL cannot be turned on or off simultaneously with the selection or deselection of the VCO clock. The VCO clock also cannot be selected as the base clock source if the factor L is programmed to a zero. This value would set up a condition inconsistent with the operation of the PLL, so that the PLL would be disabled and the crystal clock would be forced as the source of the base clock.

4.3.9 CGMB External Connections

In its typical configuration, the CGMB requires seven external components. Five of these are for the crystal oscillator and two are for the PLL.

The crystal oscillator is normally connected in a Pierce oscillator configuration, as shown in [Figure 4-2](#). [Figure 4-2](#) shows only the logical representation of the internal components and may not represent actual circuitry. The oscillator configuration uses five components:

- Crystal, X_1
- Fixed capacitor, C_1
- Tuning capacitor, C_2 (can also be a fixed capacitor)
- Feedback resistor, R_B
- Series resistor, R_S (optional)

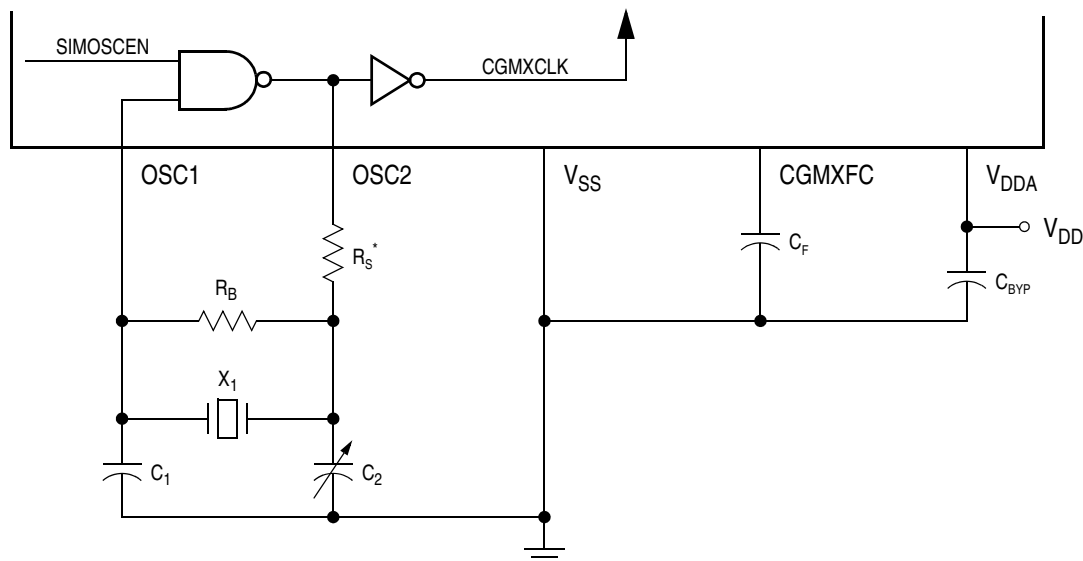
The series resistor (R_S) is included in the diagram to follow strict Pierce oscillator guidelines and may not be required for all ranges of operation, especially with high frequency crystals. Refer to the crystal manufacturer's data for more information.

[Figure 4-2](#) also shows the external components for the PLL:

- Bypass capacitor, C_{BYP}
- Filter capacitor, C_F

Routing should be done with great care to minimize signal cross talk and noise.

See [Chapter 22 Preliminary Electrical Specifications](#) for capacitor and resistor values.



* R_S can be zero (shorted) when used with higher-frequency crystals. Refer to manufacturer's data.

Figure 4-2. CGMB External Connections

4.4 I/O Signals

The following paragraphs describe the CGMB I/O signals.

4.4.1 Crystal Amplifier Input Pin (OSC1)

The OSC1 pin is an input to the crystal oscillator amplifier.

4.4.2 Crystal Amplifier Output Pin (OSC2)

The OSC2 pin is the output of the crystal oscillator inverting amplifier.

4.4.3 External Filter Capacitor Pin (CGMXFC)

The CGMXFC pin is required by the loop filter to filter out phase corrections. A small external capacitor is connected to this pin.

NOTE

To prevent noise problems, C_F should be placed as close to the CGMXFC pin as possible, with minimum routing distances and no routing of other signals across the C_F connection.

4.4.4 PLL Analog Power Pin (V_{DDA})

V_{DDA} is a power pin used by the analog portions of the PLL. Connect the V_{DDA} pin to the same voltage potential as the V_{DD} pin.

NOTE

Route V_{DDA} carefully for maximum noise immunity and place bypass capacitors as close as possible to the package.

4.4.5 PLL Analog Ground Pin (V_{SSA})

V_{SSA} is a ground pin used by the analog portions of the PLL. Connect the V_{SSA} pin to the same voltage potential as the V_{SS} pin.

NOTE

Route V_{SSA} carefully for maximum noise immunity and place bypass capacitors as close as possible to the package.

4.4.6 Buffered Crystal Clock Output (CGMVOUT)

CGMVOUT buffers the OSC1 clock for external use.

4.4.7 CGMVSEL

CGMVSEL must be tied low or floated.

4.4.8 Oscillator Enable Signal (SIMOSCEN)

The SIMOSCEN signal comes from the system integration module (SIM) and enables the oscillator and PLL.

4.4.9 Crystal Output Frequency Signal (CGMXCLK)

CGMXCLK is the crystal oscillator output signal. It runs at the full speed of the crystal (f_{XCLK}) and comes directly from the crystal oscillator circuit. [Figure 4-2](#) shows only the logical relation of CGMXCLK to OSC1 and OSC2 and may not represent the actual circuitry. The duty cycle of CGMXCLK is unknown and may depend on the crystal and other external factors. Also, the frequency and amplitude of CGMXCLK can be unstable at startup.

4.4.10 CGMB Base Clock Output (CGMOUT)

CGMOUT is the clock output of the CGMB. This signal goes to the SIM, which generates the MCU clocks. CGMOUT is a 50 percent duty cycle clock running at twice the bus frequency. CGMOUT is software programmable to be either the oscillator output, CGMXCLK, divided by two or the VCO clock, CGMVCLK, divided by two.

4.4.11 CGMB CPU Interrupt (CGMINT)

CGMINT is the interrupt signal generated by the PLL lock detector.


4.5 CGMB Registers

These registers control and monitor operation of the CGMB:

- PLL control register (PCTL) (See [4.5.1 PLL Control Register](#).)
- PLL bandwidth control register (PBWC) (See [4.5.2 PLL Bandwidth Control Register](#).)
- PLL multiplier select register high (PMSH) (See [4.5.3 PLL Multiplier Select Register High](#).)
- PLL multiplier select register low (PMSL) (See [4.5.4 PLL Multiplier Select Register Low](#).)
- PLL VCO range select register (PVRS) (See [4.5.5 PLL VCO Range Select Register](#).)
- PLL reference divider select register (PRDS) (See [4.5.6 PLL Reference Divider Select Register](#).)

Figure 4-3 is a summary of the CGMB registers.

		Bit 7	6	5	4	3	2	1	Bit 0
PCTL \$004A	Read:	PLLIE	PLLF	PLLON	BCS	PRE1	PRE0	VPR1	VPR0
	Write:								
PBWC \$004B	Read:	AUTO	LOCK	\overline{ACQ}	0	0	0	0	R
	Write:								
PMSH \$004C	Read:					MUL11	MUL10	MUL9	MUL8
	Write:								
PMSL \$004D	Read:	MUL7	MUL6	MUL5	MUL4	MUL3	MUL2	MUL1	MUL0
	Write:								
PVRS \$004E	Read:	VRS7	VRS6	VRS5	VRS4	VRS3	VRS2	VRS1	VRS0
	Write:								
PRDS \$004F	Read:					RDS3	RDS2	RDS1	RDS0
	Write:								

 = Unimplemented

 = Reserved

NOTES:

1. When AUTO = 0, PLLIE is forced clear and is read-only.
2. When AUTO = 0, PLLF and LOCK read as clear.
3. When AUTO = 1, \overline{ACQ} is read-only.
4. When PLLON = 0 or VRS7:VRS0 = \$0, BCS is forced clear and is read-only.
5. When PLLON = 1, the PLL programming register is read-only.
6. When BCS = 1, PLLON is forced set and is read-only.

Figure 4-3. CGMB I/O Register Summary

4.5.1 PLL Control Register

The PLL control register contains the interrupt enable and flag bits, the on/off switch, the base clock selector bit, the prescaler bits, and the VCO power of two range selector bits.

PCTL \$004A	Bit 7	6	5	4	3	2	1	0
Read:	PLLIE	PLLF	PLLON	BCS	PRE1	PRE0	VPR1	VPR0
Write:								
Reset:	0	0	1	0	0	0	0	0

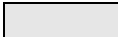
 = Unimplemented

Figure 4-4. PLL Control Register (PCTL)

PLLIE — PLL Interrupt Enable Bit

This read/write bit enables the PLL to generate an interrupt request when the LOCK bit toggles, setting the PLL flag, PLLF. When the AUTO bit in the PLL bandwidth control register (PBWC) is clear, PLLIE cannot be written and reads as logic zero. Reset clears the PLLIE bit.

- 1 = PLL interrupts enabled
- 0 = PLL interrupts disabled

PLLF — PLL Interrupt Flag Bit

This read-only bit is set whenever the LOCK bit toggles. PLLF generates an interrupt request if the PLLIE bit also is set. PLLF always reads as logic zero when the AUTO bit in the PLL bandwidth control register (PBWC) is clear. Clear the PLLF bit by reading the PLL control register. Reset clears the PLLF bit.

- 1 = Change in lock condition
- 0 = No change in lock condition

NOTE

Do not inadvertently clear the PLLF bit. Any read or read-modify-write operation on the PLL control register clears the PLLF bit.

PLLON — PLL On Bit

This read/write bit activates the PLL and enables the VCO clock, CGMVCLK. PLLON cannot be cleared if the VCO clock is driving the base clock, CGMOUT (BCS = 1). (See [4.3.8 Base Clock Selector Circuit.](#)) Reset sets this bit so that the loop can stabilize as the MCU is powering up.

- 1 = PLL on
- 0 = PLL off

BCS — Base Clock Select Bit

This read/write bit selects either the crystal oscillator output, CGMXCLK, or the VCO clock, CGMVCLK, as the source of the CGM output, CGMOUT. CGMOUT frequency is one-half the frequency of the selected clock. BCS cannot be set while the PLLON bit is clear. After toggling BCS, it may take up to three CGMXCLK and three CGMVCLK cycles to complete the transition from one source clock to the other. During the transition, CGMOUT is held in stasis. (See [4.3.8 Base Clock Selector Circuit.](#)) Reset clears the BCS bit.

- 1 = CGMVCLK divided by two drives CGMOUT
- 0 = CGMXCLK divided by two drives CGMOUT

NOTE

PLLON and BCS have built-in protection that prevents the base clock selector circuit from selecting the VCO clock as the source of the base clock if the PLL is off. Therefore, PLLON cannot be cleared when BCS is set, and BCS cannot be set when PLLON is clear. If the PLL is off (PLLON = 0), selecting CGMVCLK requires two writes to the PLL control register. (See [4.3.8 Base Clock Selector Circuit.](#))

PRE1 and PRE0 — Prescaler program bits

These read/write bits control a prescaler that selects the prescaler power-of-two multiplier P. (See [4.3.3 PLL Circuits](#) and [4.3.6 Programming the PLL.](#)) PRE1:PRE0 cannot be written when the PLLON bit is set. Reset clears these bits.

Table 4-2. PRE[1:0] Programming

PRE[1:0]	P	Prescaler Multiplier
00	0	1
01	1	2
10	2	4
11	3	8

VPR[1:0] — VCO Power-of-Two Range Select Bits

These read/write bits control the VCO's hardware power-of-two range multiplier E that, in conjunction with L (See [4.3.3 PLL Circuits](#), [4.3.6 Programming the PLL](#) and [4.5.5 PLL VCO Range Select Register](#).) controls the hardware center-of-range frequency, f_{VRS} . VPR1:VPR0 cannot be written when the PLLON bit is set. Reset clears these bits.

Table 4-3. VPR1:VPR0 Programming

VPR1:VPR0	E	VCO Power-of-Two Range Multiplier
00	0	1
01	1	2
10	2	4
11	3	8

4.5.2 PLL Bandwidth Control Register

The PLL bandwidth control register:

- Selects automatic or manual (software-controlled) bandwidth control mode
- Indicates when the PLL is locked
- In automatic bandwidth control mode, indicates when the PLL is in acquisition or tracking mode
- In manual operation, forces the PLL into acquisition or tracking mode

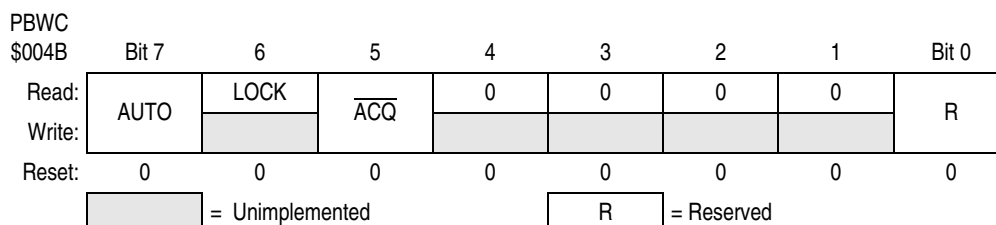


Figure 4-5. PLL Bandwidth Control Register (PBWC)

AUTO — Automatic Bandwidth Control Bit

This read/write bit selects automatic or manual bandwidth control. When initializing the PLL for manual operation (AUTO = 0), clear the \overline{ACQ} bit before turning on the PLL. Reset clears the AUTO bit.

- 1 = Automatic bandwidth control
- 0 = Manual bandwidth control

LOCK — Lock Indicator Bit

When the AUTO bit is set, LOCK is a read-only bit that becomes set when the VCO clock, CGMVCLK, is locked (running at the programmed frequency). When the AUTO bit is clear, LOCK reads as logic zero and has no meaning. The write one function of this bit is reserved for test, so this bit must **always** be written a zero. Reset clears the LOCK bit.

- 1 = VCO frequency correct or locked
- 0 = VCO frequency incorrect or unlocked

ACQ — Acquisition Mode Bit

When the AUTO bit is set, \overline{ACQ} is a read-only bit that indicates whether the PLL is in acquisition mode or tracking mode. When the AUTO bit is clear, \overline{ACQ} is a read/write bit that controls whether the PLL is in acquisition or tracking mode.

In automatic bandwidth control mode (AUTO = 1), the last-written value from manual operation is stored in a temporary location and is recovered when manual operation resumes. Reset clears this bit, enabling acquisition mode.

- 1 = Tracking mode
- 0 = Acquisition mode

4.5.3 PLL Multiplier Select Register High

The PLL multiplier select register high contains the programming information for the high byte of the modulo feedback divider.

PMSH \$004C	Bit 7	6	5	4	3	2	1	Bit 0
Read:	0	0	0	0	MUL11	MUL10	MUL9	MUL8
Write:								
Reset:	0	0	0	0	0	0	0	0

= Unimplemented

Figure 4-6. PLL Multiplier Select Register High (PMSH)

MUL[11:8] — Multiplier select bits

These read/write bits control the high byte of the modulo feedback divider that selects the VCO frequency multiplier N. (See 4.3.3 PLL Circuits and 4.3.6 Programming the PLL.) A value of \$0000 in the multiplier select registers configures the modulo feedback divider the same as a value of \$0001. Reset initializes the registers to \$0040 for a default multiply value of 64.

NOTE

The multiplier select bits have built-in protection such that they cannot be written when the PLL is on (PLLON = 1).

PMSH[7:4] — Unimplemented bits

These bits have no function and always read as logic zeros.

4.5.4 PLL Multiplier Select Register Low

The PLL multiplier select register low contains the programming information for the low byte of the modulo feedback divider.

PMSL \$004D	Bit 7	6	5	4	3	2	1	Bit 0
Read:	MUL7	MUL6	MUL5	MUL4	MUL3	MUL2	MUL1	MUL0
Write:								
Reset:	0	1	0	0	0	0	0	0

Figure 4-7. PLL Multiplier Select Register Low (PMSL)

MUL[7:0] — Multiplier select bits

These read/write bits control the low byte of the modulo feedback divider that selects the VCO frequency multiplier, N . (See [4.3.3 PLL Circuits](#) and [4.3.6 Programming the PLL](#).) MUL[7:0] cannot be written when the PLLON bit in the PCTL is set. A value of \$0000 in the multiplier select registers configures the modulo feedback divider the same as a value of \$0001. Reset initializes the register to \$40 for a default multiply value of 64.

NOTE

The multiplier select bits have built-in protection such that they cannot be written when the PLL is on (PLLON = 1).

4.5.5 PLL VCO Range Select Register

The PLL VCO range select register contains the programming information required for the hardware configuration of the VCO.

PVRS \$004E	Bit 7	6	5	4	3	2	1	0
Read:	VRS7	VRS6	VRS5	VRS4	VRS3	VRS2	VRS1	VRS0
Write:								
Reset:	0	1	0	0	0	0	0	0

Figure 4-8. PLL VCO Range Select Register (PVRS)

VRS[7:0] — VCO range select bits

These read/write bits control the hardware center-of-range linear multiplier L which, in conjunction with E (See [4.3.3 PLL Circuits](#), [4.3.6 Programming the PLL](#) and [4.5.1 PLL Control Register](#).), controls the hardware center-of-range frequency, f_{VRS} . VRS[7:0] cannot be written when the PLLON bit in the PCTL is set. See [4.3.7 Special Programming Exceptions](#).) A value of \$00 in the VCO range select register disables the PLL and clears the BCS bit in the PLL control register (PCTL). (See [4.3.8 Base Clock Selector Circuit](#) and [4.3.7 Special Programming Exceptions](#).) Reset initializes the register to \$40 for a default range multiply value of 64.

NOTE

The VCO range select bits have built-in protection such that they cannot be written when the PLL is on (PLLON = 1) and such that the VCO clock cannot be selected as the source of the base clock (BCS = 1) if the VCO range select bits are all clear.

The PLL VCO range select register must be programmed correctly. Incorrect programming can result in failure of the PLL to achieve lock.

4.5.6 PLL Reference Divider Select Register

The PLL reference divider select register contains the programming information for the modulo reference divider.

PRDS \$004F	Bit 7	6	5	4	3	2	1	Bit 0
Read:	0	0	0	0	RDS3	RDS2	RDS1	RDS0
Write:								
Reset:	0	0	0	0	0	0	0	1


 = Unimplemented

Figure 4-9. PLL Reference Divider Select Register (PRDS)

RDS[3:0] — Reference Divider Select Bits

These read/write bits control the modulo reference divider that selects the reference division factor R. (See [4.3.3 PLL Circuits](#) and [4.3.6 Programming the PLL](#).) RDS[7:0] cannot be written when the PLLON bit in the PCTL is set. A value of \$00 in the reference divider select register configures the reference divider the same as a value of \$01. (See [4.3.7 Special Programming Exceptions](#).) Reset initializes the register to \$01 for a default divide value of 1.

NOTE

The reference divider select bits have built-in protection such that they cannot be written when the PLL is on (PLLON = 1).

PRDS[7:4] — Unimplemented Bits

These bits have no function and always read as logic zeros.

4.6 Interrupts

When the AUTO bit is set in the PLL bandwidth control register (PBWC), the PLL can generate a CPU interrupt request every time the LOCK bit changes state. The PLLIE bit in the PLL control register (PCTL) enables CPU interrupts from the PLL. PLLF, the interrupt flag in the PCTL, becomes set whether interrupts are enabled or not. When the AUTO bit is clear, CPU interrupts from the PLL are disabled and PLLF reads as logic zero.

Software should read the LOCK bit after a PLL interrupt request to see if the request was due to an entry into lock or an exit from lock. When the PLL enters lock, the VCO clock, CGMVCLK, divided by two can be selected as the CGMOUT source by setting BCS in the PCTL. When the PLL exits lock, the VCO clock frequency is corrupt, and appropriate precautions should be taken. If the application is not frequency sensitive, interrupts should be disabled to prevent PLL interrupt service routines from impeding software performance or from exceeding stack limitations.

NOTE

Software can select the CGMVCLK divided by two as the CGMOUT source even if the PLL is not locked (LOCK = 0). Therefore, software should make sure the PLL is locked before setting the BCS bit.

4.7 Special Modes

The WAIT instruction puts the MCU in low-power-consumption standby modes.

4.7.1 Wait Mode

The WAIT instruction does not affect the CGMB. Before entering wait mode, software can disengage and turn off the PLL by clearing the BCS and PLLON bits in the PLL control register (PCTL) to save power. Less power-sensitive applications can disengage the PLL without turning it off, so that the PLL clock is immediately available at WAIT exit. This would also be the case when the PLL is to wake the MCU from wait mode, such as when the PLL is first enabled and waiting for LOCK, or LOCK is lost.

4.7.2 CGMB During Break Interrupts

The system integration module (SIM) controls whether status bits in other modules can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear status bits during the break state. (See [5.7.3 SIM Break Flag Control Register \(SBFCR\)](#).)

To allow software to clear status bits during a break interrupt, write a logic one to the BCFE bit. If a status bit is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect the PLLF bit during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), software can read and write the PLL control register during the break state without affecting the PLLF bit.

4.8 Acquisition/Lock Time Specifications

The acquisition and lock times of the PLL are, in many applications, the most critical PLL design parameters. Proper design and use of the PLL ensures the highest stability and lowest acquisition/lock times.

4.8.1 Acquisition/Lock Time Definitions

Typical control systems refer to the acquisition time or lock time as the reaction time, within specified tolerances, of the system to a step input. In a PLL, the step input occurs when the PLL is turned on or when it suffers a noise hit. The tolerance is usually specified as a percent of the step input or when the output settles to the desired value plus or minus a percent of the frequency change. Therefore, the reaction time is constant in this definition, regardless of the size of the step input. For example, consider a system with a 5 percent acquisition time tolerance. If a command instructs the system to change from 0 Hz to 1 MHz, the acquisition time is the time taken for the frequency to reach 1 MHz \pm 50 kHz. Fifty kHz = 5% of the 1 MHz step input. If the system is operating at 1 MHz and suffers a -100 kHz noise hit, the acquisition time is the time taken to return from 900 kHz to 1 MHz \pm 5 kHz. Five kHz = 5 percent of the 100-kHz step input.

Other systems refer to acquisition and lock times as the time the system takes to reduce the error between the actual output and the desired output to within specified tolerances. Therefore, the acquisition or lock time varies according to the original error in the output. Minor errors may not even be registered. Typical PLL applications prefer to use this definition because the system requires the output frequency to be within a certain tolerance of the desired frequency regardless of the size of the initial error.

The discrepancy in these definitions makes it difficult to specify an acquisition or lock time for a typical PLL. Therefore, the definitions for acquisition and lock times for this module are:

- Acquisition time, t_{ACQ} , is the time the PLL takes to reduce the error between the actual output frequency and the desired output frequency to less than the tracking mode entry tolerance, Δ_{TRK} . Acquisition time is based on an initial frequency error,

$(f_{DES} - f_{ORIG})/f_{DES}$, of not more than ± 100 percent. In automatic bandwidth control mode (See [4.3.5 Manual and Automatic PLL Bandwidth Modes](#).), acquisition time expires when the \overline{ACQ} bit becomes set in the PLL bandwidth control register (PBWC).

- Lock time, t_{LOCK} , is the time the PLL takes to reduce the error between the actual output frequency and the desired output frequency to less than the lock mode entry tolerance, Δ_{LOCK} . Lock time is based on an initial frequency error, $(f_{DES} - f_{ORIG})/f_{DES}$, of not more than ± 100 percent. In automatic bandwidth control mode, lock time expires when the LOCK bit becomes set in the PLL bandwidth control register (PBWC). (See [4.3.5 Manual and Automatic PLL Bandwidth Modes](#).)

Obviously, the acquisition and lock times can vary according to how large the frequency error is and may be shorter or longer in many cases.

4.8.2 Parametric Influences on Reaction Time

Acquisition and lock times are designed to be as short as possible while still providing the highest possible stability. These reaction times are not constant, however. Many factors directly and indirectly affect the acquisition time.

The most critical parameter which affects the reaction times of the PLL is the reference frequency, f_{RDV} . This frequency is the input to the phase detector and controls how often the PLL makes corrections. For stability, the corrections must be small compared to the desired frequency, so several corrections are required to reduce the frequency error. Therefore, the slower the reference the longer it takes to make these corrections. This parameter is under user control via the choice of crystal frequency f_{XCLK} and the R value programmed in the reference divider. (See [4.3.3 PLL Circuits](#), [4.3.6 Programming the PLL](#), and [4.5.6 PLL Reference Divider Select Register](#).)

Another critical parameter is the external filter capacitor. The PLL modifies the voltage on the VCO by adding or subtracting charge from this capacitor. Therefore, the rate at which the voltage changes for a given frequency error (thus change in charge) is proportional to the capacitor size. The size of the capacitor also is related to the stability of the PLL. If the capacitor is too small, the PLL cannot make small enough adjustments to the voltage and the system cannot lock. If the capacitor is too large, the PLL may not be able to adjust the voltage in a reasonable time. (See [4.8.3 Choosing a Filter Capacitor](#).)

Also important is the operating voltage potential applied to V_{DDA} . The power supply potential alters the characteristics of the PLL. A fixed value is best. Variable supplies, such as batteries, are acceptable if they vary within a known range at very slow speeds. Noise on the power supply is not acceptable, because it causes small frequency errors which continually change the acquisition time of the PLL.

Temperature and processing also can affect acquisition time because the electrical characteristics of the PLL change. The part operates as specified as long as these influences stay within the specified limits. External factors, however, can cause drastic changes in the operation of the PLL. These factors include noise injected into the PLL through the filter capacitor, filter capacitor leakage, stray impedances on the circuit board, and even humidity or circuit board contamination.

4.8.3 Choosing a Filter Capacitor

As described in [4.8.2 Parametric Influences on Reaction Time](#), the external filter capacitor, C_F , is critical to the stability and reaction time of the PLL. The PLL is also dependent on reference frequency and supply voltage. The value of the capacitor must, therefore, be chosen with supply potential and reference

frequency in mind. For proper operation, the external filter capacitor must be chosen according to this equation:

$$C_F = C_{\text{FACT}} \left(\frac{V_{\text{DDA}}}{f_{\text{RDV}}} \right)$$

For the value of V_{DDA} , choose the voltage potential at which the MCU is operating. If the power supply is variable, choose a value near the middle of the range of possible supply values.

This equation does not always yield a commonly available capacitor size, so round to the nearest available size. If the value is between two different sizes, choose the higher value for better stability. Choosing the lower size may seem attractive for acquisition time improvement, but the PLL may become unstable. Also, always choose a capacitor with a tight tolerance (± 20 percent or better) and low dissipation.

4.8.4 Reaction Time Calculation

The actual acquisition and lock times can be calculated using the equations below. These equations yield nominal values under the following conditions:

- Correct selection of filter capacitor, C_F (See [4.8.3 Choosing a Filter Capacitor.](#))
- Room temperature operation
- Negligible external leakage on CGMXFC
- Negligible noise

The K factor in the equations is derived from internal PLL parameters. K_{ACQ} is the K factor when the PLL is configured in acquisition mode, and K_{TRK} is the K factor when the PLL is configured in tracking mode. (See [4.3.4 Acquisition and Tracking Modes.](#)) Reaction time is based on an initial frequency error, $(f_{\text{DES}} - f_{\text{ORIG}})/f_{\text{DES}}$, of not more than ± 100 percent.

$$t_{\text{ACQ}} = \left(\frac{V_{\text{DDA}}}{f_{\text{RDV}}} \right) \left(\frac{8}{K_{\text{ACQ}}} \right)$$

$$t_{\text{AL}} = \left(\frac{V_{\text{DDA}}}{f_{\text{RDV}}} \right) \left(\frac{4}{K_{\text{TRK}}} \right)$$

$$t_{\text{LOCKMAX}} = t_{\text{ACQ}} + t_{\text{AL}} + 256t_{\text{VRDV}}$$

NOTE

The inverse proportionality between the lock time and the reference frequency.

In automatic bandwidth control mode, the acquisition and lock times are quantized into units based on the reference frequency. (See [4.3.5 Manual and Automatic PLL Bandwidth Modes.](#)) A certain number of clock cycles, n_{ACQ} , is required to ascertain that the PLL is within the tracking mode entry tolerance, Δ_{TRK} , before exiting acquisition mode. A certain number of clock cycles, n_{TRK} , is required to ascertain that the PLL is within the lock mode entry tolerance, Δ_{LOCK} . Therefore, the acquisition time, t_{ACQ} , is an integer multiple of $n_{\text{ACQ}}/f_{\text{RDV}}$, and the acquisition to lock time, t_{AL} , is an integer multiple of $n_{\text{TRK}}/f_{\text{RDV}}$.

In manual mode, it is usually necessary to wait considerably longer than t_{LOCKMAX} before selecting the PLL clock (See [4.3.8 Base Clock Selector Circuit.](#)), because the factors described in [4.8.2 Parametric Influences on Reaction Time](#) may slow the lock time considerably. Automatic bandwidth mode is recommended for most users.

4.9 Numerical Electrical Specifications

Table 4-4 contains numerical specification limits on environmental inputs and module outputs.

Table 4-4. Electrical Specifications

Description	Symbol	Min	Typ	Max	Notes
Operating Voltage	V_{DD}	1.8 V	—	5.5 V	
Operating Temperature	T	-40 °C	25 °C	130 °C	
Crystal Reference Frequency	f_{RCLK}	—	38.4 kHz	—	
Range Nominal Multiplier (Hz)	f_{NOM}	—	38.4 k	—	4.0–5.5 V V_{DD} only
Range Nominal Multiplier Medium Voltage (Hz)		—	38.4 k	—	2.7–4.0 V V_{DD} only
Range Nominal Multiplier Low Voltage (Hz)		—	38.4 k	—	1.8–2.7 V V_{DD}
VCO Center-of-Range Frequency (Hz)	f_{VRS}	38.4k	—	80.0 M	4.0–5.5 V V_{DD} only
Medium Voltage VCO Center-of-Range Frequency (Hz)		38.4k	—	40.0 M	2.7–4.0 V V_{DD} only
Low Voltage VCO Nominal Frequency (MHz)		38.4k	—	10.0 M	1.8–2.7 V V_{DD}
VCO Range Linear Range Multiplier	L	1	64	255	
VCO Power-of-Two Range Multiplier	2^E	1	1	8	
VCO Multiply Factor	N	1	64	4095	
VCO Prescale Multiplier	2^P	1	1	8	
Reference Divider Factor	R	1	1	15	
VCO Operating Frequency	f_{VCLK}	f_{VRSMIN}	—	f_{VRSMAX}	
Bus Operating Frequency (Hz)	f_{BUS}	—	—	8 M	4.0–5.5 V V_{DD} only
Bus Frequency (Hz) Medium Voltage	f_{BUS}	—	—	4 M	2.7–4.0 V V_{DD} only
Bus Frequency (Hz) Low Voltage	f_{BUS}	—	—	2 M	1.8–2.7 V V_{DD} only

4.10 Acquisition/Lock Time Specifications

Table 4-5 provides specifications for the entry and exit of acquisition and tracking modes, as well as required manual mode delay times.

Table 4-5. Acquisition/Lock Time Specifications

Description	Symbol	Min	Typ	Max	Notes
Filter Capacitor Multiply Factor	C_{FACT}	—	0.0145	—	F/s V
Acquisition Mode Time Factor	K_{ACQ}	—	0.117	—	V
Tracking Mode Time Factor	K_{TRK}	—	0.021	—	V
Manual Mode Time to Stable	t_{ACQ}	—	$(8 \cdot V_{DDA}) / (f_{RDV} \cdot K_{ACQ})$	—	If C_F chosen correctly
Manual Stable to Lock Time	t_{AL}	—	$(4 \cdot V_{DDA}) / (f_{RDV} \cdot K_{TRK})$	—	If C_F chosen correctly
Manual Acquisition Time	t_{LOCK}	—	$t_{ACQ} + t_{AL}$	—	
Tracking Mode Entry Frequency Tolerance	Δ_{TRK}	0	—	$\pm 3.6\%$	
Acquisition Mode Entry Frequency Tolerance	Δ_{ACQ}	$\pm 6.3\%$	—	$\pm 7.2\%$	
LOCK Entry Frequency Tolerance	Δ_{LOCK}	0	—	$\pm 0.9\%$	
LOCK Exit Frequency Tolerance	Δ_{UNL}	$\pm 0.9\%$	—	$\pm 1.8\%$	
Reference Cycles Per Acquisition Mode Measurement	n_{ACQ}		32	—	
Reference Cycles Per Tracking Mode Measurement	n_{TRK}		128	—	
Automatic Mode Time to Stable	t_{ACQ}	n_{ACQ} / f_{RDV}	$(8 \cdot V_{DDA}) / (f_{RDV} \cdot K_{ACQ})$	—	If C_F chosen correctly
Automatic Stable to Lock Time	t_{AL}	n_{TRK} / f_{RDV}	$(4 \cdot V_{DDA}) / (f_{RDV} \cdot K_{TRK})$	—	If C_F chosen correctly
Automatic Lock Time	t_{LOCK}	—	$t_{ACQ} + t_{AL}$	—	

Chapter 5

System Integration Module (SIM)

5.1 Introduction

This section describes the system integration module (SIM), which supports up to 24 external and/or internal interrupts. Together with the CPU, the SIM controls all MCU activities. A block diagram of the SIM is shown in Figure 5-2. Figure 5-1 is a summary of the SIM I/O registers. The SIM is a system state controller that coordinates CPU and exception timing. The SIM is responsible for:

- Bus clock generation and control for CPU and peripherals
 - Stop/wait/reset/break entry and recovery
 - Internal clock control
- Master reset control, including power-on reset (POR) and COP timeout
- Interrupt control
 - Acknowledge timing
 - Arbitration control timing
 - Vector address generation
- CPU enable/disable timing
- Modular architecture expandable to 128 interrupt sources

Table 5-1 shows the internal signal names used in this section.

Addr.	Register Name	Bit 7	6	5	4	3	2	1	Bit 0
\$FE00	SIM Break Status Register (SBSR)	R	R	R	R	R	R	SBSW	R
\$FE01	SIM Reset Status Register (SRSR)	POR	PIN	COP	ILOP	ILAD	0	LVI	0
\$FE03	SIM Break Flag Control Register (SBFCR)	BCFE	0	0	0	0	0	0	0
\$FE04	Interrupt Status Register 1 (INT1)	I6	I5	I4	I3	I2	I1	0	0
\$FE05	Interrupt Status Register 2 (INT2)	I14	I13	I12	I11	I10	I9	I8	I7
\$FE06	Interrupt Status Register 3 (INT3)	0	0	0	0	I18	I17	I16	I15

R = Reserved for factory test

Figure 5-1. SIM I/O Register Summary

System Integration Module (SIM)

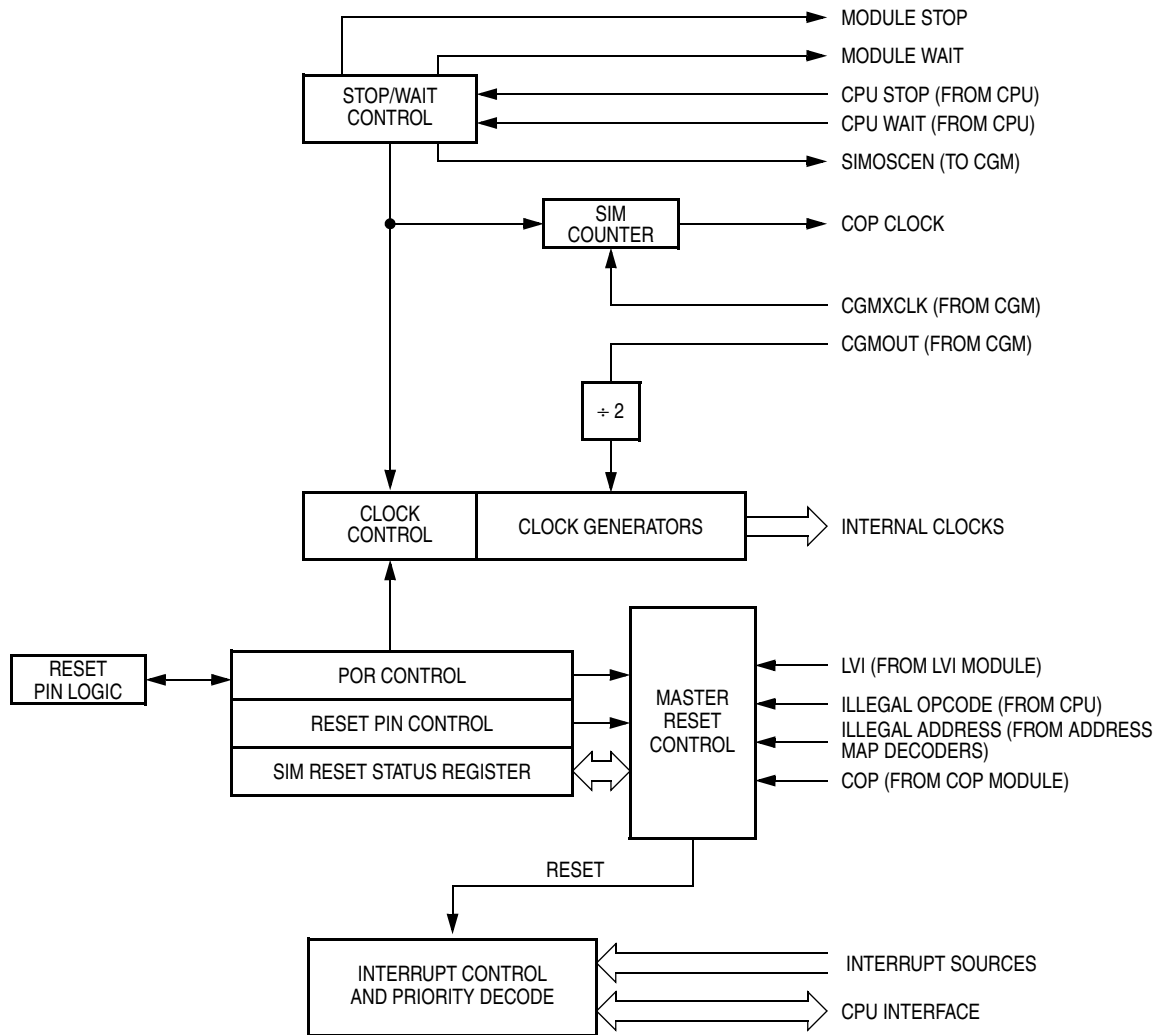


Figure 5-2. SIM Block Diagram

Table 5-1. Signal Name Conventions

Signal Name	Description
CGMXCLK	Buffered version of OSC1 from clock generator module (CGM)
CGMVCLK	PLL output
CGMOUT	PLL-based or OSC1-based clock output from CGM module (Bus clock = CGMOUT divided by two)
IAB	Internal address bus
IDB	Internal data bus
PORRST	Signal from the power-on reset module to the SIM
IRST	Internal reset signal
R/W	Read/write signal

5.2 SIM Bus Clock Control and Generation

The bus clock generator provides system clock signals for the CPU and peripherals on the MCU. The system clocks are generated from an incoming clock, CGMOUT, as shown in Figure 5-3. This clock can come from either an external oscillator or from the on-chip PLL. (See Chapter 4 Clock Generator Module (CGMB).)

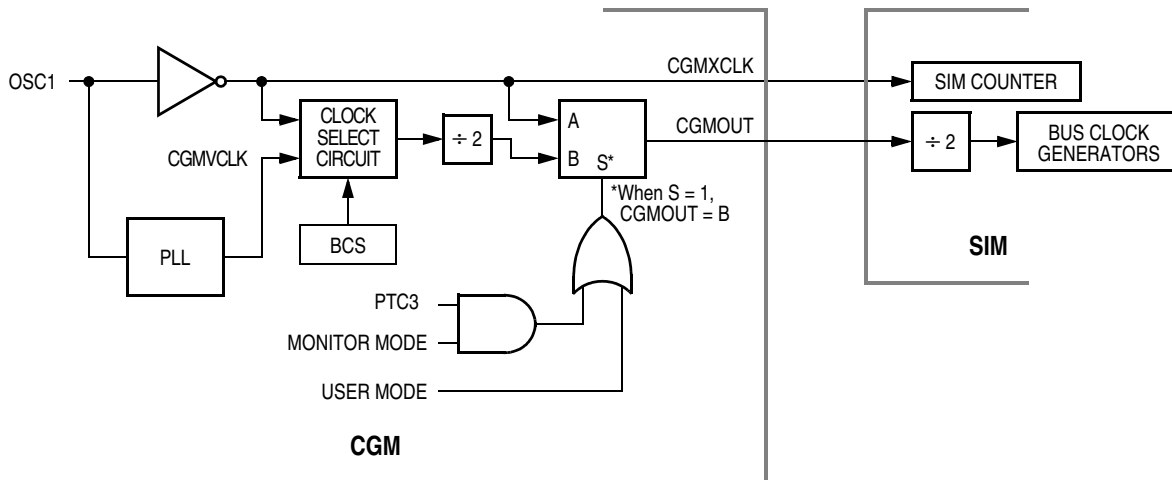


Figure 5-3. CGM Clock Signals

5.2.1 Bus Timing

In user mode, the internal bus frequency is either the crystal oscillator output (CGMXCLK) divided by four or the PLL output (CGMVCLK) divided by four. (See Chapter 8 External Interrupt Module (IRQ).)

5.2.2 Clock Start-Up from POR or LVI Reset

When the power-on reset module or the low-voltage inhibit module generates a reset, the clocks to the CPU and peripherals are inactive and held in an inactive phase until after the 4096 CGMXCLK cycle POR timeout has completed. The $\overline{\text{RST}}$ pin is driven low by the SIM during this entire period. The IBUS clocks start upon completion of the timeout.

5.2.3 Clocks in Stop Mode and Wait Mode

Upon exit from stop mode by an interrupt, break, or reset, the SIM allows CGMXCLK to clock the SIM counter. The CPU and peripheral clocks do not become active until after the stop delay timeout. This timeout is selectable as 4096 or 32 CGMXCLK cycles. (See 5.6.2 Stop Mode.)

In wait mode, the CPU clocks are inactive. The SIM also produces two sets of clocks for other modules. Refer to the wait mode subsection of each module to see if the module is active or inactive in wait mode. Some modules can be programmed to be active in wait mode.

5.3 Reset and System Initialization

The MCU has these reset sources:

- Power-on reset module (POR)
- External reset pin ($\overline{\text{RST}}$)
- Computer operating properly module (COP)
- Low-voltage inhibit module (LVI)
- Illegal opcode
- Illegal address

All of these resets produce the vector \$FFFE:FFFF (\$FEFE:FEFF in monitor mode) and assert the internal reset signal (IRST). IRST causes all registers to be returned to their default values and all modules to be returned to their reset states.

An internal reset clears the SIM counter (see [5.4 SIM Counter](#)), but an external reset does not. Each of the resets sets a corresponding bit in the SIM reset status register (SRSR). (See [5.7 SIM Registers](#).)

5.3.1 External Pin Reset

Pulling the asynchronous $\overline{\text{RST}}$ pin low halts all processing. The PIN bit of the SIM reset status register (SRSR) is set as long as $\overline{\text{RST}}$ is held low for a minimum of 67 CGMXCLK cycles, assuming that neither the POR nor the LVI was the source of the reset. See [Table 5-2](#) for details. [Figure 5-4](#) shows the relative timing.

Table 5-2. PIN Bit Set Timing

Reset Type	Number of Cycles Required to Set PIN
POR/LVI	4163 (4096 + 64 + 3)
All others	67 (64 + 3)

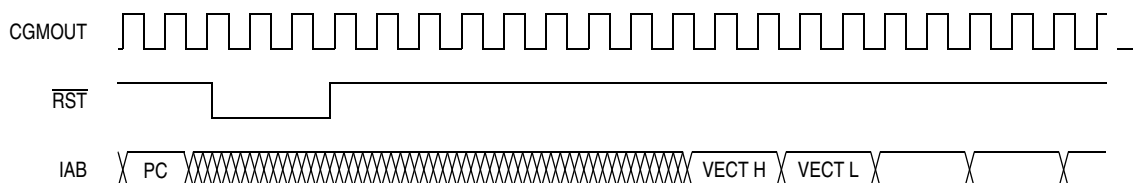


Figure 5-4. External Reset Timing

5.3.2 Active Resets from Internal Sources

All internal reset sources actively pull the $\overline{\text{RST}}$ pin low for 32 CGMXCLK cycles to allow resetting of external peripherals. The internal reset signal IRST continues to be asserted for an additional 32 cycles. See [Figure 5-5](#). An internal reset can be caused by an illegal address, illegal opcode, COP timeout, LVI, or POR. (See [Figure 5-6](#).) Note that for LVI or POR resets, the SIM cycles through 4096 CGMXCLK cycles during which the $\overline{\text{RST}}$ pin is low. The internal reset signal then follows the sequence from the falling edge of $\overline{\text{RST}}$ shown in [Figure 5-5](#).

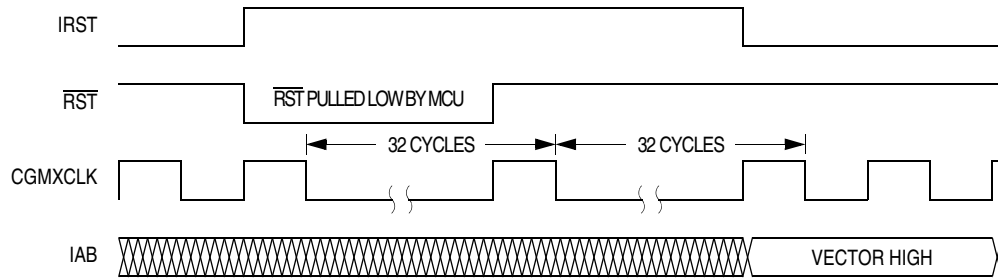


Figure 5-5. Internal Reset Timing

The COP reset is asynchronous to the bus clock.

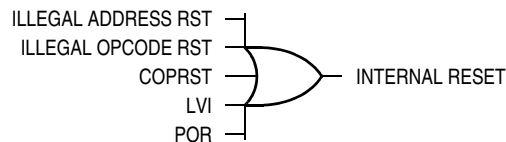


Figure 5-6. Sources of Internal Reset

The active reset feature allows the part to issue a reset to peripherals and other chips within a system built around the MCU.

5.3.2.1 Power-On Reset

When power is first applied to the MCU, the power-on reset module (POR) generates a pulse to indicate that power-on has occurred. The external reset pin ($\overline{\text{RST}}$) is held low while the SIM counter counts out 4096 CGMXCLK cycles. Sixty-four CGMXCLK cycles later, the CPU and memories are released from reset to allow the reset vector sequence to occur.

At power-on, these events occur:

- A POR pulse is generated.
- The internal reset signal is asserted.
- The SIM enables CGMOUT.
- Internal clocks to the CPU and modules are held inactive for 4096 CGMXCLK cycles to allow stabilization of the oscillator.
- The $\overline{\text{RST}}$ pin is driven low during the oscillator stabilization time.
- The POR bit of the SIM reset status register (SRSR) is set and all other bits in the register are cleared.

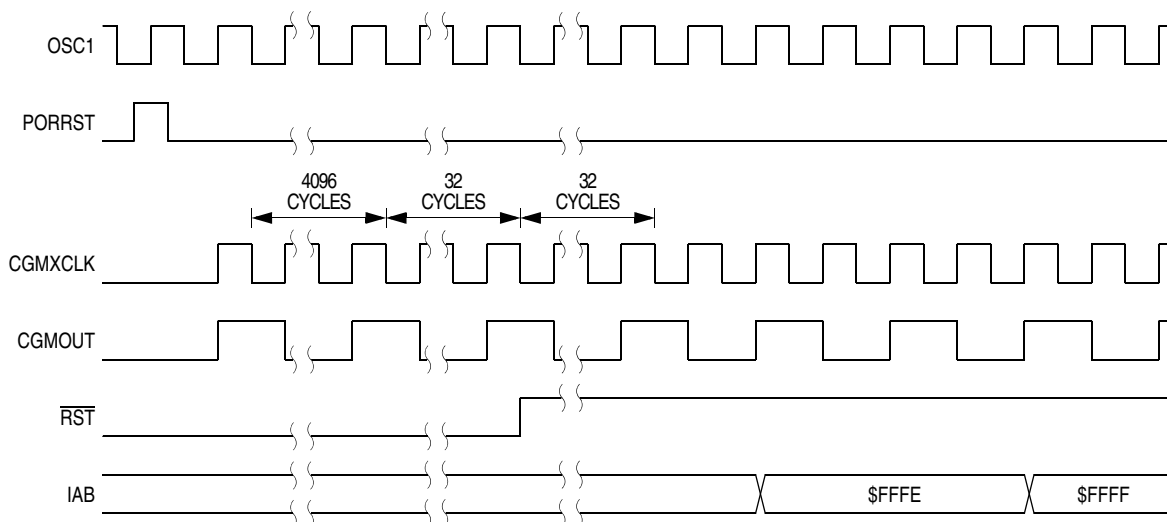


Figure 5-7. POR Recovery

5.3.2.2 Computer Operating Properly (COP) Reset

An input to the SIM is reserved for the COP reset signal. The overflow of the COP counter causes an internal reset and sets the COP bit in the SIM reset status register (SRSR). The SIM actively pulls down the $\overline{\text{RST}}$ pin for all internal reset sources.

To prevent a COP module timeout, write any value to location \$FFFF. Writing to location \$FFFF clears the COP counter and bits 12 through 4 of the SIM counter. The SIM counter output, which occurs at least every $2^{13} - 2^4$ CGMXCLK cycles, drives the COP counter. The COP should be serviced as soon as possible out of reset to guarantee the maximum amount of time before the first timeout.

The COP module is disabled if the $\overline{\text{RST}}$ pin or the $\overline{\text{IRQ1}}/\text{V}_{\text{pp}}$ pin is held at $V_{\text{DD}} + V_{\text{HI}}$ while the MCU is in monitor mode. The COP module can be disabled only through combinational logic conditioned with the high voltage signal on the $\overline{\text{RST}}$ or the $\overline{\text{IRQ1}}/\text{V}_{\text{pp}}$ pin. This prevents the COP from becoming disabled as a result of external noise. During a break state, $V_{\text{DD}} + V_{\text{HI}}$ on the $\overline{\text{RST}}$ pin disables the COP module.

5.3.2.3 Illegal Opcode Reset

The SIM decodes signals from the CPU to detect illegal instructions. An illegal instruction sets the ILOP bit in the SIM reset status register (SRSR) and causes a reset.

If the stop enable bit, STOP, in the mask option register is logic zero, the SIM treats the STOP instruction as an illegal opcode and causes an illegal opcode reset. The SIM actively pulls down the $\overline{\text{RST}}$ pin for all internal reset sources.

5.3.2.4 Illegal Address Reset

An opcode fetch from an unmapped address generates an illegal address reset. The SIM verifies that the CPU is fetching an opcode prior to asserting the ILAD bit in the SIM reset status register (SRSR) and resetting the MCU. A data fetch from an unmapped address does not generate a reset. The SIM actively pulls down the $\overline{\text{RST}}$ pin for all internal reset sources.

5.3.2.5 Low-Voltage Inhibit (LVI) Reset

The low-voltage inhibit module (LVI) asserts its output to the SIM when the V_{DD} voltage falls to the LVI_{TRIPF} voltage. The LVI bit in the SIM reset status register (SRSR) is set, and the external reset pin (\overline{RST}) is held low while the SIM counter counts out 4096 CGMXCLK cycles. Sixty-four CGMXCLK cycles later, the CPU is released from reset to allow the reset vector sequence to occur. The SIM actively pulls down the \overline{RST} pin for all internal reset sources.

5.4 SIM Counter

The SIM counter is used by the power-on reset module (POR) and in stop mode recovery to allow the oscillator time to stabilize before enabling the internal bus (IBUS) clocks. The SIM counter also serves as a prescaler for the computer operating properly module (COP). The SIM counter overflow supplies the clock for the COP module. The SIM counter is 13 bits long and is clocked by the falling edge of CGMXCLK.

5.4.1 SIM Counter During Power-On Reset

The power-on reset module (POR) detects power applied to the MCU. At power-on, the POR circuit asserts the signal PORRST. Once the SIM is initialized, it enables the clock generation module (CGM) to drive the bus clock state machine.

5.4.2 SIM Counter During Stop Mode Recovery

The SIM counter also is used for stop mode recovery. The STOP instruction clears the SIM counter. After an interrupt, break, or reset, the SIM senses the state of the short stop recovery bit, SSREC, in the mask option register. If the SSREC bit is a logic one, then the stop recovery is reduced from the normal delay of 4096 CGMXCLK cycles down to 32 CGMXCLK cycles. This is ideal for applications using canned oscillators that do not require long startup times from stop mode. External crystal applications should use the full stop recovery time, that is, with SSREC cleared.

5.4.3 SIM Counter and Reset States

External reset has no effect on the SIM counter. (See [5.6.2 Stop Mode](#) for details.) The SIM counter is free-running after all reset states. (See [5.3.2 Active Resets from Internal Sources](#) for counter control and internal reset recovery sequences.)

5.5 Exception Control

Normal, sequential program execution can be changed in three different ways:

- Interrupts
 - Maskable hardware CPU interrupts
 - Non-maskable software interrupt instruction (SWI)
- Reset
- Break interrupts

5.5.1 Interrupts

At the beginning of an interrupt, the CPU saves the CPU register contents on the stack and sets the interrupt mask (I bit) to prevent additional interrupts. At the end of an interrupt, the RTI instruction recovers the CPU register contents from the stack so that normal processing can resume. [Figure 5-8](#) shows interrupt entry timing. [Figure 5-9](#) shows interrupt recovery timing.

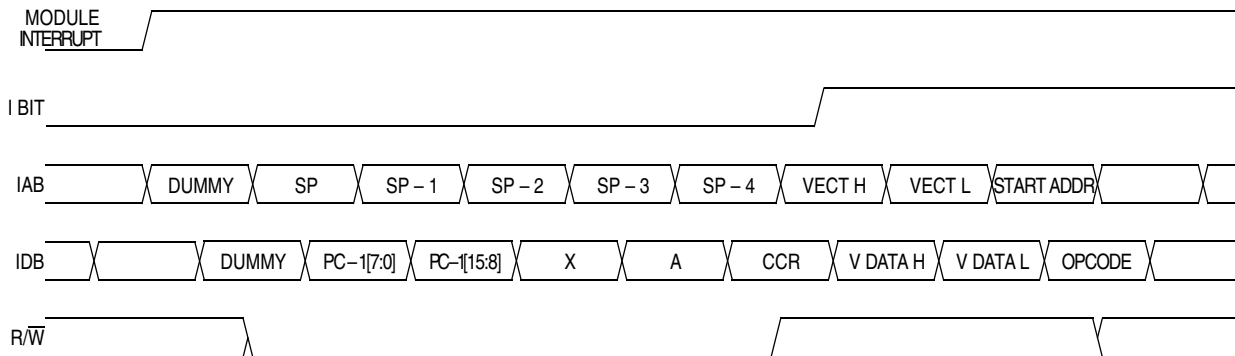


Figure 5-8. Interrupt Entry

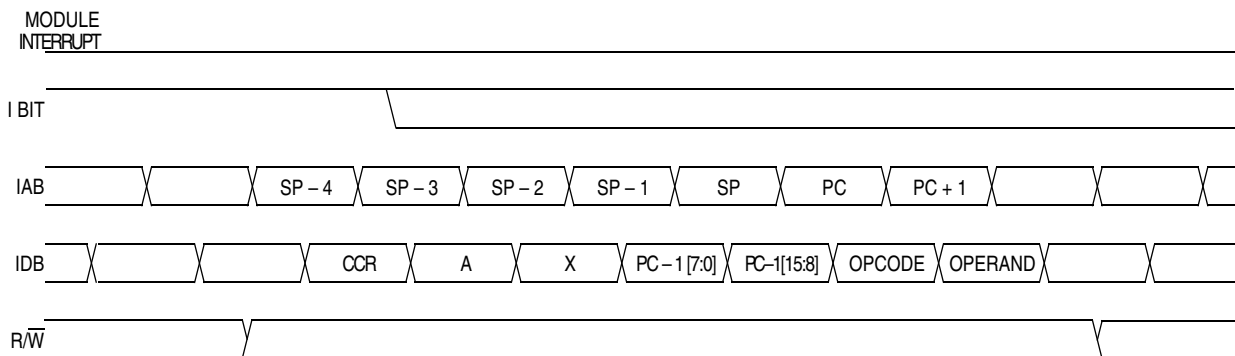


Figure 5-9. Interrupt Recovery

Interrupts are latched, and arbitration is performed in the SIM at the start of interrupt processing. The arbitration result is a constant that the CPU uses to determine which vector to fetch. Once an interrupt is latched by the SIM, no other interrupt can take precedence, regardless of priority, until the latched interrupt is serviced (or the I bit is cleared). (See [Figure 5-10](#).)

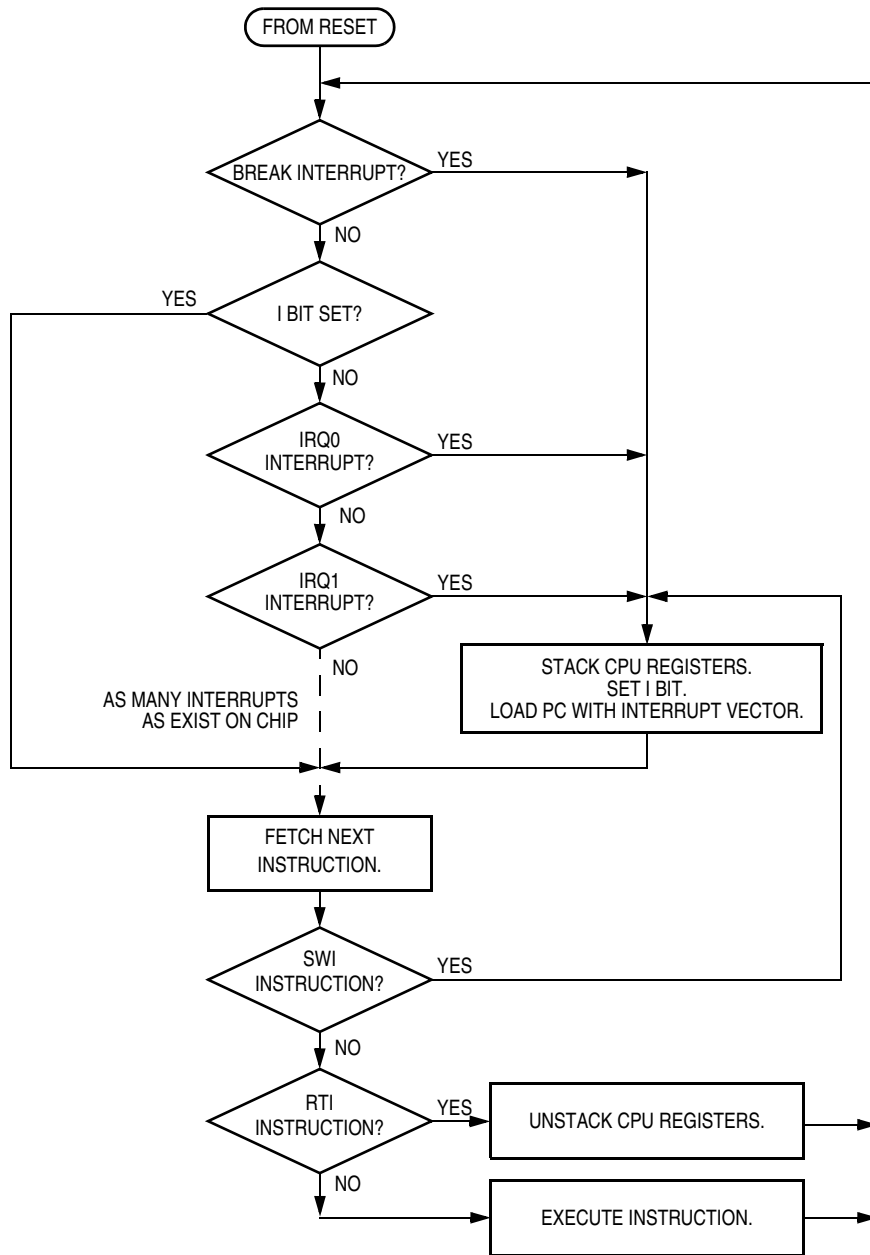


Figure 5-10. Interrupt Processing

5.5.1.1 Hardware Interrupts

A hardware interrupt does not stop the current instruction. Processing of a hardware interrupt begins after completion of the current instruction. When the current instruction is complete, the SIM checks all pending hardware interrupts. If interrupts are not masked (I bit clear in the condition code register) and if the corresponding interrupt enable bit is set, the SIM proceeds with interrupt processing; otherwise, the next instruction is fetched and executed.

If more than one interrupt is pending at the end of an instruction execution, the highest priority interrupt is serviced first. Figure 5-11 demonstrates what happens when two interrupts are pending. If an interrupt is pending upon exit from the original interrupt service routine, the pending interrupt is serviced before the LDA instruction is executed.

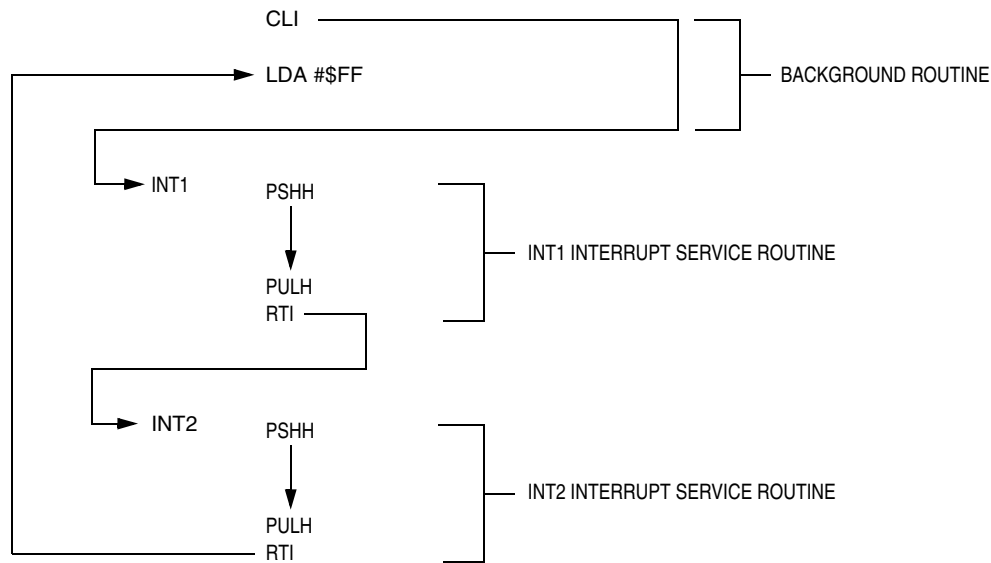


Figure 5-11. Interrupt Recognition Example

The LDA opcode is prefetched by both the INT1 and INT2 RTI instructions. However, in the case of the INT1 RTI prefetch, this is a redundant operation.

NOTE

To maintain compatibility with the M6805 Family, the H register is not pushed on the stack during interrupt entry. If the interrupt service routine modifies the H register or uses the indexed addressing mode, software should save the H register and then restore it prior to exiting the routine.

5.5.1.2 SWI Instruction

The SWI instruction is a non-maskable instruction that causes an interrupt regardless of the state of the interrupt mask (I bit) in the condition code register.

NOTE

A software interrupt pushes PC onto the stack. A software interrupt does not push PC – 1, as a hardware interrupt does.

5.5.1.3 Interrupt Status Registers

The flags in the interrupt status registers identify maskable interrupt sources. [Table 5-3](#) summarizes the interrupt sources and the interrupt status register flags that they set. The interrupt status registers can be useful for debugging.

Table 5-3. Interrupt Sources

Interrupt Source	Interrupt Status Register Flag
Reset	—
SWI Instruction	—
$\overline{\text{IRQ1}}$ Pin	I1
PLL	I2
TIM Channel 0	I3
TIM Channel 1	I4
TIM Channel 2	I5
TIM Channel 3	I6
TIM Overflow	I7
SPI 1 Receiver	I8
SPI 1 Transmitter	I9
SPI 2 Receiver	I10
SCI 2 Transmitter	I11
SCI Error	I12
SCI Receiver	I13
SCI Transmitter	I14
$\overline{\text{IRQ2}}$ Pin	I15
Keyboard Pin	I16
A/D	I17
TBM	I18

Interrupt Status Register 1

Address: \$FE04

	Bit 7	6	5	4	3	2	1	Bit 0
Read:	I6	I5	I4	I3	I2	I1	0	0
Write:	R	R	R	R	R	R	R	R
Reset:	0	0	0	0	0	0	0	0

R = Reserved

Figure 5-12. Interrupt Status Register 1 (INT1)

I6–I1 — Interrupt Flags 1–6

These flags indicate the presence of interrupt requests from the sources shown in [Table 5-3](#).

1 = Interrupt request present

0 = No interrupt request present

Bit 0 and Bit 1 — Always read 0

Interrupt Status Register 2

Address: \$FE05

	Bit 7	6	5	4	3	2	1	Bit 0
Read:	I14	I13	I12	I11	I10	I9	I8	I7
Write:	R	R	R	R	R	R	R	R
Reset:	0	0	0	0	0	0	0	0

R = Reserved

Figure 5-13. Interrupt Status Register 2 (INT2)

I14–I7 — Interrupt Flags 14–7

These flags indicate the presence of interrupt requests from the sources shown in [Table 5-3](#).

1 = Interrupt request present

0 = No interrupt request present

Interrupt Status Register 3

Address: \$FE06

	Bit 7	6	5	4	3	2	1	Bit 0
Read:	0	0	0	0	I18	I17	I16	I15
Write:	R	R	R	R	R	R	R	R
Reset:	0	0	0	0	0	0	0	0

R = Reserved

Figure 5-14. Interrupt Status Register 3 (INT3)

Bits 7–4 — Always read 0

I18–I15 — Interrupt Flags 15–18

These flags indicate the presence of an interrupt request from the source shown in [Table 5-3](#).

1 = Interrupt request present

0 = No interrupt request present

5.5.2 Reset

All reset sources always have equal and highest priority and cannot be arbitrated.

5.5.3 Break Interrupts

The break module can stop normal program flow at a software-programmable break point by asserting its break interrupt output. (See [Chapter 10 Timer Interface Module \(TIM\)](#).) The SIM puts the CPU into the break state by forcing it to the SWI vector location. Refer to the break interrupt subsection of each module to see how each module is affected by the break state.

5.5.4 Status Flag Protection in Break Mode

The SIM controls whether status flags contained in other modules can be cleared during break mode. The user can select whether flags are protected from being cleared by properly initializing the break clear flag enable bit (BCFE) in the SIM break flag control register (SBFCR).

Protecting flags in break mode ensures that set flags will not be cleared while in break mode. This protection allows registers to be freely read and written during break mode without losing status flag information.

Setting the BCFE bit enables the clearing mechanisms. Once cleared in break mode, a flag remains cleared even when break mode is exited. Status flags with a two-step clearing mechanism — for example, a read of one register followed by the read or write of another — are protected, even when the first step is accomplished prior to entering break mode. Upon leaving break mode, execution of the second step will clear the flag as normal.

5.6 Low-Power Modes

Executing the WAIT or STOP instruction puts the MCU in a low-power-consumption mode for standby situations. The SIM holds the CPU in a non-clocked state. The operation of each of these modes is described in the following subsections. Both STOP and WAIT clear the interrupt mask (I) in the condition code register, allowing interrupts to occur.

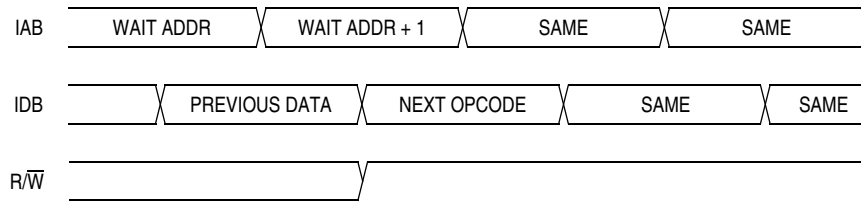
5.6.1 Wait Mode

In wait mode, the CPU clocks are inactive while the peripheral clocks continue to run. [Figure 5-15](#) shows the timing for wait mode entry.

A module that is active during wait mode can wake up the CPU with an interrupt if the interrupt is enabled. Stacking for the interrupt begins one cycle after the WAIT instruction during which the interrupt occurred. In wait mode, the CPU clocks are inactive. Refer to the wait mode subsection of each module to see if the module is active or inactive in wait mode. Some modules can be programmed to be active in wait mode.

Wait mode also can be exited by a reset or break. A break interrupt during wait mode sets the SIM break stop/wait bit, SBSW, in the SIM break status register (SBSR). If the COP disable bit, COPD, in the mask option register is logic zero, then the computer operating properly module (COP) is enabled and remains active in wait mode.

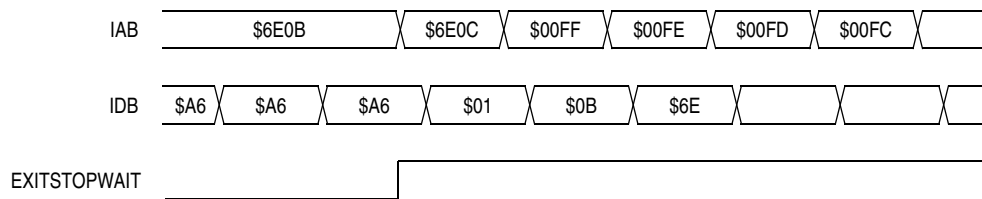
System Integration Module (SIM)



NOTE: Previous data can be operand data or the WAIT opcode, depending on the last instruction.

Figure 5-15. Wait Mode Entry Timing

Figure 5-16 and Figure 5-17 show the timing for WAIT recovery.



NOTE: EXITSTOPWAIT = $\overline{\text{RST}}$ pin, CPU interrupt, or break interrupt

Figure 5-16. Wait Recovery from Interrupt or Break

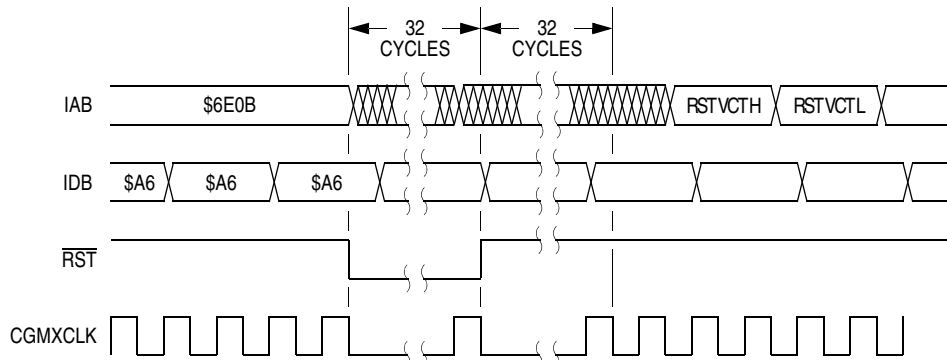


Figure 5-17. Wait Recovery from Internal Reset

5.6.2 Stop Mode

In stop mode, the SIM counter is reset and the system clocks are disabled. An interrupt request from a module can cause an exit from stop mode. Stacking for interrupts begins after the selected stop recovery time has elapsed. Reset or break also causes an exit from stop mode.

The SIM disables the clock generator module outputs (CGMOUT and CGMXCLK) in stop mode, stopping the CPU and peripherals. Stop recovery time is selectable using the SSREC bit in the mask option register (MOR). If SSREC is set, stop recovery is reduced from the normal delay of 4096 CGMXCLK cycles down to 32. This is ideal for applications using canned oscillators that do not require long startup times from stop mode.

NOTE

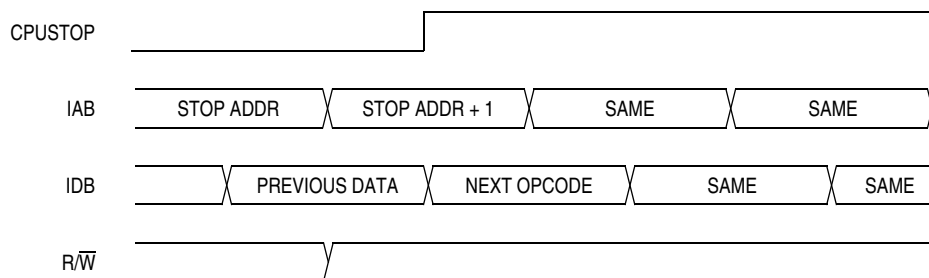
External crystal applications should use the full stop recovery time by clearing the SSREC bit.

A break interrupt during stop mode sets the SIM break stop/wait bit (SBSW) in the SIM break status register (SBSR).

The SIM counter is held in reset from the execution of the STOP instruction until the beginning of stop recovery. It is then used to time the recovery period. [Figure 5-18](#) shows stop mode entry timing.

NOTE

To minimize stop current, all pins configured as inputs shown be driven to a logic 1 or logic 0.



NOTE: Previous data can be operand data or the STOP opcode, depending on the last instruction.

Figure 5-18. Stop Mode Entry Timing

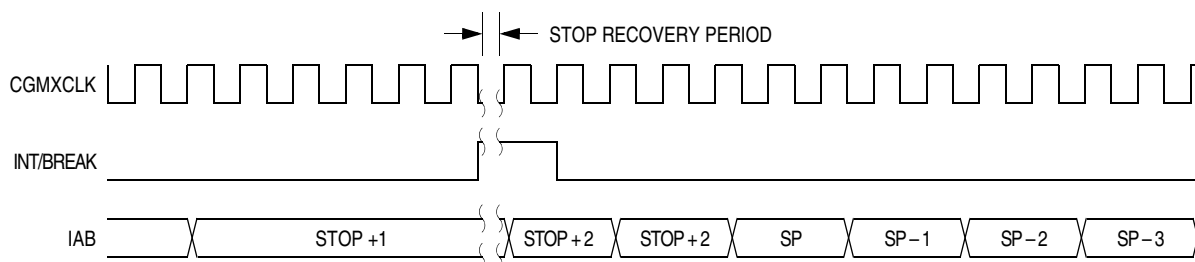


Figure 5-19. Stop Mode Recovery from Interrupt or Break

5.7 SIM Registers

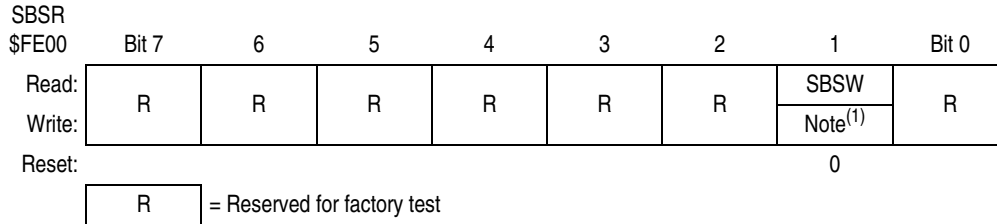
The SIM has three memory mapped registers. [Table 5-4](#) shows the mapping of these registers.

Table 5-4. SIM Registers

Address	Register	Access Mode
\$FE00	SBSR	User
\$FE01	SRSR	User
\$FE03	SBFCR	User

5.7.1 SIM Break Status Register (SBSR)

The SIM break status register contains a flag to indicate that a break caused an exit from stop or wait mode.



NOTE: 1. Writing a logic zero clears SBSW.

Figure 5-20. SIM Break Status Register (SBSR)

SBSW — SIM Break Stop/Wait

This status bit is useful in applications requiring a return to wait or stop mode after exiting from a break interrupt. Clear SBSW by writing a logic zero to it. Reset clears SBSW.

- 1 = Stop mode or wait mode was exited by break interrupt
- 0 = Stop mode or wait mode was not exited by break interrupt

SBSW can be read within the break state SWI routine. The user can modify the return address on the stack by subtracting one from it. The following code is an example of this. Writing zero to the SBSW bit clears it.

```

;This code works if the H register has been pushed onto the stack in the break
;service routine software. This code should be executed at the end of the break
;service routine software.

HIBYTE EQU 5
LOBYTE EQU 6
; If not SBSW, do RTI
BRCLR SBSW,SBSR, RETURN ;See if wait mode or stop mode was exited by
;break.
TST LOBYTE,SP ;If RETURNLO is not zero,
BNE DOLO ;then just decrement low byte.
DEC HIBYTE,SP ;Else deal with high byte, too.
DOLO DEC LOBYTE,SP ;Point to WAIT/STOP opcode.
RETURN PULH ;Restore H register.
RTI
    
```

5.7.2 SIM Reset Status Register (SRSR)

This register contains six flags that show the source of the last reset provided all previous reset status bits have been cleared. Clear the SIM reset status register by reading it. A power-on reset sets the POR bit and clears all other bits in the register.

SRSR		Bit 7	6	5	4	3	2	1	Bit 0
\$FE01									
Read:		POR	PIN	COP	ILOP	ILAD	0	LVI	0
Write:									
POR:		1	0	0	0	0	0	0	0


 = Unimplemented

Figure 5-21. SIM Reset Status Register (SRSR)

POR — Power-On Reset Bit

- 1 = Last reset caused by POR circuit
- 0 = Read of SRSR

PIN — External Reset Bit

- 1 = Last reset caused by external reset pin (\overline{RST})
- 0 = POR or read of SRSR

COP — Computer Operating Properly Reset Bit

- 1 = Last reset caused by COP counter
- 0 = POR or read of SRSR

ILOP — Illegal Opcode Reset Bit

- 1 = Last reset caused by an illegal opcode
- 0 = POR or read of SRSR

ILAD — Illegal Address Reset Bit (opcode fetches only)

- 1 = Last reset caused by an opcode fetch from an illegal address
- 0 = POR or read of SRSR

LVI — Low-Voltage Inhibit Reset Bit

- 1 = Last reset caused by the LVI circuit
- 0 = POR or read of SRSR

5.7.3 SIM Break Flag Control Register (SBFCR)

The SIM break control register contains a bit that enables software to clear status bits while the MCU is in a break state.

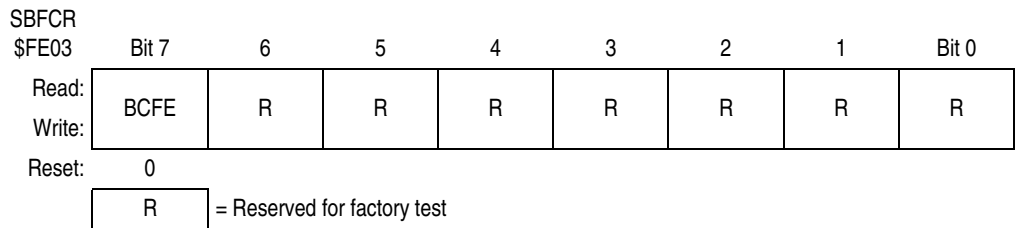


Figure 5-22. SIM Break Flag Control Register (SBFCR)

BCFE — Break Clear Flag Enable Bit

This read/write bit enables software to clear status bits by accessing status registers while the MCU is in a break state. To clear status bits during the break state, the BCFE bit must be set.

- 1 = Status bits clearable during break
- 0 = Status bits not clearable during break

Chapter 6

Random-Access Memory (RAM)

6.1 Introduction

This section describes the 1280 bytes of RAM.

6.2 Functional Description

Addresses \$0050 through \$054F are RAM locations. The location of the stack RAM is programmable. The 16-bit stack pointer allows the stack to be anywhere in the 64-Kbyte memory space.

NOTE

For correct operation, the stack pointer must point only to RAM locations.

Within page zero are 160 bytes of RAM. Because the location of the stack RAM is programmable, all page zero RAM locations can be used for I/O control and user data or code. When the stack pointer is moved from its reset location at \$00FF out of page zero, direct addressing mode instructions can efficiently access all page zero RAM locations. Page zero RAM, therefore, provides ideal locations for frequently accessed global variables.

Before processing an interrupt, the CPU uses five bytes of the stack to save the contents of the CPU registers.

NOTE

For M6805 compatibility, the H register is not stacked.

During a subroutine call, the CPU uses two bytes of the stack to store the return address. The stack pointer decrements during pushes and increments during pulls.

NOTE

Be careful when using nested subroutines. The CPU may overwrite data in the RAM during a subroutine or during the interrupt stacking operation.

Chapter 7

Low-Voltage Inhibit (LVI)

7.1 Introduction

This section describes the low-voltage inhibit module (LVI27, Version A), which monitors the voltage on the V_{DD} and can force a reset when the V_{DD} voltage falls to the LVI trip voltage.

7.2 Features

Features of the LVI module include:

- Programmable LVI Reset
- Status Flag to Monitor V_{DD}

7.3 Functional Description

Figure 7-1 shows the structure of the LVI module. The LVI module contains a bandgap reference circuit and comparator. The LVI power bit, LVIPWR, enables the LVI to monitor V_{DD} voltage. The LVI reset bit, LVIRST, enables the LVI module to generate a reset when V_{DD} falls below a voltage, V_{LVR} . LVIPWR and LVIRST are in the configuration register. (See Chapter 19 Configuration Register (CONFIG).) Once an LVI reset occurs, the MCU remains in reset until V_{DD} rises above a voltage, $V_{LVR} + H_{LVR}$. The output of the comparator controls the state of the LVIOUT flag in the LVI status register (LVISR).

An LVI reset also drives the RST pin low to provide low-voltage protection to external peripheral devices.

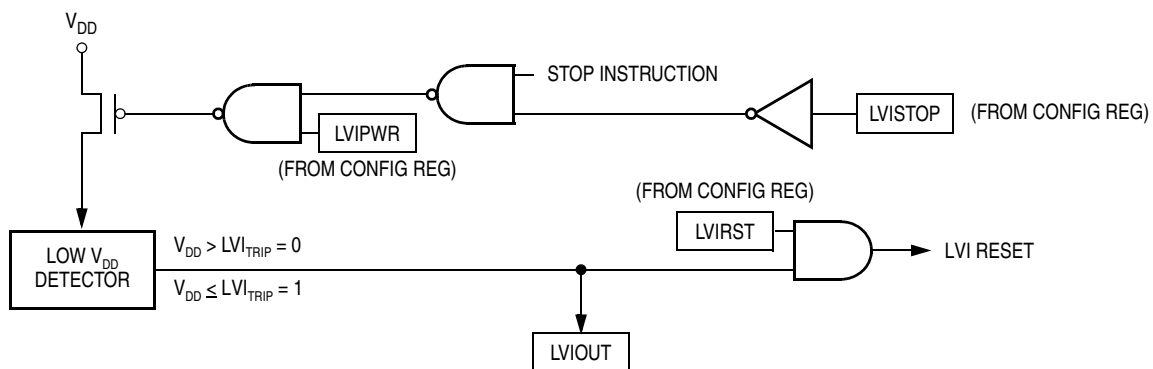


Figure 7-1. LVI Module Block Diagram

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
LVI Status Register (LVISR)	LVIOUT								\$FE0F
	= Unimplemented								

Figure 7-2. LVI I/O Register Summary

Low-Voltage Inhibit (LVI)

7.3.1 Polled LVI Operation

In applications that can operate at V_{DD} levels below the V_{LVR} level, software can monitor V_{DD} by polling the LVIOOUT bit while the LVI is enabled.

7.3.2 Forced Reset Operation

In applications that require V_{DD} to remain above the V_{LVR} trip level, enabling LVI resets allows the LVI module to reset the MCU when V_{DD} falls to the V_{LVR} level. In the mask option register, the LVIPWR and LVIRST bits must be at logic one to enable the LVI module and to enable LVI resets.

7.4 LVI Status Register (LVISR)

The LVI status register flags V_{DD} voltages below the V_{LVR} level.

	Bit 7	6	5	4	3	2	1	Bit 0
LVISR	Read: LVIOOUT	0	0	0	0	0	0	0
\$FE0F	Write:							
Reset:	0	0	0	0	0	0	0	0


 = Unimplemented

Figure 7-3. LVI Status Register (LVISR)

LVIOOUT — LVI Output Bit

This read-only flag becomes set when the V_{DD} voltage falls below the V_{LVR} trip voltage. (See [Table 7-1](#).) Reset clears the LVIOOUT bit.

Table 7-1. LVIOOUT Bit Indication

V_{DD}	LVIOOUT
$V_{DD} > V_{LVR}$	0
$V_{DD} < V_{LVR}$	1
$V_{LVR} < V_{DD} < V_{LVR} + H_{LVR}$	Previous Value

7.5 LVI Interrupts

The LVI module does not generate interrupt requests.

7.6 Low-Power Modes

The STOP and WAIT instructions put the MCU in low-power-consumption standby modes.

7.6.1 Wait Mode

With the LVIPWR bit in the mask option register programmed to logic one, the LVI module is active after a WAIT instruction.

With the LVIRST bit in the mask option register programmed to logic one, the LVI module can generate a reset and bring the MCU out of wait mode.

7.6.2 Stop Mode

When the LVIPWR and LVISTOP bits in the mask option register are programmed to logic one, the LVI module remains active after a STOP instruction.

NOTE

If the LVIPWR bit is at logic one, the LVISTOP bit must be at logic zero to meet the minimum stop mode I_{DD} specification.

Chapter 8

External Interrupt Module (IRQ)

8.1 Introduction

The IRQ provides two non-maskable interrupt inputs.

8.2 Features

Features of the IRQ module include:

- Two Dedicated External Interrupt Pins ($\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ and $\overline{\text{IRQ2}}$)
- Separate IRQ1 and IRQ2 Interrupt Control Bits
- Hysteresis Buffers
- Programmable Edge-only or Edge- and Level-Interrupt Sensitivity
- Automatic Interrupt Acknowledge

8.3 Functional Description

A logic zero applied to any of the external interrupt pins can latch a CPU interrupt request. [Figure 8-1](#) shows the structure of the IRQ module.

Interrupt signals on the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin are latched into the IRQ1 latch. Interrupt signals on the $\overline{\text{IRQ2}}$ pin are latched into the IRQ2 interrupt latch. An interrupt latch remains set until one of the following actions occurs:

- Vector fetch — A vector fetch automatically generates an interrupt acknowledge signal that clears the latch that caused the vector fetch.
- Software clear — Software can clear an interrupt latch by writing to the appropriate acknowledge bit in the interrupt status and control register (ISCR). Writing a logic one to the ACK1 bit clears the IRQ1 latch. Writing a logic one to the ACK2 bit clears the IRQ2 interrupt latch.
- Reset — A reset automatically clears both interrupt latches.

All of the external interrupt pins are falling-edge-triggered and are software-configurable to be both falling-edge and low-level-triggered. The MODE1 bit in the ISCR controls the triggering sensitivity of the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin. The MODE2 bit controls the triggering sensitivity of the $\overline{\text{IRQ2}}$ pin.

When an interrupt pin is edge-triggered only, the interrupt remains set until a vector fetch, software clear, or reset occurs.

When an interrupt pin is both falling-edge and low-level-triggered, the interrupt remains set until both of the following occur:

- Vector fetch or software clear
- Return of the interrupt pin to logic one

External Interrupt Module (IRQ)

The vector fetch or software clear can occur before or after the interrupt pin returns to logic one. As long as the pin is low, the interrupt request remains pending. A reset will clear the latch and the MODEx control bit, thereby clearing the interrupt even if the pin stays low.

When set, the IMASK1 and IMASK2 bits in the ISCR mask all external interrupt requests. A latched interrupt request is not presented to the interrupt priority logic unless the corresponding IMASK bit is clear.

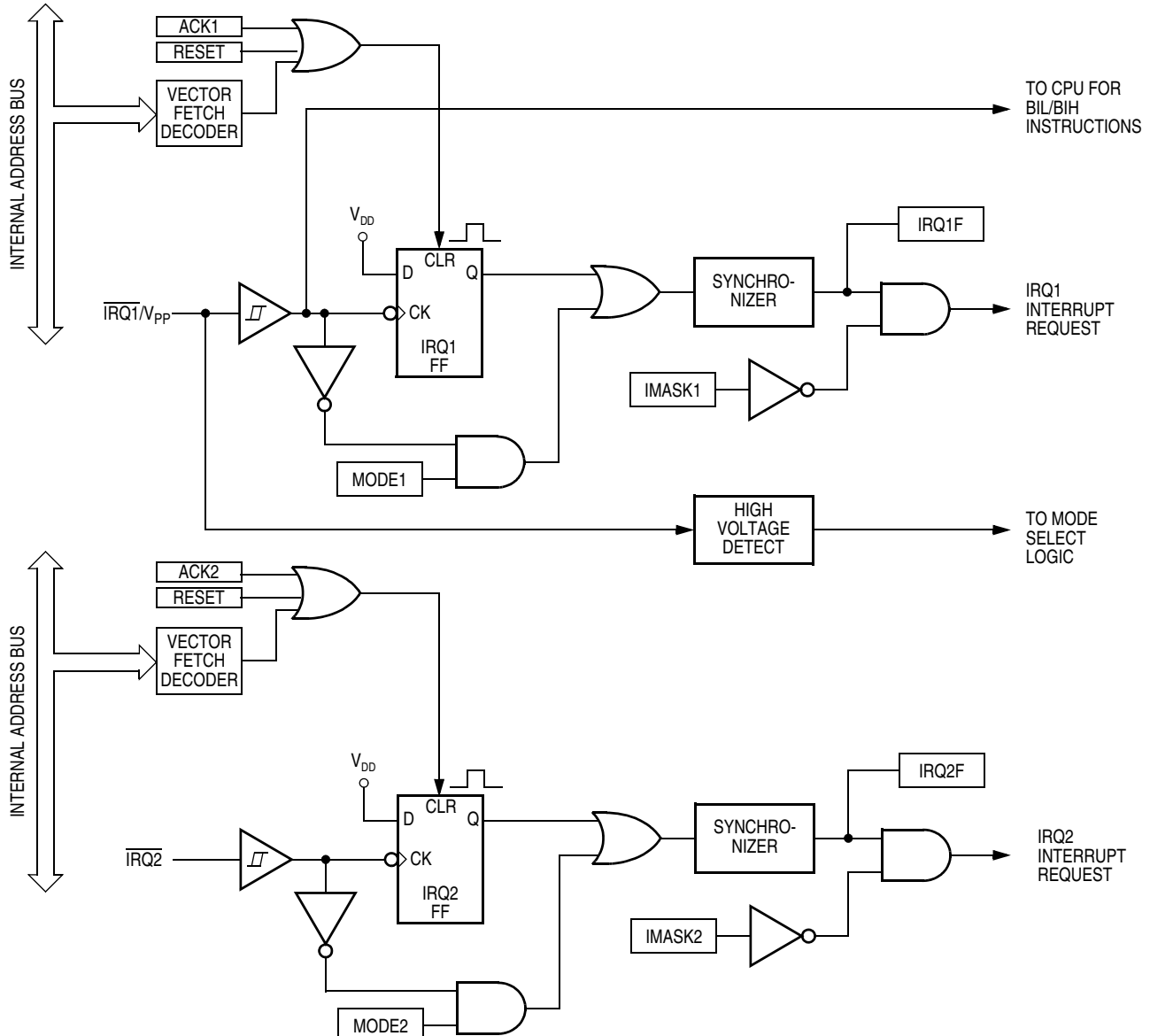


Figure 8-1. IRQ Module Block Diagram

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
IRQ Status/Control Register (ISCR)	IRQF2	ACK2	IMASK2	MODE2	IRQF1	ACK1	IMASK1	MODE1	\$0032

Figure 8-2. IRQ I/O Register Summary

8.3.1 $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ Pin

A logic zero on the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin can latch an interrupt request into the IRQ1 latch. A vector fetch, software clear, or reset clears the IRQ1 latch.

If the MODE1 bit is set, the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin is both falling-edge-sensitive and low-level-sensitive. With MODE1 set, both of the following actions must occur to clear IRQ1:

- Vector fetch or software clear — A vector fetch generates an interrupt acknowledge signal to clear the latch. Software can generate the interrupt acknowledge signal by writing a logic one to the ACK1 bit in the interrupt status and control register (ISCR). The ACK1 bit is useful in applications that poll the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin and require software to clear the IRQ1 latch. Writing to the ACK1 bit prior to leaving an interrupt service routine can also prevent spurious interrupts due to noise. Setting ACK1 does not affect subsequent transitions on the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin. A falling edge that occurs after writing to the ACK1 bit latches another interrupt request. If the IRQ1 mask bit, IMASK1, is clear, the CPU loads the program counter with the vector address at locations \$FFFA and \$FFFB.
- Return of the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin to logic one — As long as the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin is at logic zero, IRQ1 remains active.

The vector fetch or software clear and the return of the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin to logic one may occur in any order. The interrupt request remains pending as long as the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin is at logic zero. A reset will clear the latch and the MODEx control bit, thereby clearing the interrupt even if the pin stays low.

If the MODE1 bit is clear, the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin is falling-edge-sensitive only. With MODE1 clear, a vector fetch or software clear immediately clears the IRQ1 latch.

The IRQF1 bit in the ISCR register can be used to check for pending interrupts. The IRQF1 bit is not affected by the IMASK1 bit, which makes it useful in applications where polling is preferred.

Use the BIH or BIL instruction to read the logic level on the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin.

NOTE

When using the level-sensitive interrupt trigger, avoid false interrupts by masking interrupt requests in the interrupt routine.

8.3.2 $\overline{\text{IRQ2}}$ Pin

A logic zero on the $\overline{\text{IRQ2}}$ pin can latch an interrupt request into the IRQ2 interrupt latch. A vector fetch, software clear, or reset clears the IRQ2 interrupt latch.

If the MODE2 bit is set, the $\overline{\text{IRQ2}}$ pin is both falling-edge-sensitive and low-level-sensitive. With MODE2 set, both of the following actions must occur to clear IRQ2:

- Vector fetch or software clear, or reset — A vector fetch generates an interrupt acknowledge signal to clear the latch. Software may generate the interrupt acknowledge signal by writing a logic one to the ACK2 bit in the interrupt status and control register (ISCR). The ACK2 bit is useful in applications that poll the $\overline{\text{IRQ2}}$ pin and require software to clear the IRQ2 interrupt latch. Writing to the ACK2 bit prior to leaving an interrupt service routine can also prevent spurious interrupts due to noise. Setting ACK2 does not affect subsequent transitions on the $\overline{\text{IRQ2}}$ pin. A falling edge that occurs after writing to the ACK2 bit latches another interrupt request. If the IRQ2 mask bit, IMASK2, is clear, the CPU loads the program counter with the vector address at locations \$FFDE and \$FFDF.
- Return of the $\overline{\text{IRQ2}}$ pin to logic one — As long as the $\overline{\text{IRQ2}}$ pin is at logic zero, IRQ2 remains active.

External Interrupt Module (IRQ)

The vector fetch or software clear and the return of the $\overline{\text{IRQ2}}$ pin to logic one can occur in any order. The interrupt request remains pending as long as the $\overline{\text{IRQ2}}$ pin is at logic zero. A reset will clear the latch and the MODEx control bit, thereby clearing the interrupt even if the pin stays low.

If the MODE2 bit is clear, the $\overline{\text{IRQ2}}$ pin is falling-edge-sensitive only. With MODE2 clear, a vector fetch or software clear immediately clears the IRQ2 interrupt latch.

There is no direct way to determine the logic level on the $\overline{\text{IRQ2}}$ pin. However, it is possible to use the IRQF2 bit in the ISCR to infer the state of the $\overline{\text{IRQ2}}$ pin. By writing a one to the MODE2 bit, the IRQF2 bit in the ISCR will be the opposite value of the $\overline{\text{IRQ2}}$ pin as long as the $\overline{\text{IRQ2}}$ latch is cleared. (See [Figure 8-1](#).) The $\overline{\text{IRQ2}}$ latch can be cleared by writing a one to the acknowledge bit. Recall, however, that every falling edge on the $\overline{\text{IRQ2}}$ pin will set the $\overline{\text{IRQ2}}$ latch, so an additional acknowledge is necessary after each falling edge on $\overline{\text{IRQ2}}$ to maintain the opposite relationship between IRQF2 and the $\overline{\text{IRQ2}}$ pin. The user may want to set the IMASK2 bit in the ISCR to prevent the IRQF2 from generating interrupts when used in this manner.

NOTE

When using the level-sensitive interrupt trigger, avoid false interrupts by masking interrupt requests in the interrupt routine.

8.4 IRQ Module During Break Interrupts

The system integration module (SIM) controls whether the IRQ1 and IRQ2 interrupt latches can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear the latches during the break state. (See [Chapter 5 System Integration Module \(SIM\)](#).)

To allow software to clear the IRQ1 latch and the IRQ2 interrupt latch during a break interrupt, write a logic one to the BCFE bit. If a latch is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect the latches during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), writing to the ACK1 and ACK2 bits in the IRQ status and control register during the break state has no effect on the IRQ latches.

8.5 IRQ Status and Control Register

The IRQ Status and Control Register (ISCR) controls and monitors operation of the IRQ module. The ISCR has the following functions:

- Shows the state of the IRQ1 and IRQ2 interrupt flags
- Clears the IRQ1 and IRQ2 interrupt latches
- Masks IRQ1 and IRQ2 interrupt requests
- Controls triggering sensitivity of the $\overline{\text{IRQ1}}/V_{PP}$ and $\overline{\text{IRQ2}}$ interrupt pins

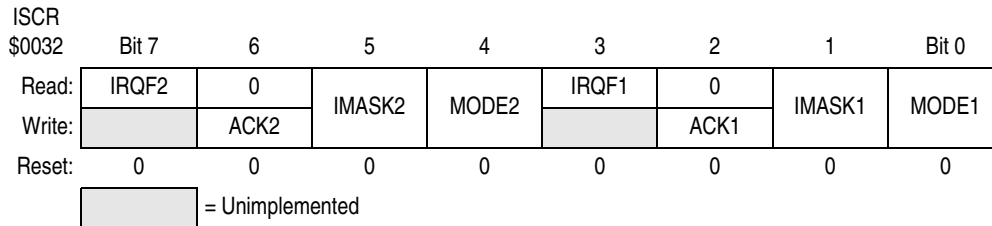


Figure 8-3. IRQ Status and Control Register (ISCR)

IRQ2F — $\overline{\text{IRQ2}}$ Flag

This read-only status bit is high when the $\overline{\text{IRQ2}}$ interrupt is pending.

- 1 = $\overline{\text{IRQ2}}$ interrupt pending
- 0 = $\overline{\text{IRQ2}}$ interrupt not pending

ACK2 — IRQ2 Interrupt Request Acknowledge Bit

Writing a logic one to this write-only bit clears the IRQ2 interrupt latch. ACK2 always reads as logic zero. Reset clears ACK2.

IMASK2 — IRQ2 Interrupt Mask Bit

Writing a logic one to this read/write bit prevents the output of the IRQ2 interrupt latch from generating interrupt requests. Reset clears IMASK2.

- 1 = $\overline{\text{IRQ2}}$ pin interrupt requests disabled
- 0 = $\overline{\text{IRQ2}}$ pin interrupt requests enabled

MODE2 — IRQ2 Interrupt Edge/Level Select Bit

This read/write bit controls the triggering sensitivity of the IRQ2 interrupt pins. Reset clears MODE2.

- 1 = $\overline{\text{IRQ2}}$ interrupt requests on falling edges and low levels
- 0 = $\overline{\text{IRQ2}}$ interrupt requests on falling edges only

IRQ1F — IRQ1 Flag

This read-only status bit is high when the IRQ1 interrupt is pending.

- 1 = $\overline{\text{IRQ1}}$ interrupt pending
- 0 = $\overline{\text{IRQ1}}$ interrupt not pending

ACK1 — IRQ1 Interrupt Request Acknowledge Bit

Writing a logic one to this write-only bit clears the IRQ1 latch. ACK1 always reads as logic zero. Reset clears ACK1.

IMASK1 — IRQ1 Interrupt Mask Bit

Writing a logic one to this read/write bit disables IRQ1 interrupt requests. Reset clears IMASK1.

- 1 = IRQ1 interrupt requests disabled
- 0 = IRQ1 interrupt requests enabled

MODE1 — IRQ1 Edge/Level Select Bit

This read/write bit controls the triggering sensitivity of the $\overline{\text{IRQ1}}/V_{PP}$ pin. Reset clears MODE1.

- 1 = $\overline{\text{IRQ1}}/V_{PP}$ interrupt requests on falling edges and low levels
- 0 = $\overline{\text{IRQ1}}/V_{PP}$ interrupt requests on falling edges only

Chapter 9

Keyboard Module (KB)

9.1 Introduction

The keyboard module provides eight independently maskable external interrupt pins.

9.2 Features

Features of the keyboard module:

- Eight Keyboard Interrupt Pins and Interrupt Masks
- Selectable Triggering Sensitivity

9.3 Functional Description

Writing to the KBIE7:KBIE0 bits in the keyboard interrupt enable register independently enables or disables each port A pin as a keyboard interrupt pin. Enabling a keyboard interrupt pin also enables its internal pullup device. A logic zero applied to an enabled keyboard interrupt pin will latch a keyboard interrupt request.

The keyboard interrupt latch becomes set when one or more keyboard pins goes low after all were high. The MODEK bit in the keyboard status and control register controls the triggering mode of the keyboard interrupt.

- If the keyboard interrupt is edge-sensitive only, a falling edge on a keyboard pin does not latch an interrupt request if another keyboard pin is already low. To prevent losing an interrupt request on one pin because another pin is still low, software can disable the latter pin while it is low.
- If the keyboard interrupt is edge- and level-sensitive, an interrupt request is present as long as any keyboard pin is low.

Addr.	Register Name		Bit 7	6	5	4	3	2	1	Bit 0
\$001A	Keyboard Status/Control Register (KBSCR)	Read:	0	0	0	0	KEYF	0	IMASKK	MODEK
		Write:						ACKK		
		Reset:	0	0	0	0	0	0	0	0
\$001B	Keyboard Interrupt Control Register (KBICR)	Read:	KB7IE	KB6IE	KB5IE	KB4IE	KB3IE	KB2IE	KB1IE	KB0IE
		Write:								
		Reset:	0	0	0	0	0	0	0	0

= Unimplemented

Figure 9-1. KB I/O Register Summary

Keyboard Module (KB)

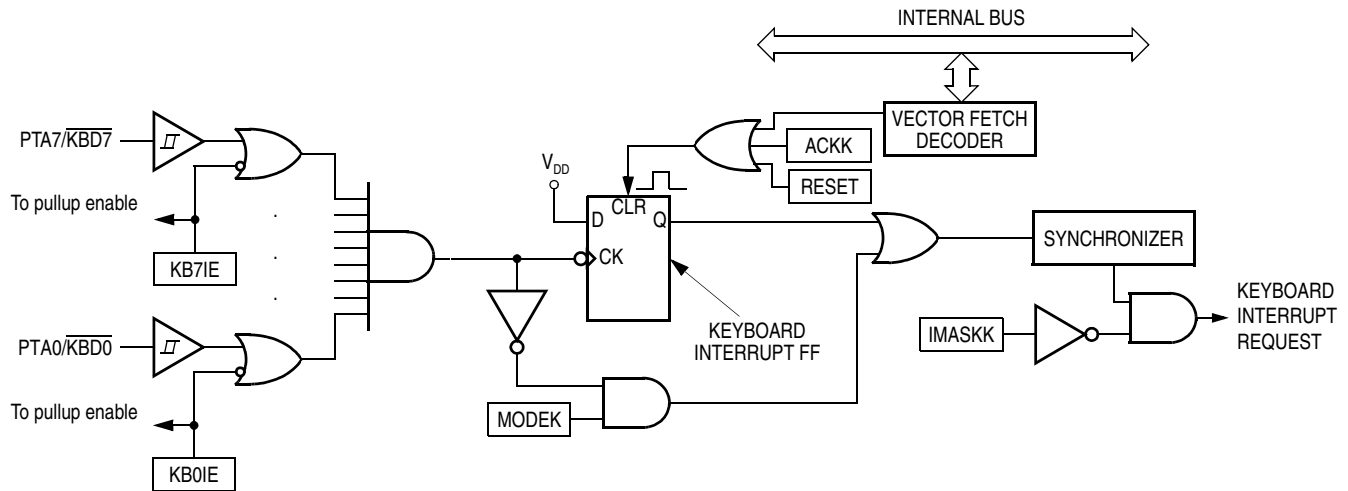


Figure 9-2. Keyboard Module Block Diagram

The MODEK bit in the keyboard status and control register controls the triggering sensitivity of the keyboard interrupt latch. If the MODEK bit is set, the keyboard interrupt pins are both falling-edge- and low-level-sensitive, and both of the following actions must occur to clear a keyboard interrupt:

- Vector fetch or software clear — A vector fetch generates an interrupt acknowledge signal to clear the latch. Software can generate the interrupt acknowledge signal by writing a logic one to the ACKK bit in the keyboard status and control register (KBSCR). The ACKK bit is useful in applications that poll the keyboard interrupt pins and require software to clear the keyboard interrupt latch. Writing to the ACKK bit prior to leaving an interrupt service routine can also prevent spurious interrupts due to noise. Setting ACKK does not affect subsequent transitions on the keyboard interrupt pins. A falling edge that occurs after writing to the ACKK bit latches another interrupt request. If the keyboard interrupt mask bit, IMASKK, is clear, the CPU loads the program counter with the vector address at locations \$FFDC and \$FFDD.
- Return of all enabled keyboard interrupt pins to logic one — As long as any enabled keyboard interrupt pin is at logic zero, the keyboard interrupt remains set.

The vector fetch or software clear and the return of all enabled keyboard interrupt pins to logic one may occur in any order. The interrupt request remains pending as long as any enabled keyboard interrupt pin is at logic zero.

If the MODEK bit is clear, the keyboard interrupt pin is falling-edge- sensitive only. With MODEK clear, a vector fetch or software clear immediately clears the keyboard interrupt latch.

Reset clears the keyboard interrupt latch and the MODEK bit, clearing the interrupt request even if a keyboard interrupt pin stays at logic zero.

The keyboard flag bit (KEYF) in the keyboard status and control register can be used to see if a pending interrupt exists. The KEYF bit is not affected by the keyboard interrupt mask bit (IMASKK) which makes it useful in applications where polling is preferred.

To determine the logic level on a keyboard interrupt pin, use the data direction register to configure the pin as an input and read the data register.

NOTE

Setting a keyboard interrupt enable bit (KBxIE) forces the corresponding keyboard interrupt pin to be an input, overriding the data direction register. However, the data direction register bit must be a logic zero for software to read the pin.

9.4 Keyboard Initialization

When a keyboard interrupt pin is enabled, it takes time for the internal pull-up to reach a logic one, so it is possible that an interrupt could occur when the pin is initially enabled.

To prevent this, it is recommended that the keyboard interrupt be masked with the IMASKK bit in the KBSCR register before enabling the pin and that the ACKK bit be used to acknowledge the potential false interrupt before setting IMASKK back to zero. An edge-only type of interrupt can be acknowledged immediately after enabling the pin. An edge- and level-triggered interrupt must be acknowledged after a delay which is dependant on the external load.

Another way to avoid a false interrupt is to set the appropriate bit of port A to an output driving a logic one, before enabling the keyboard input.

9.5 I/O Registers

These registers control and monitor operation of the keyboard module:

- Keyboard status and control register (KBSCR)
- Keyboard interrupt enable register (KBIER)

9.5.1 Keyboard Status and Control Register (KBSCR)

The keyboard status and control register performs these functions:

- Flags keyboard interrupt requests
- Acknowledges keyboard interrupt requests
- Masks keyboard interrupt requests
- Controls keyboard latch triggering sensitivity

KBSCR \$001A	Bit 7	6	5	4	3	2	1	Bit 0
Read:	0	0	0	0	KEYF	0	IMASKK	MODEK
Write:						ACKK		
Reset:	0	0	0	0	0	0	0	0


 = Unimplemented

Figure 9-3. Keyboard Status and Control Register (KBSCR)

Bits 7–4 — Not used

These read-only bits always read as logic zeros.

KEYF — Keyboard Flag Bit

This read-only bit is set when a keyboard interrupt is pending. Reset clears the KEYF bit.

1 = Keyboard interrupt pending

0 = No keyboard interrupt pending

ACKK — Keyboard Acknowledge Bit

Writing a logic one to this read/write bit clears the keyboard interrupt latch. ACKK always reads as logic zero. Reset clears ACKK.

Keyboard Module (KB)

IMASKK — Keyboard Interrupt Mask Bit

Writing a logic one to this read/write bit prevents the output of the keyboard interrupt mask from generating interrupt requests. Reset clears the IMASKK bit.

- 1 = Keyboard interrupt requests disabled
- 0 = Keyboard interrupt requests enabled

MODEK — Keyboard Triggering Sensitivity Bit

This read/write bit controls the triggering sensitivity of the keyboard interrupt pins. Reset clears MODEK.

- 1 = Keyboard interrupt requests on falling edges and low levels
- 0 = Keyboard interrupt requests on falling edges only

9.5.2 Keyboard Interrupt Enable Register (KBIER)

The keyboard interrupt enable register enables or disables each port A pin to operate as a keyboard interrupt pin.

		Bit 7	6	5	4	3	2	1	Bit 0
KBIER \$001B	Read:	KBIE7	KBIE6	KBIE5	KBIE4	KBIE3	KBIE2	KBIE1	KBIE0
	Write:								

Figure 9-4. Keyboard Interrupt Enable Register (KBIER)

KBIE7:KBIE0 — Keyboard Interrupt Enable Bits

Each of these read/write bits enables the corresponding keyboard interrupt pin to latch interrupt requests. Reset clears the keyboard interrupt enable register.

- 1 = PAX pin enabled as keyboard interrupt pin
- 0 = PAX pin not enabled as keyboard interrupt pin

9.6 Keyboard Module During Break Interrupts

The system integration module (SIM) controls whether the keyboard interrupt latch can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear the latch during the break state.

To allow software to clear the keyboard interrupt latch during a break interrupt, write a logic one to the BCFE bit. If a latch is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect the latch during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), writing has no effect during the break state to the keyboard acknowledge bit (ACKK) in the keyboard status and control register. (See [9.5.1 Keyboard Status and Control Register \(KBSCR\)](#).)

Chapter 10

Timer Interface Module (TIM)

10.1 Introduction

This section describes the timer interface module (TIM4, Version B). The TIM is a four-channel timer that provides a timing reference with input capture, output compare, and pulse-width-modulation functions. [Figure 10-1](#) is a block diagram of the TIM.

10.2 Features

Features of the TIM include:

- Four Input Capture/Output Compare Channels
 - Rising-Edge, Falling-Edge, or Any-Edge Input Capture Trigger
 - Set, Clear, or Toggle Output Compare Action
- Buffered and Unbuffered Pulse Width Modulation (PWM) Signal Generation
- Programmable TIM Clock Input
 - Seven-Frequency Internal Bus Clock Prescaler Selection
 - External TIM Clock Input (Bus Frequency $\div 2$ Maximum)
- Free-Running or Modulo Up-Count Operation
- Toggle Any Channel Pin on Overflow
- TIM Counter Stop and Reset Bits
- DMA Service Request Generation
- Modular Architecture Expandable to Eight Channels

10.3 Functional Description

NOTE

References to DMA and associated functions are only valid if the MCU has a DMA module. If the MCU has no DMA, any DMA-related register bits should be left in their reset state for expected MCU operation.

Timer Interface Module (TIM)

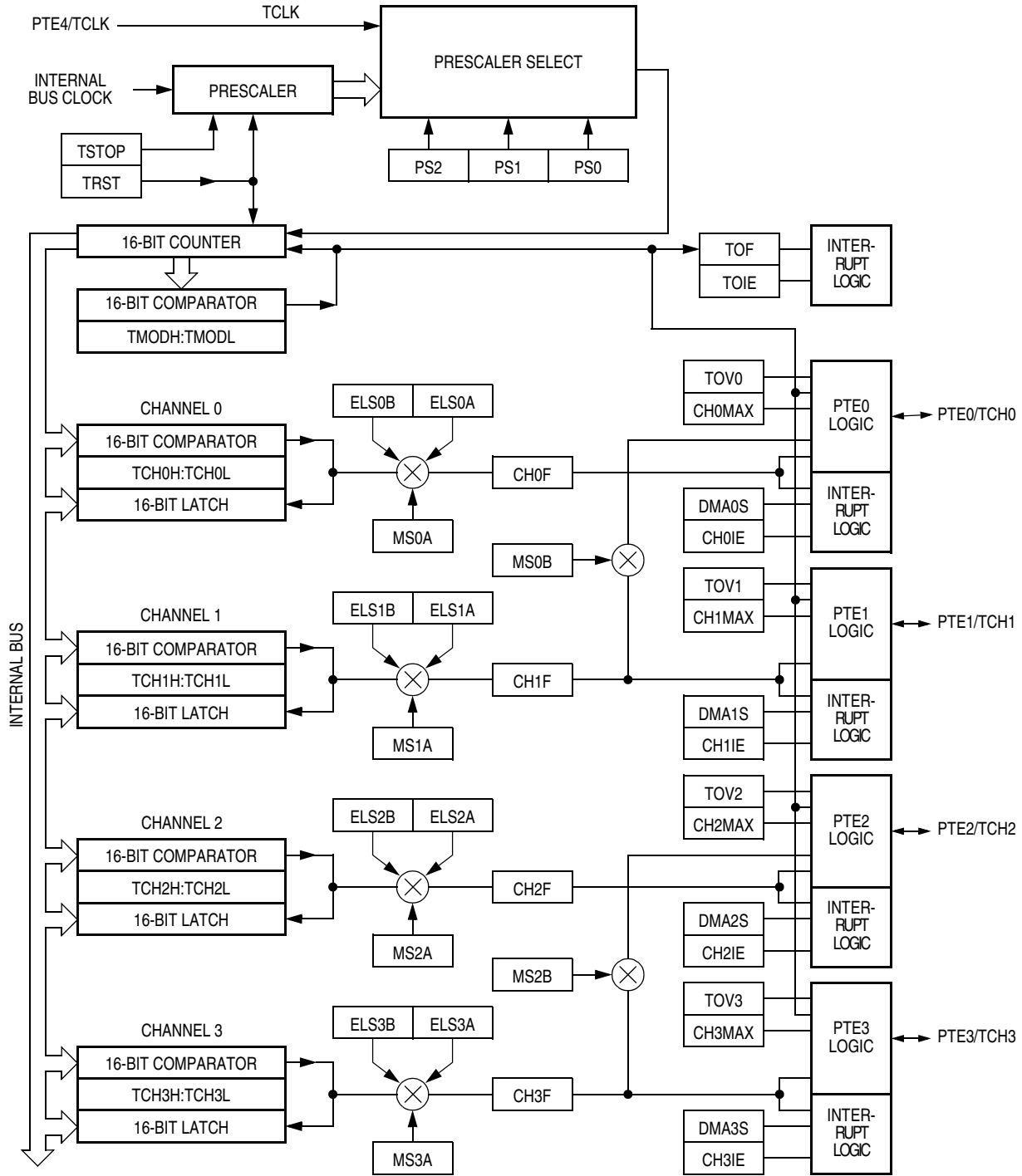


Figure 10-1. TIM Block Diagram

Table 10-1. TIM I/O Register Summary

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
TIM Status/Control Register (TSC)	TOF	TOIE	TSTOP	TRST	0	PS2	PS1	PS0	\$0020
TIM DMA Select Register (TDMA)					DMAS3	DMAS2	DMAS1	DMAS0	\$0021
TIM Counter Register High (TCNTH)	Bit 15	14	13	12	11	10	9	Bit 8	\$0022
TIM Counter Register Low (TCNTL)	Bit 7	6	5	4	3	2	1	Bit 0	\$0023
TIM Counter Modulo Reg. High (TMODH)	Bit 15	14	13	12	11	10	9	Bit 8	\$0024
TIM Counter Modulo Reg. Low (TMODL)	Bit 7	6	5	4	3	2	1	Bit 0	\$0025
TIM Channel 0 Status/Control Register (TSC0)	CH0F	CH0IE	MS0B	MS0A	ELS0B	ELS0A	TOV0	CH0MAX	\$0026
TIM Channel 0 Register High (TCH0H)	Bit 15	14	13	12	11	10	9	Bit 8	\$0027
TIM Channel 0 Register Low (TCH0L)	Bit 7	6	5	4	3	2	1	Bit 0	\$0028
TIM Channel 1 Status/Control Register (TSC1)	CH1F	CH1IE		MS1A	ELS1B	ELS1A	TOV1	CH1MAX	\$0029
TIM Channel 1 Register High (TCH1H)	Bit 15	14	13	12	11	10	9	Bit 8	\$002A
TIM Channel 1 Register Low (TCH1L)	Bit 7	6	5	4	3	2	1	Bit 0	\$002B
TIM Channel 2 Status/Control Register (TSC2)	CH2F	CH2IE	MS2B	MS2A	ELS2B	ELS2A	TOV2	CH2MAX	\$002C
TIM Channel 2 Register High (TCH2H)	Bit 15	14	13	12	11	10	9	Bit 8	\$002D
TIM Channel 2 Register Low (TCH2L)	Bit 7	6	5	4	3	2	1	Bit 0	\$002E
TIM Channel 3 Status/Control Register (TSC3)	CH3F	CH3IE		MS3A	ELS3B	ELS3A	TOV3	CH3MAX	\$002F
TIM Channel 3 Register High (TCH3H)	Bit 15	14	13	12	11	10	9	Bit 8	\$0030
TIM Channel 3 Register Low (TCH3L)	Bit 7	6	5	4	3	2	1	Bit 0	\$0031


 = Unimplemented

Figure 10-1 shows the structure of the TIM. The central component of the TIM is the 16-bit TIM counter that can operate as a free-running counter or a modulo up-counter. The TIM counter provides the timing reference for the input capture and output compare functions. The TIM counter modulo registers, TMODH:TMODL, control the modulo value of the TIM counter. Software can read the TIM counter value at any time without affecting the counting sequence.

The four TIM channels are programmable independently as input capture or output compare channels.

10.3.1 TIM Counter Prescaler

The TIM clock source can be one of the seven prescaler outputs or the TIM clock pin, PTE4/TCLK. The prescaler generates seven clock rates from the internal bus clock. The prescaler select bits, PS[2:0], in the TIM status and control register select the TIM clock source.

10.3.2 Input Capture

With the input capture function, the TIM can capture the time at which an external event occurs. When an active edge occurs on the pin of an input capture channel, the TIM latches the contents of the TIM counter into the TIM channel registers, TCHxH:TCHxL. The polarity of the active edge is programmable. Input captures can generate TIM CPU interrupt requests or TIM DMA service requests.

10.3.3 Output Compare

With the output compare function, the TIM can generate a periodic pulse with a programmable polarity, duration, and frequency. When the counter reaches the value in the registers of an output compare channel, the TIM can set, clear, or toggle the channel pin. Output compares can generate TIM CPU interrupt requests or TIM DMA service requests.

10.3.4 Unbuffered Output Compare

Any output compare channel can generate unbuffered output compare pulses as described in [10.3.3 Output Compare](#). The pulses are unbuffered because changing the output compare value requires writing the new value over the old value currently in the TIM channel registers.

An unsynchronized write to the TIM channel registers to change an output compare value could cause incorrect operation for up to two counter overflow periods. For example, writing a new value before the counter reaches the old value but after the counter reaches the new value prevents any compare during that counter overflow period. Also, using a TIM overflow interrupt routine to write a new, smaller output compare value may cause the compare to be missed. The TIM may pass the new value before it is written.

Use the following methods to synchronize unbuffered changes in the output compare value on channel x:

- When changing to a smaller value, enable channel x output compare interrupts and write the new value in the output compare interrupt routine. The output compare interrupt occurs at the end of the current output compare pulse. The interrupt routine has until the end of the counter overflow period to write the new value.
- When changing to a larger output compare value, enable channel x TIM overflow interrupts and write the new value in the TIM overflow interrupt routine. The TIM overflow interrupt occurs at the end of the current counter overflow period. Writing a larger value in an output compare interrupt routine (at the end of the current pulse) could cause two output compares to occur in the same counter overflow period.

10.3.5 Buffered Output Compare

Channels 0 and 1 can be linked to form a buffered output compare channel whose output appears on the PTE0/TCH0 pin. The TIM channel registers of the linked pair alternately control the output.

Setting the MS0B bit in TIM channel 0 status and control register (TSC0) links channel 0 and channel 1. The output compare value in the TIM channel 0 registers initially controls the output on the PTE0/TCH0 pin. Writing to the TIM channel 1 registers enables the TIM channel 1 registers to synchronously control the output after the TIM overflows. At each subsequent overflow, the TIM channel registers (0 or 1) that control the output are the ones written to last. TSC0 controls and monitors the buffered output compare function, and TIM channel 1 status and control register (TSC1) is unused. While the MS0B bit is set, the channel 1 pin, PTE1/TCH1, is available as a general-purpose I/O pin.

Channels 2 and 3 can be linked to form a buffered output compare channel whose output appears on the PTE2/TCH2 pin. The TIM channel registers of the linked pair alternately control the output.

Setting the MS2B bit in TIM channel 2 status and control register (TSC2) links channel 2 and channel 3. The output compare value in the TIM channel 2 registers initially controls the output on the PTE2/TCH2 pin. Writing to the TIM channel 3 registers enables the TIM channel 3 registers to synchronously control the output after the TIM overflows. At each subsequent overflow, the TIM channel registers (2 or 3) that control the output are the ones written to last. TSC2 controls and monitors the buffered output compare function, and TIM channel 3 status and control register (TSC3) is unused. While the MS2B bit is set, the channel 3 pin, PTE3/TCH3, is available as a general-purpose I/O pin.

NOTE

In buffered output compare operation, do not write new output compare values to the currently active channel registers. Writing to the active channel registers is the same as generating unbuffered output compares.

10.3.6 Pulse Width Modulation (PWM)

By using the toggle-on-overflow feature with an output compare channel, the TIM can generate a PWM signal. The value in the TIM counter modulo registers determines the period of the PWM signal. The channel pin toggles when the counter reaches the value in the TIM counter modulo registers. The time between overflows is the period of the PWM signal.

As [Figure 10-2](#) shows, the output compare value in the TIM channel registers determines the pulse width of the PWM signal. The time between overflow and output compare is the pulse width. Program the TIM to clear the channel pin on output compare if the state of the PWM pulse is logic one. Program the TIM to set the pin if the state of the PWM pulse is logic zero.

The value in the TIM counter modulo registers and the selected prescaler output determines the frequency of the PWM output. The frequency of an 8-bit PWM signal is variable in 256 increments. Writing \$00FF (255) to the TIM counter modulo registers produces a PWM period of 256 times the internal bus clock period if the prescaler select value is \$000. See [10.8.1 TIM Status and Control Register \(TSC\)](#).

The value in the TIM channel registers determines the pulse width of the PWM output. The pulse width of an 8-bit PWM signal is variable in 256 increments. Writing \$0080 (128) to the TIM channel registers produces a duty cycle of 128/256 or 50%.

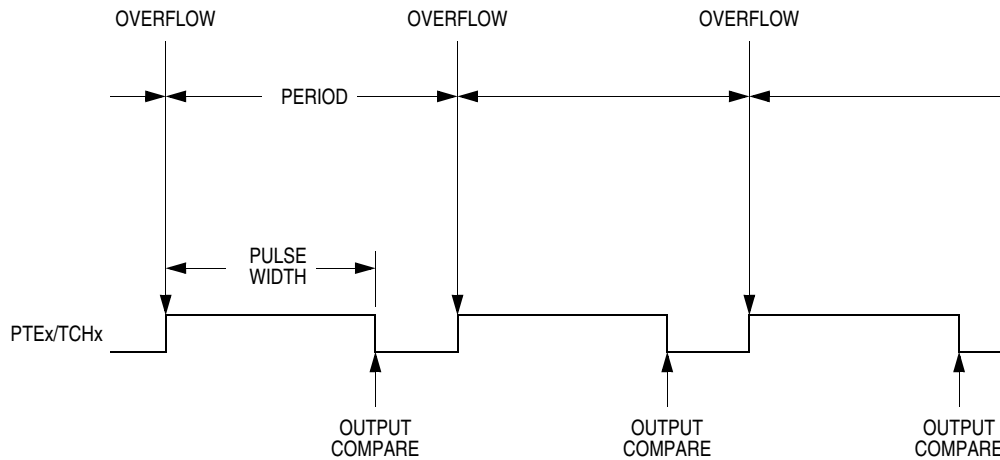


Figure 10-2. PWM Period and Pulse Width

10.3.7 Unbuffered PWM Signal Generation

Any output compare channel can generate unbuffered PWM pulses as described in [10.3.6 Pulse Width Modulation \(PWM\)](#). The pulses are unbuffered because changing the pulse width requires writing the new pulse width value over the old value currently in the TIM channel registers.

An unsynchronized write to the TIM channel registers to change a pulse width value could cause incorrect operation for up to two PWM periods. For example, writing a new value before the counter reaches the old value but after the counter reaches the new value prevents any compare during that PWM period. Also, using a TIM overflow interrupt routine to write a new, smaller pulse width value may cause the compare to be missed. The TIM may pass the new value before it is written.

Use the following methods to synchronize unbuffered changes in the PWM pulse width on channel x:

- When changing to a shorter pulse width, enable channel x output compare interrupts and write the new value in the output compare interrupt routine. The output compare interrupt occurs at the end of the current pulse. The interrupt routine has until the end of the PWM period to write the new value.
- When changing to a longer pulse width, enable channel x TIM overflow interrupts and write the new value in the TIM overflow interrupt routine. The TIM overflow interrupt occurs at the end of the current PWM period. Writing a larger value in an output compare interrupt routine (at the end of the current pulse) could cause two output compares to occur in the same PWM period.

NOTE

In PWM signal generation, do not program the PWM channel to toggle on output compare. Toggling on output compare prevents reliable 0% duty cycle generation and removes the ability of the channel to self-correct in the event of software error or noise. Toggling on output compare also can cause incorrect PWM signal generation when changing the PWM pulse width to a new, much larger value.

10.3.8 Buffered PWM Signal Generation

Channels 0 and 1 can be linked to form a buffered PWM channel whose output appears on the PTE0/TCH0 pin. The TIM channel registers of the linked pair alternately control the pulse width of the output.

Setting the MS0B bit in TIM channel 0 status and control register (TSC0) links channel 0 and channel 1. The TIM channel 0 registers initially control the pulse width on the PTE0/TCH0 pin. Writing to the TIM channel 1 registers enables the TIM channel 1 registers to synchronously control the pulse width at the beginning of the next PWM period. At each subsequent overflow, the TIM channel registers (0 or 1) that control the pulse width are the ones written to last. TSC0 controls and monitors the buffered PWM function, and TIM channel 1 status and control register (TSC1) is unused. While the MS0B bit is set, the channel 1 pin, PTE1/TCH1, is available as a general-purpose I/O pin.

Channels 2 and 3 can be linked to form a buffered PWM channel whose output appears on the PTE2/TCH2 pin. The TIM channel registers of the linked pair alternately control the pulse width of the output.

Setting the MS2B bit in TIM channel 2 status and control register (TSC2) links channel 2 and channel 3. The TIM channel 2 registers initially control the pulse width on the PTE2/TCH2 pin. Writing to the TIM channel 3 registers enables the TIM channel 3 registers to synchronously control the pulse width at the beginning of the next PWM period. At each subsequent overflow, the TIM channel registers (2 or 3) that control the pulse width are the ones written to last. TSC2 controls and monitors the buffered PWM function, and TIM channel 3 status and control register (TSC3) is unused. While the MS2B bit is set, the channel 3 pin, PTE3/TCH3, is available as a general-purpose I/O pin.

NOTE

In buffered PWM signal generation, do not write new pulse width values to the currently active channel registers. Writing to the active channel registers is the same as generating unbuffered PWM signals.

10.3.9 PWM Initialization

To ensure correct operation when generating unbuffered or buffered PWM signals, use the following initialization procedure:

1. In the TIM status and control register (TSC):
 - a. Stop the TIM counter by setting the TIM stop bit, TSTOP.
 - b. Reset the TIM counter by setting the TIM reset bit, TRST.
2. In the TIM counter modulo registers (TMODH:TMODL), write the value for the required PWM period.
3. In the TIM channel x registers (TCHxH:TCHxL), write the value for the required pulse width.
4. In TIM channel x status and control register (TSCx):
 - a. Write 0:1 (for unbuffered output compare or PWM signals) or 1:0 (for buffered output compare or PWM signals) to the mode select bits, MSxB:MSxA. See [Table 10-3](#).
 - b. Write 1 to the toggle-on-overflow bit, TOVx.
 - c. Write 1:0 (to clear output on compare) or 1:1 (to set output on compare) to the edge/level select bits, ELSxB:ELSxA. The output action on compare must force the output to the complement of the pulse width level. (See [Table 10-3](#).)

NOTE

In PWM signal generation, do not program the PWM channel to toggle on output compare. Toggling on output compare prevents reliable 0% duty cycle generation and removes the ability of the channel to self-correct in the event of software error or noise. Toggling on output compare can also

cause incorrect PWM signal generation when changing the PWM pulse width to a new, much larger value.

5. In the TIM status control register (TSC), clear the TIM stop bit, TSTOP.

Setting MS0B links channels 0 and 1 and configures them for buffered PWM operation. The TIM channel 0 registers (TCH0H:TCH0L) initially control the buffered PWM output. TIM status control register 0 (TSCR0) controls and monitors the PWM signal from the linked channels. MS0B takes priority over MS0A.

Setting MS2B links channels 2 and 3 and configures them for buffered PWM operation. The TIM channel 2 registers (TCH2H:TCH2L) initially control the PWM output. TIM status control register 2 (TSCR2) controls and monitors the PWM signal from the linked channels. MS2B takes priority over MS2A.

Clearing the toggle-on-overflow bit, TOVx, inhibits output toggles on TIM overflows. Subsequent output compares try to force the output to a state it is already in and have no effect. The result is a 0% duty cycle output.

Setting the channel x maximum duty cycle bit (CHxMAX) and clearing the TOVx bit generates a 100% duty cycle output. (See [10.8.5 TIM Channel Status and Control Registers \(TSC0:TSC3\)](#).)

10.4 Interrupts

The following TIM sources can generate interrupt requests:

- TIM overflow flag (TOF) — The TOF bit is set when the TIM counter value rolls over to \$0000 after matching the value in the TIM counter modulo registers. The TIM overflow interrupt enable bit, TOIE, enables TIM overflow CPU interrupt requests. TOF and TOIE are in the TIM status and control register.
- TIM channel flags (CH3F:CH0F) — The CHxF bit is set when an input capture or output compare occurs on channel x. Channel x TIM CPU interrupt requests and TIM DMA service requests are controlled by the channel x interrupt enable bit, CHxIE, and the channel x DMA select bit, DMAxS. Channel x TIM CPU interrupt requests are enabled when CHxIE:DMAxS = 1:0. Channel x TIM DMA service requests are enabled when CHxIE:DMAxS = 1:1. CHxF and CHxIE are in the TIM channel x status and control register. DMAxS is in the TIM DMA select register.

10.5 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

10.5.1 Wait Mode

The TIM remains active after the execution of a WAIT instruction. In wait mode the TIM registers are not accessible by the CPU. Any enabled CPU interrupt request from the TIM can bring the MCU out of wait mode.

If TIM functions are not required during wait mode, reduce power consumption by stopping the TIM before executing the WAIT instruction.

The DMA can service the TIM without exiting wait mode.

10.5.2 Stop Mode

The TIM is inactive after the execution of a STOP instruction. The STOP instruction does not affect register conditions or the state of the TIM counter. TIM operation resumes when the MCU exits stop mode after an external interrupt.

10.6 TIM During Break Interrupts

A break interrupt stops the TIM counter.

The system integration module (SIM) controls whether status bits in other modules can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear status bits during the break state. See [5.7.3 SIM Break Flag Control Register \(SBFCR\)](#).

To allow software to clear status bits during a break interrupt, write a logic one to the BCFE bit. If a status bit is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect status bits during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), software can read and write I/O registers during the break state without affecting status bits. Some status bits have a two-step read/write clearing procedure. If software does the first step on such a bit before the break, the bit cannot change during the break state as long as BCFE is at logic zero. After the break, doing the second step clears the status bit.

10.7 I/O Signals

Port E shares five of its pins with the TIM. PTE4/TCLK is an external clock input to the TIM prescaler. The four TIM channel I/O pins are PTE0/TCH0, PTE1/TCH1, PTE2/TCH2, and PTE3/TCH3.

10.7.1 TIM Clock Pin (PTE4/TCLK)

PTE4/TCLK is an external clock input that can be the clock source for the TIM counter instead of the prescaled internal bus clock. Select the PTE4/TCLK input by writing logic ones to the three prescaler select bits, PS[2:0]. See [10.8.1 TIM Status and Control Register \(TSC\)](#). The minimum TCLK pulse width, $TCLK_{L\text{MIN}}$ or $TCLK_{H\text{MIN}}$, is:

$$\frac{1}{\text{bus frequency}} + t_{\text{SU}}$$

The maximum TCLK frequency is:

$$\text{bus frequency} \div 2$$

PTE4/TCLK is available as a general-purpose I/O pin when not used as the TIM clock input. When the PTE4/TCLK pin is the TIM clock input, it is an input regardless of the state of the DDRE3 bit in data direction register E.

10.7.2 TIM Channel I/O Pins (PTE0/TCH0:PTE3/TCH3)

Each channel I/O pin is programmable independently as an input capture pin or an output compare pin. PTE0/TCH0 and PTE2/TCH2 can be configured as buffered output compare or buffered PWM pins.

10.8 I/O Registers

These I/O registers control and monitor operation of the TIM:

- TIM status and control register (TSC)
- TIM DMA select register (TDMA)
- TIM control registers (TCNTH:TCNTL)
- TIM counter modulo registers (TMODH:TMODL)
- TIM channel status and control registers (TSC0, TSC1, TSC2, and TSC3)
- TIM channel registers (TCH0H:TCH0L, TCH1H:TCH1L, TCH2H:TCH2L, and TCH3H:TCH3L)

10.8.1 TIM Status and Control Register (TSC)

The TIM status and control register:

- Enables TIM overflow interrupts
- Flags TIM overflows
- Stops the TIM counter
- Resets the TIM counter
- Prescales the TIM counter clock

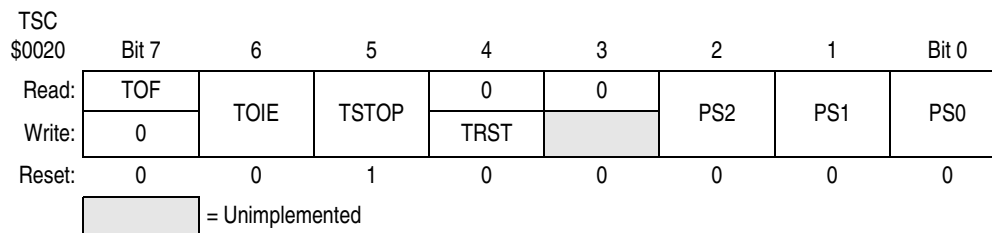


Figure 10-3. TIM Status and Control Register (TSC)

TOF — TIM Overflow Flag Bit

This read/write flag is set when the TIM counter resets to \$0000 after reaching the modulo value programmed in the TIM counter modulo registers. Clear TOF by reading the TIM status and control register when TOF is set and then writing a logic zero to TOF. If another TIM overflow occurs before the clearing sequence is complete, then writing logic zero to TOF has no effect. Therefore, a TOF interrupt request cannot be lost due to inadvertent clearing of TOF. Reset clears the TOF bit. Writing a logic one to TOF has no effect.

- 1 = TIM counter has reached modulo value
- 0 = TIM counter has not reached modulo value

TOIE — TIM Overflow Interrupt Enable Bit

This read/write bit enables TIM overflow interrupts when the TOF bit becomes set. Reset clears the TOIE bit.

- 1 = TIM overflow interrupts enabled
- 0 = TIM overflow interrupts disabled

TSTOP — TIM Stop Bit

This read/write bit stops the TIM counter. Counting resumes when TSTOP is cleared. Reset sets the TSTOP bit, stopping the TIM counter until software clears the TSTOP bit.

1 = TIM counter stopped

0 = TIM counter active

NOTE

Do not set the TSTOP bit before entering wait mode if the TIM is required to exit wait mode.

TRST — TIM Reset Bit

Setting this write-only bit resets the TIM counter and the TIM prescaler. Setting TRST has no effect on any other registers. Counting resumes from \$0000. TRST is cleared automatically after the TIM counter is reset and always reads as logic zero. Reset clears the TRST bit.

1 = Prescaler and TIM counter cleared

0 = No effect

NOTE

Setting the TSTOP and TRST bits simultaneously stops the TIM counter at a value of \$0000.

PS[2:0] — Prescaler Select Bits

These read/write bits select either the PTE4/TCLK pin or one of the seven prescaler outputs as the input to the TIM counter as [Table 10-2](#) shows. Reset clears the PS[2:0] bits.

Table 10-2. Prescaler Selection

PS[2:0]	TIM Clock Source
000	Internal Bus Clock ÷ 1
001	Internal Bus Clock ÷ 2
010	Internal Bus Clock ÷ 4
011	Internal Bus Clock ÷ 8
100	Internal Bus Clock ÷ 16
101	Internal Bus Clock ÷ 32
110	Internal Bus Clock ÷ 64
111	PTE4/TCLK

10.8.2 TIM DMA Select Register (TDMA)

The TIM DMA select register enables either TIM CPU interrupt requests or TIM DMA service requests.

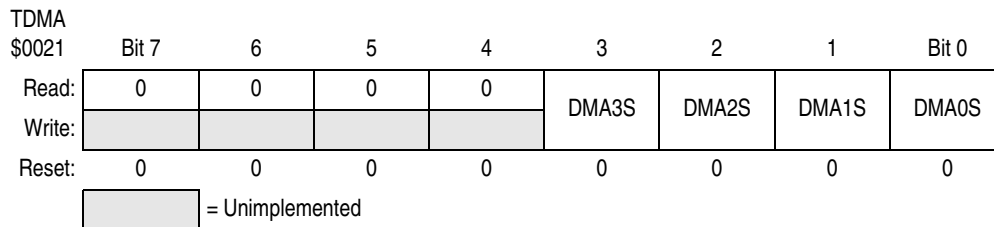


Figure 10-4. TIM DMA Select Register (TDMA)

DMA3S — DMA Channel 3 Select Bit

This read/write bit enables TIM DMA service requests on channel 3. Reset clears the DMA3S bit.

- 1 = TIM DMA service requests enabled on channel 3
TIM CPU interrupt requests disabled on channel 3
- 0 = TIM DMA service requests disabled on channel 3
TIM CPU interrupt requests enabled on channel 3

DMA2S — DMA Channel 2 Select Bit

This read/write bit enables TIM DMA service requests on channel 2. Reset clears the DMA2S bit.

- 1 = TIM DMA service requests enabled on channel 2
TIM CPU interrupt requests disabled on channel 2
- 0 = TIM DMA service requests disabled on channel 2
TIM CPU interrupt requests enabled on channel 2

DMA1S — DMA Channel 1 Select Bit

This read/write bit enables TIM DMA service requests on channel 1. Reset clears the DMA1S bit.

- 1 = TIM DMA service requests enabled on channel 1
TIM CPU interrupt requests disabled on channel 1
- 0 = TIM DMA service requests disabled on channel 1
TIM CPU interrupt requests enabled on channel 1

DMA0S — DMA Channel 0 Select Bit

This read/write bit enables TIM DMA service requests on channel 0. Reset clears the DMA0S bit.

- 1 = TIM DMA service requests enabled on channel 0
TIM CPU interrupt requests disabled on channel 0
- 0 = TIM DMA service requests disabled on channel 0
TIM CPU interrupt requests enabled on channel 0

10.8.3 TIM Counter Registers (TCNTH:TCNTL)

The two read-only TIM counter registers contain the high and low bytes of the value in the TIM counter. Reading the high byte (TCNTH) latches the contents of the low byte (TCNTL) into a buffer. Subsequent reads of TCNTH do not affect the latched TCNTL value until TCNTL is read. Reset clears the TIM counter registers. Setting the TIM reset bit (TRST) also clears the TIM counter registers

NOTE

If you read TCNTH during a break interrupt, be sure to unlatch TCNTL by reading TCNTL before exiting the break interrupt. Otherwise, TCNTL retains the value latched during the break.

TCNTH								
\$0022	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 15	14	13	12	11	10	9	Bit 8
Write:								
Reset:	0	0	0	0	0	0	0	0

TCNTL								
\$0023	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 7	6	5	4	3	2	1	Bit 0
Write:								
Reset:	0	0	0	0	0	0	0	0


 = Unimplemented

Figure 10-5. TIM Counter Registers (TCNTH:TCNTL)

10.8.4 TIM Counter Modulo Registers (TMODH:TMODL)

The read/write TIM modulo registers contain the modulo value for the TIM counter. When the TIM counter reaches the modulo value, the overflow flag (TOF) becomes set, and the TIM counter resumes counting from \$0000 at the next clock. Writing to the high byte (TMODH) inhibits the TOF bit and overflow interrupts until the low byte (TMODL) is written. Reset sets the TIM counter modulo registers.

TMODH								
\$0024	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 15	14	13	12	11	10	9	Bit 8
Write:								
Reset:	1	1	1	1	1	1	1	1

TMODL								
\$0025	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 7	6	5	4	3	2	1	Bit 0
Write:								
Reset:	1	1	1	1	1	1	1	1

Figure 10-6. TIM Counter Modulo Registers (TMODH:TMODL)

NOTE

Reset the TIM counter before writing to the TIM counter modulo registers.

10.8.5 TIM Channel Status and Control Registers (TSC0:TSC3)

Each of the TIM channel status and control registers:

- Flags input captures and output compares
- Enables input capture and output compare interrupts
- Selects input capture, output compare, or PWM operation
- Selects high, low, or toggling output on output compare
- Selects rising edge, falling edge, or any edge as the active input capture trigger
- Selects output toggling on TIM overflow
- Selects 100% PWM duty cycle
- Selects buffered or unbuffered output compare/PWM operation

TSC0								
\$0026	Bit 7	6	5	4	3	2	1	Bit 0
Read:	CH0F	CH0IE	MS0B	MS0A	ELS0B	ELS0A	TOV0	CH0MAX
Write:	0							
Reset:	0	0	0	0	0	0	0	0
TSC1								
\$0029	Bit 7	6	5	4	3	2	1	Bit 0
Read:	CH1F	CH1IE	0	MS1A	ELS1B	ELS1A	TOV1	CH1MAX
Write:	0							
Reset:	0	0	0	0	0	0	0	0
TSC2								
\$002C	Bit 7	6	5	4	3	2	1	Bit 0
Read:	CH2F	CH2IE	MS2B	MS2A	ELS2B	ELS2A	TOV2	CH2MAX
Write:	0							
Reset:	0	0	0	0	0	0	0	0
TSC3								
\$002F	Bit 7	6	5	4	3	2	1	Bit 0
Read:	CH3F	CH3IE	0	MS3A	ELS3B	ELS3A	TOV3	CH3MAX
Write:	0							
Reset:	0	0	0	0	0	0	0	0


 = Unimplemented

Figure 10-7. TIM Channel Status and Control Registers (TSC0:TSC3)

CHxF — Channel x Flag Bit

When channel x is an input capture channel, this read/write bit is set when an active edge occurs on the channel x pin. When channel x is an output compare channel, CHxF is set when the value in the TIM counter registers matches the value in the TIM channel x registers.

When TIM CPU interrupt requests are enabled (CHxIE:DMAxS = 1:0), clear CHxF by reading TIM channel x status and control register with CHxF set and then writing a logic zero to CHxF. If another interrupt request occurs before the clearing sequence is complete, then writing logic zero to CHxF has no effect. Therefore, an interrupt request cannot be lost due to inadvertent clearing of CHxF.

When TIM DMA service requests are enabled (CHxIE:DMAxS = 1:1), clear CHxF by reading or writing to the low byte of the TIM channel x registers (TCHxL).

Reset clears the CHxF bit. Writing a logic one to CHxF has no effect.

- 1 = Input capture or output compare on channel x
- 0 = No input capture or output compare on channel x

CHxIE — Channel x Interrupt Enable Bit

This read/write bit enables TIM CPU interrupts and TIM DMA service requests on channel x. The DMAxS bit in the TIM DMA select register selects channel x TIM DMA service requests or TIM CPU interrupt requests.

NOTE

TIM DMA service requests cannot be used in buffered PWM mode. In buffered PWM mode, disable TIM DMA service requests by clearing the DMAxS bit in the TIM DMA select register.

Reset clears the CHxIE bit.

- 1 = Channel x CPU interrupt requests and DMA service requests enabled
- 0 = Channel x CPU interrupt requests and DMA service requests disabled

MSxB — Mode Select Bit B

This read/write bit selects buffered output compare/PWM operation. MSxB exists only in the TIM channel 0 and TIM channel 2 status and control registers.

Setting MS0B disables the channel 1 status and control register and reverts TCH1 to general-purpose I/O.

Setting MS2B disables the channel 3 status and control register and reverts TCH3 to general-purpose I/O.

Reset clears the MSxB bit.

- 1 = Buffered output compare/PWM operation enabled
- 0 = Buffered output compare/PWM operation disabled

MSxA — Mode Select Bit A

When ELSxB:A ≠ 00, this read/write bit selects either input capture operation or unbuffered output compare/PWM operation. See [Table 10-3](#).

- 1 = Unbuffered output compare/PWM operation
- 0 = Input capture operation

When ELSxB:A = 00, this read/write bit selects the initial output level of the TCHx pin. See [Table 10-3](#).

Reset clears the MSxA bit.

- 1 = Initial output level low
- 0 = Initial output level high

NOTE

Before changing a channel function by writing to the MSxB or MSxA bit, set the TSTOP and TRST bits in the TIM status and control register (TSC).

ELSxB and ELSxA — Edge/Level Select Bits

When channel x is an input capture channel, these read/write bits control the active edge-sensing logic on channel x.

When channel x is an output compare channel, ELSxB and ELSxA control the channel x output behavior when an output compare occurs.

When ELSxB and ELSxA are both clear, channel x is not connected to port E, and pin PTE_x/TCH_x is available as a general-purpose I/O pin. Table 10-3 shows how ELSxB and ELSxA work. Reset clears the ELSxB and ELSxA bits.

Table 10-3. Mode, Edge, and Level Selection

MSxB:MSxA	ELSxB:ELSxA	Mode	Configuration
X0	00	Output Preset	Pin under Port Control; Initial Output Level High
X1	00		Pin under Port Control; Initial Output Level Low
00	01	Input Capture	Capture on Rising Edge Only
00	10		Capture on Falling Edge Only
00	11		Capture on Rising or Falling Edge
01	01	Output Compare or PWM	Toggle Output on Compare
01	10		Clear Output on Compare
01	11		Set Output on Compare
1X	01	Buffered Output Compare or Buffered PWM	Toggle Output on Compare
1X	10		Clear Output on Compare
1X	11		Set Output on Compare

NOTE

Before enabling a TIM channel register for input capture operation, make sure that the PTE/TCH_x pin is stable for at least two bus clocks.

TOV_x — Toggle On Overflow Bit

When channel x is an output compare channel, this read/write bit controls the behavior of the channel x output when the TIM counter overflows. When channel x is an input capture channel, TOV_x has no effect. Reset clears the TOV_x bit.

- 1 = Channel x pin toggles on TIM counter overflow.
- 0 = Channel x pin does not toggle on TIM counter overflow.

NOTE

When TOV_x is set, a TIM counter overflow takes precedence over a channel x output compare if both occur at the same time.

CHxMAX — Channel x Maximum Duty Cycle Bit

When the TOV_x bit is at logic zero, setting the CHxMAX bit forces the duty cycle of buffered and unbuffered PWM signals to 100%. As Figure 10-8 shows, the CHxMAX bit takes effect in the cycle after it is set or cleared. The output stays at the 100% duty cycle level until the cycle after CHxMAX is cleared.

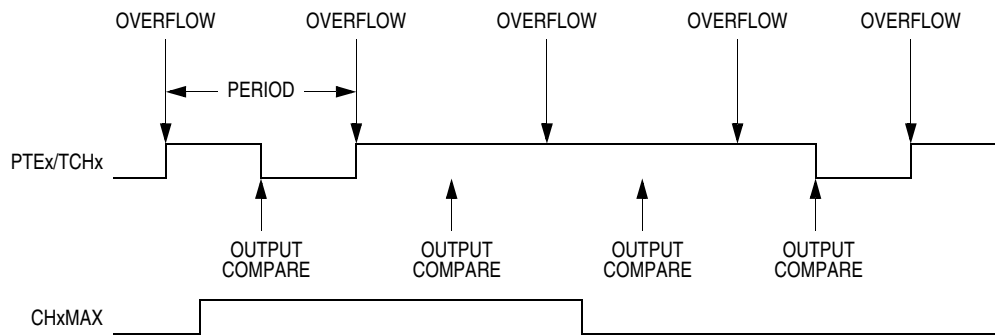


Figure 10-8. CHxMAX Latency

10.8.6 TIM Channel Registers (TCH0H/L:TCH3H/L)

These read/write registers contain the captured TIM counter value of the input capture function or the output compare value of the output compare function. The state of the TIM channel registers after reset is unknown.

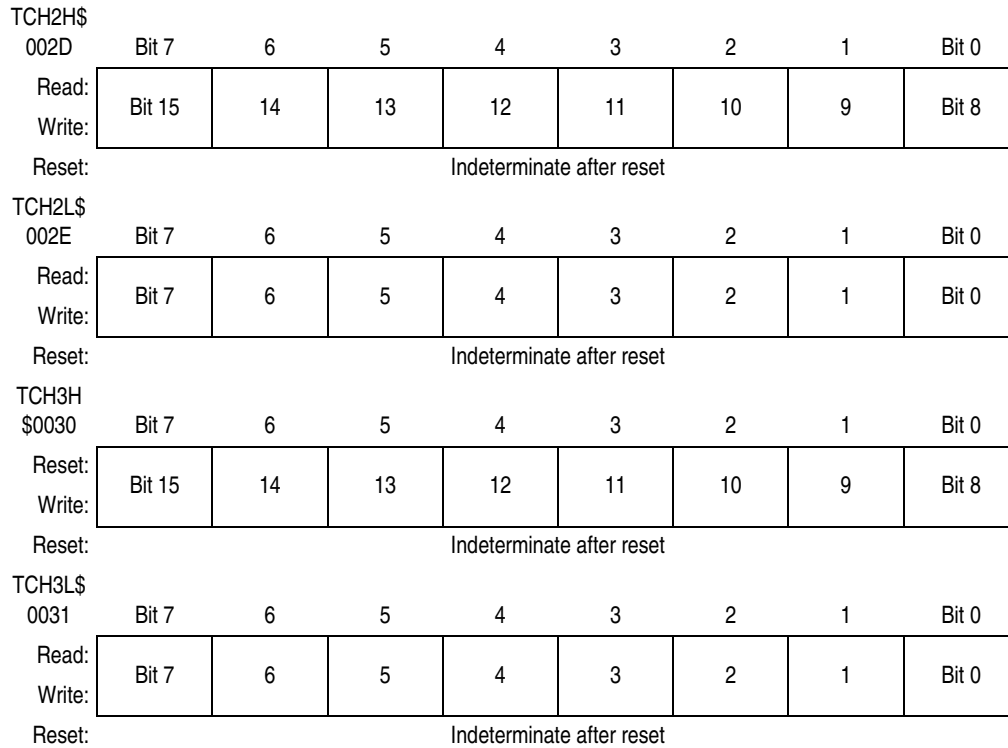
In input capture mode ($MSxB:MSxA = 0:0$), reading the high byte of the TIM channel x registers (TCHxH) inhibits input captures until the low byte (TCHxL) is read.

In output compare mode ($MSxB:MSxA \neq 0:0$), writing to the high byte of the TIM channel x registers (TCHxH) inhibits output compares until the low byte (TCHxL) is written.

TCH0H								
\$0027	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 15	14	13	12	11	10	9	Bit 8
Write:	Bit 15	14	13	12	11	10	9	Bit 8
Reset:	Indeterminate after reset							
TCH0L								
\$0028	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 7	6	5	4	3	2	1	Bit 0
Write:	Bit 7	6	5	4	3	2	1	Bit 0
Reset:	Indeterminate after reset							
TCH1H\$								
002A	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 15	14	13	12	11	10	9	Bit 8
Write:	Bit 15	14	13	12	11	10	9	Bit 8
Reset:	Indeterminate after reset							
TCH1L\$								
002B	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Bit 7	6	5	4	3	2	1	Bit 0
Write:	Bit 7	6	5	4	3	2	1	Bit 0
Reset:	Indeterminate after reset							

Figure 10-9. TIM Channel Registers (TCH0H/L:TCH3H/L) (Sheet 1 of 2)

Timer Interface Module (TIM)



**Figure 10-9. TIM Channel Registers
(TCH0H/L:TCH3H/L) (Sheet 2 of 2)**

Chapter 11

Serial Peripheral Interface Module (SPI)

11.1 Introduction

This section describes the serial peripheral interface module (SPI, Version C), which allows full-duplex, synchronous, serial communications with peripheral devices.

11.2 Features

Features of the SPI module include:

- Full-Duplex Operation
- Master and Slave Modes
- Double-Buffered Operation with Separate Transmit and Receive Registers
- Four Master Mode Frequencies (Maximum = Bus Frequency \div 2)
- Maximum Slave Mode Frequency = Bus Frequency
- Clock Ground for Reduced Radio Frequency (RF) Interference
- Serial Clock with Programmable Polarity and Phase
- Two Separately Enabled Interrupts with DMA or CPU Service:
 - SPRF (SPI Receiver Full)
 - SPTE (SPI Transmitter Empty)
- Mode Fault Error Flag with CPU Interrupt Capability
- Overflow Error Flag with CPU Interrupt Capability
- Programmable Wired-OR Mode
- I²C (Inter-Integrated Circuit) Compatibility

NOTE

References to DMA and associated functions are only valid if the MCU has a DMA module. If the MCU has no DMA, any DMA related register bits should be left in their reset state for expected MCU operation.

11.3 Pin Name Conventions and I/O Register Addresses

The text that follows describes both SPI1 and SPI2. The SPI I/O pin names are \overline{SS} (slave select), SPSCCK (SPI serial clock), CGND (clock ground), MOSI (master out slave in), and MISO (master in slave out). The two SPIs share eight I/O pins with one parallel I/O ports. The full names of the SPI I/O pins are shown in [Table 11-1](#).

Table 11-1. Pin Name Conventions

SPI Generic Pin Names:		MISO	MOSI	\overline{SS}	SCK	CGND
Full SPI Pin Names:	SPI1	PTD0/MISO1	PTD1/MOSI1	PTD2/ $\overline{SS1}$	PTD3/SCK1	CGND
	SPI2	PTD7/MISO2	PTD6/MOSI2	PTD5/ $\overline{SS2}$	PTD4/SCK2	CGND

Table 11-2. I/O Register Addresses

Register Name	Register Address
SPI1 Control Register (SPI1CR)	\$0010
SPI1 Status and Control Register (SPI1SCR)	\$0011
SPI1 Data Register (SPI1DR)	\$0012
SPI2 Control Register (SPI2CR)	\$001C
SPI2 Status and Control Register (SPI2SCR)	\$001D
SPI2 Data Register (SPI2DR)	\$001E

The generic pins names appear in the text that follows.

11.4 Functional Description

[Figure 11-1](#) summarizes the SPI I/O registers and [Figure 11-2](#) shows the structure of the SPI module.

Register Name	R/W	Bit 7	6	5	4	3	2	1	Bit 0
SPI Control Register (SPCR)	Read:	SPRIE	DMAS	SPMSTR	CPOL	CPHA	SPWOM	SPE	SPTIE
	Write:								
	Reset:	0	0	1	0	1	0	0	0
SPI Status and Control Register (SPSCR)	Read:	SPRF	ERRIE	OVRF	MODF	SPTE	MODFEN	SPR1	SPR0
	Write:								
	Reset:	0	0	0	0	1	0	0	0
SPI Data Register (SPDR)	Read:	R7	R6	R5	R4	R3	R2	R1	R0
	Write:	T7	T6	T5	T4	T3	T2	T1	T0
	Reset:	Unaffected by reset							

= Unimplemented

Figure 11-1. SPI I/O Register Summary

11.4.1 Master Mode

The SPI operates in master mode when the SPI master bit, SPMSTR, is set.

NOTE

Configure the SPI modules as master or slave before enabling them. Enable the master SPI before enabling the slave SPI. Disable the slave SPI before disabling the master SPI. (See 11.13.1 SPI Control Register.)

Only a master SPI module can initiate transmissions. Software begins the transmission from a master SPI module by writing to the transmit data register. If the shift register is empty, the byte immediately transfers to the shift register, setting the SPI transmitter empty bit, SPTE. The byte begins shifting out on the MOSI pin under the control of the serial clock. See Figure 11-3

The SPR1 and SPR0 bits control the baud rate generator and determine the speed of the shift register. (See 11.13.2 SPI Status and Control Register.) Through the SPSCCK pin, the baud rate generator of the master also controls the shift register of the slave peripheral.

As the byte shifts out on the MOSI pin of the master, another byte shifts in from the slave on the master's MISO pin. The transmission ends when the receiver full bit, SPRF, becomes set. At the same time that SPRF becomes set, the byte from the slave transfers to the receive data register. In normal operation, SPRF signals the end of a transmission. Software clears SPRF by reading the SPI status and control register with SPRF set and then reading the SPI data register. Writing to the SPI data register clears the SPTE bit.

When the DMAS bit is set, the SPI status and control register does not have to be read to clear the SPRF bit. A read of the SPI data register by either the CPU or the DMA clears the SPRF bit. A write to the SPI data register by the CPU or by the DMA clears the SPTE bit.

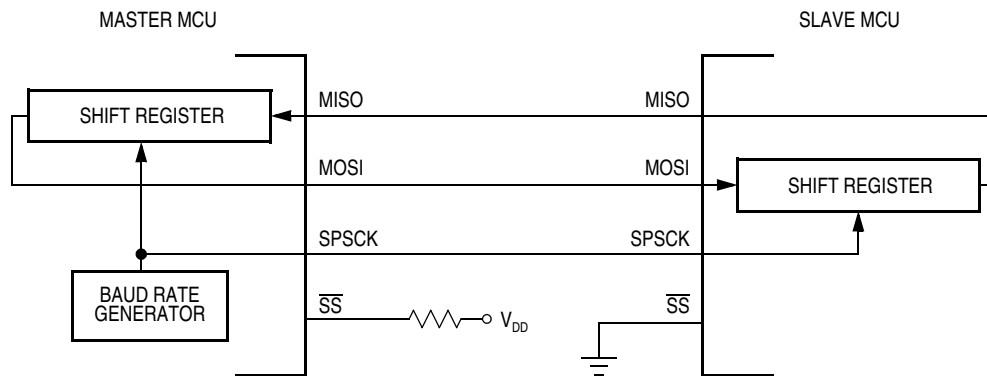


Figure 11-3. Full-Duplex Master-Slave Connections

11.4.2 Slave Mode

The SPI operates in slave mode when the SPMSTR bit is clear. In slave mode the SPSCCK pin is the input for the serial clock from the master MCU. Before a data transmission occurs, the \overline{SS} pin of the slave SPI must be at logic zero. \overline{SS} must remain low until the transmission is complete. (See 11.7.2 Mode Fault Error.)

In a slave SPI module, data enters the shift register under the control of the serial clock from the master SPI module. After a byte enters the shift register of a slave SPI, it transfers to the receive data register, and the SPRF bit is set. To prevent an overflow condition, slave software then must read the receive data register before another full byte enters the shift register.

The maximum frequency of the SPSCCK for an SPI configured as a slave is the bus clock speed (which is twice as fast as the fastest master SPSCCK clock that can be generated). The frequency of the SPSCCK for an SPI configured as a slave does not have to correspond to any SPI baud rate. The baud rate only controls the speed of the SPSCCK generated by an SPI configured as a master. Therefore, the frequency of the SPSCCK for an SPI configured as a slave can be any frequency less than or equal to the bus speed.

When the master SPI starts a transmission, the data in the slave shift register begins shifting out on the MISO pin. The slave can load its shift register with a new byte for the next transmission by writing to its transmit data register. The slave must write to its transmit data register at least one bus cycle before the master starts the next transmission. Otherwise the byte already in the slave shift register shifts out on the MISO pin. Data written to the slave shift register during a transmission remains in a buffer until the end of the transmission.

When the clock phase bit (CPHA) is set, the first edge of SPSCCK starts a transmission. When CPHA is clear, the falling edge of \overline{SS} starts a transmission. (See [11.5 Transmission Formats](#).)

NOTE

SPSCCK must be in the proper idle state before the slave is enabled to prevent SPSCCK from appearing as a clock edge.

11.5 Transmission Formats

During an SPI transmission, data is simultaneously transmitted (shifted out serially) and received (shifted in serially). A serial clock synchronizes shifting and sampling on the two serial data lines. A slave select line allows selection of an individual slave SPI device; slave devices that are not selected do not interfere with SPI bus activities. On a master SPI device, the slave select line can optionally be used to indicate multiple-master bus contention.

11.5.1 Clock Phase and Polarity Controls

Software can select any of four combinations of serial clock (SPSCCK) phase and polarity using two bits in the SPI control register (SPCR). The clock polarity is specified by the CPOL control bit, which selects an active high or low clock and has no significant effect on the transmission format.

The clock phase (CPHA) control bit selects one of two fundamentally different transmission formats. The clock phase and polarity should be identical for the master SPI device and the communicating slave device. In some cases, the phase and polarity are changed between transmissions to allow a master device to communicate with peripheral slaves having different requirements.

NOTE

Before writing to the CPOL bit or the CPHA bit, disable the SPI by clearing the SPI enable bit (SPE).

11.5.2 Transmission Format When CPHA = 0

[Figure 11-4](#) shows an SPI transmission in which CPHA is logic zero. The figure should not be used as a replacement for data sheet parametric information. Two waveforms are shown for SPSCCK: one for CPOL = 0 and another for CPOL = 1. The diagram may be interpreted as a master or slave timing diagram since the serial clock (SPSCCK), master in/slave out (MISO), and master out/slave in (MOSI) pins are directly connected between the master and the slave. The MISO signal is the output from the slave, and the MOSI signal is the output from the master. The \overline{SS} line is the slave select input to the slave. The slave SPI drives its MISO output only when its slave select input (\overline{SS}) is at logic zero, so that only the

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selected slave drives to the master. The \overline{SS} pin of the master is not shown but is assumed to be inactive. The \overline{SS} pin of the master must be high or must be reconfigured as general-purpose I/O not affecting the SPI. (See [11.7.2 Mode Fault Error](#).) When $CPHA = 0$, the first SPSCCK edge is the MSB capture strobe. Therefore the slave must begin driving its data before the first SPSCCK edge, and a falling edge on the \overline{SS} pin is used to start the slave data transmission. The slave's \overline{SS} pin must be toggled back to high and then low again between each byte transmitted as shown in [Figure 11-5](#).

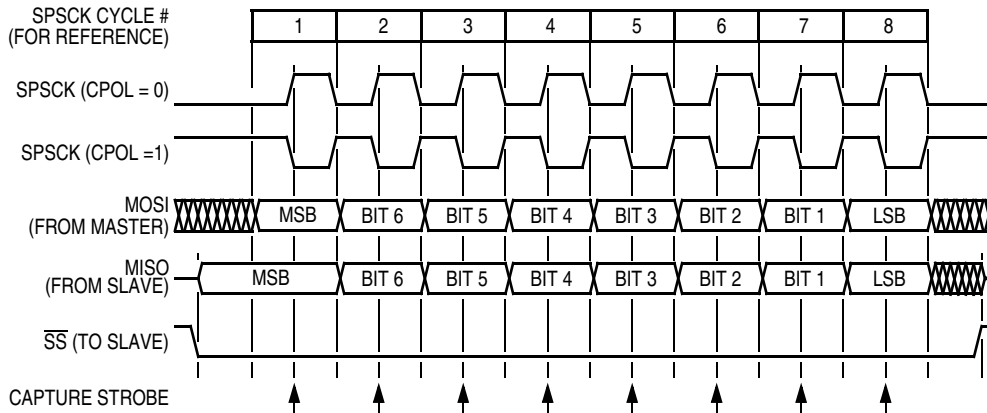


Figure 11-4. Transmission Format (CPHA = 0)

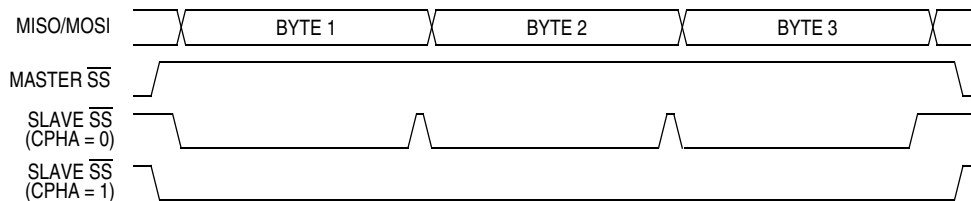


Figure 11-5. CPHA/SS Timing

When $CPHA = 0$ for a slave, the falling edge of \overline{SS} indicates the beginning of the transmission. This causes the SPI to leave its idle state and begin driving the MISO pin with the MSB of its data. Once the transmission begins, no new data is allowed into the shift register from the transmit data register. Therefore, the SPI data register of the slave must be loaded with transmit data before the falling edge of \overline{SS} . Any data written after the falling edge is stored in the transmit data register and transferred to the shift register after the current transmission.

11.5.3 Transmission Format When $CPHA = 1$

[Figure 11-6](#) shows an SPI transmission in which $CPHA$ is logic one. The figure should not be used as a replacement for data sheet parametric information. Two waveforms are shown for SPSCCK: one for $CPOL = 0$ and another for $CPOL = 1$. The diagram may be interpreted as a master or slave timing diagram since the serial clock (SPSCCK), master in/slave out (MISO), and master out/slave in (MOSI) pins are directly connected between the master and the slave. The MISO signal is the output from the slave, and the MOSI signal is the output from the master. The \overline{SS} line is the slave select input to the slave. The slave SPI drives its MISO output only when its slave select input (\overline{SS}) is at logic zero, so that only the selected slave drives to the master. The \overline{SS} pin of the master is not shown but is assumed to be inactive. The \overline{SS} pin of the master must be high or must be reconfigured as general-purpose I/O not affecting the

SPI. (See [11.7.2 Mode Fault Error](#).) When $CPHA = 1$, the master begins driving its MOSI pin on the first SPSCCK edge. Therefore the slave uses the first SPSCCK edge as a start transmission signal. The \overline{SS} pin can remain low between transmissions. This format may be preferable in systems having only one master and only one slave driving the MISO data line.

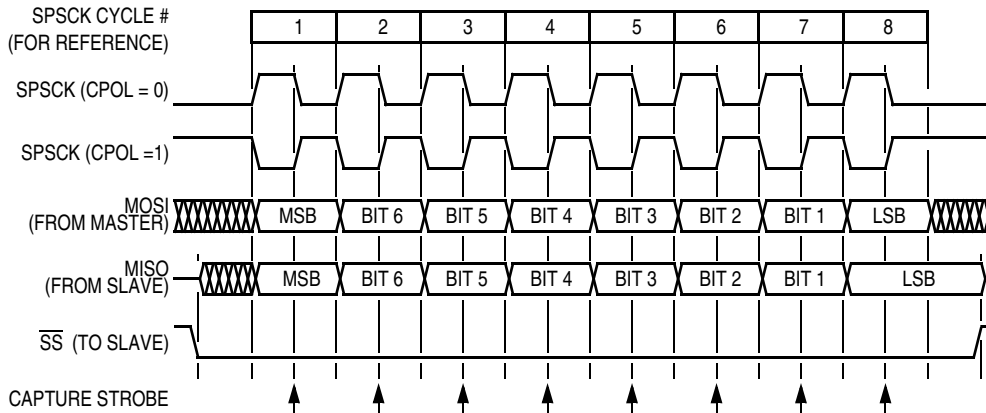


Figure 11-6. Transmission Format ($CPHA = 1$)

When $CPHA = 1$ for a slave, the first edge of the SPSCCK indicates the beginning of the transmission. This causes the SPI to leave its idle state and begin driving the MISO pin with the MSB of its data. Once the transmission begins, no new data is allowed into the shift register from the transmit data register. Therefore, the SPI data register of the slave must be loaded with transmit data before the first edge of SPSCCK. Any data written after the first edge is stored in the transmit data register and transferred to the shift register after the current transmission.

11.5.4 Transmission Initiation Latency

When the SPI is configured as a master ($SPMSTR = 1$), writing to the SPDR starts a transmission. $CPHA$ has no effect on the delay to the start of the transmission, but it does affect the initial state of the SPSCCK signal. When $CPHA = 0$, the SPSCCK signal remains inactive for the first half of the first SPSCCK cycle. When $CPHA = 1$, the first SPSCCK cycle begins with an edge on the SPSCCK line from its inactive to its active level. The SPI clock rate (selected by $SPR1:SPR0$) affects the delay from the write to SPDR and the start of the SPI transmission. (See [Figure 11-7](#).) The internal SPI clock in the master is a free-running derivative of the internal MCU clock. To conserve power, it is enabled only when both the SPE and SPMSTR bits are set. SPSCCK edges occur halfway through the low time of the internal MCU clock. Since the SPI clock is free-running, it is uncertain where the write to the SPDR occurs relative to the slower SPSCCK. This uncertainty causes the variation in the initiation delay shown in [Figure 11-7](#). This delay is no longer than a single SPI bit time. That is, the maximum delay is two MCU bus cycles for DIV2, eight MCU bus cycles for DIV8, 32 MCU bus cycles for DIV32, and 128 MCU bus cycles for DIV128.

11.6 Queuing Transmission Data

The double-buffered transmit data register allows a data byte to be queued and transmitted. For an SPI configured as a master, a queued data byte is transmitted immediately after the previous transmission has completed. The SPI transmitter empty flag (SPTE) indicates when the transmit data buffer is ready to accept new data. Write to the transmit data register only when the SPTE bit is high. [Figure 11-8](#) shows the timing associated with doing back-to-back transmissions with the SPI (SPSCCK has $CPHA:CPOL = 1:0$).

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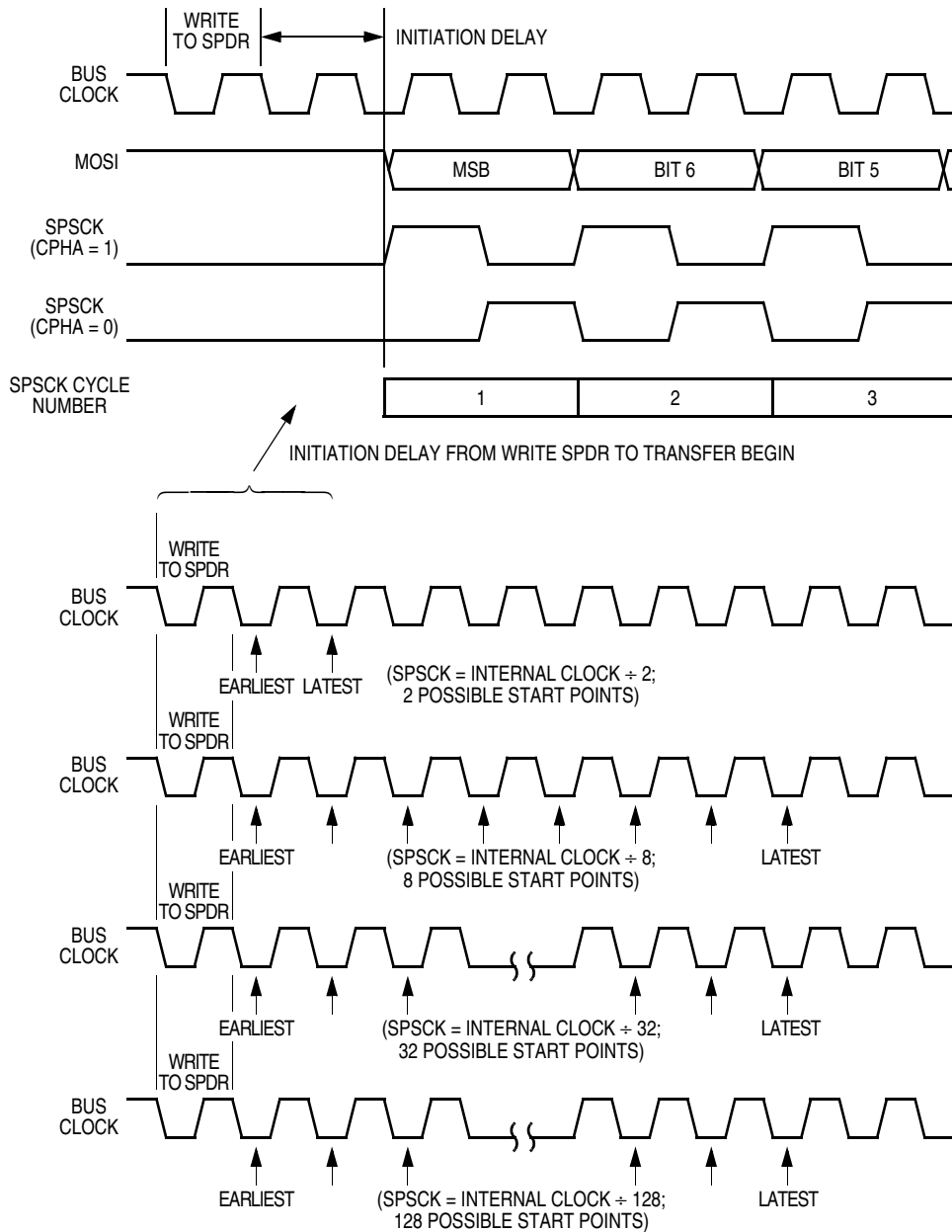


Figure 11-7. Transmission Start Delay (Master)

The transmit data buffer allows back-to-back transmissions without the slave precisely timing its writes between transmissions as in a system with a single data buffer. Also, if no new data is written to the data buffer, the last value contained in the shift register is the next data word to be transmitted.

For an idle master or idle slave that has no data loaded into its transmit buffer, the SPTE is set again no more than two bus cycles after the transmit buffer empties into the shift register. This allows the user to queue up a 16-bit value to send. For an already active slave, the load of the shift register cannot occur until the transmission is completed. This implies that a back-to-back write to the transmit data register is not possible. The SPTE indicates when the next write can occur.

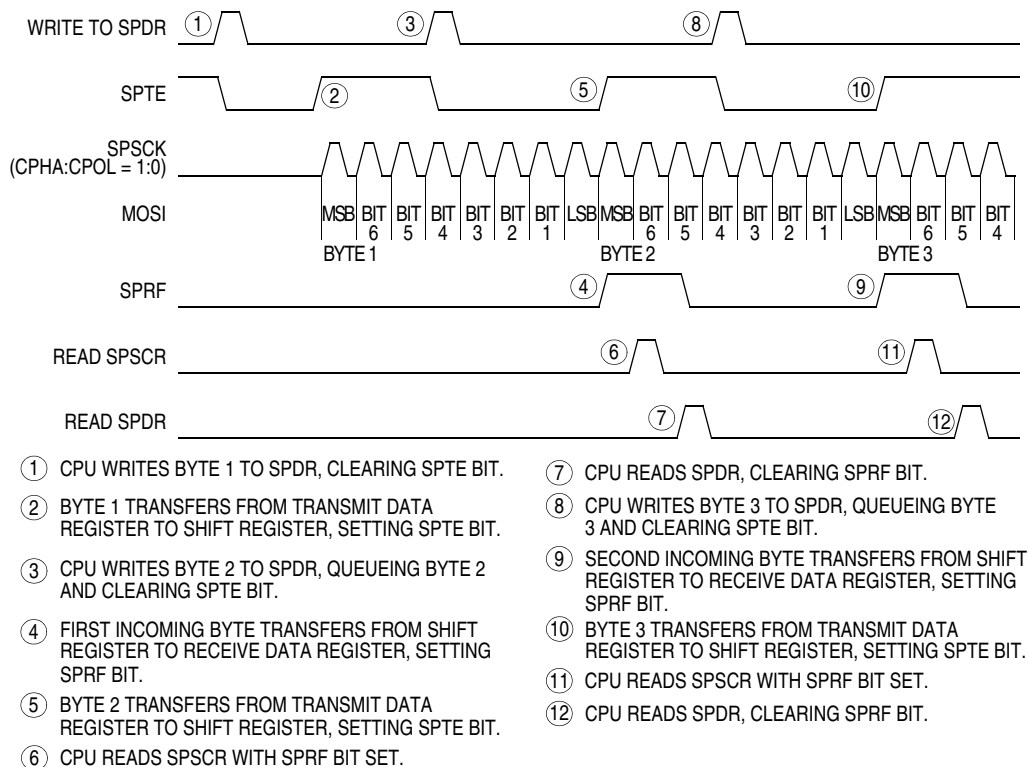


Figure 11-8. SPRF/SPTE CPU Interrupt Timing

11.7 Error Conditions

The following flags signal SPI error conditions:

- **Overflow (OVRF)** — Failing to read the SPI data register before the next full byte enters the shift register sets the OVRF bit. The new byte does not transfer to the receive data register, and the unread byte still can be read. OVRF is in the SPI status and control register.
- **Mode fault error (MODF)** — The MODF bit indicates that the voltage on the slave select pin (\overline{SS}) is inconsistent with the mode of the SPI. MODF is in the SPI status and control register.

11.7.1 Overflow Error

The overflow flag (OVRF) becomes set if the receive data register still has unread data from a previous transmission when the capture strobe of bit 1 of the next transmission occurs. The bit 1 capture strobe occurs in the middle of SPSCK cycle 7. (See [Figure 11-4](#) and [Figure 11-6](#).) If an overflow occurs, all data received after the overflow and before the OVRF bit is cleared does not transfer to the receive data register and does not set the SPI receiver full bit (SPRF). The unread data that transferred to the receive data register before the overflow occurred can still be read. Therefore, an overflow error always indicates the loss of data. Clear the overflow flag by reading the SPI status and control register and then reading the SPI data register.

OVRF generates a receiver/error CPU interrupt request if the error interrupt enable bit (ERRIE) is also set. When the DMAS bit is low, the SPRF, MODF, and OVRF interrupts share the same CPU interrupt vector. When the DMAS bit is high, SPRF generates a receiver DMA service request, and MODF and OVRF can generate a receiver/error CPU interrupt request. (See [Figure 11-12](#).) It is not possible to enable

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MODF or OVRF individually to generate a receiver/error CPU interrupt request. However, leaving MODFEN low prevents MODF from being set.

When the DMA is enabled to service the SPRF flag, it clears SPRF when it reads the receive data register. The OVRF bit, however, still requires the two-step clearing mechanism of reading the flag when it is set and then reading the receive data register. In this way, the DMA cannot directly clear the OVRF. However, if the CPU reads the SPI status and control register with the OVRF bit set, and then the DMA reads the receive data register, the OVRF bit is cleared.

OVRF interrupt requests to the CPU should be enabled when using the DMA to service the SPRF if there is any chance that the overflow condition might occur. (See [Figure 11-9](#).) Even if the DMA clears the SPRF bit, no new data transfers from the shift register to the receive data register with the OVRF bit high. This means that no new SPRF interrupt requests are generated until the CPU clears the OVRF bit. If the CPU reads the data register to clear the OVRF bit, it could clear a pending SPRF service request to the DMA.

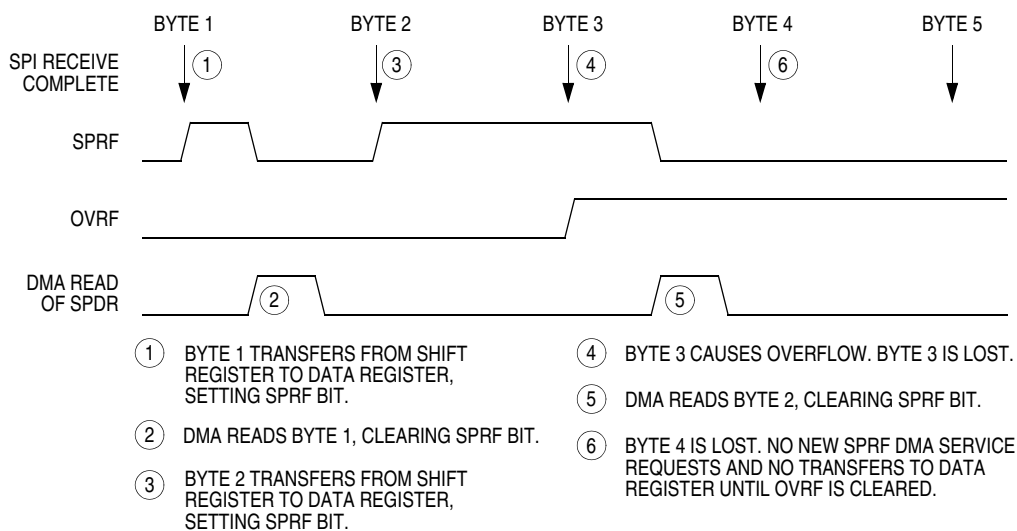


Figure 11-9. Overflow Condition with DMA Service of SPRF

The overflow service routine may need to disable the DMA and manually recover since an overflow indicates the loss of data. Loss of data may prevent the DMA from reaching its byte count.

If your application requires the DMA to bring the MCU out of wait mode, enable the OVRF bit to generate CPU interrupt requests. An overflow condition in wait mode can cause the MCU to hang in wait mode because the DMA cannot reach its byte count. Setting the error interrupt enable bit (ERRIE) in the SPI status and control register enables the OVRF bit to bring the MCU out of wait mode.

If the CPU SPRF interrupt is enabled and the OVRF interrupt is not, watch for an overflow condition. [Figure 11-10](#) shows how it is possible to miss an overflow. The first part of [Figure 11-10](#) shows how it is possible to read the SPSCR and SPDR to clear the SPRF without problems. However, as illustrated by the second transmission example, the OVRF bit can be set in between the time that SPSCR and SPDR are read.

In this case, an overflow can easily be missed. Since no more SPRF interrupts can be generated until this OVRF is serviced, it is not obvious that bytes are being lost as more transmissions are completed. To prevent this, either enable the OVRF interrupt or do another read of the SPSCR following the read of the SPDR. This ensures that the OVRF was not set before the SPRF was cleared and that future

transmissions can set the SPRF bit. [Figure 11-11](#) illustrates this process. Generally, to avoid this second SPSCR read, enable the OVRF to the CPU by setting the ERRIE bit.

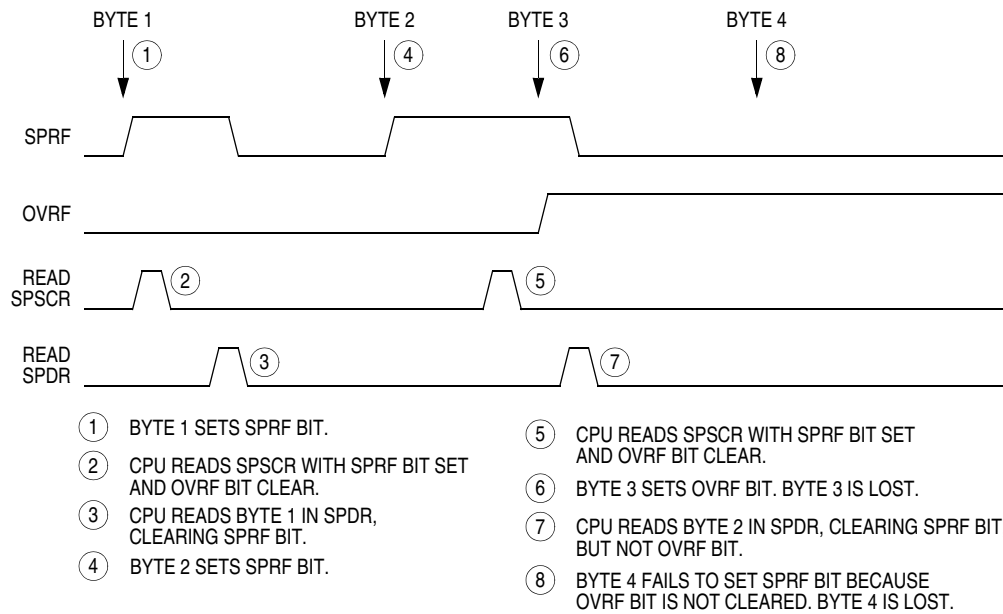


Figure 11-10. Missed Read of Overflow Condition

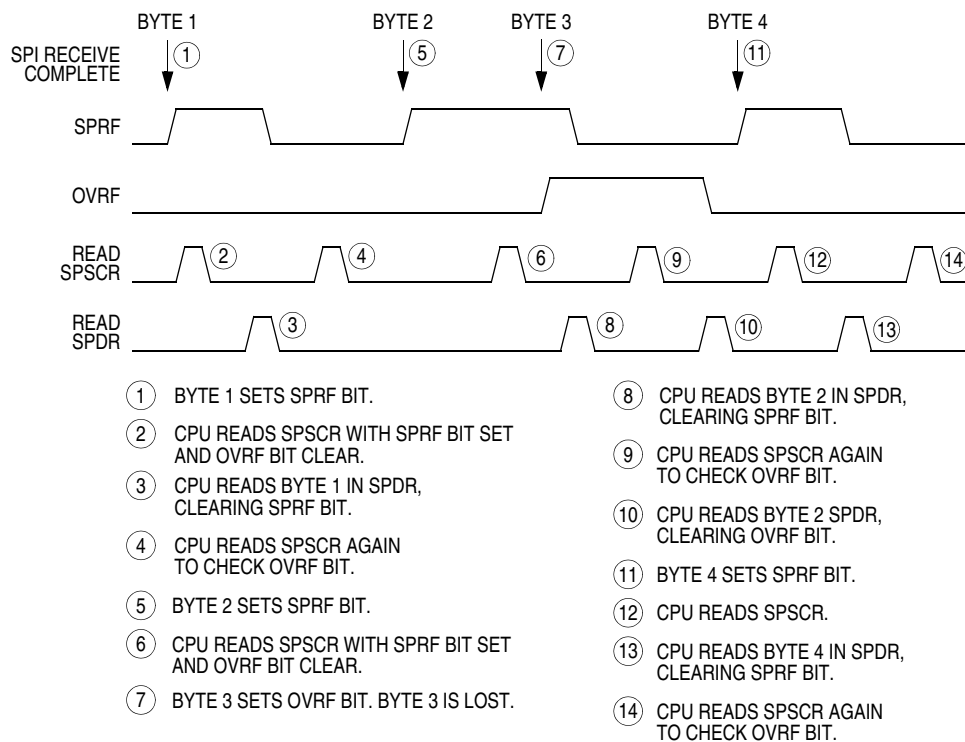


Figure 11-11. Clearing SPRF When OVRF Interrupt Is Not Enabled

11.7.2 Mode Fault Error

Setting the SPMSTR bit selects master mode and configures the SPSCCK and MOSI pins as outputs and the MISO pin as an input. Clearing SPMSTR selects slave mode and configures the SPSCCK and MOSI pins as inputs and the MISO pin as an output. The mode fault bit, MODF, becomes set any time the state of the slave select pin, \overline{SS} , is inconsistent with the mode selected by SPMSTR. To prevent SPI pin contention and damage to the MCU, a mode fault error occurs if:

- The \overline{SS} pin of a slave SPI goes high during a transmission
- The \overline{SS} pin of a master SPI goes low at any time.

For the MODF flag to be set, the mode fault error enable bit (MODFEN) must be set. Clearing the MODFEN bit does not clear the MODF flag but does prevent MODF from being set again after MODF is cleared.

MODF generates a receiver/error CPU interrupt request if the error interrupt enable bit (ERRIE) is also set. When the DMAS bit is low, the SPRF, MODF, and OVRF interrupts share the same CPU interrupt vector. When the DMAS bit is high, SPRF generates a receiver DMA service request instead of a CPU interrupt request, but MODF and OVRF can generate a receiver/error CPU interrupt request. (See [Figure 11-12](#).) It is not possible to enable MODF or OVRF individually to generate a receiver/error CPU interrupt request. However, leaving MODFEN low prevents MODF from being set.

In a master SPI with the mode fault enable bit (MODFEN) set, the mode fault flag (MODF) is set if \overline{SS} goes to logic zero. A mode fault in a master SPI causes the following events to occur:

- If ERRIE = 1, the SPI generates an SPI receiver/error CPU interrupt request.
- The SPE bit is cleared.
- The SPTE bit is set.
- The SPI state counter is cleared.
- The data direction register of the shared I/O port regains control of port drivers.

NOTE

To prevent bus contention with another master SPI after a mode fault error, clear all SPI bits of the data direction register of the shared I/O port before enabling the SPI.

When configured as a slave (SPMSTR = 0), the MODF flag is set if \overline{SS} goes high during a transmission. When CPHA = 0, a transmission begins when \overline{SS} goes low and ends once the incoming SPSCCK goes back to its idle level following the shift of the eighth data bit. When CPHA = 1, the transmission begins when the SPSCCK leaves its idle level and \overline{SS} is already low. The transmission continues until the SPSCCK returns to its idle level following the shift of the last data bit. (See [11.5 Transmission Formats](#).)

NOTE

Setting the MODF flag does not clear the SPMSTR bit. The SPMSTR bit has no function when SPE = 0. Reading SPMSTR when MODF = 1 shows the difference between a MODF occurring when the SPI is a master and when it is a slave.

When CPHA = 0, a MODF occurs if a slave is selected (\overline{SS} is at logic 0) and later unselected (\overline{SS} is at logic 1) even if no SPSCCK is sent to that slave. This happens because \overline{SS} at logic 0 indicates the start of the transmission (MISO driven out with the value of MSB) for CPHA = 0. When CPHA = 1, a slave can be selected and then later unselected with no transmission

occurring. Therefore, MODF does not occur since a transmission was never begun.

In a slave SPI (MSTR = 0), the MODF bit generates an SPI receiver/error CPU interrupt request if the ERRIE bit is set. The MODF bit does not clear the SPE bit or reset the SPI in any way. Software can abort the SPI transmission by clearing the SPE bit of the slave.

NOTE

A logic one voltage on the \overline{SS} pin of a slave SPI puts the MISO pin in a high impedance state. Also, the slave SPI ignores all incoming SPSCCK clocks, even if it was already in the middle of a transmission.

To clear the MODF flag, read the SPSCR with the MODF bit set and then write to the SPCR register. This entire clearing mechanism must occur with no MODF condition existing or else the flag is not cleared.

11.8 Interrupts

Four SPI status flags can be enabled to generate CPU interrupt requests or DMA service requests:

Table 11-3. SPI Interrupts

Flag	Request
SPTIE (Transmitter Empty)	SPI Transmitter CPU Interrupt Request (DMAS = 0, SPTIE = 1, SPE = 1) SPI Transmitter DMA Service Request (DMAS = 1, SPTIE = 1, SPE = 1)
SPRF (Receiver Full)	SPI Receiver CPU Interrupt Request (DMAS = 0, SPRIE = 1) SPI Receiver DMA Service Request (DMAS = 1, SPRIE = 1)
OVRF (Overflow)	SPI Receiver/Error Interrupt Request (ERRIE = 1)
MODF (Mode Fault)	SPI Receiver/Error Interrupt Request (ERRIE = 1)

The DMA select bit (DMAS) controls whether SPTIE and SPRF generate CPU interrupt requests or DMA service requests. When DMAS = 0, reading the SPI status and control register with SPRF set and then reading the receive data register clears SPRF. When DMAS = 1, any read of the receive data register clears the SPRF flag. The clearing mechanism for the SPTIE flag is always just a write to the transmit data register.

The SPI transmitter interrupt enable bit (SPTIE) enables the SPTIE flag to generate transmitter CPU interrupt requests or transmitter DMA service requests, provided that the SPI is enabled (SPE = 1).

The SPI receiver interrupt enable bit (SPRIE) enables the SPRF bit to generate receiver CPU interrupt requests or receiver DMA service requests, regardless of the state of the SPE bit. (See [Figure 11-12](#).)

The error interrupt enable bit (ERRIE) enables both the MODF and OVRF bits to generate a receiver/error CPU interrupt request.

The mode fault enable bit (MODFEN) can prevent the MODF flag from being set so that only the OVRF bit is enabled by the ERRIE bit to generate receiver/error CPU interrupt requests.

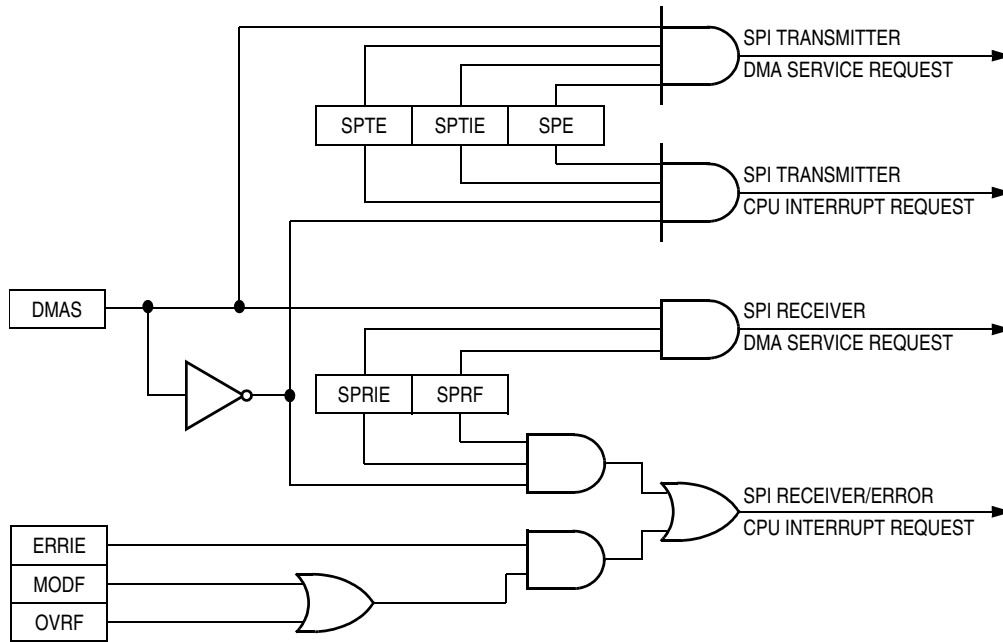


Figure 11-12. SPI Interrupt Request Generation

The following sources in the SPI status and control register can generate CPU interrupt requests or DMA service requests:

- SPI receiver full bit (SPRF) — The SPRF bit becomes set every time a byte transfers from the shift register to the receive data register. If the SPI receiver interrupt enable bit, SPRIE, is also set, SPRF can generate either an SPI receiver/error CPU interrupt request or an SPRF DMA service request.

If the DMA select bit, DMAS, is clear, SPRF generates an SPRF CPU interrupt request. If DMAS is set, SPRF generates an SPRF DMA service request.
- SPI transmitter empty (SPTE) — The SPTE bit becomes set every time a byte transfers from the transmit data register to the shift register. If the SPI transmit interrupt enable bit, SPTIE, is also set, SPTE can generate either an SPTE CPU interrupt request or an SPTE DMA service request.

If the DMAS bit is clear, SPTE generates an SPTE CPU interrupt request. If DMAS is set, SPTE generates an SPTE DMA service request.

11.9 Resetting the SPI

Any system reset completely resets the SPI. Partial resets occur whenever the SPI enable bit (SPE) is low. Whenever SPE is low, the following occurs:

- The SPTE flag is set
- Any transmission currently in progress is aborted
- The shift register is cleared
- The SPI state counter is cleared, making it ready for a new complete transmission
- All the SPI port logic is defaulted back to being general purpose I/O.

The following items are reset only by a system reset:

- All control bits in the SPCR register
- All control bits in the SPSCR register (MODFEN, ERRIE, SPR1, and SPR0)
- The status flags SPRF, OVRF, and MODF

By not resetting the control bits when SPE is low, the user can clear SPE between transmissions without having to set all control bits again when SPE is set back high for the next transmission.

By not resetting the SPRF, OVRF, and MODF flags, the user can still service these interrupts after the SPI has been disabled. The user can disable the SPI by writing 0 to the SPE bit. The SPI can also be disabled by a mode fault occurring in an SPI that was configured as a master with the MODFEN bit set.

11.10 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power-consumption standby modes.

11.10.1 Wait Mode

The SPI module remains active after the execution of a WAIT instruction. In wait mode the SPI module registers are not accessible by the CPU. Any enabled CPU interrupt request from the SPI module can bring the MCU out of wait mode.

If SPI module functions are not required during wait mode, reduce power consumption by disabling the SPI module before executing the WAIT instruction.

The DMA can service DMA service requests generated by the SPTE and SPRF flags without exiting wait mode. To exit wait mode when an overflow condition occurs, enable the OVRF bit to generate CPU interrupt requests by setting the error interrupt enable bit (ERRIE). (See [11.8 Interrupts](#).)

11.10.2 Stop Mode

The SPI module is inactive after the execution of a STOP instruction. The STOP instruction does not affect register conditions. SPI operation resumes after an external interrupt. If stop mode is exited by reset, any transfer in progress is aborted, and the SPI is reset.

11.11 SPI During Break Interrupts

The system integration module (SIM) controls whether status bits in other modules can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear status bits during the break state. (See [Chapter 5 System Integration Module \(SIM\)](#).)

To allow software to clear status bits during a break interrupt, write a logic one to the BCFE bit. If a status bit is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect status bits during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), software can read and write I/O registers during the break state without affecting status bits. Some status bits have a two-step read/write clearing procedure. If software does the first step on such a bit before the break, the bit cannot change during the break state as long as BCFE is at logic zero. After the break, doing the second step clears the status bit.

Since the SPTE bit cannot be cleared during a break with the BCFE bit cleared, a write to the transmit data register in break mode does not initiate a transmission, nor is this data transferred into the shift register. Therefore, a write to the SPDR in break mode with the BCFE bit cleared has no effect.

11.12 I/O Signals

The SPI module has five I/O pins and shares four of them with a parallel I/O port.

- MISO — Data received
- MOSI — Data transmitted
- SPCK — Serial clock
- \overline{SS} — Slave select
- CGND — Clock ground

The SPI has limited inter-integrated circuit (I²C) capability (requiring software support) as a master in a single-master environment. To communicate with I²C peripherals, MOSI becomes an open-drain output when the SPWOM bit in the SPI control register is set. In I²C communication, the MOSI and MISO pins are connected to a bidirectional pin from the I²C peripheral and through a pullup resistor to V_{DD}.

11.12.1 MISO (Master In/Slave Out)

MISO is one of the two SPI module pins that transmits serial data. In full duplex operation, the MISO pin of the master SPI module is connected to the MISO pin of the slave SPI module. The master SPI simultaneously receives data on its MISO pin and transmits data from its MOSI pin.

Slave output data on the MISO pin is enabled only when the SPI is configured as a slave. The SPI is configured as a slave when its SPMSTR bit is logic zero and its \overline{SS} pin is at logic zero. To support a multiple-slave system, a logic one on the \overline{SS} pin puts the MISO pin in a high-impedance state.

When enabled, the SPI controls data direction of the MISO pin regardless of the state of the data direction register of the shared I/O port.

11.12.2 MOSI (Master Out/Slave In)

MOSI is one of the two SPI module pins that transmits serial data. In full duplex operation, the MOSI pin of the master SPI module is connected to the MOSI pin of the slave SPI module. The master SPI simultaneously transmits data from its MOSI pin and receives data on its MISO pin.

When enabled, the SPI controls data direction of the MOSI pin regardless of the state of the data direction register of the shared I/O port.

11.12.3 SPCK (Serial Clock)

The serial clock synchronizes data transmission between master and slave devices. In a master MCU, the SPCK pin is the clock output. In a slave MCU, the SPCK pin is the clock input. In full duplex operation, the master and slave MCUs exchange a byte of data in eight serial clock cycles.

When enabled, the SPI controls data direction of the SPCK pin regardless of the state of the data direction register of the shared I/O port.

11.12.4 \overline{SS} (Slave Select)

The \overline{SS} pin has various functions depending on the current state of the SPI. For an SPI configured as a slave, the \overline{SS} is used to select a slave. For $CPHA = 0$, the \overline{SS} is used to define the start of a transmission. (See [11.5 Transmission Formats](#).) Since it is used to indicate the start of a transmission, the \overline{SS} must be toggled high and low between each byte transmitted for the $CPHA = 0$ format. However, it can remain low between transmissions for the $CPHA = 1$ format. See [Figure 11-13](#).

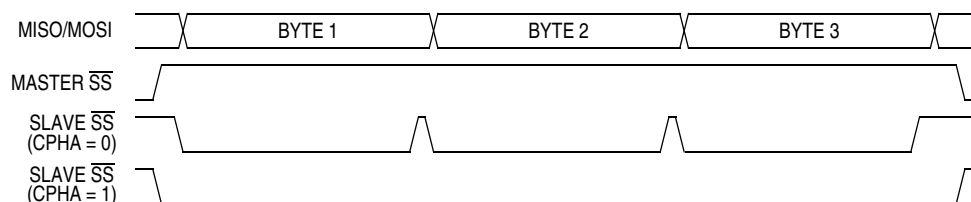


Figure 11-13. CPHA/ \overline{SS} Timing

When an SPI is configured as a slave, the \overline{SS} pin is always configured as an input. It cannot be used as a general purpose I/O regardless of the state of the MODFEN control bit. However, the MODFEN bit can still prevent the state of the \overline{SS} from creating a MODF error. (See [11.13.2 SPI Status and Control Register](#).)

NOTE

A logic one voltage on the \overline{SS} pin of a slave SPI puts the MISO pin in a high-impedance state. The slave SPI ignores all incoming SPSCCK clocks, even if it was already in the middle of a transmission.

When an SPI is configured as a master, the \overline{SS} input can be used in conjunction with the MODF flag to prevent multiple masters from driving MOSI and SPSCCK. (See [11.7.2 Mode Fault Error](#).) For the state of the \overline{SS} pin to set the MODF flag, the MODFEN bit in the SPSCCK register must be set. If the MODFEN bit is low for an SPI master, the \overline{SS} pin can be used as a general purpose I/O under the control of the data direction register of the shared I/O port. With MODFEN high, it is an input-only pin to the SPI regardless of the state of the data direction register of the shared I/O port.

The CPU can always read the state of the \overline{SS} pin by configuring the appropriate pin as an input and reading the port data register. (See [Table 11-4](#).)

Table 11-4. SPI Configuration

SPE	SPMSTR	MODFEN	SPI Configuration	State of \overline{SS} Logic
0	X ⁽¹⁾	X	Not Enabled	General-purpose I/O; \overline{SS} ignored by SPI
1	0	X	Slave	Input-only to SPI
1	1	0	Master without MODF	General-purpose I/O; \overline{SS} ignored by SPI
1	1	1	Master with MODF	Input-only to SPI

1. X = don't care

11.12.5 CGND (Clock Ground)

CGND is the ground return for the serial clock pin, SPSCCK, and the ground for the port output buffers. To reduce the ground return path loop and minimize radio frequency (RF) emissions, connect the ground pin of the slave to the CGND pin of the master.

11.13 I/O Registers

Three registers control and monitor SPI operation:

- SPI control register (SPCR)
- SPI status and control register (SPSCR)
- SPI data register (SPDR)

11.13.1 SPI Control Register

The SPI control register does the following:

- Enables SPI module interrupt requests
- Selects CPU interrupt requests or DMA service requests
- Configures the SPI module as master or slave
- Selects serial clock polarity and phase
- Configures the SPSCCK, MOSI, and MISO pins as open-drain outputs
- Enables the SPI module

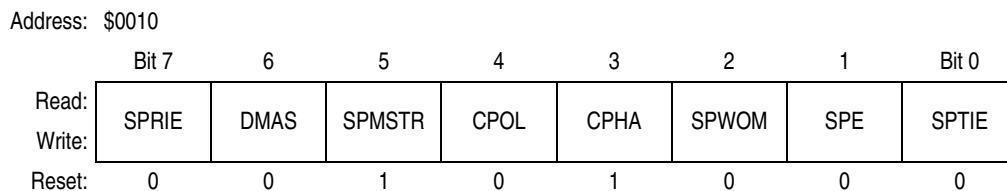


Figure 11-14. SPI Control Register (SPCR)

SPRIE — SPI Receiver Interrupt Enable Bit

This read/write bit enables CPU interrupt requests or DMA service requests generated by the SPRF bit. The SPRF bit is set when a byte transfers from the shift register to the receive data register. Reset clears the SPRIE bit.

- 1 = SPRF CPU interrupt requests or SPRF DMA service requests enabled
- 0 = SPRF CPU interrupt requests or SPRF DMA service requests disabled

DMAS —DMA Select Bit

This read/write bit selects DMA service requests when the SPI receiver full bit, SPRF, or the SPI transmitter empty bit, SPTE, becomes set. Setting the DMAS bit disables SPRF CPU interrupt requests and SPTE CPU interrupt requests. Reset clears the DMAS bit.

- 1 = SPRF DMA and SPTE DMA service requests enabled
(SPRF CPU and SPTE CPU interrupt requests disabled)
- 0 = SPRF DMA and SPTE DMA service requests disabled
(SPRF CPU and SPTE CPU interrupt requests enabled)

SPMSTR — SPI Master Bit

This read/write bit selects master mode operation or slave mode operation. Reset sets the SPMSTR bit.

- 1 = Master mode
- 0 = Slave mode

CPOL — Clock Polarity Bit

This read/write bit determines the logic state of the SPSCCK pin between transmissions. (Figure 11-4 and Figure 11-6.) To transmit data between SPI modules, the SPI modules must have identical CPOL values. Reset clears the CPOL bit.

CPHA — Clock Phase Bit

This read/write bit controls the timing relationship between the serial clock and SPI data. (See Figure 11-4 and Figure 11-6.) To transmit data between SPI modules, the SPI modules must have identical CPHA values. When CPHA = 0, the \overline{SS} pin of the slave SPI module must be set to logic one between bytes. (See Figure 11-13.) Reset sets the CPHA bit.

SPWOM — SPI Wired-OR Mode Bit

This read/write bit disables the pull-up devices on pins SPSCCK, MOSI, and MISO so that those pins become open-drain outputs.

- 1 = Wired-OR SPSCCK, MOSI, and MISO pins
- 0 = Normal push-pull SPSCCK, MOSI, and MISO pins

SPE — SPI Enable

This read/write bit enables the SPI module. Clearing SPE causes a partial reset of the SPI. (See 11.9 [Resetting the SPI](#).) Reset clears the SPE bit.

- 1 = SPI module enabled
- 0 = SPI module disabled

SPTIE— SPI Transmit Interrupt Enable

This read/write bit enables CPU interrupt requests or DMA service requests generated by the SPTE bit. SPTE is set when a byte transfers from the transmit data register to the shift register. Reset clears the SPTIE bit.

- 1 = SPTE CPU interrupt requests or SPTE DMA service requests enabled
- 0 = SPTE CPU interrupt requests or SPTE DMA service requests disabled

11.13.2 SPI Status and Control Register

The SPI status and control register contains flags to signal the following conditions:

- Receive data register full
- Failure to clear SPRF bit before next byte is received (overflow error)
- Inconsistent logic level on \overline{SS} pin (mode fault error)
- Transmit data register empty

The SPI status and control register also contains bits that perform the following functions:

- Enable error interrupts
- Enable mode fault error detection
- Select master SPI baud rate

Serial Peripheral Interface Module (SPI)

Address: \$0011

	Bit 7	6	5	4	3	2	1	Bit 0
Read:	SPRF	ERRIE	OVRF	MODF	SPTE	MODFEN	SPR1	SPR0
Write:								
Reset:	0	0	0	0	1	0	0	0


 = Unimplemented

Figure 11-15. SPI Status and Control Register (SPSCR)

SPRF — SPI Receiver Full Bit

This clearable, read-only flag is set each time a byte transfers from the shift register to the receive data register. SPRF generates a CPU interrupt request or a DMA service request if the SPRIE bit in the SPI control register is set also.

The DMA select bit (DMAS) in the SPI control register determines whether SPRF generates an SPRF CPU interrupt request or an SPRF DMA service request. During an SPRF CPU interrupt (DMAS = 0), the CPU clears SPRF by reading the SPI status and control register with SPRF set and then reading the SPI data register. During an SPRF DMA transmission (DMAS = 1), any read of the SPI data register clears the SPRF bit.

Reset clears the SPRF bit.

- 1 = Receive data register full
- 0 = Receive data register not full

NOTE

When the DMA is configured to service the SPI (DMAS = 1), a read by the CPU of the receive data register can inadvertently clear the SPRF bit and cause the DMA to miss a service request.

ERRIE — Error Interrupt Enable Bit

This read/write bit enables the MODF and OVRF bits to generate CPU interrupt requests. Reset clears the ERRIE bit.

- 1 = MODF and OVRF can generate CPU interrupt requests
- 0 = MODF and OVRF cannot generate CPU interrupt requests

OVRF — Overflow Bit

This clearable, read-only flag is set if software does not read the byte in the receive data register before the next full byte enters the shift register. In an overflow condition, the byte already in the receive data register is unaffected, and the byte that shifted in last is lost. Clear the OVRF bit by reading the SPI status and control register with OVRF set and then reading the receive data register. Reset clears the OVRF bit.

- 1 = Overflow
- 0 = No overflow

MODF — Mode Fault Bit

This clearable, read-only flag is set in a slave SPI if the \overline{SS} pin goes high during a transmission with the MODFEN bit set. In a master SPI, the MODF flag is set if the \overline{SS} pin goes low at any time with the MODFEN bit set. Clear the MODF bit by reading the SPI status and control register (SPSCR) with MODF set and then writing to the SPI control register (SPCR). Reset clears the MODF bit.

- 1 = \overline{SS} pin at inappropriate logic level
- 0 = \overline{SS} pin at appropriate logic level

SPTE — SPI Transmitter Empty Bit

This clearable, read-only flag is set each time the transmit data register transfers a byte into the shift register. SPTE generates an SPTE CPU interrupt request or an SPTE DMA service request if the SPTIE bit in the SPI control register is set also.

NOTE

Do not write to the SPI data register unless the SPTE bit is high.

The DMA select bit (DMAS) in the SPI control register determines whether SPTE generates an SPTE CPU interrupt request or an SPTE DMA service request. During an SPTE CPU interrupt (DMAS = 0), the CPU clears the SPTE bit by writing to the transmit data register. During an SPTE DMA transmission (DMAS = 1), the DMA automatically clears SPTE when it writes to the transmit data register.

NOTE

When the DMA is configured to service the SPI (DMAS = 1), a write by the CPU of the transmit data register can inadvertently clear the SPTE bit and cause the DMA to miss a service request.

Reset sets the SPTE bit.

1 = Transmit data register empty

0 = Transmit data register not empty

MODFEN — Mode Fault Enable Bit

This read/write bit, when set to 1, allows the MODF flag to be set. If the MODF flag is set, clearing the MODFEN does not clear the MODF flag. If the SPI is enabled as a master and the MODFEN bit is low, then the \overline{SS} pin is available as a general purpose I/O.

If the MODFEN bit is set, then this pin is not available as a general purpose I/O. When the SPI is enabled as a slave, the \overline{SS} pin is not available as a general purpose I/O regardless of the value of MODFEN. (See [11.12.4 SS \(Slave Select\)](#).)

If the MODFEN bit is low, the level of the \overline{SS} pin does not affect the operation of an enabled SPI configured as a master. For an enabled SPI configured as a slave, having MODFEN low only prevents the MODF flag from being set. It does not affect any other part of SPI operation. (See [11.7.2 Mode Fault Error](#).)

SPR1 and SPR0 — SPI Baud Rate Select Bits

In master mode, these read/write bits select one of four baud rates as shown in [Table 11-5](#). SPR1 and SPR0 have no effect in slave mode. Reset clears SPR1 and SPR0.

Table 11-5. SPI Master Baud Rate Selection

SPR1:SPR0	Baud Rate Divisor (BD)
00	2
01	8
10	32
11	128

Use the following formula to calculate the SPI baud rate:

$$\text{Baud rate} = \frac{\text{CGMOUT}}{2 \times \text{BD}}$$

where:

CGMOUT = base clock output of the clock generator module (CGM)

BD = baud rate divisor

11.13.3 SPI Data Register

The SPI data register consists of the read-only receive data register and the write-only transmit data register. Writing to the SPI data register writes data into the transmit data register. Reading the SPI data register reads data from the receive data register. The transmit data and receive data registers are separate registers that can contain different values. (See [Figure 11-2](#).)

Address: \$0012

	Bit 7	6	5	4	3	2	1	Bit 0
Read:	R7	R6	R5	R4	R3	R2	R1	R0
Write:	T7	T6	T5	T4	T3	T2	T1	T0
Reset:	Indeterminate after reset							

Figure 11-16. SPI Data Register (SPDR)

R7:R0/T7:T0 — Receive/Transmit Data Bits

NOTE

Do not use read-modify-write instructions on the SPI data register since the register read is not the same as the register written.

Chapter 12

Serial Communications Interface Module (SCI)

12.1 Introduction

The SCI allows asynchronous communications with peripheral devices and other MCUs.

NOTE

References to DMA and associated functions are only valid if the MCU has a DMA module. If the MCU has no DMA, any DMA related register bits should be left in their reset state for expected MCU operation.

12.2 Features

Features of the SCI module include:

- Full Duplex Operation
- Standard Mark/Space Non-Return-to-Zero (NRZ) Format
- 32 Programmable Baud Rates
- Programmable 8-Bit or 9-Bit Character Length
- Separately Enabled Transmitter and Receiver
- Separate Receiver and Transmitter CPU Interrupt Requests
- Separate Receiver and Transmitter DMA Service Requests
- Programmable Transmitter Output Polarity
- Two Receiver Wake-Up Methods:
 - Idle Line Wake-Up
 - Address Mark Wake-Up
- Interrupt-Driven Operation with Eight Interrupt Flags:
 - Transmitter Empty
 - Transmission Complete
 - Receiver Full
 - Idle Receiver Input
 - Receiver Overrun
 - Noise Error
 - Framing Error
 - Parity Error
- Receiver Framing Error Detection
- Hardware Parity Checking
- 1/16 Bit-Time Noise Detection

12.3 Pin Name Conventions

The generic names of the SCI I/O pins are:

- RxD (receive data)
- TxD (transmit data)

SCI I/O lines are implemented by sharing parallel I/O port pins. The full name of an SCI input or output reflects the name of the shared port pin. [Table 12-1](#) shows the full names and the generic names of the SCI I/O pins. The generic pin names appear in the text of this section.

Table 12-1. Pin Name Conventions

Generic Pin Names:	RxD	TxD
Full Pin Names:	PTE6/RxD	PTE5/TxD

12.4 Functional Description

[Figure 12-1](#) shows the structure of the SCI module. The SCI allows full-duplex, asynchronous, NRZ serial communication among the MCU and remote devices, including other MCUs. The transmitter and receiver of the SCI operate independently, although they use the same baud rate generator. During normal operation, the CPU monitors the status of the SCI, writes the data to be transmitted, and processes received data. During DMA transfers, the DMA fetches data from memory for the SCI to transmit and/or the DMA stores received data in memory.

Serial Communications Interface Module (SCI)

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	
SCI Control Register 1 (SCC1)	Read:	LOOPS	ENSCI	TXINV	M	WAKE	ILTY	PEN	PTY
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 2 (SCC2)	Read:	SCTIE	TCIE	SCRIE	ILIE	TE	RE	RWU	SBK
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 3 (SCC3)	Read:	R8	T8	DMARE	DMATE	ORIE	NEIE	FEIE	PEIE
	Write:								
	Reset:	U	U	0	0	0	0	0	0
SCI Status Register 1 (SCS1)	Read:	SCTE	TC	SCRF	IDLE	OR	NF	FE	PE
	Write:								
	Reset:	1	1	0	0	0	0	0	0
SCI Status Register 2 (SCS2)	Read:							BKF	RPF
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Data Register (SCDR)	Read:	R7	R6	R5	R4	R3	R2	R1	R0
	Write:	T7	T6	T5	T4	T3	T2	T1	T0
	Reset:	Unaffected by reset							
SCI Baud Rate Register (SCBR)	Read:			SCP1	SCP0	R	SCR2	SCR1	SCR0
	Write:								
	Reset:	0	0	0	0	0	0	0	0

= Unimplemented U = Unaffected R = Reserved

Figure 12-2. SCI I/O Register Summary

Table 12-2. SCI I/O Register Address Summary

Register:	SCC1	SCC2	SCC3	SCS1	SCS2	SCDR	SCBR
Address:	\$0013	\$0014	\$0015	\$0016	\$0017	\$0018	\$0019

12.4.1 Data Format

The SCI uses the standard non-return-to-zero mark/space data format illustrated in [Figure 12-3](#).

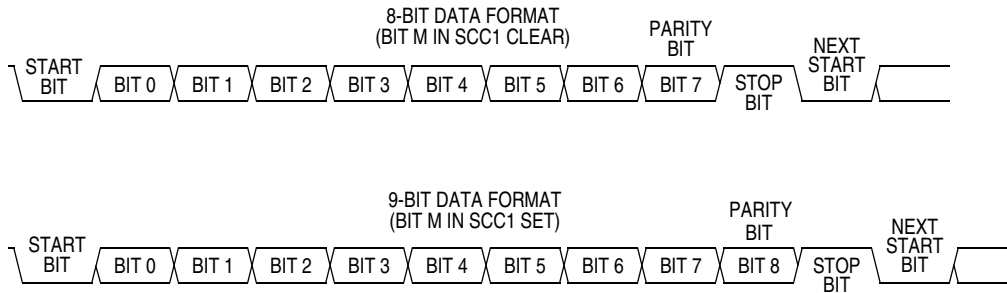


Figure 12-3. SCI Data Formats

12.4.2 Transmitter

[Figure 12-4](#) shows the structure of the SCI transmitter.

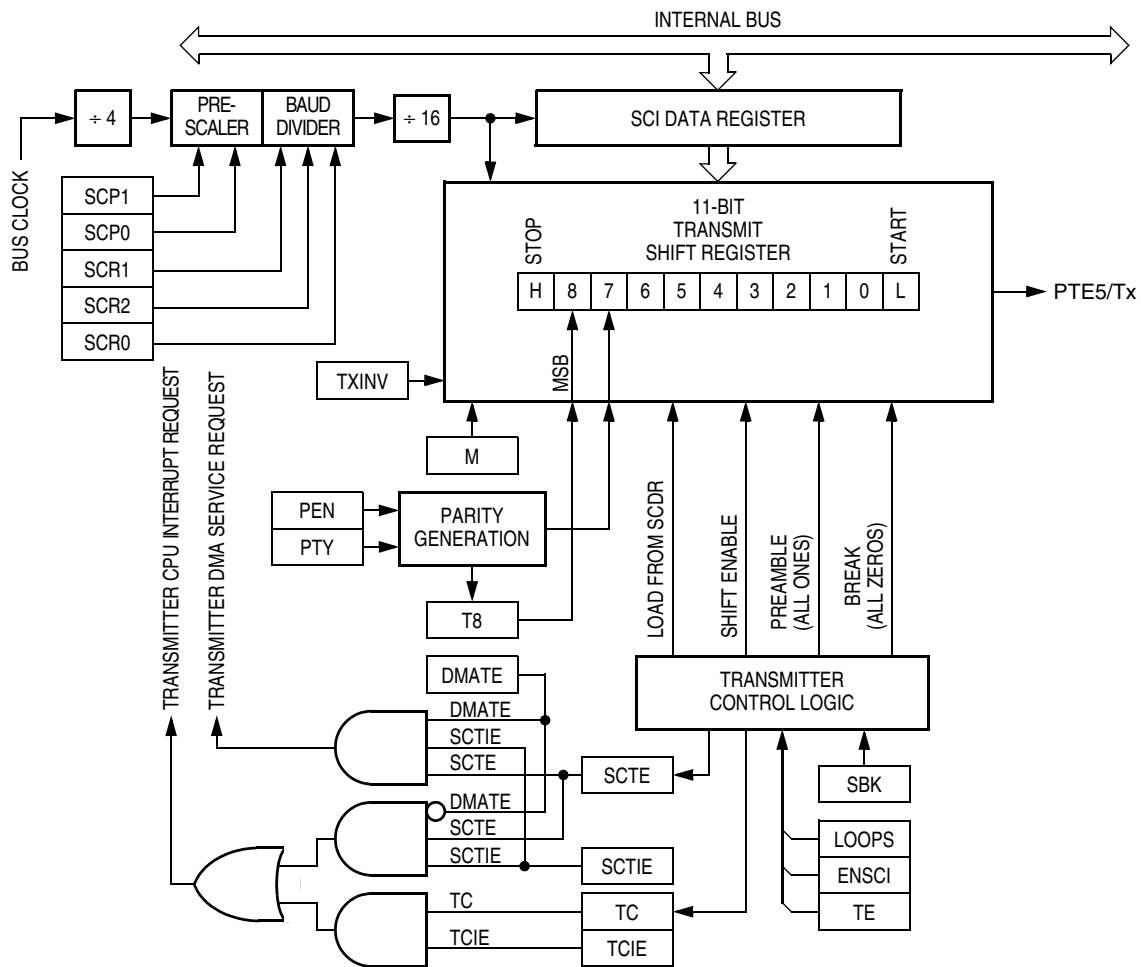


Figure 12-4. SCI Transmitter

Serial Communications Interface Module (SCI)

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	
SCI Control Register 1 (SCC1)	Read:	LOOPS	ENSCI	TXINV	M	WAKE	ILTY	PEN	PTY
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 2 (SCC2)	Read:	SCTIE	TCIE	SCRIE	ILIE	TE	RE	RWU	SBK
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 3 (SCC3)	Read:	R8	T8	DMARE	DMATE	ORIE	NEIE	FEIE	PEIE
	Write:								
	Reset:	U	U	0	0	0	0	0	0
SCI Status Register 1 (SCS1)	Read:	SCTE	TC	SCRIF	IDLE	OR	NF	FE	PE
	Write:								
	Reset:	1	1	0	0	0	0	0	0
SCI Data Register (SCDR)	Read:	R7	R6	R5	R4	R3	R2	R1	R0
	Write:	T7	T6	T5	T4	T3	T2	T1	T0
	Reset:	Unaffected by reset							
SCI Baud Rate Register (SCBR)	Read:			SCP1	SCP0	R	SCR2	SCR1	SCR0
	Write:								
	Reset:	0	0	0	0	0	0	0	0

= Unimplemented U = Unaffected R = Reserved

Figure 12-5. SCI Transmitter I/O Register Summary

Table 12-3. SCI Transmitter I/O Address Summary

Register:	SCC1	SCC2	SCC3	SCS1	SCDR	SCBR
Address:	\$0013	\$0014	\$0015	\$0016	\$0018	\$0019

12.4.2.1 Character Length

The transmitter can accommodate either 8-bit or 9-bit data. The state of the M bit in SCI control register 1 (SCC1) determines character length. When transmitting 9-bit data, bit T8 in SCI control register 3 (SCC3) is the ninth bit (bit 8).

12.4.2.2 Character Transmission

During an SCI transmission, the transmit shift register shifts a character out to the PTE5/TxD pin. The SCI data register (SCDR) is the write-only buffer between the internal data bus and the transmit shift register. To initiate an SCI transmission:

1. Enable the SCI by writing a logic one to the enable SCI bit (ENSCI) in SCI control register 1 (SCC1).
2. Enable the transmitter by writing a logic one to the transmitter enable bit (TE) in SCI control register 2 (SCC2).
3. Clear the SCI transmitter empty bit by first reading SCI status register 1 (SCS1) and then writing to the SCDR. In a DMA transfer, the DMA automatically clears the SCTE bit by writing to the SCDR.
4. Repeat step 3 for each subsequent transmission.

At the start of a transmission, transmitter control logic automatically loads the transmit shift register with a preamble of logic ones. After the preamble shifts out, control logic transfers the SCDR data into the transmit shift register. A logic zero start bit automatically goes into the least significant bit position of the transmit shift register. A logic one stop bit goes into the most significant bit position.

The SCI transmitter empty bit, SCTE, in SCS1 becomes set when the SCDR transfers a byte to the transmit shift register. The SCTE bit indicates that the SCDR can accept new data from the internal data bus. If the SCI transmit interrupt enable bit, SCTIE, in SCC2 is also set, the SCTE bit generates a transmitter CPU interrupt request or a transmitter DMA service request.

The SCTE bit generates a transmitter DMA service request if the DMA transfer enable bit, DMATE, in SCI control register 3 (SCC3) is set. Setting the DMATE bit enables the SCTE bit to generate transmitter DMA service requests and disables transmitter CPU interrupt requests.

When the transmit shift register is not transmitting a character, the PTE5/TxD pin goes to the idle condition, logic one. If at any time software clears the ENSCI bit in SCI control register 1 (SCC1), the transmitter and receiver relinquish control of the port E pins.

12.4.2.3 Break Characters

Writing a logic one to the send break bit, SBK, in SCC2 loads the transmit shift register with a break character. A break character contains all logic zeros and has no start, stop, or parity bit. Break character length depends on the M bit in SCC1. As long as SBK is at logic one, transmitter logic continuously loads break characters into the transmit shift register. After software clears the SBK bit, the shift register finishes transmitting the last break character and then transmits at least one logic one. The automatic logic one at the end of a break character guarantees the recognition of the start bit of the next character.

The SCI recognizes a break character when a start bit is followed by eight or nine logic zero data bits and a logic zero where the stop bit should be. Receiving a break character has the following effects on SCI registers:

- Sets the framing error bit (FE) in SCS1
- Sets the SCI receiver full bit (SCRF) in SCS1
- Clears the SCI data register (SCDR)
- Clears the R8 bit in SCC3
- Sets the break flag bit (BKF) in SCS2
- May set the overrun (OR), noise flag (NF), parity error (PE), or reception in progress flag (RPF) bits

12.4.2.4 Idle Characters

An idle character contains all logic ones and has no start, stop, or parity bit. Idle character length depends on the M bit in SCC1. The preamble is a synchronizing idle character that begins every transmission.

If the TE bit is cleared during a transmission, the PTE5/TxD pin becomes idle after completion of the transmission in progress. Clearing and then setting the TE bit during a transmission queues an idle character to be sent after the character currently being transmitted.

NOTE

When queueing an idle character, return the TE bit to logic one before the stop bit of the current character shifts out to the TxD pin. Setting TE after the stop bit appears on TxD causes data previously written to the SCDR to be lost.

A good time to toggle the TE bit for a queued idle character is when the SCTE bit becomes set and just before writing the next byte to the SCDR.

12.4.2.5 Inversion of Transmitted Output

The transmit inversion bit (TXINV) in SCI control register 1 (SCC1) reverses the polarity of transmitted data. All transmitted values, including idle, break, start, and stop bits, are inverted when TXINV is at logic one. (See [12.8.1 SCI Control Register 1 \(SCC1\)](#).)

12.4.2.6 Transmitter Interrupts

The following conditions can generate CPU interrupt requests from the SCI transmitter:

- SCI transmitter empty (SCTE) — The SCTE bit in SCS1 indicates that the SCDR has transferred a character to the transmit shift register. SCTE can generate a transmitter CPU interrupt request or a transmitter DMA service request. Setting the SCI transmit interrupt enable bit, SCTIE, in SCC2 enables the SCTE bit to generate transmitter CPU interrupt requests. Setting both the SCTIE bit and the DMA transfer enable bit, DMATE, in SCC3 enables the SCTE bit to generate transmitter DMA service requests.
- Transmission complete (TC) — The TC bit in SCS1 indicates that the transmit shift register and the SCDR are empty and that no break or idle character has been generated. The transmission complete interrupt enable bit, TCIE, in SCC2 enables the TC bit to generate transmitter CPU interrupt requests.

12.4.3 Receiver

[Figure 12-6](#) shows the structure of the SCI receiver.

12.4.3.1 Character Length

The receiver can accommodate either 8-bit or 9-bit data. The state of the M bit in SCI control register 1 (SCC1) determines character length. When receiving 9-bit data, bit R8 in SCI control register 2 (SCC2) is the ninth bit (bit 8). When receiving 8-bit data, bit R8 is a copy of the eighth bit (bit 7).

12.4.3.2 Character Reception

During an SCI reception, the receive shift register shifts characters in from the PTE6/RxD pin. The SCI data register (SCDR) is the read-only buffer between the internal data bus and the receive shift register.

After a complete character shifts into the receive shift register, the data portion of the character transfers to the SCDR. The SCI receiver full bit, SCRF, in SCI status register 1 (SCS1) becomes set, indicating that the received byte can be read. If the SCI receive interrupt enable bit, SCRIE, in SCC2 is also set, the SCRF bit generates a receiver CPU interrupt request or a receiver DMA service request.

The SCRF bit generates a receiver DMA service request if the DMA receive enable bit, DMARE, in SCI control register 3 (SCC3) is set. Setting the DMARE bit enables the SCRF bit to generate receiver DMA service requests and disables receiver CPU interrupt requests.

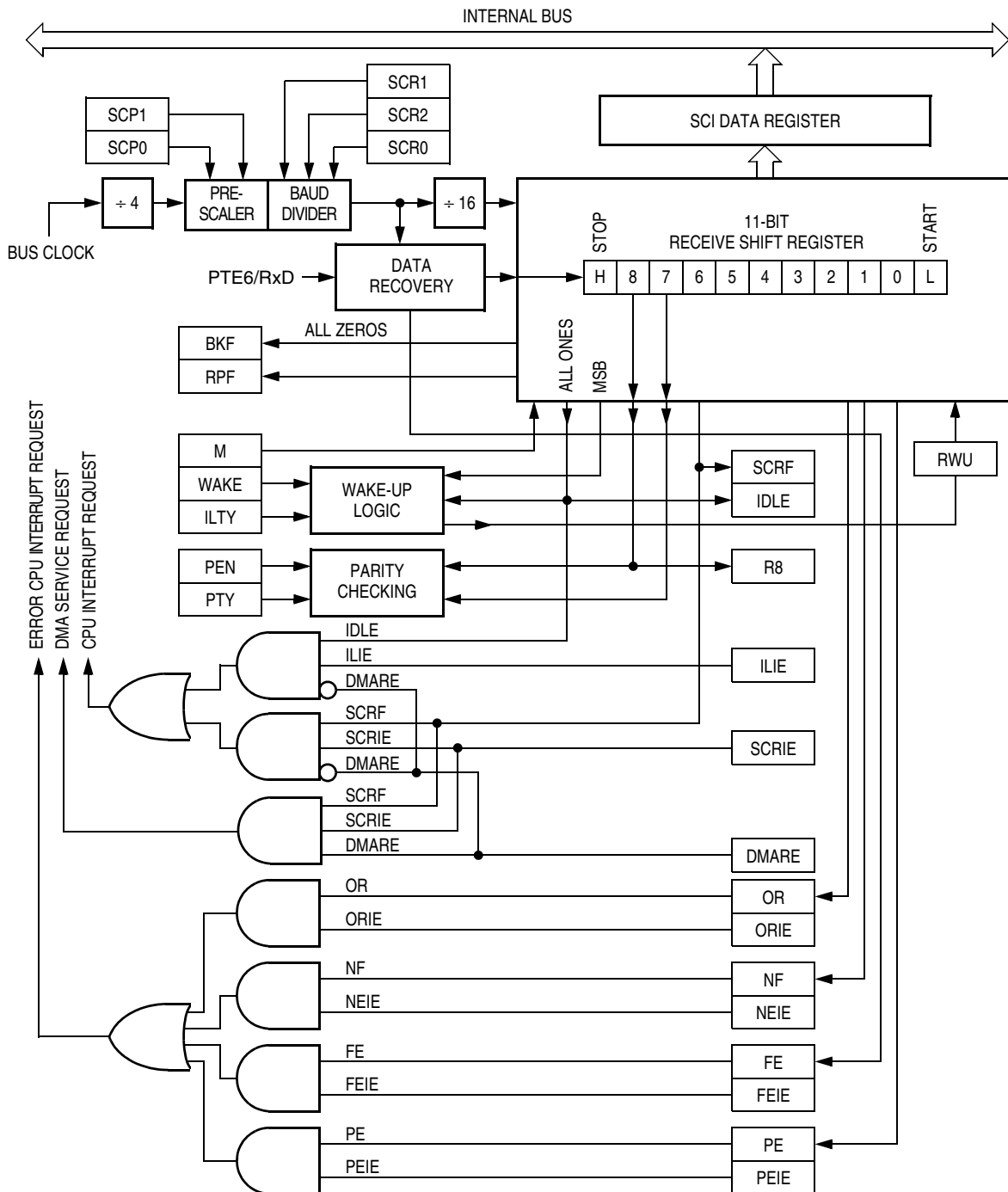


Figure 12-6. SCI Receiver Block Diagram

Serial Communications Interface Module (SCI)

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	
SCI Control Register 1 (SCC1)	Read:	LOOPS	ENSCI	TXINV	M	WAKE	ILTY	PEN	PTY
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 2 (SCC2)	Read:	SCTIE	TCIE	SCRIE	ILIE	TE	RE	RWU	SBK
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Control Register 3 (SCC3)	Read:	R8	T8	DMARE	DMATE	ORIE	NEIE	FEIE	PEIE
	Write:								
	Reset:	U	U	0	0	0	0	0	0
SCI Status Register 1 (SCS1)	Read:	SCTE	TC	SCRF	IDLE	OR	NF	FE	PE
	Write:								
	Reset:	1	1	0	0	0	0	0	0
SCI Status Register 2 (SCS2)	Read:							BKF	RPF
	Write:								
	Reset:	0	0	0	0	0	0	0	0
SCI Data Register (SCDR)	Read:	R7	R6	R5	R4	R3	R2	R1	R0
	Write:	T7	T6	T5	T4	T3	T2	T1	T0
	Reset:	Unaffected by reset							
SCI Baud Rate Register (SCBR)	Read:			SCP1	SCP0	R	SCR2	SCR1	SCR0
	Write:								
	Reset:	0	0	0	0	0	0	0	0

= Unimplemented U = Unaffected R = Reserved

Figure 12-7. SCI I/O Register Summary

Table 12-4. SCI Receiver I/O Address Summary

Register:	SCC1	SCC2	SCC3	SCS1	SCS2	SCDR	SCBR
Address:	\$0013	\$0014	\$0015	\$0016	\$0017	\$0018	\$0019

12.4.3.3 Data Sampling

The receiver samples the PTE6/RxD pin at the RT clock rate. The RT clock is an internal signal with a frequency 16 times the baud rate. To adjust for baud rate mismatch, the RT clock is resynchronized at the following times (see [Figure 12-8](#)):

- After every start bit
- After the receiver detects a data bit change from logic one to logic zero (after the majority of data bit samples at RT8, RT9, and RT10 returns a valid logic one and the majority of the next RT8, RT9, and RT10 samples returns a valid logic zero)

To locate the start bit, data recovery logic does an asynchronous search for a logic zero preceded by three logic ones. When the falling edge of a possible start bit occurs, the RT clock begins to count to 16.

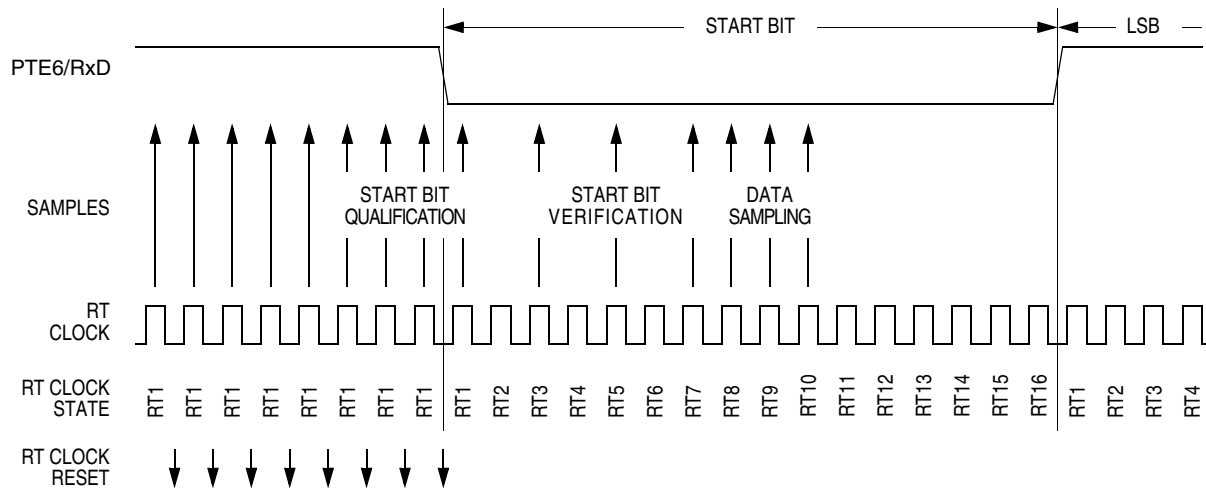


Figure 12-8. Receiver Data Sampling

To verify the start bit and to detect noise, data recovery logic takes samples at RT3, RT5, and RT7. [Table 12-5](#) summarizes the results of the start bit verification samples.

Table 12-5. Start Bit Verification

RT3, RT5, and RT7 Samples	Start Bit Verification	Noise Flag
000	Yes	0
001	Yes	1
010	Yes	1
011	No	0
100	Yes	1
101	No	0
110	No	0
111	No	0

If start bit verification is not successful, the RT clock is reset and a new search for a start bit begins.

To determine the value of a data bit and to detect noise, recovery logic takes samples at RT8, RT9, and RT10. [Table 12-6](#) summarizes the results of the data bit samples.

Table 12-6. Data Bit Recovery

RT8, RT9, and RT10 Samples	Data Bit Determination	Noise Flag
000	0	0
001	0	1
010	0	1
011	1	1
100	0	1
101	1	1

Table 12-6. Data Bit Recovery (Continued)

RT8, RT9, and RT10 Samples	Data Bit Determination	Noise Flag
110	1	1
111	1	0

NOTE

The RT8, RT9, and RT10 samples do not affect start bit verification. If any or all of the RT8, RT9, and RT10 start bit samples are logic ones following a successful start bit verification, the noise flag (NF) is set and the receiver assumes that the bit is a start bit.

To verify a stop bit and to detect noise, recovery logic takes samples at RT8, RT9, and RT10. [Table 12-7](#) summarizes the results of the stop bit samples.

Table 12-7. Stop Bit Recovery

RT8, RT9, and RT10 Samples	Framing Error Flag	Noise Flag
000	1	0
001	1	1
010	1	1
011	0	1
100	1	1
101	0	1
110	0	1
111	0	0

12.4.3.4 Framing Errors

If the data recovery logic does not detect a logic one where the stop bit should be in an incoming character, it sets the framing error bit, FE, in SCS1. A break character also sets the FE bit because a break character has no stop bit. The FE bit is set at the same time that the SCRF bit is set.

12.4.3.5 Baud Rate Tolerance

A transmitting device may be operating at a baud rate below or above the receiver baud rate. Accumulated bit time misalignment can cause one of the three stop bit data samples to fall outside the actual stop bit. Then a noise error occurs. If more than one of the samples is outside the stop bit, a framing error occurs. In most applications, the baud rate tolerance is much more than the degree of misalignment that is likely to occur.

As the receiver samples an incoming character, it resynchronizes the RT clock on any valid falling edge within the character. Resynchronization within characters corrects misalignments between transmitter bit times and receiver bit times.

Slow Data Tolerance

Figure 12-9 shows how much a slow received character can be misaligned without causing a noise error or a framing error. The slow stop bit begins at RT8 instead of RT1 but arrives in time for the stop bit data samples at RT8, RT9, and RT10.

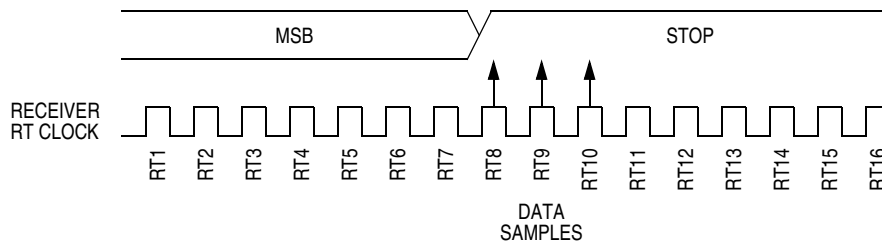


Figure 12-9. Slow Data

For an 8-bit character, data sampling of the stop bit takes the receiver $9 \text{ bit times} \times 16 \text{ RT cycles} + 10 \text{ RT cycles} = 154 \text{ RT cycles}$.

With the misaligned character shown in Figure 12-9, the receiver counts 154 RT cycles at the point when the count of the transmitting device is $9 \text{ bit times} \times 16 \text{ RT cycles} + 3 \text{ RT cycles} = 147 \text{ RT cycles}$.

The maximum per cent difference between the receiver count and the transmitter count of a slow 8-bit character with no errors is

$$\left| \frac{154 - 147}{154} \right| \times 100 = 4.54\%$$

For a 9-bit character, data sampling of the stop bit takes the receiver $10 \text{ bit times} \times 16 \text{ RT cycles} + 10 \text{ RT cycles} = 170 \text{ RT cycles}$.

With the misaligned character shown in Figure 12-9, the receiver counts 170 RT cycles at the point when the count of the transmitting device is $10 \text{ bit times} \times 16 \text{ RT cycles} + 3 \text{ RT cycles} = 163 \text{ RT cycles}$.

The maximum per cent difference between the receiver count and the transmitter count of a slow 9-bit character with no errors is

$$\left| \frac{170 - 163}{170} \right| \times 100 = 4.12\%$$

Fast Data Tolerance

Figure 12-10 shows how much a fast received character can be misaligned without causing a noise error or a framing error. The fast stop bit ends at RT10 instead of RT16 but is still there for the stop bit data samples at RT8, RT9, and RT10.

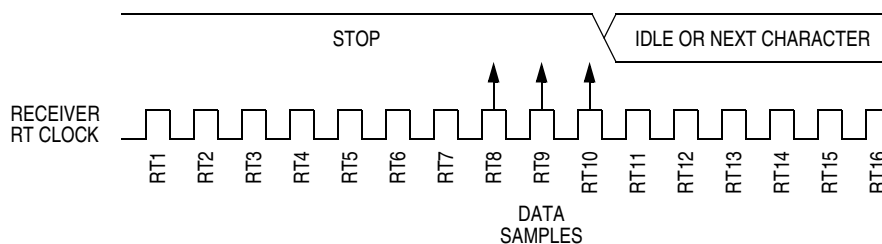


Figure 12-10. Fast Data

Serial Communications Interface Module (SCI)

For an 8-bit character, data sampling of the stop bit takes the receiver
9 bit times \times 16 RT cycles + 10 RT cycles = 154 RT cycles.

With the misaligned character shown in [Figure 12-10](#), the receiver counts 154 RT cycles at the point when the count of the transmitting device is 10 bit times \times 16 RT cycles = 160 RT cycles.

The maximum per cent difference between the receiver count and the transmitter count of a fast 8-bit character with no errors is

$$\left| \frac{154 - 160}{154} \right| \times 100 = 3.90\%$$

For a 9-bit character, data sampling of the stop bit takes the receiver
10 bit times \times 16 RT cycles + 10 RT cycles = 170 RT cycles.

With the misaligned character shown in [Figure 12-10](#), the receiver counts 170 RT cycles at the point when the count of the transmitting device is 11 bit times \times 16 RT cycles = 176 RT cycles.

The maximum per cent difference between the receiver count and the transmitter count of a fast 9-bit character with no errors is

$$\left| \frac{170 - 176}{170} \right| \times 100 = 3.53\%$$

12.4.3.6 Receiver Wake-Up

So that the MCU can ignore transmissions intended only for other receivers in multiple-receiver systems, the receiver can be put into a standby state. Setting the receiver wake-up bit, RWU, in SCC2 puts the receiver into a standby state during which receiver interrupts are disabled.

Depending on the state of the WAKE bit in SCC1, either of two conditions on the PTE6/RxD pin can bring the receiver out of the standby state:

- Address mark — An address mark is a logic one in the most significant bit position of a received character. When the WAKE bit is set, an address mark wakes the receiver from the standby state by clearing the RWU bit. The address mark also sets the SCI receiver full bit, SCRF. Software can then compare the character containing the address mark to the user-defined address of the receiver. If they are the same, the receiver remains awake and processes the characters that follow. If they are not the same, software can set the RWU bit and put the receiver back into the standby state.
- Idle input line condition — When the WAKE bit is clear, an idle character on the PTE6/RxD pin wakes the receiver from the standby state by clearing the RWU bit. The idle character that wakes the receiver does not set the receiver idle bit, IDLE, or the SCI receiver full bit, SCRF. The idle line type bit, ILTY, determines whether the receiver begins counting logic ones as idle character bits after the start bit or after the stop bit.

NOTE

With the WAKE bit clear, setting the RWU bit after the RxD pin has been idle may cause the receiver to wake up immediately.

12.4.3.7 Receiver Interrupts

The following sources can generate CPU interrupt requests from the SCI receiver:

- SCI receiver full (SCRF) — The SCRF bit in SCS1 indicates that the receive shift register has transferred a character to the SCDR. SCRF can generate a receiver CPU interrupt request or a receiver DMA service request. Setting the SCI receive interrupt enable bit, SCRIE, in SCC2 enables the SCRF bit to generate receiver CPU interrupts. Setting both the SCRIE bit and the DMA receive enable bit, DMARE, in SCC3 enables receiver DMA service requests and disables receiver CPU interrupt requests.
- Idle input (IDLE) — The IDLE bit in SCS1 indicates that 10 or 11 consecutive logic ones shifted in from the PTE6/RxD pin. The idle line interrupt enable bit, ILIE, in SCC2 enables the IDLE bit to generate CPU interrupt requests.

NOTE

When receiver DMA service requests are enabled (DMARE = 1), then receiver CPU interrupt requests are disabled.

12.4.3.8 Error Interrupts

The following receiver error flags in SCS1 can generate CPU interrupt requests:

- Receiver overrun (OR) — The OR bit indicates that the receive shift register shifted in a new character before the previous character was read from the SCDR. The previous character remains in the SCDR, and the new character is lost. The overrun interrupt enable bit, ORIE, in SCC3 enables OR to generate SCI error CPU interrupt requests.
- Noise flag (NF) — The NF bit is set when the SCI detects noise on incoming data or break characters, including start, data, and stop bits. The noise error interrupt enable bit, NEIE, in SCC3 enables NF to generate SCI error CPU interrupt requests.
- Framing error (FE) — The FE bit in SCS1 is set when a logic zero occurs where the receiver expects a stop bit. The framing error interrupt enable bit, FEIE, in SCC3 enables FE to generate SCI error CPU interrupt requests.
- Parity error (PE) — The PE bit in SCS1 is set when the SCI detects a parity error in incoming data. The parity error interrupt enable bit, PEIE, in SCC3 enables PE to generate SCI error CPU interrupt requests.

12.4.3.9 Error Flags During DMA Service Requests

When the DMA is servicing the SCI receiver, it clears the SCRF bit when it reads the SCI data register. The DMA does not clear the other status bits (BKF or RPF), nor does it clear error flags (OR, NF, FE, and PE). To clear error flags while the DMA is servicing the receiver, enable SCI error CPU interrupts and clear the bits in an interrupt routine. The application may require retransmission in case of error. If the application requires the receptions to continue, note the following latency considerations:

1. If interrupt latency is short enough for an error bit to be serviced before the next SCRF, then it can be determined which byte caused the error. If interrupt latency is long enough for a new SCRF to occur before servicing an error bit, then:
 - a. It cannot be determined whether the error bit being serviced is due to the byte in the SCI data register or to a previous byte. Multiple errors can accumulate that correspond to different bytes. In a message-based system, you may have to repeat the entire message.

- b. When the DMA is enabled to service the SCI receiver, merely reading the SCI data register clears the SCRF bit. The second step in clearing an error bit, reading the SCI data register, could inadvertently clear a new, unserviced SCRF that occurred during the error-servicing routine. Then the DMA would ignore the byte that set the new SCRF, and the new byte would be lost.
To prevent clearing of an unserviced SCRF bit, clear the SCRIE bit at the beginning of the error-servicing interrupt routine and set it at the end. Clearing SCRIE disables DMA service so that both a read of SCS1 and a read of SCDR are required to clear the SCRF bit. Setting SCRIE enables DMA service so that the DMA can recognize a service request that occurred during the error-servicing interrupt routine.
 - c. In the CPU interrupt routine to service error bits, do not use BRSET or BRCLR instructions. BRSET and BRCLR read the SCS1 register, which is the first step in clearing the register. Then the DMA could read the SCI data register, the second step in clearing it, thereby clearing all error bits. The next read of the data register would miss any error bits that were set.
2. DMA latency should be short enough so that an SCRF is serviced before the next SCRF occurs. If DMA latency is long enough for a new SCRF to occur before servicing an error bit, then:
 - a. Overruns occur. Set the ORIE bit to enable SCI error CPU interrupt requests and service the overrun in an interrupt routine. In a message-based system, disable the DMA in the interrupt routine and manually recover. Otherwise, the byte that was lost in the overrun could prevent the DMA from reaching its byte count. If the DMA reaches its byte count in the following message, two messages may be corrupted.
 - b. If the CPU does not service an overrun interrupt request, the DMA can eventually clear the SCRF bit by reading the SCI data register. The OR bit remains set. Each time a new byte sets the SCRF bit, new data transfers from the shift register to the SCI data register (provided that another overrun does not occur), even though the OR bit is set. The DMA removed the overrun condition by reading the data register, but the OR bit has not been cleared.

12.5 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

12.5.1 Wait Mode

The SCI module remains active after the execution of a WAIT instruction. In wait mode the SCI module registers are not accessible by the CPU. Any enabled CPU interrupt request from the SCI module can bring the MCU out of wait mode.

If SCI module functions are not required during wait mode, reduce power consumption by disabling the module before executing the WAIT instruction.

The DMA can service the SCI without exiting wait mode.

12.5.2 Stop Mode

The SCI module is inactive after the execution of a STOP instruction. The STOP instruction does not affect SCI register states. SCI module operation resumes after an external interrupt.

Because the internal clock is inactive during stop mode, entering stop mode during an SCI transmission or reception results in invalid data.

12.6 SCI During Break Module Interrupts

The system integration module (SIM) controls whether status bits in other modules can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear status bits during the break state.

To allow software to clear status bits during a break interrupt, write a logic one to the BCFE bit. If a status bit is cleared during the break state, it remains cleared when the MCU exits the break state.

To protect status bits during the break state, write a logic zero to the BCFE bit. With BCFE at logic zero (its default state), software can read and write I/O registers during the break state without affecting status bits. Some status bits have a two-step read/write clearing procedure. If software does the first step on such a bit before the break, the bit cannot change during the break state as long as BCFE is at logic zero. After the break, doing the second step clears the status bit.

12.7 I/O Signals

Port E shares two of its pins with the SCI module. The two SCI I/O pins are:

- PTE5/TxD — Transmit data
- PTE6/RxD — Receive data

12.7.1 PTE5/TxD (Transmit Data)

The PTE5/TxD pin is the serial data output from the SCI transmitter. The SCI shares the PTE5/TxD pin with port E. When the SCI is enabled, the PTE5/TxD pin is an output regardless of the state of the DDRE2 bit in data direction register E (DDRE).

12.7.2 PTE6/RxD (Receive Data)

The PTE6/RxD pin is the serial data input to the SCI receiver. The SCI shares the PTE6/RxD pin with port E. When the SCI is enabled, the PTE6/RxD pin is an input regardless of the state of the DDRE1 bit in data direction register E (DDRE).

12.8 I/O Registers

The following I/O registers control and monitor SCI operation:

- SCI control register 1 (SCC1)
- SCI control register 2 (SCC2)
- SCI control register 3 (SCC3)
- SCI status register 1 (SCS1)
- SCI status register 2 (SCS2)
- SCI data register (SCDR)
- SCI baud rate register (SCBR)

12.8.1 SCI Control Register 1 (SCC1)

SCI control register 1:

- Enables loop mode operation
- Enables the SCI
- Controls output polarity
- Controls character length
- Controls SCI wake-up method
- Controls idle character detection
- Enables parity function
- Controls parity type

SCC1 \$0013	Bit 7	6	5	4	3	2	1	Bit 0
Read:	LOOPS	ENSCI	TXINV	M	WAKE	ILTY	PEN	PTY
Write:								
Reset:	0	0	0	0	0	0	0	0

Figure 12-11. SCI Control Register 1 (SCC1)

LOOPS — Loop Mode Select Bit

This read/write bit enables loop mode operation. In loop mode the PTE6/RxD pin is disconnected from the SCI, and the transmitter output goes into the receiver input. Both the transmitter and the receiver must be enabled to use loop mode. Reset clears the LOOPS bit.

- 1 = Loop mode enabled
- 0 = Normal operation enabled

ENSCI — Enable SCI Bit

This read/write bit enables the SCI and the SCI baud rate generator. Clearing ENSCI sets the SCTE and TC bits in SCI status register 1 and disables transmitter interrupts. Reset clears the ENSCI bit.

- 1 = SCI enabled
- 0 = SCI disabled

TXINV — Transmit Inversion Bit

This read/write bit reverses the polarity of transmitted data. Reset clears the TXINV bit.

- 1 = Transmitter output inverted
- 0 = Transmitter output not inverted

NOTE

Setting the TXINV bit inverts all transmitted values, including idle, break, start, and stop bits.

M — Mode (Character Length) Bit

This read/write bit determines whether SCI characters are eight or nine bits long. (See [Table 12-8](#).) The ninth bit can serve as an extra stop bit, as a receiver wake-up signal, or as a parity bit. Reset clears the M bit.

- 1 = 9-bit SCI characters
- 0 = 8-bit SCI characters

WAKE — Wake-Up Condition Bit

This read/write bit determines which condition wakes up the SCI: a logic one (address mark) in the most significant bit position of a received character or an idle condition on the PTE6/RxD pin. Reset clears the WAKE bit.

- 1 = Address mark wake-up
- 0 = Idle line wake-up

ILTY — Idle Line Type Bit

This read/write bit determines when the SCI starts counting logic ones as idle character bits. The counting begins either after the start bit or after the stop bit. If the count begins after the start bit, then a string of logic ones preceding the stop bit may cause false recognition of an idle character. Beginning the count after the stop bit avoids false idle character recognition, but requires properly synchronized transmissions. Reset clears the ILTY bit.

- 1 = Idle character bit count begins after stop bit
- 0 = Idle character bit count begins after start bit

PEN — Parity Enable Bit

This read/write bit enables the SCI parity function. (See [Table 12-8.](#)) When enabled, the parity function inserts a parity bit in the most significant bit position. (See [Figure 12-3.](#)) Reset clears the PEN bit.

- 1 = Parity function enabled
- 0 = Parity function disabled

PTY — Parity Bit

This read/write bit determines whether the SCI generates and checks for odd parity or even parity. (See [Table 12-8.](#)) Reset clears the PTY bit.

- 1 = Odd parity
- 0 = Even parity

NOTE

Changing the PTY bit in the middle of a transmission or reception can generate a parity error.

Table 12-8. Character Format Selection

Control Bits		Character Format				
M	PEN:PTY	Start Bits	Data Bits	Parity	Stop Bits	Character Length
0	0X	1	8	None	1	10 bits
1	0X	1	9	None	1	11 bits
0	10	1	7	Even	1	10 bits
0	11	1	7	Odd	1	10 bits
1	10	1	8	Even	1	11 bits
1	11	1	8	Odd	1	11 bits

12.8.2 SCI Control Register 2 (SCC2)

SCI control register 2 does the following:

- Enables the following CPU interrupt requests and DMA service requests:
 - Enables the SCTE bit to generate transmitter CPU interrupt requests or transmitter DMA service requests
 - Enables the TC bit to generate transmitter CPU interrupt requests
 - Enables the SCRF bit to generate receiver CPU interrupt requests or receiver DMA service requests
 - Enables the IDLE bit to generate receiver CPU interrupt requests
- Enables the transmitter
- Enables the receiver
- Enables SCI wake-up
- Transmits SCI break characters

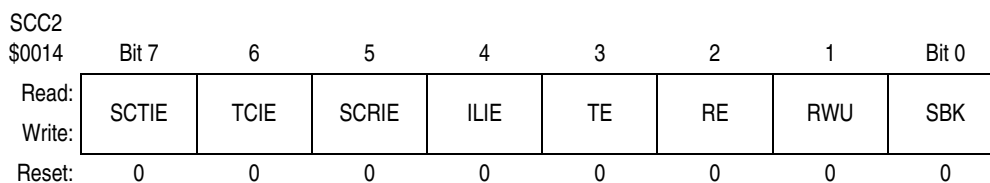


Figure 12-12. SCI Control Register 2 (SCC2)

SCTIE — SCI Transmit Interrupt Enable Bit

This read/write bit enables the SCTE bit to generate SCI transmitter CPU interrupt requests or DMA service requests. Setting the SCTIE bit and clearing the DMA transfer enable bit, DMATE, in SCC3 enables the SCTE bit to generate CPU interrupt requests. Setting both the SCTIE and DMATE bits enables the SCTE bit to generate DMA service requests. Reset clears the SCTIE bit.

1 = SCTE enabled to generate CPU interrupt or DMA service requests

0 = SCTE not enabled to generate CPU interrupt or DMA service requests

TCIE — Transmission Complete Interrupt Enable Bit

This read/write bit enables the TC bit to generate SCI transmitter CPU interrupt requests. Reset clears the TCIE bit.

1 = TC enabled to generate CPU interrupt requests

0 = TC not enabled to generate CPU interrupt requests

SCRIE — SCI Receive Interrupt Enable Bit

This read/write bit enables the SCRF bit to generate SCI receiver CPU interrupt requests or SCI receiver DMA service requests. Setting the SCRIE bit and clearing the DMA receive enable bit, DMARE, in SCC3 enables the SCRF bit to generate CPU interrupt requests. Setting both SCRIE and DMARE enables SCRF to generate DMA service requests. Reset clears the SCRIE bit.

1 = SCRF enabled to generate CPU interrupt or DMA service requests

0 = SCRF not enabled to generate CPU interrupt or DMA service requests

ILIE — Idle Line Interrupt Enable Bit

This read/write bit enables the IDLE bit to generate SCI receiver CPU interrupt requests. Reset clears the ILIE bit.

1 = IDLE enabled to generate CPU interrupt requests

0 = IDLE not enabled to generate CPU interrupt requests

NOTE

When SCI receiver DMA service requests are enabled (DMARE = 1), then SCI receiver CPU interrupt requests are disabled, and the state of the ILIE bit has no effect.

TE — Transmitter Enable Bit

Setting this read/write bit begins the transmission by sending a preamble of 10 or 11 logic ones from the transmit shift register to the PTE5/TxD pin. If software clears the TE bit, the transmitter completes any transmission in progress before the PTE5/TxD returns to the idle condition (logic one). Clearing and then setting TE during a transmission queues an idle character to be sent after the character currently being transmitted. Reset clears the TE bit.

- 1 = Transmitter enabled
- 0 = Transmitter disabled

NOTE

Writing to the TE bit is not allowed when the enable SCI bit (ENSCI) is clear. ENSCI is in SCI control register 1.

RE — Receiver Enable Bit

Setting this read/write bit enables the receiver. Clearing the RE bit disables the receiver but does not affect receiver interrupt flag bits. Reset clears the RE bit.

- 1 = Receiver enabled
- 0 = Receiver disabled

NOTE

Writing to the RE bit is not allowed when the enable SCI bit (ENSCI) is clear. ENSCI is in SCI control register 1.

RWU — Receiver Wake-Up Bit

This read/write bit puts the receiver in a standby state during which receiver interrupts are disabled. The WAKE bit in SCC1 determines whether an idle input or an address mark brings the receiver out of the standby state and clears the RWU bit. Reset clears the RWU bit.

- 1 = Standby state
- 0 = Normal operation

SBK — Send Break Bit

Setting and then clearing this read/write bit transmits a break character followed by a logic one. The logic one after the break character guarantees recognition of a valid start bit. If SBK remains set, the transmitter continuously transmits break characters with no logic ones between them. Reset clears the SBK bit.

- 1 = Transmit break characters
- 0 = No break characters being transmitted

NOTE

Do not toggle the SBK bit immediately after setting the SCTE bit. Toggling SBK before the preamble begins causes the SCI to send a break character instead of a preamble.

12.8.3 SCI Control Register 3 (SCC3)

SCI control register 3:

- Stores the ninth SCI data bit received and the ninth SCI data bit to be transmitted
- Enables SCI receiver full (SCRF) DMA service requests
- Enables SCI transmitter empty (SCTE) DMA service requests
- Enables these interrupts:
 - Receiver overrun interrupts
 - Noise error interrupts
 - Framing error interrupts
 - Parity error interrupts

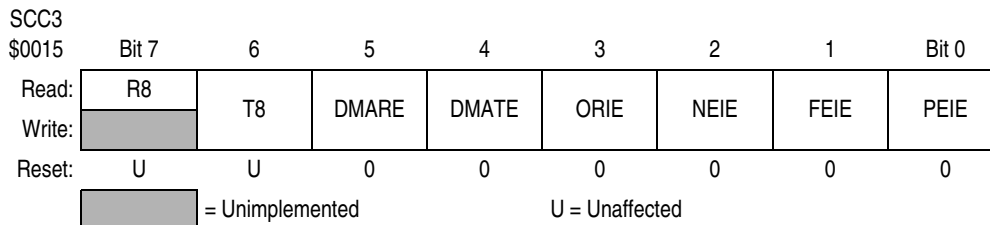


Figure 12-13. SCI Control Register 3 (SCC3)

R8 — Received Bit 8

When the SCI is receiving 9-bit characters, R8 is the read-only ninth bit (bit 8) of the received character. R8 is received at the same time that the SCDR receives the other 8 bits.

When the SCI is receiving 8-bit characters, R8 is a copy of the eighth bit (bit 7). Reset has no effect on the R8 bit.

T8 — Transmitted Bit 8

When the SCI is transmitting 9-bit characters, T8 is the read/write ninth bit (bit 8) of the transmitted character. T8 is loaded into the transmit shift register at the same time that the SCDR is loaded into the transmit shift register. Reset has no effect on the T8 bit.

DMARE — DMA Receive Enable Bit

This read/write bit enables the DMA to service SCI receiver DMA service requests generated by the SCRF bit. Setting the DMARE bit disables SCI receiver CPU interrupt requests. Reset clears the DMARE bit.

- 1 = DMA enabled to service SCI receiver DMA service requests generated by the SCRF bit (SCI receiver CPU interrupt requests disabled)
- 0 = DMA not enabled to service SCI receiver DMA service requests generated by the SCRF bit (SCI receiver CPU interrupt requests enabled)

NOTE

To enable the SCRF bit to generate DMA service requests, the SCI receive interrupt enable bit (SCRIE) must be set.

DMATE — DMA Transfer Enable Bit

This read/write bit enables SCI transmitter empty (SCTE) DMA service requests. (See [12.8.4 SCI Status Register 1 \(SCS1\)](#).) Setting the DMATE bit disables SCTE CPU interrupt requests. Reset clears DMATE.

- 1 = SCTE DMA service requests enabled; SCTE CPU interrupt requests disabled
- 0 = SCTE DMA service requests disabled; SCTE CPU interrupt requests enabled

NOTE

To enable the SCTE bit to generate DMA service requests, the SCI transmit interrupt enable bit (SCTIE) must be set.

ORIE — Receiver Overrun Interrupt Enable Bit

This read/write bit enables SCI error CPU interrupt requests generated by the receiver overrun bit, OR.

1 = SCI error CPU interrupt requests from OR bit enabled

0 = SCI error CPU interrupt requests from OR bit disabled

NEIE — Receiver Noise Error Interrupt Enable Bit

This read/write bit enables SCI error CPU interrupt requests generated by the noise error bit, NE.

Reset clears NEIE.

1 = SCI error CPU interrupt requests from NE bit enabled

0 = SCI error CPU interrupt requests from NE bit disabled

FEIE — Receiver Framing Error Interrupt Enable Bit

This read/write bit enables SCI error CPU interrupt requests generated by the framing error bit, FE.

Reset clears FEIE.

1 = SCI error CPU interrupt requests from FE bit enabled

0 = SCI error CPU interrupt requests from FE bit disabled

PEIE — Receiver Parity Error Interrupt Enable Bit

This read/write bit enables SCI receiver CPU interrupt requests generated by the parity error bit, PE.

(See [12.8.4 SCI Status Register 1 \(SCS1\)](#).) Reset clears PEIE.

1 = SCI error CPU interrupt requests from PE bit enabled

0 = SCI error CPU interrupt requests from PE bit disabled

12.8.4 SCI Status Register 1 (SCS1)

SCI status register 1 contains flags to signal these conditions:

- Transfer of SCDR data to transmit shift register complete
- Transmission complete
- Transfer of receive shift register data to SCDR complete
- Receiver input idle
- Receiver overrun
- Noisy data
- Framing error
- Parity error

SCS1 \$0016	Bit 7	6	5	4	3	2	1	Bit 0
Read:	SCTE	TC	SCRF	IDLE	OR	NF	FE	PE
Write:								
Reset:	1	1	0	0	0	0	0	0


 = Unimplemented

Figure 12-14. SCI Status Register 1 (SCS1)

SCTE — SCI Transmitter Empty Bit

This clearable, read-only bit is set when the SCDR transfers a character to the transmit shift register. SCTE can generate an SCI transmitter CPU interrupt request or an SCI transmitter DMA service request. When the SCTIE bit in SCC2 is set and the DMATE bit in SCC3 is clear, SCTE generates an SCI transmitter CPU interrupt request. With both the SCTIE and DMATE bits set, SCTE generates an SCI transmitter DMA service request. In normal operation, clear the SCTE bit by reading SCS1 with SCTE set and then writing to SCDR. In DMA transfers, the DMA automatically clears the SCTE bit when it writes to the SCDR. Reset sets the SCTE bit.

- 1 = SCDR data transferred to transmit shift register
- 0 = SCDR data not transferred to transmit shift register

NOTE

When DMATE = 1, a write by the CPU to the SCI data register can inadvertently clear the SCTE bit and cause the DMA to miss a service request.

*Setting the TE bit for the first time also sets the SCTE bit. When enabling SCI transmitter DMA service requests, set the TE bit **after** setting the DMATE bit. Otherwise setting the TE and SCTIE bits generates an SCI transmitter CPU interrupt request instead of a DMA service request.*

TC — Transmission Complete Bit

This read-only bit is set when the SCTE bit is set, and no data, preamble, or break character is being transmitted. TC generates an SCI transmitter CPU interrupt request if the TCIE bit in SCC2 is also set. When the DMA services an SCI transmitter DMA service request, the DMA clears the TC bit by writing to the SCDR. TC is automatically cleared when data, preamble or break is queued and ready to be sent. There may be up to 1.5 transmitter clocks of latency between queueing data, preamble, and break and the transmission actually starting. Reset sets the TC bit.

- 1 = No transmission in progress
- 0 = Transmission in progress

SCRF — SCI Receiver Full Bit

This clearable, read-only bit is set when the data in the receive shift register transfers to the SCI data register. SCRF can generate an SCI receiver CPU interrupt request or an SCI receiver DMA service request. When the SCRIE bit in SCC2 is set and the DMARE bit in SCC3 is clear, SCRF generates a CPU interrupt request. With both the SCRIE and DMARE bits set, SCRF generates a DMA service request. In normal operation, clear the SCRF bit by reading SCS1 with SCRF set and then reading the SCDR. In DMA transfers, the DMA clears the SCRF bit when it reads the SCDR. Reset clears SCRF.

- 1 = Received data available in SCDR
- 0 = Data not available in SCDR

NOTE

When DMARE = 1, a read by the CPU of the SCI data register can inadvertently clear the SCRF bit and cause the DMA to miss a service request.

IDLE — Receiver Idle Bit

This clearable, read-only bit is set when 10 or 11 consecutive logic ones appear on the receiver input. IDLE generates an SCI error CPU interrupt request if the ILIE bit in SCC2 is also set and the DMARE bit in SCC3 is clear. Clear the IDLE bit by reading SCS1 with IDLE set and then reading the SCDR.

After the receiver is enabled, it must receive a valid character that sets the SCRF bit before an idle condition can set the IDLE bit. Also, after the IDLE bit has been cleared, a valid character must again set the SCRF bit before an idle condition can set the IDLE bit. Reset clears the IDLE bit.

1 = Receiver input idle

0 = Receiver input active (or idle since the IDLE bit was cleared)

OR — Receiver Overrun Bit

This clearable, read-only bit is set when software fails to read the SCDR before the receive shift register receives the next character. The OR bit generates an SCI error CPU interrupt request if the ORIE bit in SCC3 is also set. The data in the shift register is lost, but the data already in the SCDR is not affected. Clear the OR bit by reading SCS1 with OR set and then reading the SCDR. Reset clears the OR bit.

1 = Receive shift register full and SCRF = 1

0 = No receiver overrun

Software latency may allow an overrun to occur between reads of SCS1 and SCDR in the flag-clearing sequence. [Figure 12-15](#) shows the normal flag-clearing sequence and an example of an overrun caused by a delayed flag-clearing sequence. The delayed read of SCDR does not clear the OR bit because OR was not set when SCS1 was read. Byte 2 caused the overrun and is lost. The next flag-clearing sequence reads byte 3 in the SCDR instead of byte 2.

In applications that are subject to software latency or in which it is important to know which byte is lost due to an overrun, the flag-clearing routine can check the OR bit in a second read of SCS1 after reading the data register.

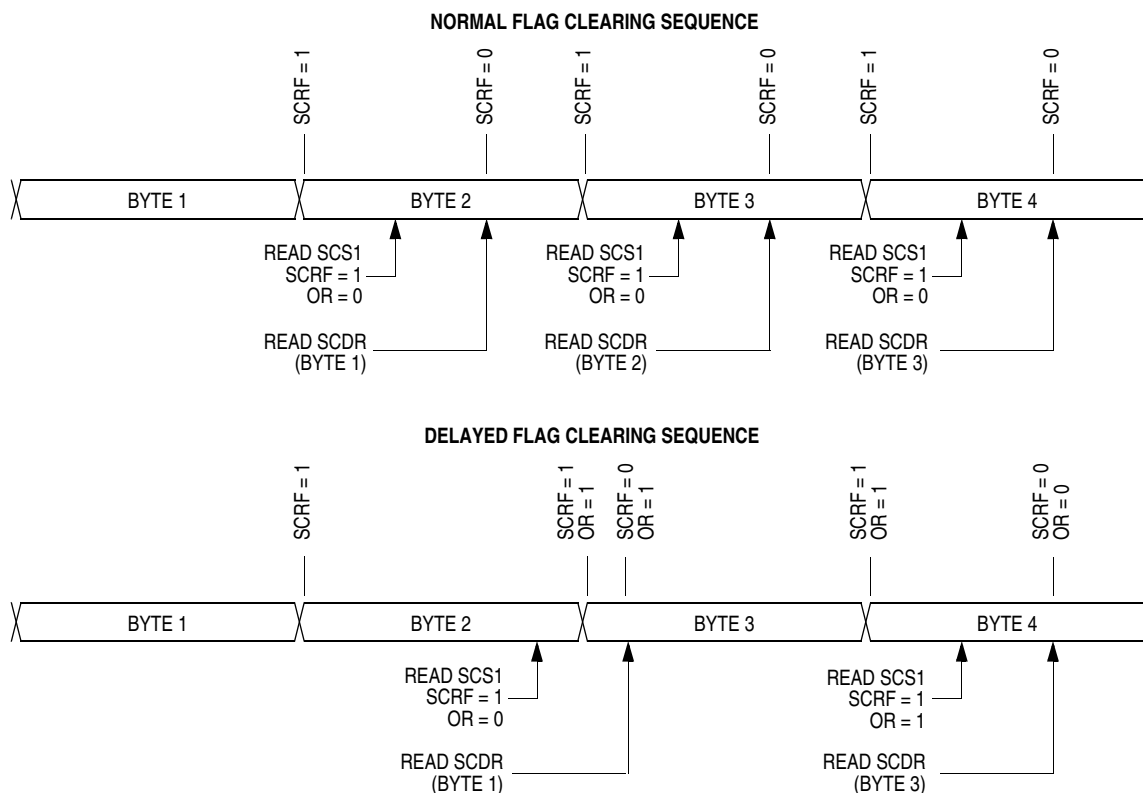


Figure 12-15. Flag Clearing Sequence

NF — Receiver Noise Flag Bit

This clearable, read-only bit is set when the SCI detects noise on the PTE6/RxD pin. NF generates an NF CPU interrupt request if the NEIE bit in SCC3 is also set. Clear the NF bit by reading SCS1 and then reading the SCDR. Reset clears the NF bit.

- 1 = Noise detected
- 0 = No noise detected

FE — Receiver Framing Error Bit

This clearable, read-only bit is set when a logic 0 is accepted as the stop bit. FE generates an SCI error CPU interrupt request if the FEIE bit in SCC3 also is set. Clear the FE bit by reading SCS1 with FE set and then reading the SCDR. Reset clears the FE bit.

- 1 = Framing error detected
- 0 = No framing error detected

PE — Receiver Parity Error Bit

This clearable, read-only bit is set when the SCI detects a parity error in incoming data. PE generates a PE CPU interrupt request if the PEIE bit in SCC3 is also set. Clear the PE bit by reading SCS1 with PE set and then reading the SCDR. Reset clears the PE bit.

- 1 = Parity error detected
- 0 = No parity error detected

12.8.5 SCI Status Register 2 (SCS2)

SCI status register 2 contains flags to signal the following conditions:

- Break character detected
- Incoming data

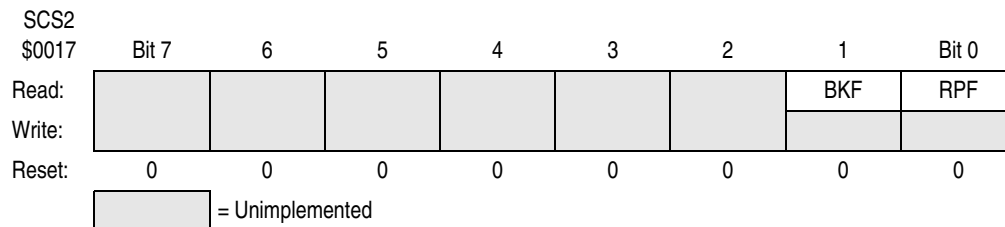


Figure 12-16. SCI Status Register 2 (SCS2)

BKF — Break Flag Bit

This clearable, read-only bit is set when the SCI detects a break character on the PTE6/RxD pin. In SCS1, the FE and SCRF bits are also set. In 9-bit character transmissions, the R8 bit in SCC3 is cleared. BKF does not generate a CPU interrupt request or a DMA service request. Clear BKF by reading SCS2 with BKF set and then reading the SCDR. Once cleared, BKF can become set again only after logic ones again appear on the PTE6/RxD pin followed by another break character. Reset clears the BKF bit.

- 1 = Break character detected
- 0 = No break character detected

RPF — Reception in Progress Flag Bit

This read-only bit is set when the receiver detects a logic zero during the RT1 time period of the start bit search. RPF does not generate an interrupt request. RPF is reset after the receiver detects false start bits (usually from noise or a baud rate mismatch) or when the receiver detects an idle character. Polling RPF before disabling the SCI module or entering stop mode can show whether a reception is in progress.

- 1 = Reception in progress
- 0 = No reception in progress

12.8.6 SCI Data Register (SCDR)

The SCI data register is the buffer between the internal data bus and the receive and transmit shift registers. Reset has no effect on data in the SCI data register.

SCDR \$0018	Bit 7	6	5	4	3	2	1	Bit 0
Read:	R7	R6	R5	R4	R3	R2	R1	R0
Write:	T7	T6	T5	T4	T3	T2	T1	T0
Reset:	Unaffected by reset							

Figure 12-17. SCI Data Register (SCDR)

R7/T7:R0/T0 — Receive/Transmit Data Bits

Reading address \$0018 accesses the read-only received data bits, R7:R0. Writing to address \$0018 writes the data to be transmitted, T7:T0. Reset has no effect on the SCI data register.

NOTE

Do not use read modify write instructions on the SCI data register.

12.8.7 SCI Baud Rate Register (SCBR)

The baud rate register selects the baud rate for both the receiver and the transmitter.

SCBR \$0019	Bit 7	6	5	4	3	2	1	Bit 0
Read:			SCP1	SCP0	R	SCR2	SCR1	SCR0
Write:								
Reset:	0	0	0	0	0	0	0	0

= Unimplemented
 R = Reserved for Factory Test

Figure 12-18. SCI Baud Rate Register (SCBR)

SCP1 and SCP0 — SCI Baud Rate Prescaler Bits

These read/write bits select the baud rate prescaler divisor as shown in [Table 12-9](#). Reset clears SCP1 and SCP0.

Table 12-9. SCI Baud Rate Prescaling

SCP1:SCP0	Prescaler Divisor (PD)
00	1
01	3
10	4
11	13

SCR2:SCR0 — SCI Baud Rate Select Bits

These read/write bits select the SCI baud rate divisor as shown in [Table 12-10](#). Reset clears SCR2:SCR0.

Table 12-10. SCI Baud Rate Selection

SCR2:SCR1:SCR0	Baud Rate Divisor (BD)
000	1
001	2
010	4
011	8
100	16
101	32
110	64
111	128

Use the following formula to calculate the SCI baud rate:

$$\text{Baud rate} = \frac{f_{\text{BUS}}}{64 \times \text{PD} \times \text{BD}}$$

where:

f_{BUS} = bus frequency

PD = prescaler divisor

BD = baud rate divisor

SCI_BDSRC is an input to the SCI. Normally it will be tied off low at the top level to select the bus clock as the clock source. This makes the formula:

$$\text{Baud rate} = \frac{f_{\text{BUS}}}{64 \times \text{PD} \times \text{BD}}$$

[Table 12-11](#) shows the SCI baud rates that can be generated with a 4.9152-MHz bus clock.

Table 12-11. SCI Baud Rate Selection Examples

SCP1:SCP0	Prescaler Divisor (PD)	SCR2:SCR1:SCR0	Baud Rate Divisor (BD)	Baud Rate ($f_{BUS} = 4.9152 \text{ MHz}$)
00	1	000	1	76,800
00	1	001	2	38,400
00	1	010	4	19,200
00	1	011	8	9600
00	1	100	16	4800
00	1	101	32	2400
00	1	110	64	1200
00	1	111	128	600
01	3	000	1	25,600
01	3	001	2	12,800
01	3	010	4	6400
01	3	011	8	3200
01	3	100	16	1600
01	3	101	32	800
01	3	110	64	400
01	3	111	128	200
10	4	000	1	19,200
10	4	001	2	9600
10	4	010	4	4800
10	4	011	8	2400
10	4	100	16	1200
10	4	101	32	600
10	4	110	64	300
10	4	111	128	150
11	13	000	1	5908
11	13	001	2	2954
11	13	010	4	1477
11	13	011	8	739
11	13	100	16	369
11	13	101	32	185
11	13	110	64	92
11	13	111	128	46

Chapter 13

I/O Ports

13.1 Introduction

Forty two (42) bidirectional input-output (I/O) pins form six parallel ports. All I/O pins are programmable as inputs or outputs.

NOTE

Connect any unused I/O pins to an appropriate logic level, either V_{DD} or V_{SS} . Although the I/O ports do not require termination for proper operation, termination reduces excess current consumption and the possibility of electrostatic damage.

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
Port A Data Register (PTA)	PTA7	PTA6	PTA5	PTA4	PTA3	PTA2	PTA1	PTA0	\$0000
Port B Data Register (PTB)	PTB7	PTB6	PTB5	PTB4	PTB3	PTB2	PTB1	PTB0	\$0001
Port C Data Register (PTC)	0	PTC6	PTC5	PTC4	PTC3	PTC2	PTC1	PTC0	\$0002
Port D Data Register (PTD)	PTD7	PTD6	PTD5	PTD4	PTD3	PTD2	PTD1	PTD0	\$0003
Data Direction Register A (DDRA)	DDRA7	DDRA6	DDRA5	DDRA4	DDRA3	DDRA2	DDRA1	DDRA0	\$0004
Data Direction Register B (DDRB)	DDRB7	DDRB6	DDRB5	DDRB4	DDRB3	DDRB2	DDRB1	DDRB0	\$0005
Data Direction Register C (DDRC)	0	DDRC6	DDRC5	DDRC4	DDRC3	DDRC2	DDRC1	DDRC0	\$0006
Data Direction Register D (DDRD)	DDRD7	DDRD6	DDRD5	DDRD4	DDRD3	DDRD2	DDRD1	DDRD0	\$0005
Port E Data Register (PTE)	0	PTE6	PTE5	PTE4	PTE3	PTE2	PTE1	PTE0	\$0008
Port F Data Register (PTF)	0	0	0	0	PTF3	PTF2	PTF1	PTF0	\$0009
Data Direction Register E (DDRE)	0	DDRE6	DDRE5	DDRE4	DDRE3	DDRE2	DDRE1	DDRE0	\$000C
Data Direction Register F (DDRF)	0	0	0	0	DDRF3	DDRF2	DDRF1	DDRF0	\$000D

Figure 13-1. I/O Ports

**Table 13-1. Port Control Register
Bits Summary (Sheet 1 of 2)**

Port	Bit	DDR	Module Control	Pin	
A	0	DDRA0	KBD	KB0IE	PTA0/KBD0
	1	DDRA1		KB1IE	PTA1/KBD1
	2	DDRA2		KB2IE	PTA2/KBD2
	3	DDRA3		KB3IE	PTA3/KBD3
	4	DDRA4		KB4IE	PTA4/KBD4
	5	DDRA5		KB5IE	PTA5/KBD5
	6	DDRA6		KB6IE	PTA6/KBD6
	7	DDRA7		KB7IE	PTA7/KBD7
B	0	DDRB0	A/D	CH0	PTB0/AD0
	1	DDRB1		CH1	PTB1/AD1
	2	DDRB2		CH2	PTB2/AD2
	3	DDRB3		CH3	PTB3/AD3
	4	DDRB4			PTB4
	5	DDRB5			PTB5
	6	DDRB6			PTB6
	7	DDRB7			PTB7
C	0	DDRC0			PTC0
	1	DDRC1			PTC1
	2	DDRC2			PTC2
	3	DDRC3			PTC3
	4	DDRC4			PTC4
	5	DDRC5			PTC5
	6	DDRC6			PTC6
D	0	DDRD0	SPI1		PTD0/MISO1
	1	DDRD1			PTD1/MOSI1
	2	DDRD2			PTD2/ $\overline{SS1}$
	3	DDRD3			PTD3/SCK1
	4	DDRD4	SPI2		PTD4/SCK2
	5	DDRD5			PTD5/ $\overline{SS2}$
	6	DDRD6			PTD6/MOSI2
	7	DDRD7			PTD7/MISO2

**Table 13-1. Port Control Register
Bits Summary (Sheet 2 of 2)**

Port	Bit	DDR	Module Control	Pin
E	0	DDRE0	TIM	PTE0/TCH0
	1	DDRE1		PTE1/TCH1
	2	DDRE2		PTE2/TCH2
	3	DDRE3		PTE3/TCH3
	4	DDRE4		PTE4/TCLK
	5	DDRE5	SCI	PTE5/TxD
	6	DDRE6		PTE6/RxD
F	0	DDRF0	—	PTF0
	1	DDRF1		PTF1
	2	DDRF2		PTF2
	3	DDRF3		PTF3

13.2 Port A

Port A is an 8-bit general-purpose bidirectional I/O port.

13.2.1 Port A Data Register

The port A data register contains a data latch for each of the eight port A pins.

PTA								
\$0000	Bit 7	6	5	4	3	2	1	Bit 0
Read:	PTA7	PTA6	PTA5	PTA4	PTA3	PTA2	PTA1	PTA0
Write:								
Reset:	Unaffected by reset							
Alternate Function:	KBD7	KBD6	KBD5	KBD4	KBD3	KBD2	KBD1	KBD0

Figure 13-2. Port A Data Register (PTA)

PTA[7:0] — Port A Data Bits

These read/write bits are software programmable. Data direction of each port A pin is under the control of the corresponding bit in data direction register A. Reset has no effect on port A data.

KBD[7:0] — Keyboard Inputs

The keyboard interrupt enable bits, KBIE[7:0], in the keyboard interrupt control register (KBICR), enable the port A pins as external interrupt pins. (See [Chapter 9 Keyboard Module \(KB\)](#).)

13.2.2 Data Direction Register A

Data direction register A determines whether each port A pin is an input or an output. Writing a logic one to a DDRA bit enables the output buffer for the corresponding port A pin; a logic zero disables the output buffer.

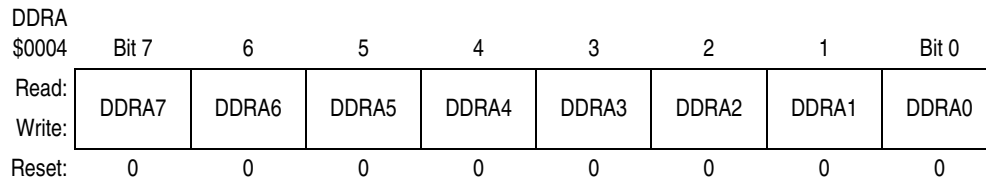


Figure 13-3. Data Direction Register A (DDRA)

DDRA[7:0] — Data Direction Register A Bits

These read/write bits control port A data direction. Reset clears DDRA[7:0], configuring all port A pins as inputs.

- 1 = Corresponding port A pin configured as output
- 0 = Corresponding port A pin configured as input

NOTE

Avoid glitches on port A pins by writing to the port A data register before changing data direction register A bits from 0 to 1.

Figure 13-4 shows the port A I/O logic.

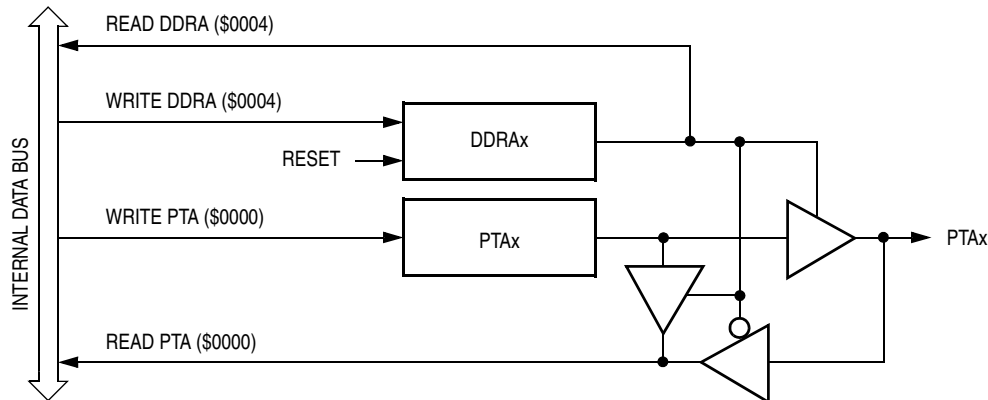


Figure 13-4. Port A I/O Circuit

When bit DDRAx is a logic one, reading address \$0000 reads the PTAx data latch. When bit DDRAx is a logic zero, reading address \$0000 reads the voltage level on the pin. The data latch can always be written, regardless of the state of its data direction bit. Table 13-2 summarizes the operation of the port A pins.

Table 13-2. Port A Pin Functions

DDRA Bit	PTA Bit	I/O Pin Mode	Accesses to DDRA	Accesses to PTA	
			Read/Write	Read	Write
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRA[7:0]	Pin	PTA[7:0] ⁽³⁾
1	X	Output	DDRA[7:0]	PTA[7:0]	PTA[7:0]

NOTES:

1.X = don't care

2.Hi-Z = high impedance

3.Writing affects data register, but does not affect input

13.3 Port B

Port B is an 8-bit special function port that shares four of its pins with the A/D converter module.

13.3.1 Port B Data Register

The port B data register contains a data latch for each of the eight port pins.

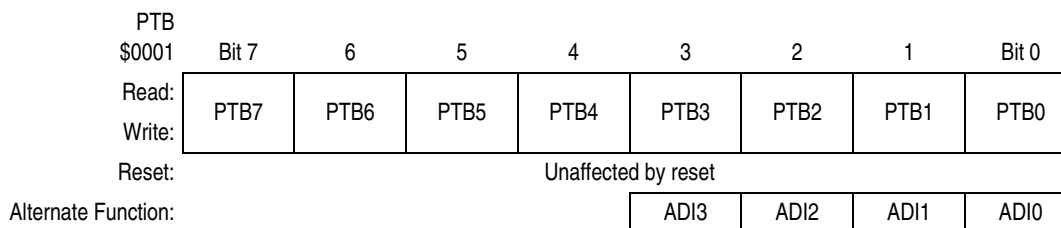


Figure 13-5. Port B Data Register (PTB)

PTB[7:0] — Port B Data Bits

These read/write bits are software-programmable. Data direction of each port B pin is under the control of the corresponding bit in data direction register B. Reset has no effect on port B data.

ADI[3:0] — Analog-to-Digital Input Bits

ADI[3:0] are pins used for the input channels to the analog-to-digital converter module. The channel select bits in the A/D status and control register define which port B pin will be used as an A/D input and overrides any control from the port I/O logic by forcing that pin as the input to the analog circuitry.

NOTE

Care must be taken when reading port B while applying analog voltages to AD3:AD0 pins. If the appropriate A/D channel is not enabled, excessive current drain may occur if analog voltages are applied to the PTBx/ANx pin, while PTB is read as a digital input. Those ports not selected as analog input channels are considered digital I/O ports.

13.3.2 Data Direction Register B

Data direction register B determines whether each port B pin is an input or an output. Writing a logic one to a DDRB bit enables the output buffer for the corresponding port B pin; a logic zero disables the output buffer.

DDR B	Bit 7	6	5	4	3	2	1	Bit 0
\$0005								
Read:	DDRB7	DDRB6	DDRB5	DDRB4	DDRB3	DDRB2	DDRB1	DDRB0
Write:								
Reset:	0	0	0	0	0	0	0	0

Figure 13-6. Data Direction Register B (DDRB)

DDRB[7:0] — Data Direction Register B Bits

These read/write bits control port B data direction. Reset clears DDRB[7:0], configuring all port B pins as inputs.

- 1 = Corresponding port B pin configured as output
- 0 = Corresponding port B pin configured as input

NOTE

Avoid glitches on port B pins by writing to the port B data register before changing data direction register B bits from 0 to 1.

Figure 13-7 shows the port B I/O logic.

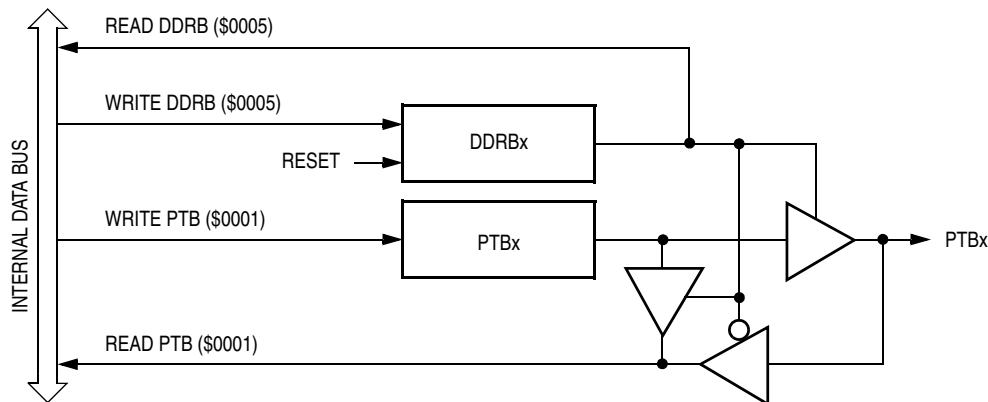


Figure 13-7. Port B I/O Circuit

When bit DDRBx is a logic one, reading address \$0001 reads the PTBx data latch. When bit DDRBx is a logic zero, reading address \$0001 reads the voltage level on the pin. The data latch can always be written, regardless of the state of its data direction bit. Table 13-3 summarizes the operation of the port B pins.

Table 13-3. Port B Pin Functions

DDRB Bit	PTB Bit	I/O Pin Mode	Accesses to DDRB		Accesses to PTB	
			Read/Write	Read	Write	
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRB[7:0]	Pin	PTB[7:0] ⁽³⁾	
1	X	Output	DDRB[7:0]	PTB[7:0]	PTB[7:0]	

NOTES:

1.X = don't care

2.Hi-Z = high impedance

3.Writing affects data register, but does not affect input

13.4 Port C

Port C is a 7-bit general-purpose bidirectional I/O port.

13.4.1 Port C Data Register

The port C data register contains a data latch for each of the seven port C pins.

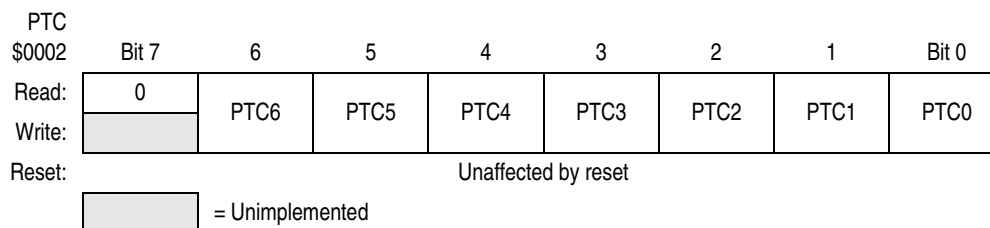


Figure 13-8. Port C Data Register (PTC)

PTC[6:0] — Port C Data Bits

These read/write bits are software-programmable. Data direction of each port C pin is under the control of the corresponding bit in data direction register C. Reset has no effect on port C data.

13.4.2 Data Direction Register C

Data direction register C determines whether each port C pin is an input or an output. Writing a logic one to a DDRC bit enables the output buffer for the corresponding port C pin; a logic zero disables the output buffer.

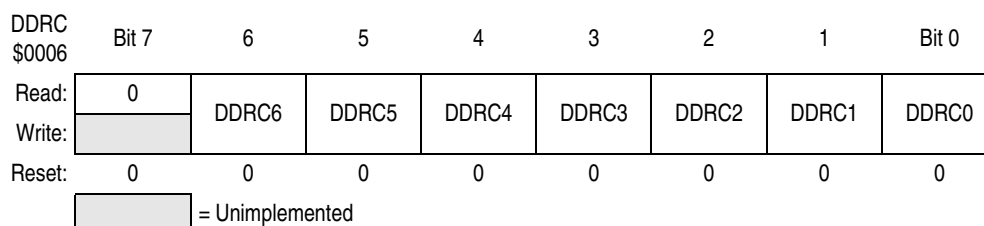


Figure 13-9. Data Direction Register C (DDRC)

DDRC[6:0] — Data Direction Register C Bits

These read/write bits control port C data direction. Reset clears DDRC[6:0], configuring all port C pins as inputs.

- 1 = Corresponding port C pin configured as output
- 0 = Corresponding port C pin configured as input

NOTE

Avoid glitches on port C pins by writing to the port C data register before changing data direction register C bits from 0 to 1.

Figure 13-10 shows the port C I/O logic.

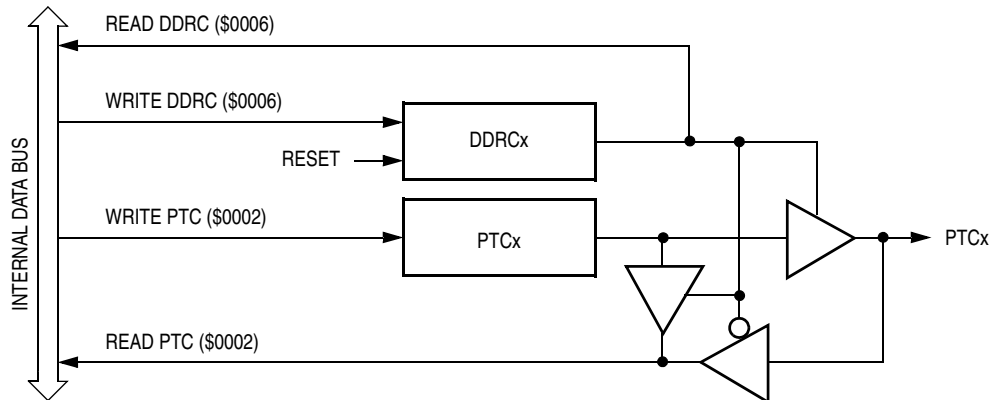


Figure 13-10. Port C I/O Circuit

When bit DDRCx is a logic one, reading address \$0002 reads the PTCx data latch. When bit DDRCx is a logic zero, reading address \$0002 reads the voltage level on the pin. The data latch can always be written, regardless of the state of its data direction bit. Table 13-4 summarizes the operation of the port C pins.

Table 13-4. Port C Pin Functions

DDRC Bit	PTC Bit	I/O Pin Mode	Accesses to DDRC		Accesses to PTC	
			Read/Write	Read	Write	
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRC[6:0]	Pin	PTC[6:0] ⁽³⁾	
1	X	Output	DDRC[6:0]	PTC[6:0]	PTC[6:0]	

NOTES:

- 1.X = don't care
- 2.Hi-Z = high impedance
- 3.Writing affects data register, but does not affect input

13.5 Port D

Port D is an 8-bit special function port that shares all eight of its pins with two serial peripheral interface modules (SPI).

13.5.1 Port D Data Register

The port D data register contains a data latch for each of the eight port D pins.

PTD \$0003	Bit 7	6	5	4	3	2	1	Bit 0
Read:	PTD7	PTD6	PTD5	PTD4	PTD3	PTD2	PTD1	PTD0
Write:								
Reset:	Unaffected by reset							
Alternate Function:	MISO2	MOSI2	$\overline{SS}2$	SPSCK2	SPSCK1	$\overline{SS}1$	MOSI1	MISO1

Figure 13-11. Port D Data Register (PTD)

PTD[7:0] — Port D Data Bits

These read/write bits are software-programmable. Data direction of each port D pin is under the control of the corresponding bit in data direction register D. Reset has no effect on port D data.

MISO1 — Master In/Slave Out1

The PTD0/MISO1 pin is the master in/slave out terminal of the SPI1 module. When the SPI enable bit, SPE, is clear, the SPI module is disabled, and the PTD0/MISO1 pin is available for general-purpose I/O.

Data direction register D (DDRD) does not affect the data direction of port D pins that are being used by the SPI1 module. However, the DDRD bits always determine whether reading port D returns the states of the latches or the states of the pins. See [Table 13-5](#).

MOSI1 — Master Out/Slave In 1

The PTD1/MOSI1 pin is the master out/slave in terminal of the SPI1 module. When the SPE bit is clear, the PTD1/MOSI1 pin is available for general-purpose I/O.

$\overline{SS}1$ — Slave Select 1

The PTD2/ $\overline{SS}1$ pin is the slave select input of the SPI1 module. When the SPE bit is clear, or when the SPI master bit, SPMSTR, is set, the PTD2/ $\overline{SS}1$ pin is available for general-purpose I/O. When the SPI is enabled, the DDRB2 bit in data direction register B (DDRB) has no effect on the PTD2/ $\overline{SS}1$ pin.

SPSCK1 — SPI1 Serial Clock

The PTD3/SPSCK1 pin is the serial clock input of the SPI1 module. When the SPE bit is clear, the PTD3/SPSCK1 pin is available for general-purpose I/O.

SPSCK2 — SPI2 Serial Clock

The PTD4/SPSCK2 pin is the serial clock input of the SPI2 module. When the SPE bit is clear, the PTD4/SPSCK2 pin is available for general-purpose I/O.

$\overline{SS}2$ — Slave Select 2

The PTD5/ $\overline{SS}2$ pin is the slave select input of the SPI2 module. When the SPE bit is clear, or when the SPI master bit, SPMSTR, is set, the PTD5/ $\overline{SS}2$ pin is available for general-purpose I/O. When the SPI2 is enabled, the DDRD5 bit in data direction register D (DDRD) has no effect on the PTD5/ $\overline{SS}2$ pin.

MOSI2 — Master Out/Slave In 2

The PTD6/MOSI2 pin is the master out/slave in terminal of the SPI2 module. When the SPE bit is clear, the PTD6/MOSI2 pin is available for general-purpose I/O.

MISO2 — Master In/Slave Out 2

The PTD7/MISO2 pin is the master in/slave out terminal of the SPI2 module. When the SPI2 enable bit, SPE2, is clear, the SPI2 module is disabled, and the PTD7/MISO2 pin is available for general-purpose I/O.

13.5.2 Data Direction Register D

Data direction register D determines whether each port D pin is an input or an output. Writing a logic one to a DDRD bit enables the output buffer for the corresponding port D pin; a logic zero disables the output buffer.

DDRD \$000C	Bit 7	6	5	4	3	2	1	Bit 0
Read:	DDRD7	DDRD6	DDRD5	DDRD4	DDRD3	DDRD2	DDRD1	DDRD0
Write:								
Reset:	0	0	0	0	0	0	0	0

Figure 13-12. Data Direction Register D (DDRD)

DDRD[7:0] — Data Direction Register D Bits

These read/write bits control port D data direction. Reset clears DDRD[7:0], configuring all port D pins as inputs.

- 1 = Corresponding port D pin configured as output
- 0 = Corresponding port D pin configured as input

NOTE

Avoid glitches on port D pins by writing to the port D data register before changing data direction register D bits from 0 to 1.

Figure 13-13 shows the port D I/O logic.

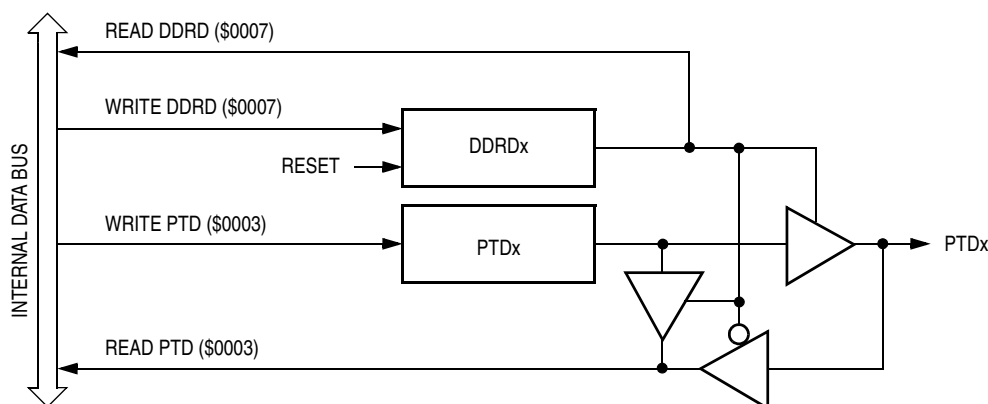


Figure 13-13. Port D I/O Circuit

When bit DDRD_x is a logic one, reading address \$0003 reads the PTD_x data latch. When bit DDRD_x is a logic zero, reading address \$0003 reads the voltage level on the pin. The data latch can always be

written, regardless of the state of its data direction bit. [Table 13-5](#) summarizes the operation of the port D pins.

Table 13-5. Port D Pin Functions

DDRD Bit	PTD Bit	I/O Pin Mode	Accesses to DDRD	Accesses to PTD	
			Read/Write	Read	Write
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRD[7:0]	Pin	PTD[7:0] ⁽³⁾
1	X	Output	DDRD[7:0]	PTD[7:0]	PTD[7:0]

NOTES:

- 1.X = don't care
- 2.Hi-Z = high impedance
- 3.Writing affects data register, but does not affect input

13.6 Port E

Port E is a 7-bit special function port that shares five of its pins with the timer interface (TIM) module and two of its pins with the serial communications interface module (SCI).

13.6.1 Port E Data Register

The port E data register contains a data latch for each of the seven port E pins.

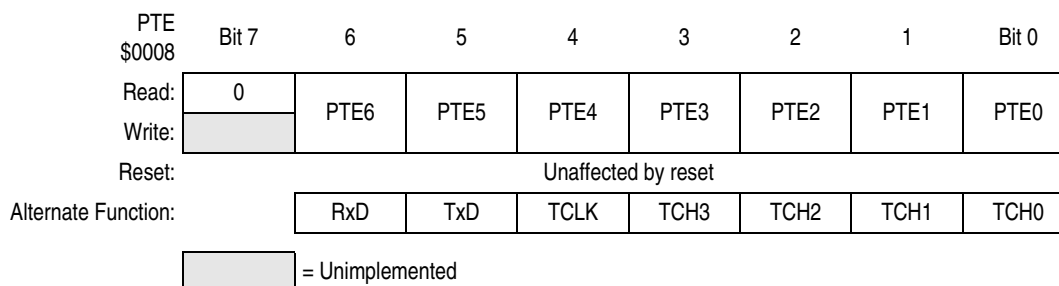


Figure 13-14. Port E Data Register (PTE)

PTE[6:0] — Port E Data Bits

PTE[6:0] are read/write, software programmable bits. Data direction of each port E pin is under the control of the corresponding bit in data direction register E.

NOTE

Data direction register E (DDRE) does not affect the data direction of port E pins that are being used by the TIM. However, the DDRE bits always determine whether reading port E returns the states of the latches or the states of the pins. See [Table 13-6](#).

TCH[3:0] — Timer Channel I/O Bits

The PTE3/TCH3:PTE0/TCH0 pins are the TIM input capture/output compare pins. The edge/level select bits, ELSxB:ELSxA, determine whether the PTE3/TCH3:PTE0/TCH0 pins are timer channel I/O pins or general-purpose I/O pins. See [Chapter 10 Timer Interface Module \(TIM\)](#).

TCLK — Timer Clock Input

The PTE4/TCLK pin is the external clock input for the TIM. The pre-scaler select bits, PS[2:0], select PTE4/TCLK as the TIM clock input. See [Chapter 10 Timer Interface Module \(TIM\)](#). When not selected as the TIM clock, PTE4/TCLK is available for general-purpose I/O.

TxD — SCI Transmit Data Output

The PTE5/TxD pin is the transmit data output for the SCI module. When the enable SCI bit, ENSCI, is clear, the SCI module is disabled, and the PTE5/TxD pin is available for general-purpose I/O. See [Chapter 12 Serial Communications Interface Module \(SCI\)](#).

NOTE

Data direction register E (DDRE) does not affect the data direction of port E pins that are being used by the SCI module. However, the DDRE bits always determine whether reading port E returns the states of the latches or the states of the pins. See [Table 13-6](#).

RxD — SCI Receive Data Input

The PTE7/RxD pin is the receive data input for the SCI module. When the enable SCI bit, ENSCI, is clear, the SCI module is disabled, and the PTE1/RxD pin is available for general-purpose I/O. See [Chapter 12 Serial Communications Interface Module \(SCI\)](#).

13.6.2 Data Direction Register E

Data direction register E determines whether each port E pin is an input or an output. Writing a logic one to a DDRE bit enables the output buffer for the corresponding port E pin; a logic zero disables the output buffer.

DDRE[6:0] — Data Direction Register E Bits

These read/write bits control port E data direction. Reset clears DDRE[6:0], configuring all port E pins as inputs.

- 1 = Corresponding port E pin configured as output
- 0 = Corresponding port E pin configured as input

NOTE

Avoid glitches on port E pins by writing to the port E data register before changing data direction register E bits from 0 to 1.

[Figure 13-15](#) shows the port E I/O logic.

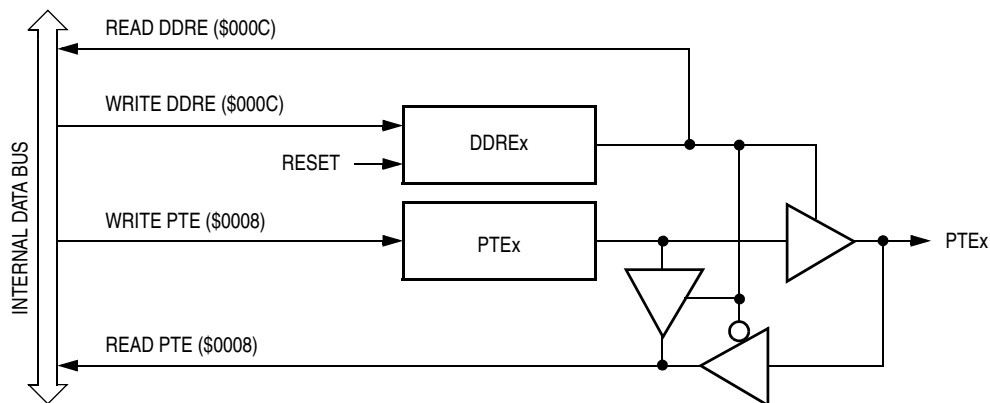


Figure 13-15. Port E I/O Circuit

When bit DDREx is a logic one, reading address \$0008 reads the PTE_x data latch. When bit DDRE_x is a logic zero, reading address \$0008 reads the voltage level on the pin. The data latch can always be written, regardless of the state of its data direction bit. Table 13-6 summarizes the operation of the port E pins.

Table 13-6. Port E Pin Functions

DDRE Bit	PTE Bit	I/O Pin Mode	Accesses to DDRE		Accesses to PTE	
			Read/Write	Read	Write	
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRE[6:0]	Pin	PTE[6:0] ⁽³⁾	
1	X	Output	DDRE[6:0]	PTE[6:0]	PTE[6:0]	

NOTES:

1.X = don't care

2.Hi-Z = high impedance

3.Writing affects data register, but does not affect input

13.7 Port F

Port F is a 4-bit, general-purpose bidirectional I/O port.

13.7.1 Port F Data Register

The port F data register contains a data latch for each of the four port F pins.



Figure 13-16. Port F Data Register (PTF)

PTF[3:0] — Port F Data Bits

These read/write bits are software programmable. Data direction of each port F pin is under the control of the corresponding bit in data direction register F. Reset has no effect on PTF[3:0].

13.7.2 Data Direction Register F

Data direction register F determines whether each port F pin is an input or an output. Writing a logic one to a DDRF bit enables the output buffer for the corresponding port F pin; a logic zero disables the output buffer.

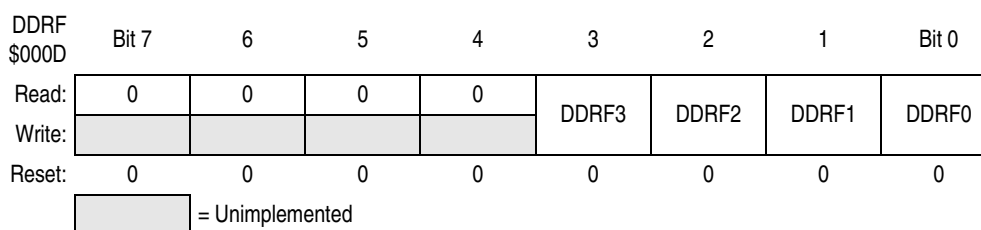


Figure 13-17. Data Direction Register F (DDRF)

DDRF[3:0] — Data Direction Register F Bits

These read/write bits control port F data direction. Reset clears DDRF[3:0], configuring all port F pins as inputs.

1 = Corresponding port F pin configured as output

0 = Corresponding port F pin configured as input

NOTE

Avoid glitches on port F pins by writing to the port F data register before changing data direction register F bits from 0 to 1.

Figure 13-18 shows the port F I/O logic.

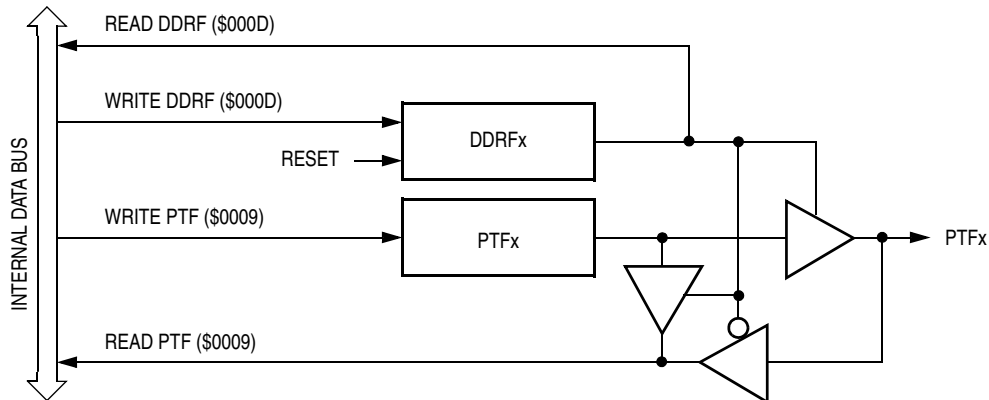


Figure 13-18. Port F I/O Circuit

When bit DDRFx is a logic one, reading address \$0009 reads the PTFx data latch. When bit DDRFx is a logic zero, reading address \$0009 reads the voltage level on the pin. The data latch can always be written, regardless of the state of its data direction bit. Table 13-7 summarizes the operation of the port F pins.

Table 13-7. Port F Pin Functions

DDRF Bit	PTF Bit	I/O Pin Mode	Accesses to DDRF	Accesses to PTF	
			Read/Write	Read	Write
0	X ⁽¹⁾	Input, Hi-Z ⁽²⁾	DDRF[3:0]	Pin	PTF[3:0] ⁽³⁾
1	X	Output	DDRF[3:0]	PTF[3:0]	PTF[3:0]

NOTES:

1.X = don't care

2.Hi-Z = high impedance

3.Writing affects data register, but does not affect input

Chapter 14

Analog-to-Digital Converter (ADC)

14.1 Introduction

This section describes the analog-to-digital converter. The ADC is an 8-bit analog-to-digital converter.

14.2 Features

Features of the ADC module include:

- Four Channels with Multiplexed Input
- Linear Successive Approximation
- 8-Bit Resolution
- Single or Continuous Conversion
- Conversion Complete Flag Or Conversion Complete Interrupt
- Selectable ADC Clock

14.3 Functional Description

The A/D provides four pins for sampling external sources at pins PTB3/AN3:PTB0/AN0. An analog multiplexer allows the single ADC converter to select one of four ADC channels as ADC voltage in (ADCVIN). ADCVIN is converted by the successive approximation register-based analog-to-digital converter. When the conversion is completed, ADC places the result in the ADC data register and sets a flag or generates an interrupt. (See [Figure 14-1](#).)

NOTE

References to DMA and associated functions are only valid if the MCU has a DMA module. If the MCU has no DMA, any DMA-related register bits should be left in their reset state for expected MCU operation.

14.3.1 ADC Port I/O Pins

PTB3/AN3:PTB0/AN0 are general-purpose I/O pins that share with the ADC channels. The channel select bits define which ADC channel/port pin will be used as the input signal. The ADC overrides the port I/O logic by forcing that pin as input to the ADC. The remaining ADC channels/port pins are controlled by the port I/O logic and can be used as general-purpose I/O. Writes to the port register or DDR will not have any affect on the port pin that is selected by the ADC. Read of a port pin in use by the ADC will return a logic zero.

Analog-to-Digital Converter (ADC)

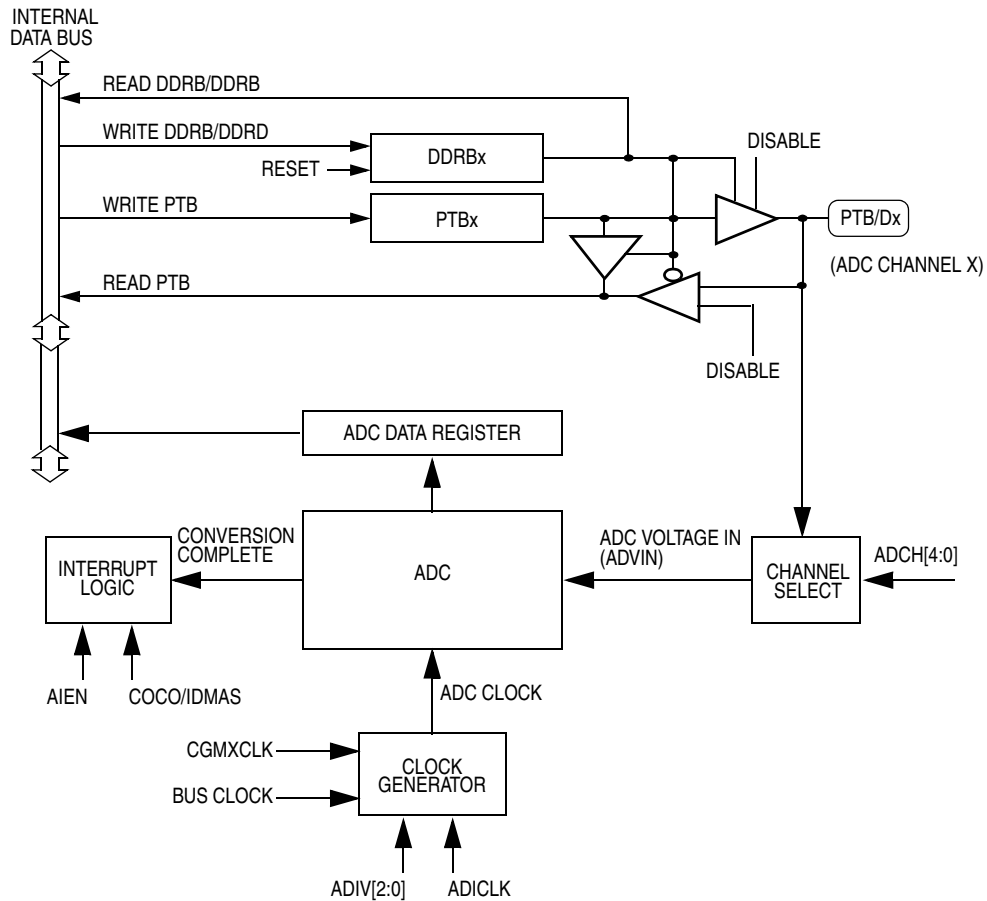


Figure 14-1. ADC Block Diagram

14.3.2 Voltage Conversion

When the input voltage to the ADC equals V_{RH} , the ADC converts the signal to \$FFF (full scale). If the input voltage equals AV_{SS} , the ADC converts it to \$00. Input voltages between V_{RH} and AV_{SS} are a straight-line linear conversion. All other input voltages will result in \$FF, if greater than V_{RH} .

NOTE

Input voltage should not exceed the analog supply voltages.

14.3.3 Conversion Time

Conversion starts after a write to the ADSCR. Conversion time in terms of the number of bus cycles is a function of oscillator frequency, bus frequency, and ADIV prescaler bits. For example, with an oscillator frequency of 4 MHz, bus frequency of 8 MHz and ADC clock frequency of 1 MHz, one conversion will take between 16 ADC and 17 ADC clock cycles or between 16 and 17 μ s. There will be 128 bus cycles between each conversion. Sample rate is approximately 60 kHz.

$$\text{Conversion Time} = \frac{16\text{-}17 \text{ ADC cycles}}{\text{ADC frequency}}$$

$$\text{Number of Bus Cycles} = \text{Conversion Time} \times \text{Bus Frequency}$$

14.3.4 Conversion

In the continuous conversion mode, the ADC data register will be filled with new data after each conversion. Data from the previous conversion will be overwritten whether that data has been read or not. Conversions will continue until the ADCO bit is cleared. The COCO/IDMAS bit is set after the first conversion and will stay set until the next write of the ADC status and control register or the next read of the ADC data register.

In the single conversion mode, conversion begins with a write to the ADSCR. Only one conversion occurs between writes to the ADSCR.

14.3.5 Accuracy and Precision

The conversion process is monotonic and has no missing codes.

14.4 Interrupts

When the AIEN bit is set, the ADC module is capable of generating either CPU or DMA interrupts after each ADC conversion. A CPU interrupt is generated if the COCO/IDMAS bit is at logic zero. If COCO/IDMAS bit is set, a DMA interrupt is generated. The COCO/IDMAS bit is not used as a conversion complete flag when interrupts are enabled.

14.5 Low-Power Modes

The WAIT and STOP instruction can put the MCU in low-power- consumption standby modes.

14.5.1 Wait mode

The ADC continues normal operation during wait mode. Any enabled CPU interrupt request from the ADC can bring the MCU out of wait mode. If the ADC is not required to bring the MCU out of wait mode, power down the ADC by setting ADCH[4:0] bits in the ADC status and control register before executing the WAIT instruction.

14.5.2 Stop Mode

The ADC module is inactive after the execution of a STOP instruction. Any pending conversion is aborted. ADC conversions resume when the MCU exits stop mode after an external interrupt. Allow one conversion cycle to stabilize the analog circuitry.

14.6 I/O Signals

The ADC module has four pins shared with port B.

14.6.1 ADC Analog Power Pin (AV_{DD})

The ADC analog portion uses AV_{DD} as its power pin. Connect the AV_{DD} pin to the same voltage potential as V_{DD} . External filtering may be necessary to ensure clean AV_{DD} for good results.

NOTE

Route AV_{DD} carefully for maximum noise immunity and place bypass capacitors as close as possible to the package.

14.6.2 ADC Analog Ground Pin (AV_{SS})

The ADC analog portion uses AV_{SS} as its ground pin. Connect the AV_{SS} pin to the same voltage potential as V_{SS} .

NOTE

Route AV_{SS} cleanly to avoid any offset errors.

14.6.3 ADC Voltage Reference Pin (V_{RH})

V_{RH} is the power supply for setting the reference voltage V_{RH} . Connect the V_{RH} pin to a voltage potential $\leq AV_{DD}$, not less than 1.5 V.

NOTE

Route R_{RH} cleanly to avoid any offset errors.

14.6.4 ADC Voltage In (ADVIN)

ADVIN is the input voltage signal from one of the four ADC channels to the ADC module.

14.7 I/O Registers

These I/O registers control and monitor operation of the ADC:

- ADC status and control register (ADSCR)
- ADC data register (ADR)
- ADC clock register (ADCLK)

14.7.1 ADC Status and Control Register

The following paragraphs describe the function of the ADC status and control register.

ADSCR								
\$0040	Bit 7	6	5	4	3	2	1	Bit 0
Read:	COCO/ IDMAS	AIEN	ADCO	ADCH4	ADCH3	ADCH2	ADCH1	ADCH0
Write:								
Reset:	0	0	0	1	1	1	1	1

Figure 14-2. ADC Status and Control Register (ADSCR)

COCO/IDMAS — Conversions Complete/Interrupt DMA Select

When AIEN bit is a logic zero, the COCO/IDMAS is a read-only bit which is set each time a conversion is completed except in the continuous conversion mode where it is set after the first conversion. This bit is cleared whenever the ADC status and control register is written or whenever the ADC data register is read.

If AIEN bit is a logic one, the COCO/IDMAS is a read/write bit which selects either CPU or DMA to service the ADC interrupt request. Reset clears this bit.

- 1 = Conversion completed (AIEN = 0)/DMA interrupt (AIEN = 1)
- 0 = Conversion not completed (AIEN = 0)/CPU interrupt (AIEN = 1)

AIEN — ADC Interrupt Enable

When this bit is set, an interrupt is generated at the end of an ADC conversion. The interrupt signal is cleared when the data register is read or the status/control register is written. Reset clears AIEN bit.

- 1 = ADC interrupt enabled
- 0 = ADC interrupt disabled

ADCO — ADC Continuous Conversion

When set, the ADC will convert samples continuously and update the ADR register at the end of each conversion. Only one conversion is completed between writes to the ADSCR when this bit is cleared. Reset clears the ADCO bit.

- 1 = Continuous ADC conversion
- 0 = One ADC conversion

ADCH[4:0] — ADC Channel Select Bits

ADCH4, ADCH3, ADCH2, ADCH1, and ADCH0 form a 5-bit field which is used to select one of 16 ADC channels. Only four channels, ADCH[3:0], are available on this MCU. The channels are detailed in the [Table 14-1](#). Care should be taken when using a port pin as both an analog and digital input simultaneously to prevent switching noise from corrupting the analog signal. (See [Table 14-1](#).) The ADC subsystem is turned off when the channel select bits are all set to one. This feature allows for reduced power consumption for the MCU when the ADC is not being used.

NOTE

Recovery from the disabled state requires one conversion cycle to stabilize.

The voltage levels supplied from internal reference nodes as specified in [Table 14-1](#) are used to verify the operation of the ADC converter both in production test and for user applications.

Table 14-1. Mux Channel Select

ADCH4	ADCH3	ADCH2	ADCH1	ADCH0	Input Select
0	0	0	0	0	PTB0/AD0
0	0	0	0	1	PTB1/AD1
0	0	0	1	0	PTB2/AD2
0	0	0	1	1	PTB3/AD3
0	0	1	0	0	Reserved
↓	↓	↓	↓	↓	Reserved
1	1	0	1	1	Reserved
1	1	1	0	0	V _{RH}
1	1	1	0	1	V _{RH}
1	1	1	1	0	AV _{SS}
1	1	1	1	1	[ADC power off]

NOTE:

If any unused channels are selected, the resulting ADC conversion will be unknown.

14.7.2 ADC Data Register

One 8-bit result register is provided. This register is updated each time an ADC conversion completes.



Figure 14-3. ADC Data Register (ADR)

14.7.3 ADC Clock Register

This register selects the clock frequency for the ADC.

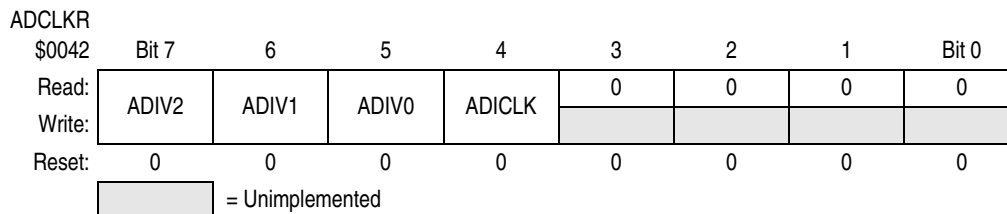


Figure 14-4. ADC Clock Register (ADCLKR)

ADIV2:ADIV0 — ADC Clock Prescaler Bits

ADIV2, ADIV1, and ADIV0 form a 3-bit field which selects the divide ratio used by the ADC to generate the internal ADC clock. Table 14-2 shows the available clock configurations. The ADC clock should be set to approximately 1 MHz.

Table 14-2. ADC Clock Divide Ratio

ADIV2	ADIV1	ADIV0	ADC Clock Rate
0	0	0	ADC input clock / 1
0	0	1	ADC input clock / 2
0	1	0	ADC input clock / 4
0	1	1	ADC input clock / 8
1	X	X	ADC input clock / 16

X = don't care

ADICLK — ADC Input Clock Select

ADICLK selects either bus clock or CGMXCLK as the input clock source to generate the internal ADC clock. Reset selects CGMXCLK as the ADC clock source.

If the external clock (CGMXCLK) is equal to or greater than 1 MHz, CGMXCLK can be used as the clock source for the ADC. If CGMXCLK is less than 1 MHz, use the PLL-generated bus clock as the clock source. As long as the internal ADC clock is at approximately 1 MHz, correct operation can be guaranteed.

1 = Internal bus clock

0 = External clock (CGMXCLK)

$$1 \text{ MHz} = \frac{\text{ADC input clock frequency}}{\text{ADIV}[2:0]}$$

Chapter 15

Liquid Crystal Display Driver (LCD)

15.1 Introduction

The LCD driver module supports a 40 frontplane by 32 backplane display. This allows a maximum of 1280 LCD segments to be driven. Each segment is controlled by a corresponding bit in the LCD RAM. On reset or on power-up, the drivers are disabled via a display ON (DISON) bit in the LCD control register (LCDCR).

15.2 Features

Features of the LCD driver include:

- 40 Frontplane (FP) drivers by 32 Backplane (BP) Drivers
- 160 Bytes of Memory Mapped RAM Organized for Easy Bit-Mapped Character Display
- Internal Charge Pump Voltage Generator for Creation of Analog Voltage Levels

15.3 Functional Description

The LCD driver consists of five major submodules:

- Timing and control — contains registers and generates frame clock and backplane selects at the programmed frequency to produce the waveforms
- Display RAM — contains the data to be displayed on the LCD panel
- Segment drivers — consists of 40 frontplane drivers
- Backplane drivers — consists of 32 backplane drivers
- Voltage generator — internal charge pump circuit to generate analog voltages
- Contrast control — 8-bit contrast resolution allowing analog voltages to remain constant over operating range of power supply

Figure 15-1 shows a block diagram of the LCD driver module.

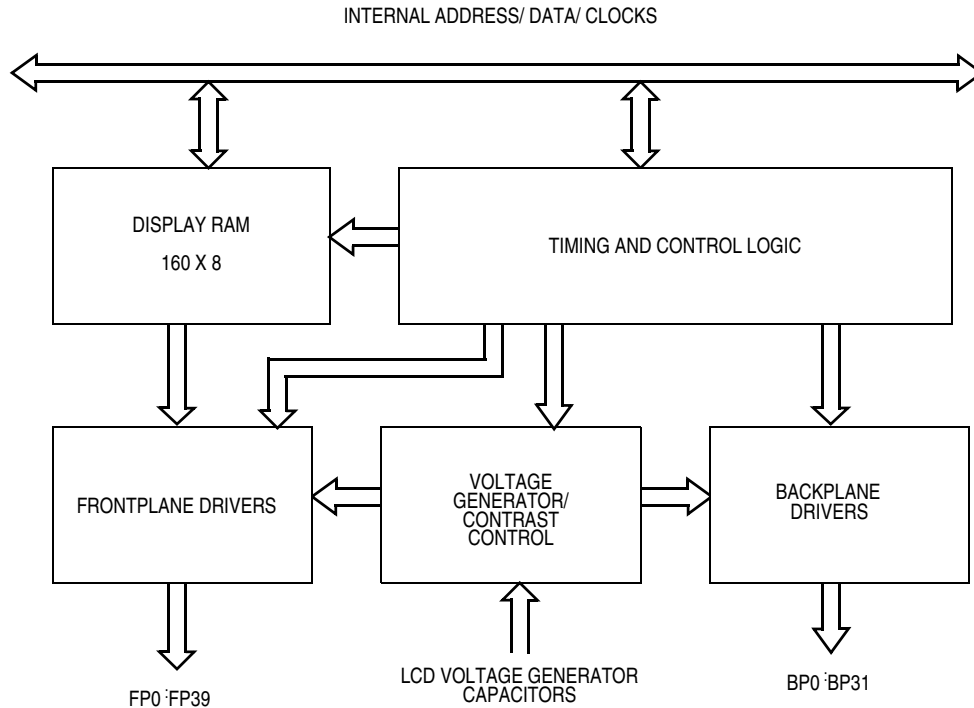


Figure 15-1. LCD Driver Block Diagram

15.4 LCD RAM

The data to be displayed by the LCD is written to a 160-byte display RAM located between locations \$0E00:\$0FFF in the memory map. The bits are organized as shown in [Table 15-1](#), [Table 15-2](#), and [Table 15-3](#) with a 1 stored in a given location, resulting in the corresponding display segment being activated (turned on). The LCD RAM is a dual port RAM that interfaces with the internal address and data buses of the MCU. It is possible to read from the LCD RAM locations for software-controlled scrolling.

If the LCD is disabled (DISON = 0 in the LCD control register), the 160 byte LCD RAM may be used as general-purpose on-chip RAM.

If any of the frontplanes are unused, it is recommended that the corresponding locations in the LCD RAM be written to a 0 to minimize the power consumption. In this case, the only consumed power due to the unused frontplanes will be the switching between fields in the frame.

The LCD RAM is not initialized at power-on or by any reset. Therefore, it is recommended that valid data be written to the LCD RAM before the DISON bit is enabled in the LCD control register.

15.4.1 LCD RAM Organization

As an example, to display the character A on the panel, the following data is written to the RAM as shown in Table 15-1.

Table 15-1. LCD RAM Organization Example

ADDR	DATA									FP
	Hex	BP7	BP6	BP5	BP4	BP3	BP2	BP1	BP0	
		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
\$0E00	\$7C	0	1	1	1	1	1	0	0	FP0
\$0E01	\$12	0	0	0	1	0	0	1	0	FP1
\$0E02	\$11	0	0	0	1	0	0	0	1	FP2
\$0E03	\$12	0	0	0	1	0	0	1	0	FP3
\$0E04	\$7C	0	1	1	1	1	1	0	0	FP4

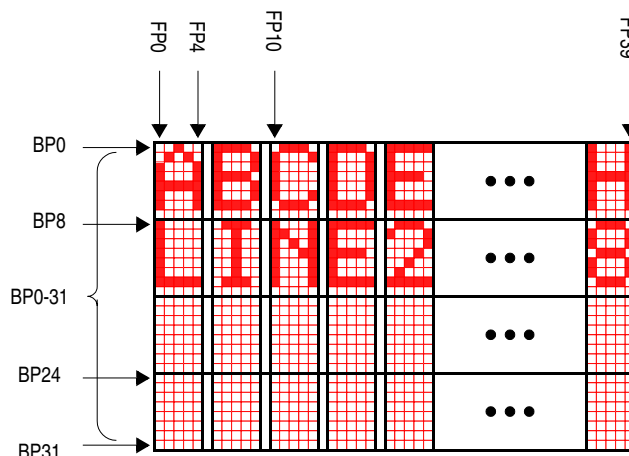


Figure 15-2. LCD Panel Dot Matrix Example

15.4.2 LCD RAM Memory Map

To display 40 frontplanes by 32 backplanes, only 160 bytes of RAM are required. However, holes in the memory map exist for future expansion. This is shown in Table 15-2.

Table 15-2. LCD RAM Memory Map

ADDR	DATA							
	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
\$0E00	FP0-BP7	FP0-BP6	FP0-BP5	FP0-BP4	FP0-BP3	FP0-BP2	FP0-BP1	FP0-BP0
\$0E01	FP1-BP7	FP1-BP6	FP1-BP5	FP1-BP4	FP1-BP3	FP1-BP2	FP1-BP1	FP1-BP0
\$0E02	FP2-BP7	FP2-BP6	FP2-BP5	FP2-BP4	FP2-BP3	FP2-BP2	FP2-BP1	FP2-BP0
.
.
.
\$0E25	FP37-BP7	FP37-BP6	FP37-BP5	FP37-BP4	FP37-BP3	FP37-BP2	FP37-BP1	FP37-BP0
\$0E26	FP38-BP7	FP38-BP6	FP38-BP5	FP38-BP4	FP38-BP3	FP38-BP2	FP38-BP1	FP38-BP0
\$0E27	FP39-BP7	FP39-BP6	FP39-BP5	FP39-BP4	FP39-BP3	FP39-BP2	FP39-BP1	FP39-BP0
\$0E28– \$0E7F	Reserved for Future Expansion							
\$0E80	FP0-BP15	FP0-BP14	FP0-BP13	FP0-BP12	FP0-BP11	FP0-BP10	FP0-BP9	FP0-BP8
\$0E81	FP1-BP15	FP1-BP14	FP1-BP13	FP1-BP12	FP1-BP11	FP1-BP10	FP1-BP9	FP1-BP8
\$0E82	FP2-BP15	FP2-BP14	FP2-BP13	FP2-BP12	FP2-BP11	FP2-BP10	FP2-BP9	FP2-BP8
.
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.
\$0EA5	FP37-BP15	FP37-BP14	FP37-BP13	FP37-BP12	FP37-BP11	FP37-BP10	FP37-BP9	FP37-BP8
\$0EA6	FP38-BP15	FP38-BP14	FP38-BP13	FP38-BP12	FP38-BP11	FP38-BP10	FP38-BP9	FP38-BP8
\$0EA7	FP39-BP15	FP39-BP14	FP39-BP13	FP39-BP12	FP39-BP11	FP39-BP10	FP39-BP9	FP39-BP8
\$0EA8– \$0EFF	Reserved for Future Expansion							
\$0F00	FP0-BP23	FP0-BP22	FP0-BP21	FP0-BP20	FP0-BP19	FP0-BP18	FP0-BP17	FP0-BP16
\$0F01	FP1-BP23	FP1-BP22	FP1-BP21	FP1-BP20	FP1-BP19	FP1-BP18	FP1-BP17	FP1-BP16
\$0F02	FP2-BP23	FP2-BP22	FP2-BP21	FP2-BP20	FP2-BP19	FP2-BP18	FP2-BP17	FP2-BP16
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\$0F25	FP37-BP23	FP37-BP22	FP37-BP21	FP37-BP20	FP37-BP19	FP37-BP18	FP37-BP17	FP37-BP16
\$0F26	FP38-BP23	FP38-BP22	FP38-BP21	FP38-BP20	FP38-BP19	FP38-BP18	FP38-BP17	FP38-BP16
\$0F27	FP39-BP23	FP39-BP22	FP39-BP21	FP39-BP20	FP39-BP19	FP39-BP18	FP39-BP17	FP39-BP16
\$0F28– \$0F7F	Reserved for Future Expansion							
\$0F80	FP0-BP31	FP0-BP30	FP0-BP29	FP0-BP28	FP0-BP27	FP0-BP26	FP0-BP25	FP0-BP24
\$0F81	FP1-BP31	FP1-BP30	FP1-BP29	FP1-BP28	FP1-BP27	FP1-BP26	FP1-BP25	FP1-BP24
\$0F82	FP2-BP31	FP2-BP30	FP2-BP29	FP2-BP28	FP2-BP27	FP2-BP26	FP2-BP25	FP2-BP24
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\$0FA5	FP37-BP31	FP37-BP30	FP37-BP29	FP37-BP28	FP37-BP27	FP37-BP26	FP37-BP25	FP37-BP24
\$0FA6	FP38-BP31	FP38-BP30	FP38-BP29	FP38-BP28	FP38-BP27	FP38-BP26	FP38-BP25	FP38-BP24
\$0FA7	FP39-BP31	FP39-BP30	FP39-BP29	FP39-BP28	FP39-BP27	FP39-BP26	FP39-BP25	FP39-BP24
\$0FA8– \$0FFF	Reserved for Future Expansion							

15.5 LCD Operation

Figure 15-3 through Figure 15-8 show the backplane waveforms and some examples of frontplane waveforms. Each on segment must have a high enough differential driving voltage (BP-FP) applied to it once in each frame. The LCD driver module hardware uses the data in the LCD RAM to construct the frontplane waveforms. The backplane waveforms are not affected by the data in the LCD RAM. During wait mode, the LCD drivers function normally and will keep the display active if the DISON bit in the LCD control register is set. During stop mode, the DISON bit should be turned off to allow all the frontplane and backplane drivers to drive to V_{SS} .

15.6 LCD Waveforms

The LCD waveforms are generated using multiple analog voltage levels to yield an on RMS voltage or off RMS voltage at the intersection of each frontplane and backplane driver. The RMS voltage is defined to be:

$$V_{RMS} = \sqrt{\frac{1}{T} \int f^2(t) dt}$$

A frame consists of two fields. Field 1 and field 2 represent identical data at complimentary polarities to obtain a 0 V average DC value required by the display crystal. During each field, the backplanes are consecutively asserted. A more common style of backplane waveforms has a backplane switching to its complementary value before the next backplane is asserted, which results in more switching and power consumption. The field/frame approach is preferred for this reason. If data in the LCD RAM is not changed, the same waveforms will be generated each frame.

In this section multiple examples showing the appropriate waveforms are presented.

15.6.1 Backplane Waveform

The backplane waveform is a periodic waveform that does not depend on the data to be displayed. For 32 backplanes that are multiplexed in time, each backplane driver waveform will have 1/64 of a frame period at V_{LL7} in field 1, and 1/64 of a frame period at V_{SS} in field 2 as shown in Figure 15-3. This is its “active” time. The remaining 62/64 of the frame period is divided between V_{LL1} in field 1 and V_{LL6} in field 2.

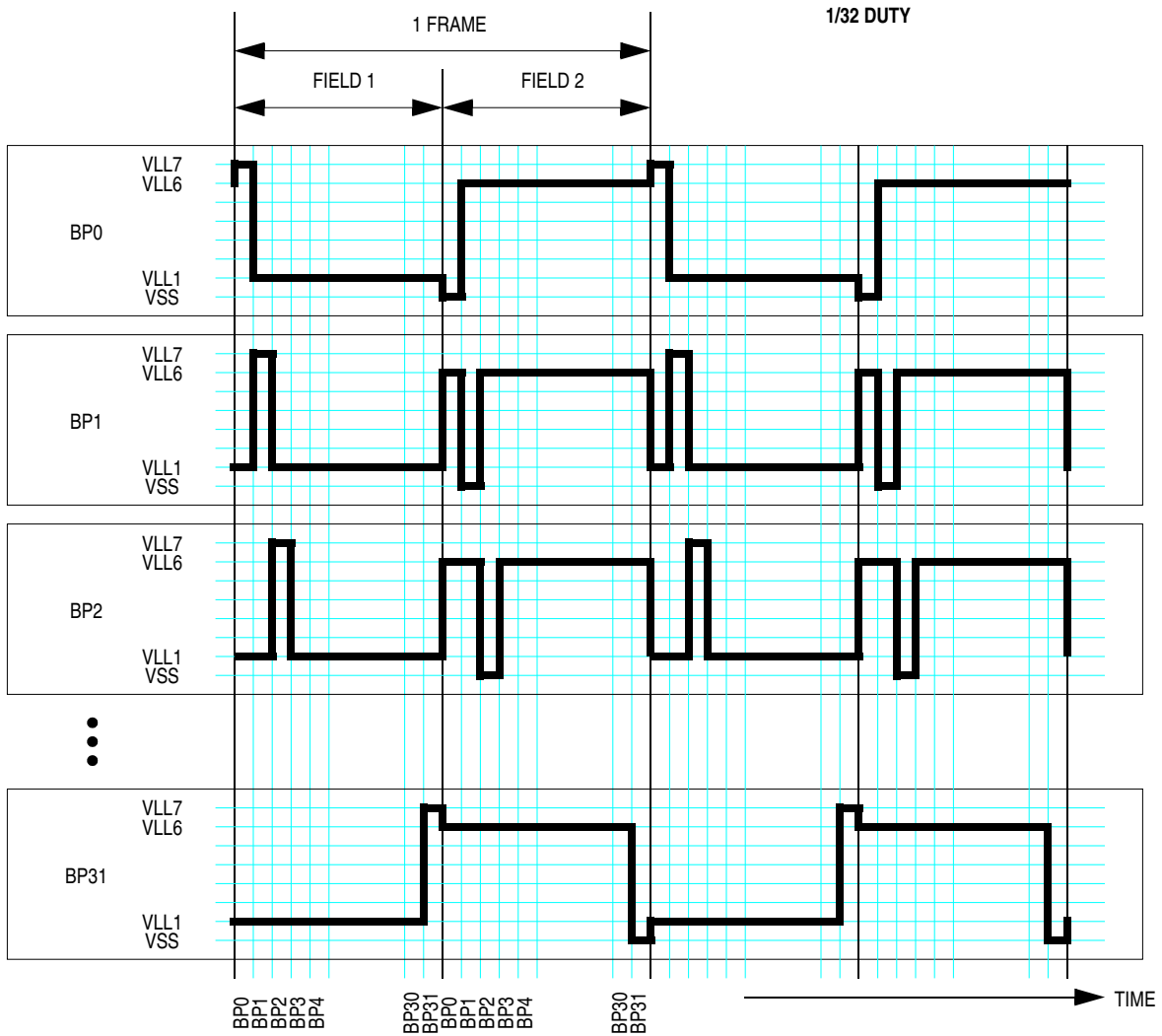


Figure 15-3. Backplane (BP) Waveforms (1/32 Duty)

15.6.2 Frontplane Waveform

The frontplane waveform is a periodic waveform that depends on the data to be displayed stored in the RAM. For 32 backplanes that are multiplexed in time, each frontplane driver waveform will have 1/64 of a frame period at V_{SS} in field 1 and 1/64 of a frame period at V_{LL7} in field 2 for each segment that is on and 1/64 of a frame period of V_{LL2} in field 1 and 1/64 of a frame period of V_{LL5} in field 2 for each segment that is off, as shown in Figure 15-4.

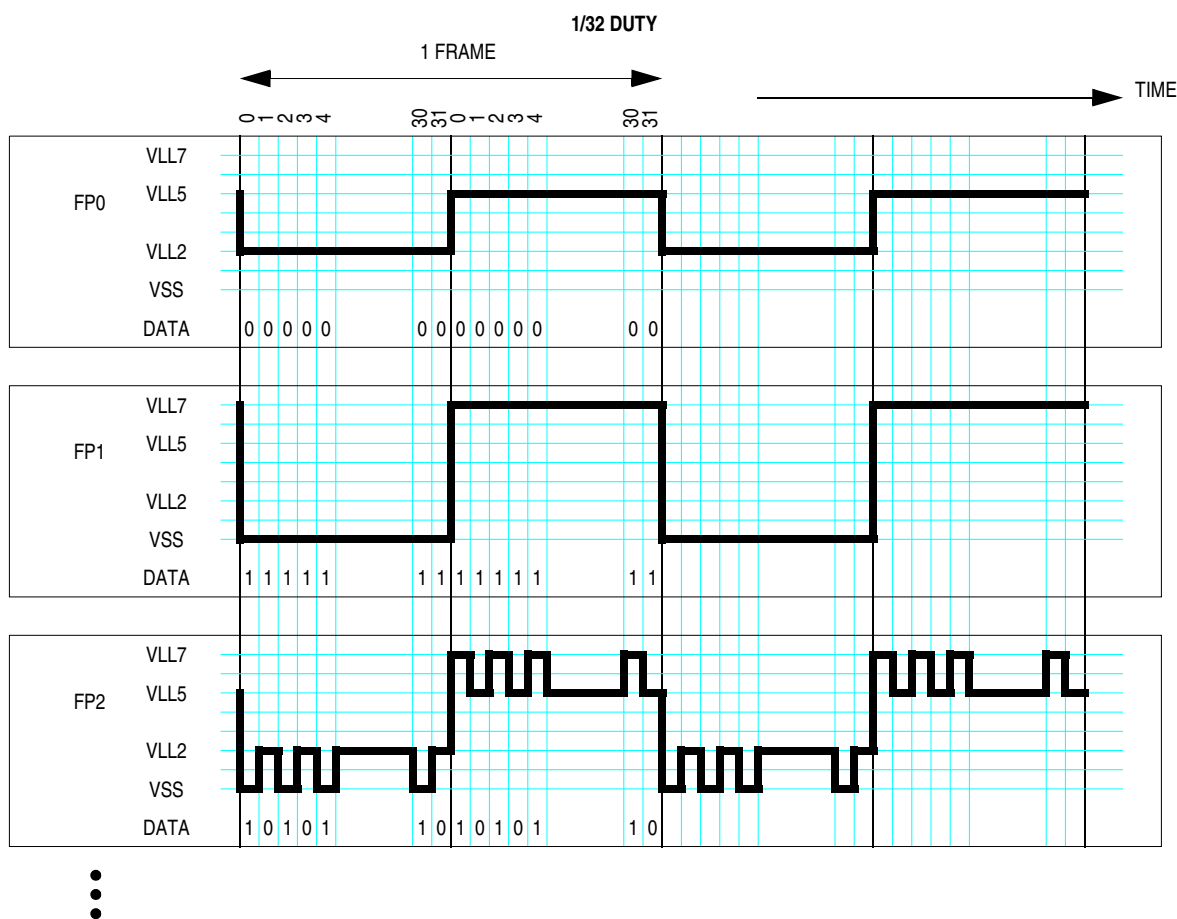


Figure 15-4. Example Frontplane (FP) Waveforms (1/32 Duty)

15.6.3 Example Segment Waveforms and RMS Values

The voltage across a pixel (segment) of an LCD panel is the difference between the backplane (BP) and the frontplane (FP) driver voltages where they intersect.

As an example, the waveforms for FP data of all ones and the voltage waveform for the segment at BP0/FPx are shown in [Figure 15-5](#).

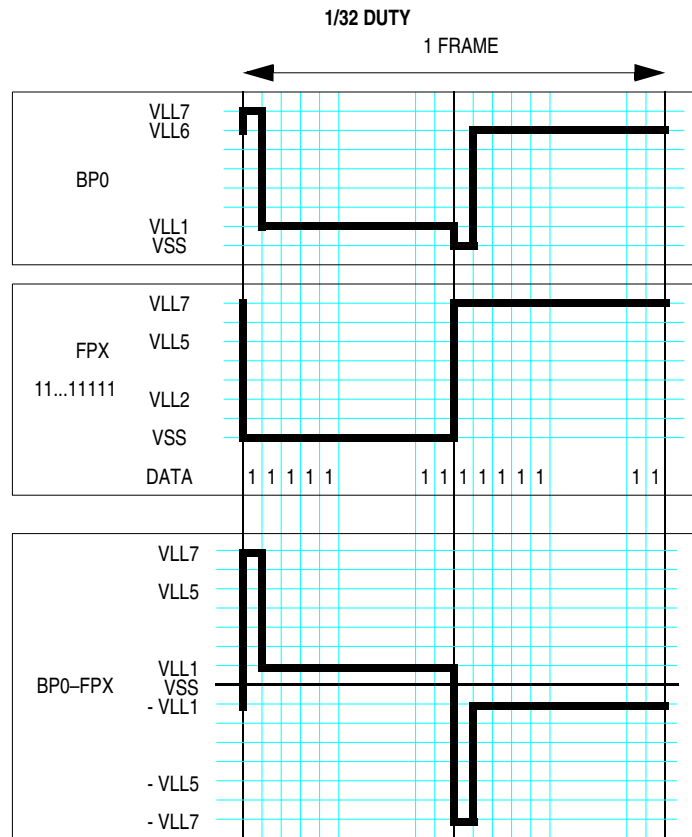


Figure 15-5. LCD Waveforms Example for Data of 11...11111

The RMS voltage at the intersection of BP0 and FPx of [Figure 15-5](#) is

$$V_{RMSA1} = \sqrt{\frac{1}{64} \cdot (V_{LL7}^2 \cdot 2 + V_{LL1}^2 \cdot 62)}$$

Using $V_{LL7} = 7.0 \text{ V}$ and $V_{LL1} = 1.0 \text{ V}$, the RMS voltage at the intersection of BP0 and FPx of [Figure 15-5](#) will be

$$V_{RMSA1} = \sqrt{\frac{1}{64} \cdot (7^2 \cdot 2 + 1^2 \cdot 62)} \approx 1.5811 \text{ V}$$

Thus, the segment at the intersection of BP0 and FPx should be turned on.

Waveforms for FP data of all zeros and the voltage waveform for the segment at BP0/FPx are in Figure 15-6.

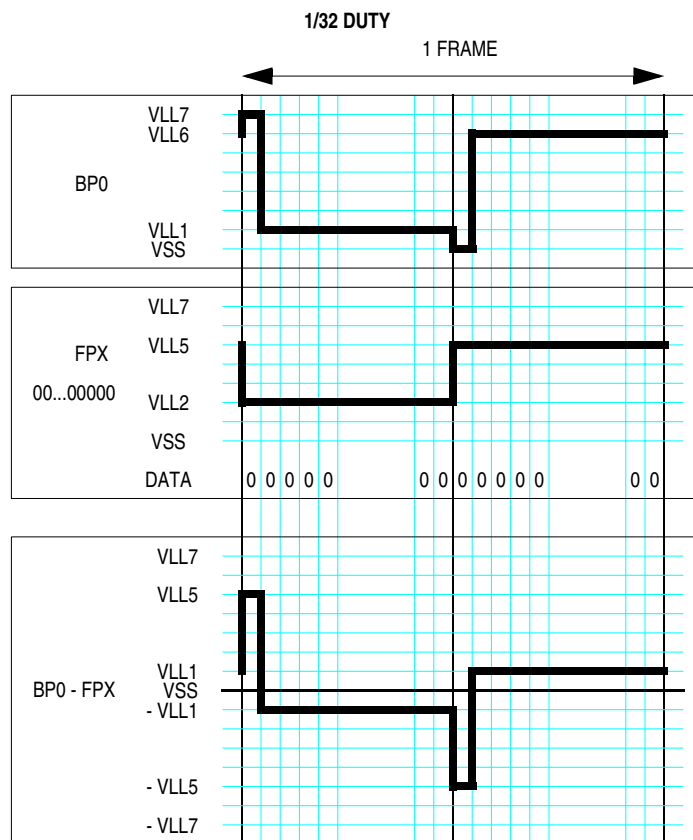


Figure 15-6. LCD Waveforms Example for Data of 00...00000

The RMS voltage at the intersection of BP0 and FPx of Figure 15-6 is

$$V_{\text{RMSA0}} = \sqrt{\frac{1}{64} \cdot (V_{\text{LL5}}^2 \cdot 2 + V_{\text{LL1}}^2 \cdot 62)}$$

Using $V_{\text{LL5}} = 5.0 \text{ V}$ and $V_{\text{LL1}} = 1.0 \text{ V}$, the RMS voltage at the intersection of BP0 and FPx of Figure 15-6 will be

$$V_{\text{RMSA0}} = \sqrt{\frac{1}{64} \cdot (5^2 \cdot 2 + 1^2 \cdot 62)} \approx 1.3229\text{V}$$

Thus, the segment at the intersection of BP0 and FPx should be turned off.

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Waveforms for FP data of alternating ones and zeros and the voltage waveform for the segment at BP0/FPx are shown in [Figure 15-7](#) and for the segment at BP1/FPx are shown in [Figure 15-8](#).

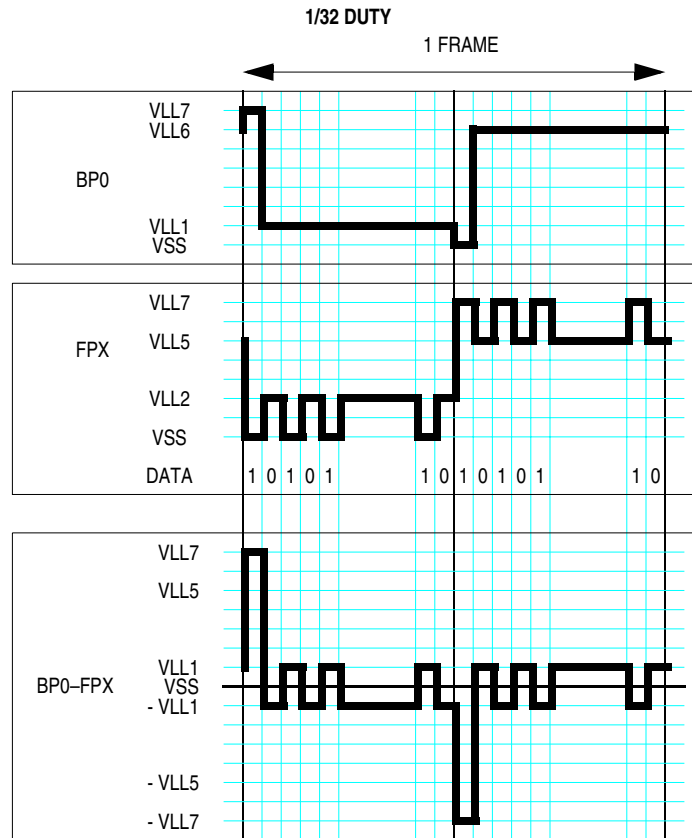


Figure 15-7. LCD Waveforms Example for BP0 and FP Data of 01...10101

The RMS voltage at the intersection of BP0 and FPx of [Figure 15-7](#) is

$$V_{\text{RMST}} = \sqrt{\frac{1}{64} \cdot (V_{\text{LL}7}^2 \cdot 2 + V_{\text{LL}1}^2 \cdot 62)}$$

Using $V_{\text{LL}7} = 7.0 \text{ V}$ and $V_{\text{LL}1} = 1.0 \text{ V}$, the RMS voltage at the intersection of BP0 and FPx of [Figure 15-7](#) will be

$$V_{\text{RMST}} = \sqrt{\frac{1}{64} \cdot (7^2 \cdot 2 + 1^2 \cdot 62)} \approx 1.5811 \text{ V}$$

Thus, the segment at the intersection of BP0 and FPx should be turned on.

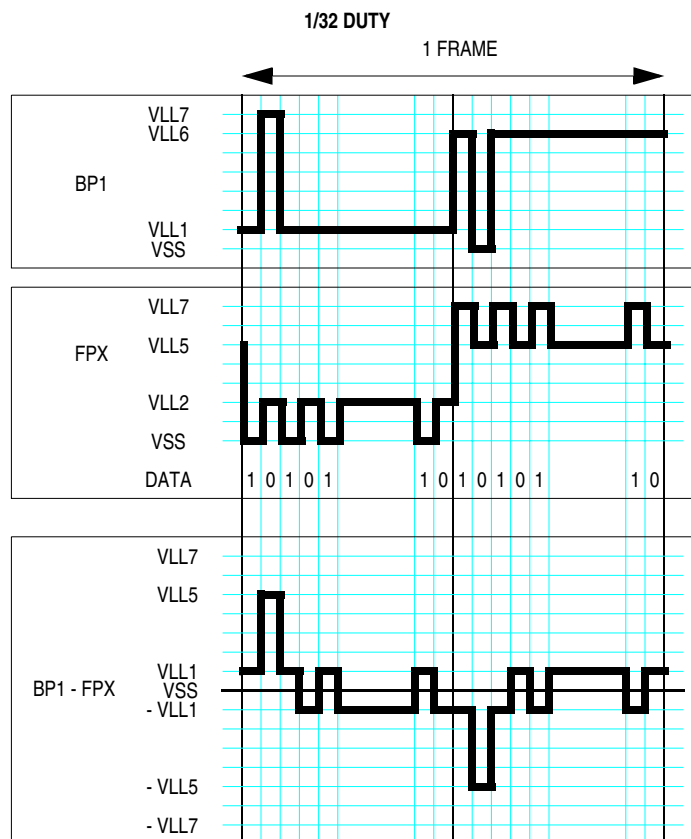


Figure 15-8. LCD Waveforms Example for BP 1 and FP Data of 01...10101

The RMS voltage at the intersection of BP1 and FPx of [Figure 15-8](#) is

$$V_{RMST} = \sqrt{\frac{1}{64} \cdot (V_{LL5}^2 \cdot 2 + V_{LL1}^2 \cdot 62)}$$

Using $V_{LL5} = 5.0 \text{ V}$ and $V_{LL1} = 1.0 \text{ V}$, the RMS voltage at the intersection of BP1 and FPx of [Figure 15-8](#) will be

$$V_{RMST} = \sqrt{\frac{1}{64} \cdot (5^2 \cdot 2 + 1^2 \cdot 62)} \approx 1.3229\text{V}$$

Thus, the segment at the intersection of BP1 and FPx should be turned off.

NOTE

The difference in on and off voltages is only 0.258 V in this example. Only the “active” time voltage determines the difference between the on and off voltage. The voltages during the non-active time always contribute the same amount to the total RMS voltage.

As another example, the waveforms for FP2 data to display the character A are shown in [Figure 15-9](#). The differential voltage for the BP4-FP2 pixel is shown.

Table 15-3. LCD RAM Organization Example

Addr	Data									FP
	Hex	BP7	BP6	BP5	BP4	BP3	BP2	BP1	BP0	
		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
\$0E00	\$7C	0	1	1	1	1	1	0	0	FP0
\$0E01	\$12	0	0	0	1	0	0	1	0	FP1
\$0E02	\$11	0	0	0	1	0	0	0	1	FP2
\$0E03	\$12	0	0	0	1	0	0	1	0	FP3
\$0E04	\$7C	0	1	1	1	1	1	0	0	FP4

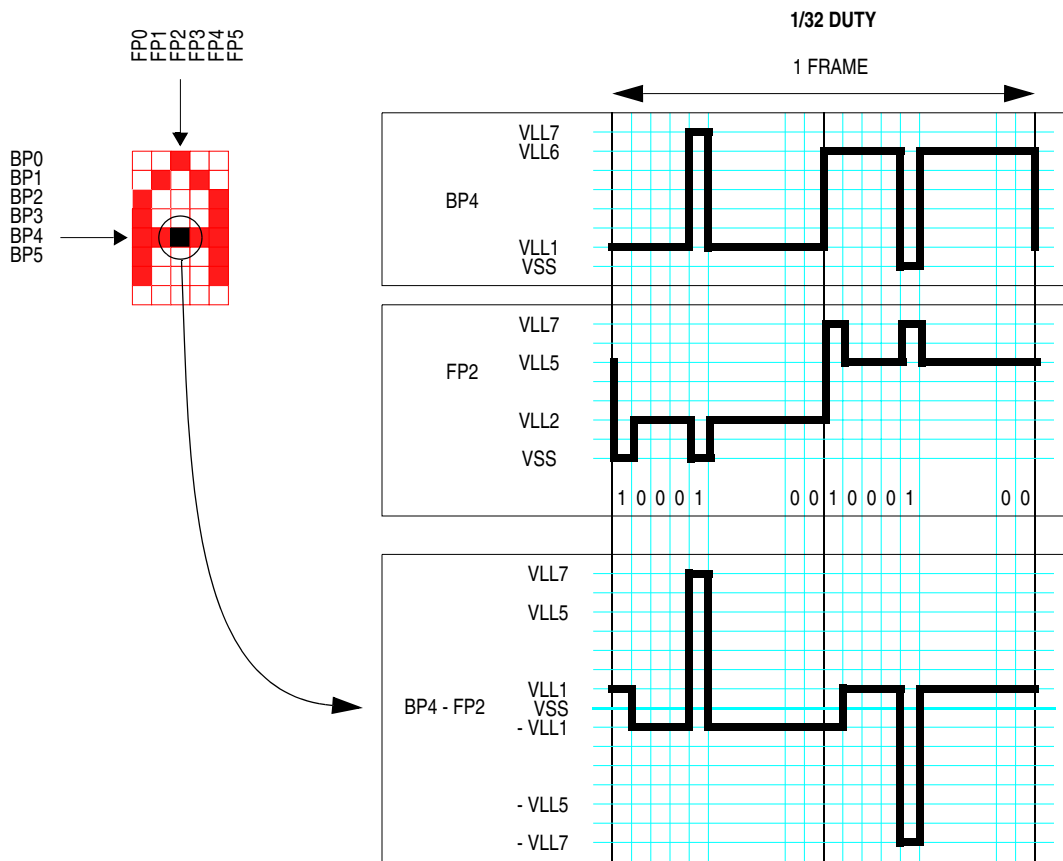


Figure 15-9. LCD Waveform Example for Data of 00010001, Contents of \$0E02

Using $V_{LL7} = 7.0 \text{ V}$ and $V_{LL1} = 1.0 \text{ V}$, the RMS voltage at the intersection of BP4 and FP2 of Figure 15-9 will be

$$V_{\text{RMST}} = \sqrt{\frac{1}{64} \cdot (7^2 \cdot 2 + 1^2 \cdot 62)} \approx 1.5811 \text{ V}$$

15.6.4 RMS Voltages

The RMS voltages for the waveforms shown in the examples are generalized with this formula:

$$V_{\text{RMSON}} = \sqrt{\frac{1}{64} \cdot \left(\left(\frac{7}{7} \cdot V_{\text{LL7}} \right)^2 \cdot 2 + \left(\frac{1}{7} \cdot V_{\text{LL7}} \right)^2 \cdot 62 \right)} = \frac{\sqrt{10}}{14} \cdot V_{\text{LL7}}$$

$$V_{\text{RMSOFF}} = \sqrt{\frac{1}{64} \cdot \left(\left(\frac{5}{7} \cdot V_{\text{LL7}} \right)^2 \cdot 2 + \left(\frac{1}{7} \cdot V_{\text{LL7}} \right)^2 \cdot 62 \right)} = \frac{\sqrt{7}}{14} \cdot V_{\text{LL7}}$$

15.7 LCD Voltage Generation

The actual LCD analog voltages for the frontplane and backplane waveforms (shown in [Table 15-5](#)) are generated by a charge pump, which uses external capacitors for charge storing and switching. A diagram indicating external capacitance values for the charge pump is shown in [Figure 15-10](#).

Upon power-up of the chip, the absolute value of the LCD charge pump voltage levels will be set as a result of the reset condition of the LCD contrast control register (LCDCCR). The LCD system can be disabled and have all frontplane and backplane drivers driven to V_{SS} by clearing the DISON bit in the LCD control register.

[Figure 15-11](#) illustrates a conceptual block diagram of a resistive divider chain network used to produce the various LCD waveforms outlined in the previous section. Software control of the contrast can be accomplished by measurement of the supply voltage with the ADC, and based on this reading, selecting the appropriate resistors by programming the contrast control bits (CC5:CC0) in the LCD contrast control register (LCDCCR).

The SUPV bit in the LCD control register should also be programmed accordingly for 3 V or 5 V nominal operation. The accuracy of this setting is determined by the accuracy of the reference voltage used by the ADC as well as the quantization error due to the ADC and that of the digital-to-analog conversion done by the contrast control circuitry. It is recommended that some means of manual contrast control adjustment be available to the user of the system containing the microcontroller to achieve the desired visual contrast on the LCD. Software controlled periodic adjustments of the contrast control register can then be performed, combining the ADC reading of the supply with the manual user adjustment, into a single value used in the LCD contrast control register (LCDCCR).

NOTE

For 5 V operation, set SUPV = 1, for 3 V operation SUPV = 0.

15.7.1 LCD Contrast Control

Contrast of the LCD display can be adjusted by setting the LCD contrast control register (LCDCCR). For a desired value of V_{LL7} , the following equation determines the decimal value to which the register should be set.

$$\text{CC} = \text{RND} \left(\frac{V_{\text{LL7}}}{V_{\text{DD}}} (47.143 \cdot \text{SUPV} + 94.286) - 160 \right)$$

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For the allowed range of top voltages, [Table 15-4](#) lists the V_{RMSON} , V_{RMSOFF} , and the difference between them. This should be matched to the corresponding requirements of the LCD panel.

Table 15-4. LCD RMS Voltages (1/7 bias)

V_{LL7} (V)	V_{RMSON} (V)	V_{RMSOFF} (V)	V_{DIFF} (V)
6.3	1.4230	1.1906	0.2324
6.4	1.4456	1.2095	0.2361
6.5	1.4682	1.2284	0.2398
6.6	1.4908	1.2473	0.2435
6.7	1.5134	1.2662	0.2472
6.8	1.5360	1.2851	0.2509
6.9	1.5586	1.3040	0.2546
7.0	1.5811	1.3229	0.2583

Table 15-5. LCD Voltages

$V_{\text{LL7}} = 7.0 \text{ V}$, 1/7 Bias		
V_{LL7}	7/7	7.0 V
V_{LL6}	6/7	6.0 V
V_{LL5}	5/7	5.0 V
V_{LL2}	2/7	2.0 V
V_{LL1}	1/7	1.0 V
V_{SS}	0/7	0.0 V

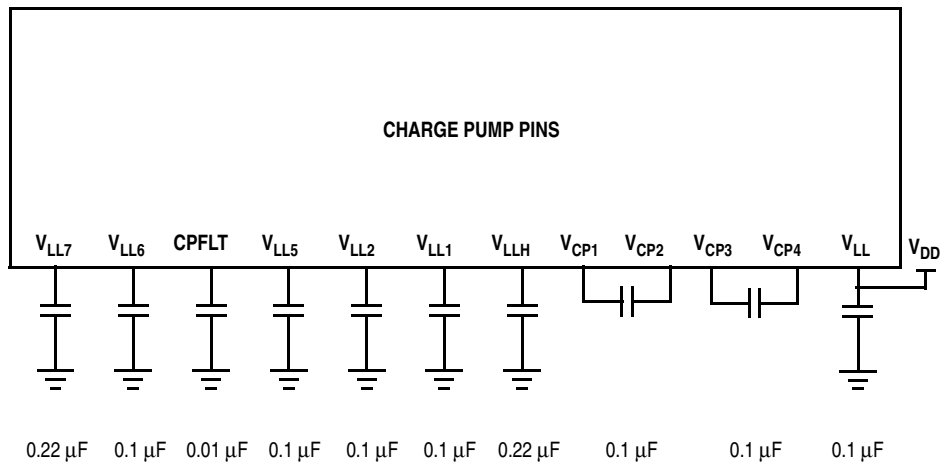


Figure 15-10. Charge Pump Capacitor Connection Diagram

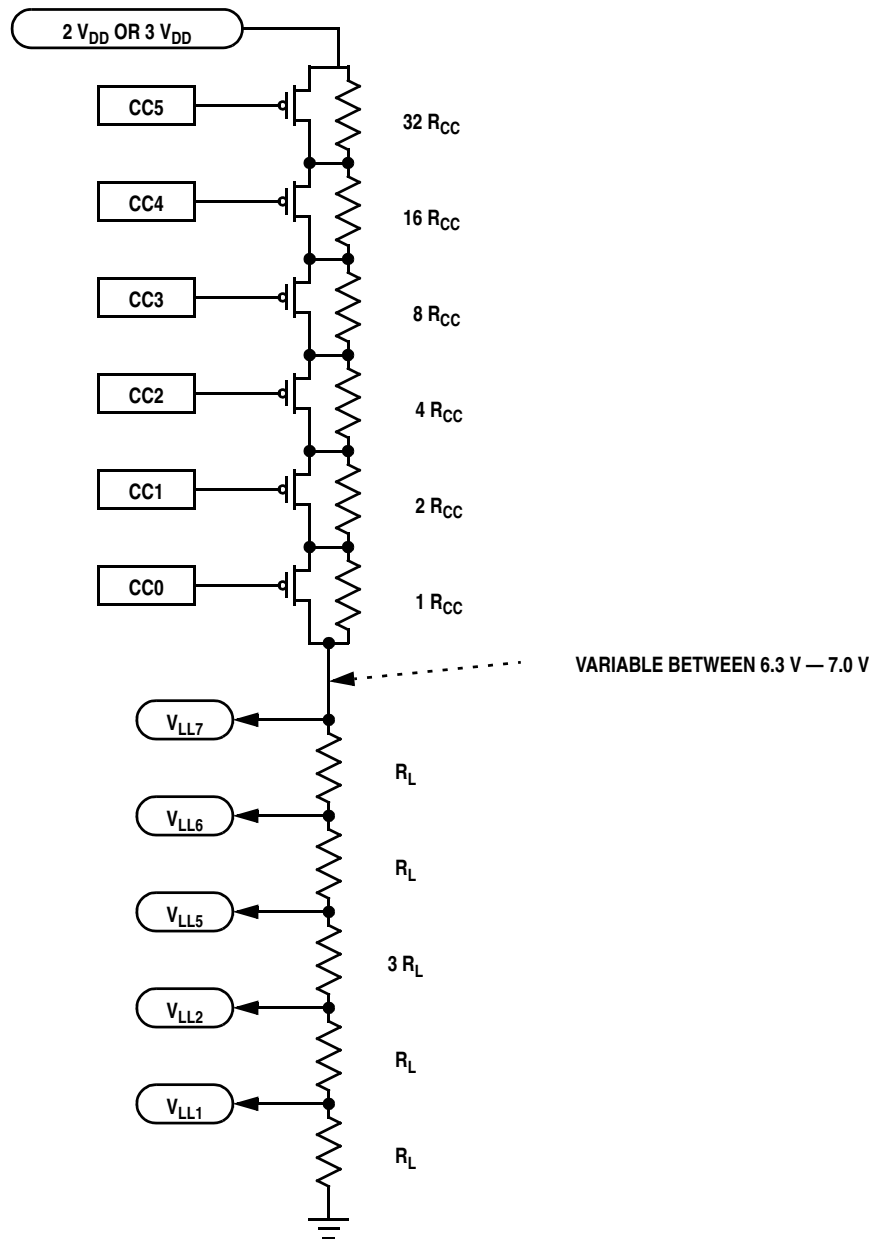


Figure 15-11. Contrast Control Conceptual Block Diagram

15.8 LCD Register Programming

A frame consists of two complimentary fields. Thus, the frame frequency is 1/2 that of the field frequency. See [Figure 15-3](#) for the relationship of field and frame to the waveforms.

CGMXCLK provides the clock from which the LCD timing is derived. The prescaler bits (DIV6:DIV0) and the prescaler enable bit (PE) in the LCD prescaler divider register (LCDDIV) are provided to adjust for various CGMXCLK frequencies. They should be programmed to provide a reference clock of approximately 32.768 kHz for the charge pump. If CGMXCLK frequency is 32.768 kHz, PE should be cleared to allow CGMXCLK to become the charge pump clock. If CGMXCLK is much higher, then PE

Liquid Crystal Display Driver (LCD)

should be set to enable the 7-bit programmable divider which is further divided by 4 to control the reference clock. This allows for a maximum CGMXCLK frequency of approximately 16.6 MHz. See [Figure 15-12](#).

The frame rate bits (FR3:FR0) in the LCD frame rate register (LCDFR) are provided to select an appropriate frame/field rate. See [Table 15-6](#).

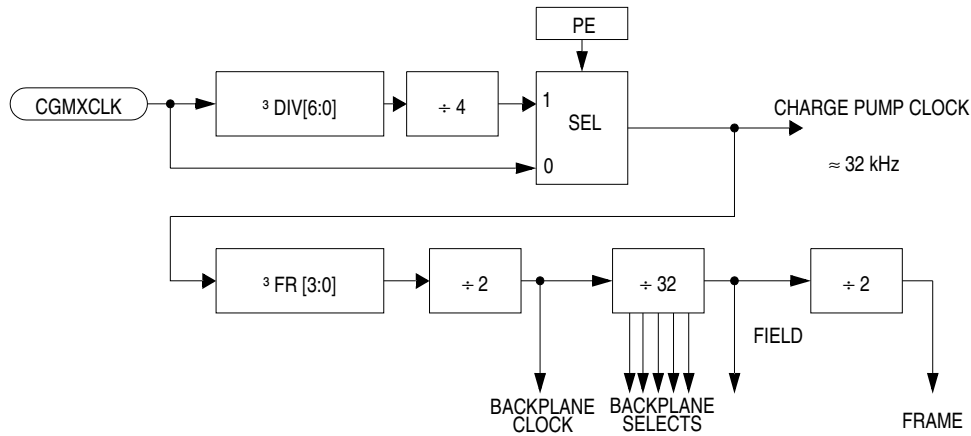


Figure 15-12. LCD Frame Frequency Block Diagram

15.9 Programming the LCD

The LCD prescaler divider register (LCDDIV) should be set according to the following formula in order to produce a charge pump frequency of 32.768 kHz.

$$DIV = \text{RND}\left(\frac{\text{CGMXCLK}}{\text{CPF} \cdot 4 \cdot \text{PE}}\right)$$

where CPF is the charge pump frequency, CGMXCLK is the OSC1 (crystal) frequency; PE is the prescale enable bit in LCDDIV, and DIV is the 7-bit divider.

For example if CGMXCLK = 5.12 MHz, PE should be set and DIV = 39. If CGMXCLK = 32.768 kHz, PE should be cleared and the DIV bits will be disregarded.

NOTE

For correct operation, program PE and DIV[6:0] bits such that the charge pump clock is approximately 32.768 KHz for a given CGMXCLK (crystal) frequency.

The LCD frame rate register (LCDFR) should be set according to the following formula.

$$\text{LCDFR} = \frac{\text{CGMXCLK}}{((\text{DIV} \cdot 4 \cdot \text{PE}) + (1 - \text{PE})) \cdot \text{FRAME} \cdot 128}$$

where CGMXCLK is the OSC1 (crystal) frequency; PE is the prescale enable bit in LCDDIV, DIV is the 7-bit divider, and FRAME is the desired frame rate.

Some examples of programmed frame frequencies are listed in [Table 15-6](#).

Table 15-6. Example LCD Field/Frame Frequencies Assuming a Charge Pump Clock of 32.768 kHz

FR[3:0]	Divider	Frame Frequency (Hz)	Field Frequency (Hz)
0100	4	64	128
0101	5	51.2	102.4
0110	6	42.67	85.3
0111	7	36.57	73.1
1000	8	32	64
1001	9	28.4	56.9

15.10 LCD Registers

There are nine LCD registers. Four are control type registers: LCD control register (LCDCR), LCD prescaler divider register (LCDDIV), LCD frame rate register (LCDFR), and LCD contrast control register (LCDCCR). Five are read-only frontplane latch registers (LCDFL0:LCDFL4) that contain a latched version of the frontplane data for the 40 frontplane drivers. [Figure 15-13](#) shows a summary of the registers.

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
LCD Frontplane Latch 0 (LCDFL0)	FP7	FP6	FP5	FP4	FP3	FP2	FP1	FP0	\$0033
LCD Frontplane Latch 1 (LCDFL1)	FP15	FP14	FP13	FP12	FP11	FP10	FP9	FP8	\$0034
LCD Frontplane Latch 2 (LCDFL2)	FP23	FP22	FP21	FP20	FP19	FP18	FP17	FP16	\$0035
LCD Frontplane Latch 3 (LCDFL3)	FP31	FP30	FP29	FP28	FP27	FP26	FP25	FP24	\$0036
LCD Frontplane Latch 4 (LCDFL4)	FP39	FP38	FP37	FP36	FP35	FP34	FP33	FP32	\$0037
LCD Control Register (LCDCR)	DISON	SUPV	R	R	R	R	R	R	\$0038
LCD Contrast Control Register (LCDCCR)	R	R	CC5	CC4	CC3	CC2	CC1	CC0	\$0039
LCD Prescaler/Divider Register (LCDDIV)	PE	DIV6	DIV5	DIV4	DIV3	DIV2	DIV1	DIV0	\$003A
LCD Frame Rate Register (LCDFR)	0	0	0	0	FR3	FR2	FR1	FR0	\$003B

R = Reserved

Figure 15-13. LCD Register Summary

15.10.1 LCD Frontplane Latch Registers (LCDFLx)

These read-only registers are a latched version of the frontplane data outputs from the LCD RAM for the current backplane. This is provided for debug purposes and is not meant to be part of any user software routine. These registers are reset to all zeros.

LCDFL0								
\$0033	Bit 7	6	5	4	3	2	1	Bit 0
Read:	FP7	FP6	FP5	FP4	FP3	FP2	FP1	FP0
Write:								
Reset:	0	0	0	0	0	0	0	0
LCDFL1								
\$0034	Bit 7	6	5	4	3	2	1	Bit 0
Read:	FP15	FP14	FP13	FP12	FP11	FP10	FP9	FP8
Write:								
Reset:	0	0	0	0	0	0	0	0
LCDFL2								
\$0035	Bit 7	6	5	4	3	2	1	Bit 0
Read:	FP23	FP22	FP21	FP20	FP19	FP18	FP17	FP16
Write:								
Reset:	0	0	0	0	0	0	0	0
LCDFL3								
\$0036	Bit 7	6	5	4	3	2	1	Bit 0
Read:	FP31	FP30	FP29	FP28	FP27	FP26	FP25	FP24
Write:								
Reset:	0	0	0	0	0	0	0	0
LCDFL4								
\$0037	Bit 7	6	5	4	3	2	1	Bit 0
Read:	FP39	FP38	FP37	FP36	FP35	FP34	FP33	FP32
Write:								
Reset:	0	0	0	0	0	0	0	0


 = Unimplemented

Figure 15-14. LCD Frontplane Latches

15.10.2 LCD Control Register

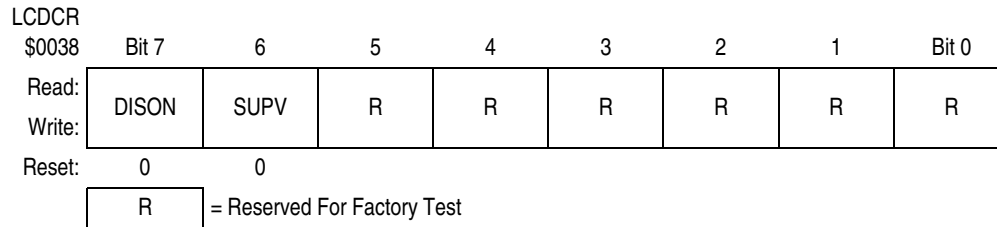


Figure 15-15. LCD Control Register

DISON — LCD Display on Bit

This bit enables the charge pump and the driver timing logic and will enable the drivers when valid data is latched from the RAM. If the LCD driver logic is disabled, the charge pump is turned off and the timing logic is shut off to save power, and all the frontplane and backplane pins are driven at V_{SS} . This bit should be turned off prior to entering stop mode to prevent an average DC voltage from existing on the FP and BP drivers for the duration of stop mode. Reset clears this bit.

- 1 = LCD display is enabled
- 0 = LCD display is disabled

SUPV — LCD Supply Voltage

This bit configures the charge pump appropriately based on a nominal V_{DD} . Reset clears this bit.

- 1 = LCD nominal $V_{DD} = 5\text{ V}$
- 0 = LCD nominal $V_{DD} = 3\text{ V}$

15.10.3 LCD Contrast Control Register (LCDCCR)

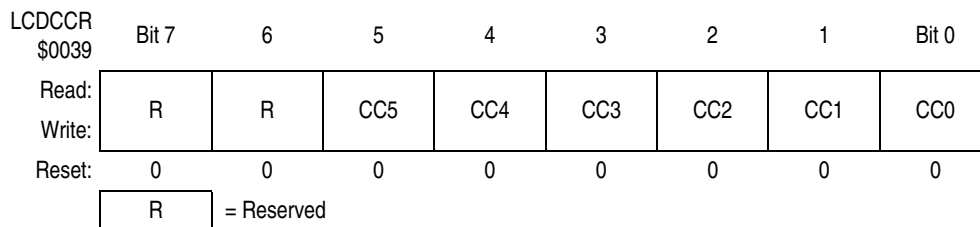


Figure 15-16. LCD Contrast Control Register

CC5:CC0 — Contrast Control

These bits control the contrast control up to 64 levels.

Table 15-7. LCD Contrast Control

CC[5:0]	Contrast Control
111111	Highest VRMS Level
111110	
...	
00000	Lowest VRMS Level

15.10.4 LCD Prescaler Divider Register (LCDDIV)

LCDDIV \$003A	Bit 7	6	5	4	3	2	1	Bit 0
Read:	PE	DIV6	DIV5	DIV4	DIV3	DIV2	DIV1	DIV0
Write:								
Reset:	0	0	0	0	0	0	0	1

Figure 15-17. LCD Prescaler Divider Register

PE — Prescaler Enable

When this bit is set, the output of the 7-bit programmable divider which is further divided by 4 is used as the charge pump reference clock and the input clock for generating the field and frame rates as shown in Figure 15-12.

1 = Use XCLK/(DIV*4) as the reference clock source

0 = Use XCLK directly as the reference clock source

DIV6:DIV0 — LCD Prescaler Divider Ratio Selection

These bits can be programmed to provide a reference clock of approximately 32.768 kHz to the charge pump and frame/field rate circuitry if PE = 1. If PE = 0, these bits are not used.

NOTE

Programming the prescale divider register with \$00 when the PE bit is enabled will result in the maximum divisible value with a 7-bit counter (= 128).

The LCD prescaler divider register should be configured and modified with the LCD disabled (DISON = 0 in LCDCCR).

15.10.5 LCD Frame Rate Register (LCDFR)

LCDFR \$003B	Bit 7	6	5	4	3	2	1	Bit 0
Read:	0	0	0	0	FR3	FR2	FR1	FR0
Write:								
Reset:	0	0	0	0	0	0	0	1


 = Unimplemented

Figure 15-18. LCD Frame Rate Register

FR3:FR0 — LCD Frame Rate Selection

These bits can be programmed to select an appropriate field and frame rate. See Table 15-6. The charge pump is optimized for a field frequency of 60 to 120 Hz. Therefore, this register should be programmed accordingly.

NOTE

Programming the frame rate register with \$00 is equivalent to division by zero and will result in the maximum divisible value with a 4-bit counter = 16.

The LCD frame rate register should be configured and modified with the LCD disabled (DISON = 0 in LCDCCR).

15.11 Interrupts

The LCD module does not generate interrupts.

15.12 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

15.12.1 Wait Mode

The LCD remains active after the execution of a WAIT instruction but the LCD registers are not accessible by the CPU. Therefore, the LCD RAM data cannot be modified. To make the LCD inactive in wait mode (all FP/BP drivers drive V_{SS}) the DISON bit in the LCD control register should be turned off prior to executing the WAIT instruction.

15.12.2 Stop Mode

The LCD is inactive after execution of a STOP instruction because the STOP instruction halts the oscillator. The STOP instruction does not affect register conditions. The DISON bit in the LCD control register should be turned off prior to executing the STOP instruction to ensure that all FP/BP drivers maintain a V_{SS} level. This prevents an average DC offset voltage for the duration of stop mode.

Chapter 16

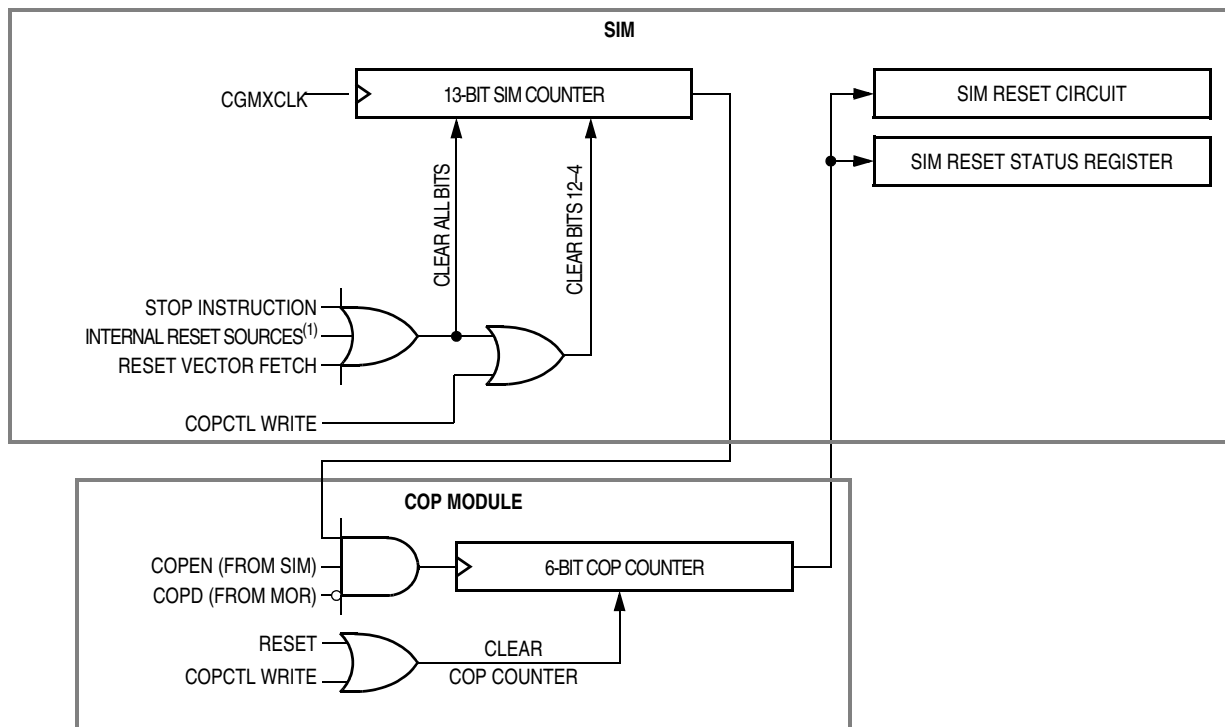
Computer Operating Properly Module (COP)

16.1 Introduction

This section describes the computer operating properly module (COP, Version B), a free-running counter that generates a reset if allowed to overflow. The COP module helps software recover from runaway code. Prevent a COP reset by periodically clearing the COP counter.

16.2 Functional Description

Figure 16-1 shows the structure of the COP module.



NOTE:

1. See SIM section for more details.

Figure 16-1. COP Block Diagram

Computer Operating Properly Module (COP)

The COP counter is a free-running 6-bit counter preceded by the 13-bit system integration module (SIM) counter. If not cleared by software, the COP counter overflows and generates an asynchronous reset after $2^{18} - 2^4$ CGMXCLK cycles. With a 4.9152-MHz crystal, the COP timeout period is 53.3 ms. Writing any value to location \$FFFF before overflow occurs clears the COP counter and prevents reset.

A COP reset pulls the $\overline{\text{RST}}$ pin low for 32 CGMXCLK cycles and sets the COP bit in the SIM reset status register (SRSR) (See SIM section for more details). Clear the COP immediately before entering or after exiting stop mode to assure a full COP timeout period after entering or exiting stop mode. A CPU interrupt routine or a DMA service routine can be used to clear the COP.

NOTE

Place COP clearing instructions in the main program and not in an interrupt subroutine. Such an interrupt subroutine could keep the COP from generating a reset even while the main program is not working properly.

16.3 I/O Signals

The following paragraphs describe the signals shown in [Figure 16-1](#).

16.3.1 CGMXCLK

CGMXCLK is the crystal oscillator output signal. CGMXCLK frequency is equal to the crystal frequency.

16.3.2 STOP Instruction

The STOP instruction clears the SIM counter.

16.3.3 COPCTL Write

Writing any value to the COP control register (COPCTL) (See [16.4 COP Control Register \(COPCTL\)](#)) clears the COP counter and clears bits 12 through 4 of the SIM counter. Reading the COP control register returns the reset vector.

16.3.4 Power-On Reset

The power-on reset (POR) circuit in the SIM clears the SIM counter 4096 CGMXCLK cycles after power-up.

16.3.5 Internal Reset

An internal reset clears the SIM counter and the COP counter.

16.3.6 Reset Vector Fetch

A reset vector fetch occurs when the vector address appears on the data bus. A reset vector fetch clears the SIM counter.

16.3.7 COPD (COP Disable)

The COPD signal reflects the state of the COP disable bit (COPD) in the mask option register (MOR). (See [Chapter 19 Configuration Register \(CONFIG\)](#) for more details.)

16.4 COP Control Register (COPCTL)

The COP control register is located at address \$FFFF and overlaps the reset vector. Writing any value to \$FFFF clears the COP counter and starts a new timeout period. Reading location \$FFFF returns the low byte of the reset vector.

COPCTL \$FFFF	Bit 7	6	5	4	3	2	1	Bit 0
Read:	Low Byte of Reset Vector							
Write:	Clear COP Counter							
Reset:	Unaffected by Reset							

Figure 16-2. COP Control Register (COPCTL)

16.5 Interrupts

The COP does not generate CPU interrupt requests or DMA service requests.

16.6 Monitor Mode

The COP is disabled in monitor mode when $V_{DD} + V_{HI}$ is present on the $\overline{IRQ1}/V_{PP}$ pin or on the \overline{RST} pin.

16.7 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

16.7.1 Wait Mode

The COP continues to operate during wait mode. To prevent a COP reset during wait mode, periodically clear the COP counter in a CPU interrupt routine or a DMA service routine.

16.7.2 Stop Mode

Stop mode turns off the CGMXCLK input to the COP and clears the SIM counter. Service the COP immediately before entering or after exiting stop mode to ensure a full COP timeout period after entering or exiting stop mode.

16.8 COP Module During Break Interrupts

The COP is disabled during a break interrupt when $V_{DD} + V_{HI}$ is present on the \overline{RST} pin.

Chapter 17

Break Module (BREAK)

17.1 Introduction

This section describes the break module (Break, Version B). The break module can generate a break interrupt that stops normal program flow at a defined address to enter a background program.

17.2 Features

Features of the break module include:

- Accessible I/O Registers during the Break Interrupt
- CPU-Generated Break Interrupts
- Software-Generated Break Interrupts
- COP Disabling during Break Interrupts

17.3 Functional Description

When the internal address bus matches the value written in the break address registers, the break module issues a breakpoint signal ($\overline{\text{BKPT}}$) to the SIM. The SIM then causes the CPU to load the instruction register with a software interrupt instruction (SWI) after completion of the current CPU instruction. The program counter vectors to \$FFFC and \$FFFD (\$FEFC and \$FEFD in monitor mode).

The following events can cause a break interrupt to occur:

- A CPU-generated address (the address in the program counter) matches the contents of the break address registers.
- Software writes a logic one to the BRKA bit in the break status and control register.

When a CPU-generated address matches the contents of the break address registers, the break interrupt begins after the CPU completes its current instruction. A return from interrupt instruction (RTI) in the break routine ends the break interrupt and returns the MCU to normal operation. [Figure 17-1](#) shows the structure of the break module.

Break Module (BREAK)

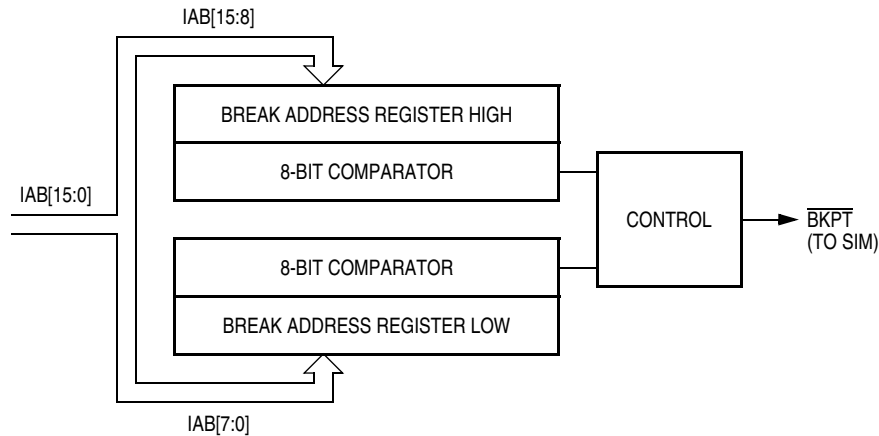


Figure 17-1. Break Module Block Diagram

Register Name	Bit 7	6	5	4	3	2	1	Bit 0	Addr.
Break Address Register High (BRKH)	Bit 15	14	13	12	11	10	9	Bit 8	\$FE0C
Break Address Register Low (BRKL)	Bit 7	6	5	4	3	2	1	Bit 0	\$FE0D
Break Status/Control Register (BRKSCR)	BRKE	BRKA							\$FE0E


 = Unimplemented

Figure 17-2. Break I/O Register Summary

17.3.1 Flag Protection During Break Interrupts

The system integration module (SIM) controls whether or not module status bits can be cleared during the break state. The BCFE bit in the SIM break flag control register (SBFCR) enables software to clear status bits during the break state. (See [5.7.3 SIM Break Flag Control Register \(SBFCR\)](#) and see the **Break Interrupts** subsection for each module.)

17.3.2 CPU During Break Interrupts

The CPU starts a break interrupt by:

- Loading the instruction register with the SWI instruction
- Loading the program counter with \$FFFC:\$FFFD (\$FEFC:\$FEFD in monitor mode)

The break interrupt begins after completion of the CPU instruction in progress. If the break address register match occurs on the last cycle of a CPU instruction, the break interrupt begins immediately.

17.3.3 TIM During Break Interrupts

A break interrupt stops the timer counter.

17.3.4 COP During Break Interrupts

The COP is disabled during a break interrupt when $V_{DD} + V_{HI}$ is present on the \overline{RST} pin.

17.4 Break Module Registers

Three registers control and monitor operation of the break module:

- Break status and control register (BRKSCR)
- Break address register high (BRKH)
- Break address register low (BRKL)

17.4.1 Break Status and Control Register

The break status and control register contains break module enable and status bits.

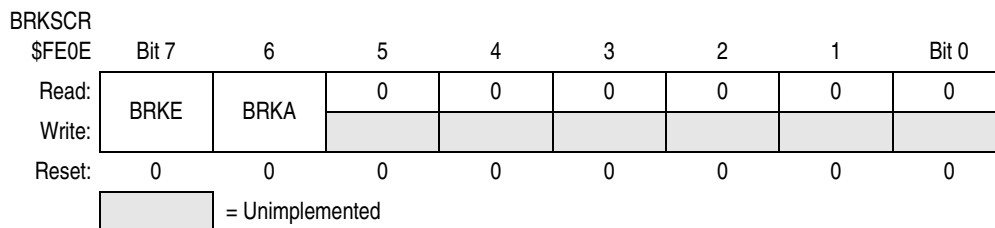


Figure 17-3. Break Status and Control Register (BRKSCR)

BRKE — Break Enable Bit

This read/write bit enables breaks on break address register matches. Clear BRKE by writing a logic zero to bit 7. Reset clears the BRKE bit.

- 1 = Breaks enabled on 16-bit address match
- 0 = Breaks disabled on 16-bit address match

BRKA — Break Active Bit

This read/write status and control bit is set when a break address match occurs. Writing a logic one to BRKA generates a break interrupt. Clear BRKA by writing a logic zero to it before exiting the break routine. Reset clears the BRKA bit.

- 1 = Break address match
- 0 = No break address match

17.4.2 Break Address Registers

The break address registers contain the high and low bytes of the desired breakpoint address. Reset clears the break address registers.

BRKH																
\$FE0C	Bit 7	6	5	4	3	2	1	Bit 0								
Read:	<table border="1" style="width:100%; text-align:center;"> <tr> <td>Bit 15</td> <td>14</td> <td>13</td> <td>12</td> <td>11</td> <td>10</td> <td>9</td> <td>Bit 8</td> </tr> </table>								Bit 15	14	13	12	11	10	9	Bit 8
Bit 15	14	13	12	11	10	9	Bit 8									
Write:																
Reset:	0	0	0	0	0	0	0	0								
BRKL																
\$FE0D	Bit 7	6	5	4	3	2	1	Bit 0								
Read:	<table border="1" style="width:100%; text-align:center;"> <tr> <td>Bit 7</td> <td>6</td> <td>5</td> <td>4</td> <td>3</td> <td>2</td> <td>1</td> <td>Bit 0</td> </tr> </table>								Bit 7	6	5	4	3	2	1	Bit 0
Bit 7	6	5	4	3	2	1	Bit 0									
Write:																
Reset:	0	0	0	0	0	0	0	0								

Figure 17-4. Break Address Registers (BRKH and BRKL)

17.5 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

17.5.1 Wait Mode

If enabled, the break module is active in wait mode. In the break routine, the user can subtract one from the return address on the stack if SBSW is set. (See [5.6 Low-Power Modes](#).) Clear the SBSW bit by writing logic zero to it.

17.5.2 Stop Mode

A break interrupt causes exit from stop mode and sets the SBSW bit in the SIM break status register. See [5.7 SIM Registers](#).

Chapter 18

EPROM/OTPROM

18.1 Introduction

This section describes the non-volatile memory (EPROM/OTPROM).

18.2 Functional Description

An MCU with a quartz window has 56 Kbytes of erasable, programmable ROM (EPROM). The quartz window allows EPROM erasure by using ultraviolet light. In an MCU without the quartz window, the EPROM cannot be erased and serves as 56 Kbytes of one-time programmable ROM (OTPROM). An unprogrammed or erased location reads as \$00. Hardware interlocks are provided to protect stored data corruption from accidental programming. These addresses are user EPROM/OTPROM locations:

- \$1E00:\$FDFF
- \$FFD8:\$FFFF (These locations are reserved for user-defined interrupt and reset vectors.)

Programming tools are available from Freescale. Contact your local Freescale representative for more information.

NOTE

If the security feature is enabled, viewing of the EPROM/OTPROM contents is prevented.⁽¹⁾

18.3 EPROM/OTPROM Control Registers (EPMCR1, EPMCR2)

The EPROM control registers control EPROM/OTPROM programming.

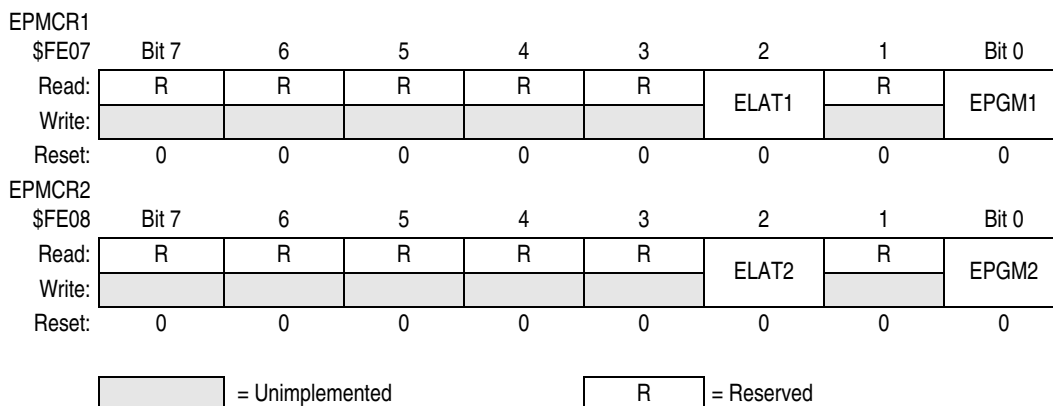


Figure 18-1. EPROM/OTPROM Control Registers (EPMCR1, EPMCR2)

1. No security feature is absolutely secure. However, Freescale's strategy is to make reading or copying the EPROM/OTPROM difficult for unauthorized users.

EPROM/OTPROM

EPROMCR1 is used to program addresses \$1E00:\$8DFF. EPMCR2 is used to program addresses \$8E00:\$FDFF and \$FFD8:\$FFFF.

ELAT — EPROM/OTPROM Latch Control Bit

This read/write bit latches the address and data buses for programming the EPROM/OTPROM.

Clearing ELAT also clears the EPGM bit. EPROM/OTPROM data cannot be read when ELAT is set.

1 = Buses configured for EPROM/OTPROM programming

0 = Buses configured for normal operation

EPGM — EPROM/OTPROM Program Control Bit

This read/write bit applies the programming voltage from the $\overline{\text{IRQ1}}/V_{\text{PP}}$ pin to the EPROM/OTPROM.

To write to the EPGM bit, the ELAT bit must be set already. Reset clears the EPGM bit.

1 = EPROM/OTPROM programming power switched on

0 = EPROM/OTPROM programming power switched off

Programming time of the array can be reduced by writing to both arrays simultaneously.

18.4 EPROM/OTPROM Programming

The unprogrammed state is a 0. Programming changes the state to a 1.

Use the following procedure to program a byte of EPROM/OTPROM:

1. Apply $V_{\text{DD}} + V_{\text{PP}}$ to the $\overline{\text{IRQ1}}/V_{\text{PP}}$ pin.
2. Set the ELAT bit.

NOTE

Writing logic ones to both the ELAT and EPGM bits with a single instruction sets only the ELAT bit. EPGM must be set by a separate instruction in the programming sequence.

3. Write to any user EPROM/OTPROM address.

NOTE

Writing to an invalid address prevents the programming voltage from being applied.

4. Set the EPGM bit.
5. Wait for a time, t_{EPGM} .
6. Clear the ELAT and EPGM bits.

Setting the ELAT bit configures the address and data buses to latch data for programming the array. Only data written to a valid EPROM address will be latched. Attempts to read any other valid EPROM address after step 2 will read the latched data written in step 3. Further writes to valid EPROM addresses after the first write (step 3) are ignored.

The EPGM bit cannot be set if the ELAT bit is cleared. This is to ensure proper programming sequence. If EPGM is set and a valid EPROM write occurred, V_{PP} will be applied to the user EPROM array. When the EPGM bit is cleared, the program voltage is removed from the array.

By latching the appropriate address and data with each of the two control registers, followed by setting of each of the EPGM bits, programming time for the total array can be reduced by almost half.

Chapter 19

Configuration Register (CONFIG)

19.1 Introduction

This section describes the configuration register (CONFIG). The configuration register enables or disables these options:

- Resets caused by the low voltage inhibit module (LVI)
- Power to the LVI module
- Stop mode recovery time (32 CGMXCLK cycles or 4096 CGMXCLK cycles)
- STOP instruction
- Computer operating properly module (COP)

19.2 Functional Description

The configuration register is used in the initialization of various options. The configuration register can be written once after each reset. All of the configuration register bits are cleared during reset. Since the various options affect the operation of the MCU, it is recommended that this register be written immediately after reset. The configuration register is located at \$001F. For compatibility, a write to the ROM version of the MCU at this location will have no effect. The configuration register may be read at any time.

NOTE

The CONFIG module is known as an MOR (mask option register) on a ROM device. For references in the documentation which refer to the MOR (mask option register), the CONFIG would be applicable for the EPROM/OTPROM version of the device.

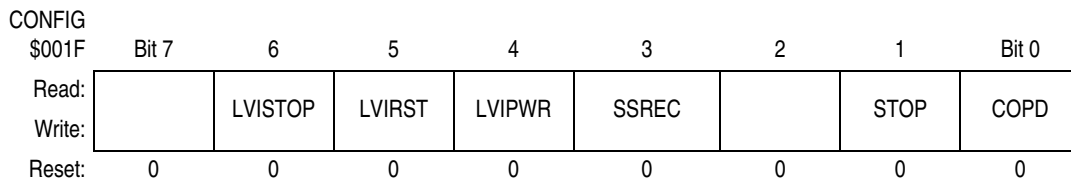


Figure 19-1. Configuration Register (CONFIG)

LVISTOP — LVI Enable in Stop Mode Bit

When the LVIPWR bit is set, LVISTOP enables the LVI to operated during stop mode.

- 1 = LVI not disabled during stop instruction
- 0 = LVI disabled during stop instruction

NOTE

To meet the stop mode I_{DD} specification, LVISTOP must be 0.

Configuration Register (CONFIG)

LVIPWR — LVI Module Power Disable Bit

LVIPWR disables the LVI module. (See [Section 7. Low-Voltage Inhibit \(LVI\)](#).)

- 1 = LVI module power disabled
- 0 = LVI module power enabled

LVIRST — LVI Module Reset Disable Bit

LVIRST disables the reset signal from the LVI module. (See [Section 7. Low-Voltage Inhibit \(LVI\)](#).)

- 1 = LVI module reset disabled
- 0 = LVI module reset enabled

SSREC — Short Stop Recovery Bit

SSREC enables the CPU to exit stop mode with a delay of 32 CGMXCLK cycles instead of a 4096-CGMXCLK cycle delay.

- 1 = Stop mode recovery after 32 CGMXCLK cycles
- 0 = Stop mode recovery after 4096 CGMXCLK cycles

NOTE

*Exiting stop mode by pulling reset will result in the long stop recovery.
If using an external crystal oscillator, do not set the SSREC bit.*

STOP — STOP Instruction Enable Bit

STOP enables the STOP instruction.

- 1 = STOP instruction enabled
- 0 = STOP instruction treated as illegal opcode

COPD — COP Disable Bit

COPD disables the COP module. (See [Section 16. Computer Operating Properly Module \(COP\)](#).)

- 1 = COP module disabled
- 0 = COP module enabled

Chapter 20

Time Base Module (TBM)

20.1 Introduction

The time base module consists of a counter clocked by the crystal clock, which will generate periodic interrupts at user selectable rates.

20.2 Features

Software programmable 1-Hz, 4-Hz, 16-Hz, and 256-Hz periodic interrupt using 32.768-kHz crystal.

20.3 Functional Description

NOTE

This module is designed for a 32.768-kHz oscillator.

This module can generate a periodic interrupt by dividing the crystal frequency, CGMXCLK. The counter is initialized to all zeros when TBON bit is cleared. The counter, shown in Figure 20-1, starts counting when the TBON bit is set. When the counter overflows at the tap selected by TBR1:TBR0, the TBIF bit gets set. If the TBIE bit is set, an interrupt request is sent to the CPU. The TBIF flag is cleared by writing a one to the TACK bit. The first time the TBIF flag is set after enabling the time base module, the interrupt is generated at approximately half of the overflow period. Subsequent events occur at the exact period.

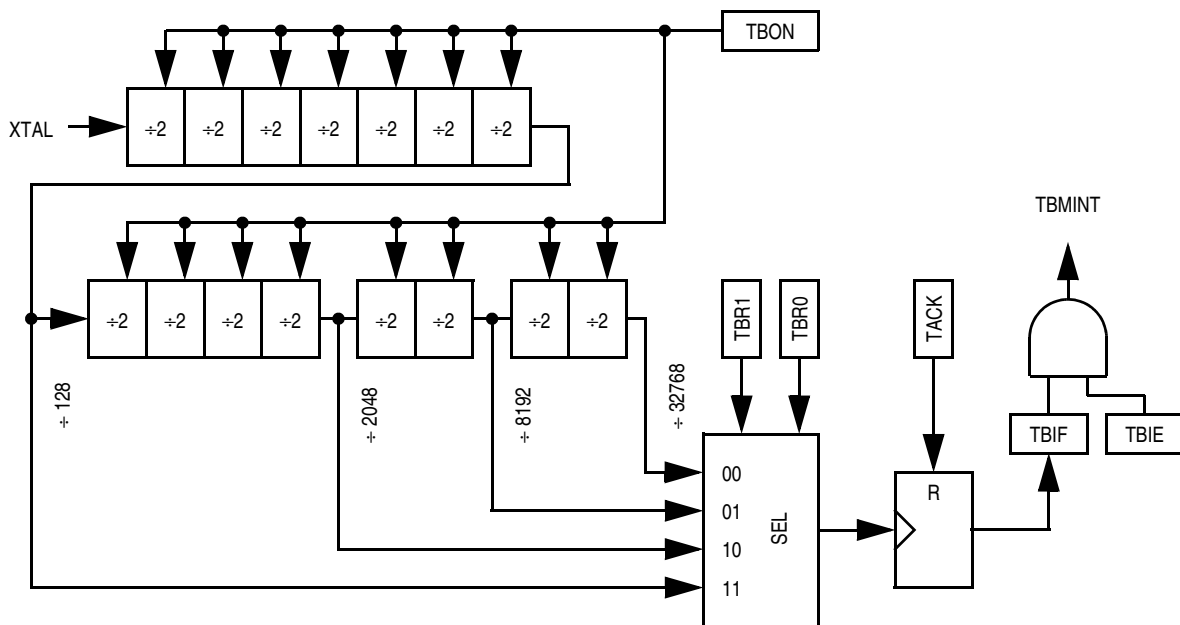


Figure 20-1. Time Base Block Diagram

20.4 Time Base Register Description

The time base has one register, the TBCR, which is used to enable the time base interrupts and set the rate.

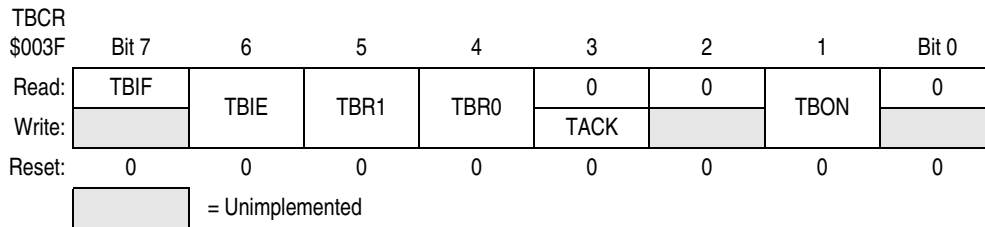


Figure 20-2. Time Base Control Register

TBIF — Time Base Interrupt Flag

This read-only flag bit is set when the time base counter has rolled over.

- 1 = Time base interrupt pending
- 0 = Time base interrupt not pending

TBIE — Time Base Interrupt Enabled

This read/write bit enables the time base interrupt when the TBIF bit becomes set. Reset clears the TBIE bit

- 1 = Time base interrupt is enabled
- 0 = Time base interrupt is disabled

TBR1:TBR0 — Time Base Rate Selection

These read/write bits are used to select the rate of time base interrupts as shown in [Table 20-1](#).

Table 20-1. Time Base Rate Selection for OSC1 = 32.768 kHz

TBR1:TBR0	Divider	TIME BASE INTERRUPT RATE	
		(Hz)	(ms)
00	1/32768	1	1000
01	1/8192	4	250
10	1/2048	16	62.5
11	1/128	256	~ 3.9

NOTE

Do not change TBR1:TBR0 bits while the time base is enabled (TBON = 1).

TACK— Time base ACKnowledge

The TACK bit is write only bit and always reads as 0. Writing a logic one to this bit clears TBIF, the time base Interrupt flag bit. Writing a logic zero to this bit has no effect.

- 1 = Clear time base interrupt flag
- 0 = No effect

TBON — Time Base Enabled

This read/write bit enables the time base. Time base may be turned off to reduce power consumption when its function is not necessary. The counter can be initialized by clearing and then setting this bit. Reset clears the TBON bit.

- 1 = Time base is enabled
- 0 = Time base is disabled and the counter initialized to zeros

20.5 Interrupts

The time base module can interrupt the CPU on a regular basis with a rate defined by TBR1 and TBR0. When the time base counter chain rolls over, the TBIF flag is set. If the TBIE bit is set, enabling the time base interrupt, the counter chain overflow will generate a CPU interrupt request.

Interrupts must be acknowledged by writing a logic one to TACK bit.

20.6 Low-Power Modes

The WAIT and STOP instructions put the MCU in low-power- consumption standby modes.

20.6.1 Wait Mode

The time base module remains active after execution of the WAIT instruction. In WAIT mode the time base register is not accessible by the CPU.

If the time base functions are not required during wait mode, reduce the power consumption by stopping the time base before enabling the WAIT instruction.

20.6.2 Stop Mode

The time base is inactive after execution of the STOP instruction. The STOP instruction does not affect register conditions or the state of the time base counter. The time base operation continues when the MCU exits stop mode with an external interrupt, after the system clock resumes.

Chapter 21

Monitor ROM (MON)

21.1 Introduction

This section describes the use of the monitor ROM (MON08) firmware. Execution of code in the monitor ROM in monitor mode allows complete testing of the MCU through a single-wire interface with a host computer.

21.2 Features

Features of monitor mode include the following:

- Normal User-Mode Pin Functionality
- One Pin Dedicated to Serial Communication between Monitor ROM and Host Computer
- Standard Mark/Space Non-Return-to-Zero (NRZ) Communication with Host Computer
- Execution of Code in either RAM or ROM/EPROM
- (E)EPROM/OTPROM Programming

21.3 Functional Description

The monitor ROM receives and executes commands from a host computer. [Figure 21-1](#) shows an example circuit used to enter monitor mode and communicate with a host computer via a standard RS-232 interface.

Simple monitor commands can access any memory address. In monitor mode, the MCU can execute code in RAM which has been loaded by the host computer, while all MCU pins retain normal operating mode functions. All communication between the host computer and the MCU is through the PTA0 pin, at a chosen baud rate. A level-shifting and multiplexing interface is required between PTA0 and the host computer. PTA0 is used in a wired-OR configuration and requires a pullup resistor.

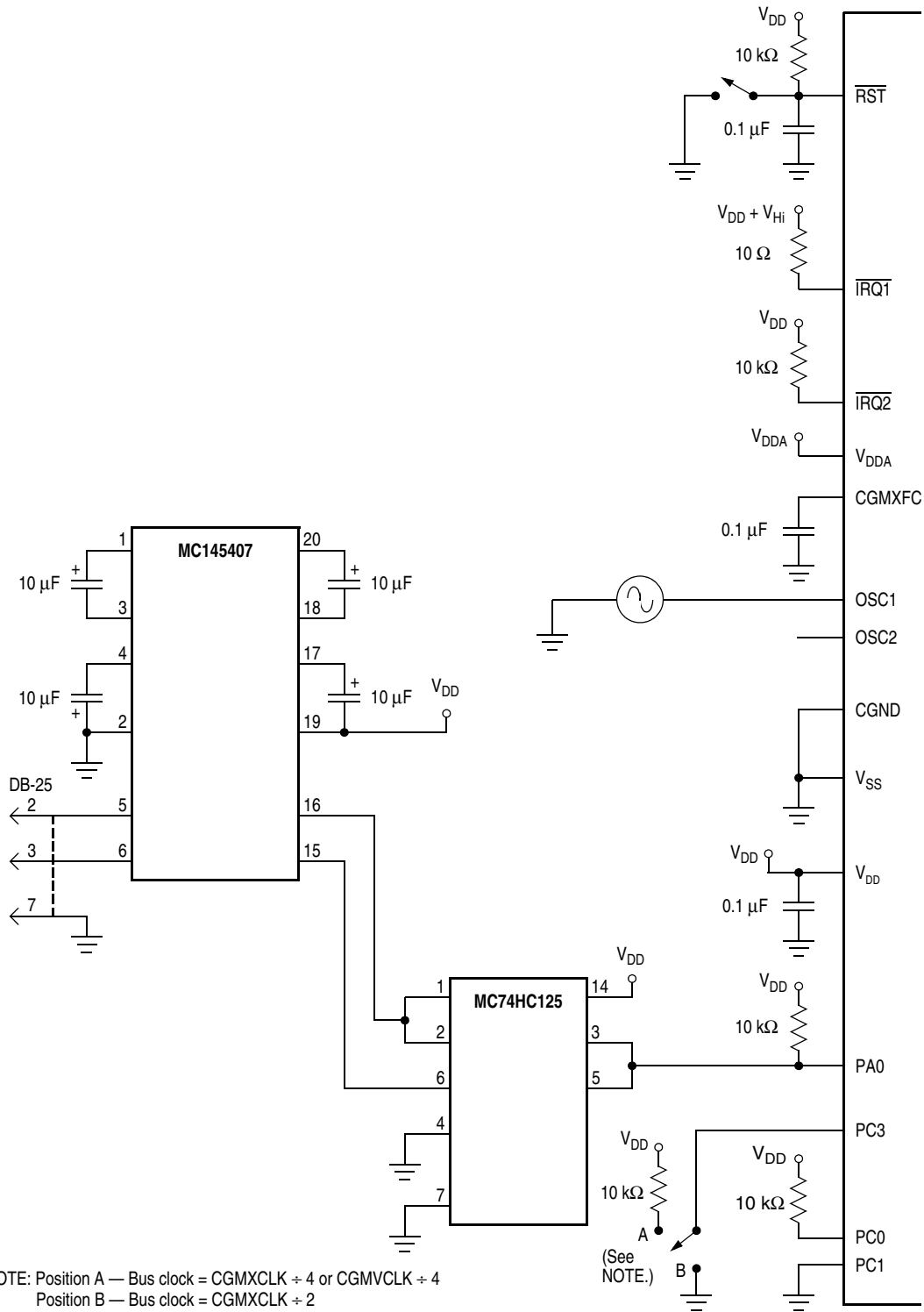


Figure 21-1. Monitor Mode Circuit

21.3.1 Entering Monitor Mode

Table 21-1 shows the pin conditions for entering monitor mode.

Table 21-1. Mode Selection

$\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ Pin	PTC0 Pin	PTC1 Pin	PTA0 Pin	PTC3 Pin	Mode	CGMOUT	Bus Frequency
$V_{\text{DD}} + V_{\text{HI}}$	1	0	1	1	Monitor	$\frac{\text{CGMXCLK}}{2}$ or $\frac{\text{CGMVCLK}}{2}$	$\frac{\text{CGMOUT}}{2}$
$V_{\text{DD}} + V_{\text{HI}}$	1	0	1	0	Monitor	CGMXCLK	$\frac{\text{CGMOUT}}{2}$

CGMOUT/2 is the internal bus clock frequency. If PTC3 is low upon monitor mode entry, CGMOUT is equal to the frequency of CGMXCLK, which is a buffered version of the clock on the OSC1 pin. The bus frequency in this case is a divide-by-two of the input clock. If PTC3 is high upon monitor mode entry, the bus frequency will be a divide-by-four of the input clock if the PLL is not engaged. The PLL can be engaged to multiply the bus frequency by programming the CGM. Refer to [Chapter 4 Clock Generator Module \(CGMB\)](#) for information on how to program the PLL. When the PLL is used, PTC3 must be logic one during monitor mode entry, and the bus frequency will be a divide-by-four of CGMVCLK, the output clock of the PLL.

NOTE

Holding the PTC3 pin low when entering monitor mode causes a bypass of a divide-by-two stage in the oscillator. In this case the CGMOUT frequency is equal to the CGMXCLK (external clock) frequency. The OSC1 signal must have a 50% duty cycle at maximum bus frequency.

Enter monitor mode with the pin configuration shown above by pulling $\overline{\text{RST}}$ low and then high. The rising edge of $\overline{\text{RST}}$ latches monitor mode. Once monitor mode is latched, the values on the specified pins can change.

Once out of reset, the MCU monitor mode firmware then sends a break signal (10 consecutive logic zeros) to the host computer, indicating that it is ready to receive a command. The break signal also serves as a timing reference to allow the host to determine the necessary baud rate.

Monitor mode uses different vectors for reset, SWI, and a break interrupt than those used in user mode. The alternate vectors are in the \$FE page instead of the \$FF page, and allow code execution from the internal monitor firmware instead of user code.

When the host computer has completed downloading code into the MCU RAM, this code can be executed by driving PTA0 low while asserting $\overline{\text{RST}}$ low and then high. The internal monitor ROM firmware will interpret the low on PTA0 as an indication to jump RAM, and execution control will then continue from RAM. The location jumped to is always the second byte of RAM (i.e. the first RAM byte address + 1). Execution of an SWI from the downloaded code will return program control to the internal monitor ROM firmware. Alternatively, the host can send a RUN command, which executes an RTI, and this can be used to send control to the address on the stack pointer.

The COP module is disabled in monitor mode as long as $V_{\text{DD}} + V_{\text{HI}}$ is applied to either the $\overline{\text{IRQ1}}/\text{V}_{\text{PP}}$ pin or the $\overline{\text{RST}}$ pin. (See [Chapter 5 System Integration Module \(SIM\)](#) for more information on modes of operation.)

Table 21-2 is a summary of the differences between user mode and monitor mode.

Table 21-2. Mode Differences

Modes	Functions						
	COP	Reset Vector High	Reset Vector Low	Break Vector High	Break Vector Low	SWI Vector High	SWI Vector Low
User	Enabled	\$FFFE	\$FFFF	\$FFFC	\$FFFD	\$FFFC	\$FFFD
Monitor	Disabled ⁽¹⁾	\$FEFE	\$FEFF	\$FEFC	\$FEFD	\$FEFC	\$FEFD

1. If the high voltage ($V_{DD} + V_{HI}$) is removed from the $\overline{IRQ1}/V_{PP}$ pin or the \overline{RST} pin, the SIM asserts its COP enable output. The COP is a mask option enabled or disabled by the COPD bit in the mask option register.

21.3.2 Data Format

Communication with the monitor ROM is in standard non-return-to-zero (NRZ) mark/space data format. (See Figure 21-2 and Figure 21-3.) Transmit and receive baud rates must be identical.

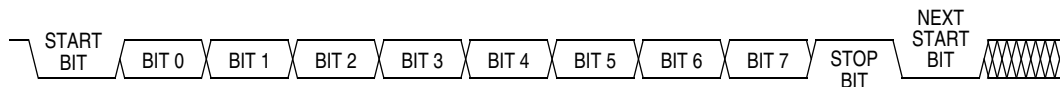


Figure 21-2. Monitor Data Format

21.3.3 Break Signal

A start bit (low) followed by nine low bits is a break signal. (See Figure 21-3.) When the monitor receives a break signal, it drives the PTA0 pin high for the duration of two bits, and then echos back the break signal.

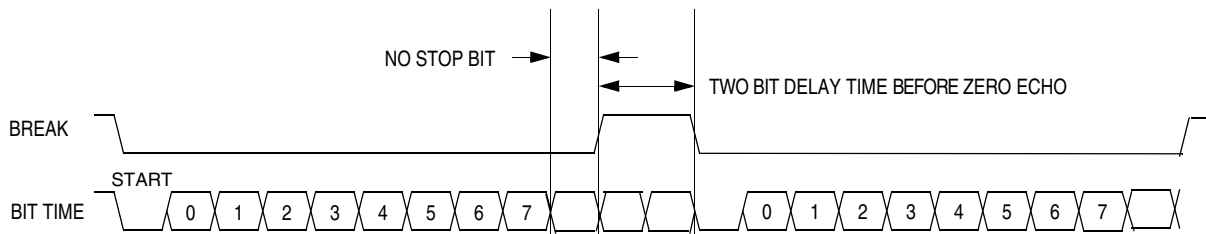


Figure 21-3. Break Transaction

21.3.4 Baud Rate

The bus clock frequency for the MCU in monitor mode is determined by the external clock frequency, the value on PTC3 during monitor mode entry, and whether or not the PLL is engaged. The internal monitor firmware performs a division by 256 (for sampling data), therefore, the bus frequency divided by 256 is the baud rate of the monitor mode data transfer.

For example, with a 4.9152-MHz external clock and the PTC3 pin at logic one during reset, data is transferred between the monitor and host at 4800 baud. If the PTC3 pin is at logic zero during reset, the monitor baud rate is 9600.

The internal PLL can be engaged to increase the baud rate of instruction transfer between the host and the MCU and to increase the speed of program execution. Refer to [Chapter 4 Clock Generator Module \(CGMB\)](#) for information on how to program the PLL. If use of the PLL is desired, the monitor mode must be entered with PTC high. (See [21.3.1 Entering Monitor Mode](#).) Initially, the bus frequency is a divide-by-four of the input clock. After the PLL is programmed, and enabled onto the bus, communication between the host and MCU must be reestablished at the new baud rate. One way of accomplishing this would be for the host to download a program into the MCU RAM that would program the PLL, and send a new baud rate “flag” to the host just prior to engaging the PLL onto the bus. Upon completion of execution, an SWI would return program control to the monitor firmware.

21.3.5 Commands

The monitor ROM firmware uses the following commands:

- READ (read memory)
- WRITE (write memory)
- IREAD (indexed read)
- IWRITE (indexed write)
- READSP (read stack pointer)
- RUN (run user program)

As the host computer sends commands through PTA0, the monitor ROM firmware immediately echoes each received byte back to the PTA0 pin for error checking, as shown in the example command in [Figure 21-4](#).

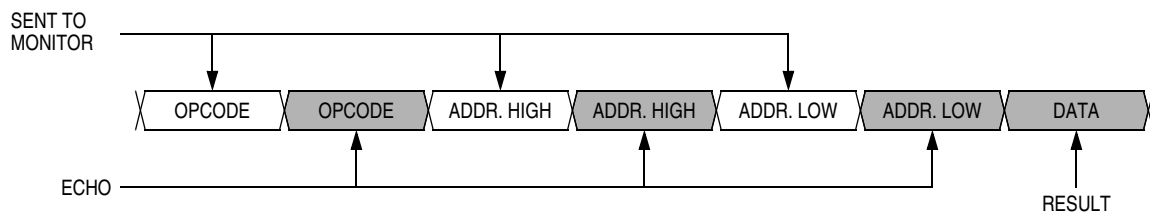


Figure 21-4. Read Transaction

The resultant data of a read type of command appears after the echo of the last byte of the command.

A brief description of each monitor mode command follows.

A sequence of IREAD or IWRITE commands can access a block of memory sequentially over the full 64-Kbyte memory map.

Table 21-3. READ (Read Memory) Command

Description	Read byte from memory
Operand	Specifies 2-byte address in high byte:low byte order
Data Returned	Returns contents of specified address
Opcode	\$4A
Command Sequence	

Table 21-4. WRITE (Write Memory) Command

Description	Write byte to memory
Operand	Specifies 2-byte address in high byte:low byte order; low byte followed by data byte
Data Returned	None
Opcode	\$49
Command Sequence	

Table 21-5. IREAD (Indexed Read) Command

Description	Read next 2 bytes in memory from last address accessed
Operand	Specifies 2-byte address in high byte:low byte order
Data Returned	Returns contents of next two addresses
Opcode	\$1A
Command Sequence	

Table 21-6. IWRITE (Indexed Write) Command

Description	Write to last address accessed + 1
Operand	Specifies single data byte
Data Returned	None
Opcode	\$19
<p>Command Sequence</p> <p>The diagram shows a sequence of four data bytes: IWRITE, IWRITE, DATA, and DATA. The first IWRITE and the second DATA are marked as 'SENT TO MONITOR'. The second IWRITE and the second DATA are marked as 'ECHO'.</p>	

Table 21-7. READSP (Read Stack Pointer) Command

Description	Reads stack pointer
Operand	None
Data Returned	Returns stack pointer in high byte:low byte order
Opcode	\$0C
<p>Command Sequence</p> <p>The diagram shows a sequence of four data bytes: READSP, READSP, SP HIGH, and SP LOW. The first READSP is marked as 'SENT TO MONITOR'. The second READSP is marked as 'ECHO'. The SP HIGH and SP LOW operands are marked as 'RESULT'.</p>	

Table 21-8. RUN (Run User Program) Command

Description	Executes RTI instruction
Operand	None
Data Returned	None
Opcode	\$28
<p>Command Sequence</p> <p>The diagram shows a sequence of two data bytes: RUN and RUN. The first RUN is marked as 'SENT TO MONITOR'. The second RUN is marked as 'ECHO'.</p>	

Chapter 22

Preliminary Electrical Specifications

22.1 Introduction

This section contains electrical and timing specifications. These values are design targets and have not yet been tested.

22.2 Absolute Maximum Ratings

Maximum ratings are the extreme limits to which the microcontroller unit (MCU) can be exposed without permanently damaging it.

The MCU contains circuitry to protect the inputs against damage from high static voltages; however, do not apply voltages higher than those shown in the table below. Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN} \text{ or } V_{OUT}) \leq V_{DD}$. Connect unused inputs to the appropriate voltage level, either V_{SS} or V_{DD} .

Table 22-1. Absolute Maximum Ratings⁽¹⁾

Characteristic	Symbol	Value	Unit
Supply Voltage	V_{DD}	-0.3 to +6.0	V
Input Voltage	V_{IN}	$V_{SS} - 0.3$ to $V_{DD} + 0.3$	V
Programming Voltage	V_{PP}	$V_{SS} - 0.3$ to 14.0	V
Maximum Current Per Pin Excluding V_{DD} and V_{SS}	I	$\pm \pm 25$	mA
Storage Temperature	T_{STG}	-55 to +150	°C
Maximum Current out of V_{SS}	I_{MVSS}	100	mA
Maximum Current into V_{DD}	I_{MVDD}	100	mA

1. Voltages referenced to V_{SS} .

NOTE

This device is not guaranteed to operate properly at the maximum ratings. Refer to [Table 22-4](#) and [Table 22-5](#) for guaranteed operating conditions.

22.3 Functional Operating Range

Table 22-2. Operating Range

Characteristic	Symbol	Value	Unit
Operating Temperature Range	T_A	0 to 85	°C
Operating Voltage Range ⁽¹⁾	V_{DD}	3.3 ± ±10% 5.0 ± ±10%	V

1. LCD charge pump optimized for given ranges

22.4 Thermal Characteristics

Table 22-3. Thermal Characteristics

Characteristic	Symbol	Value	Unit
Thermal Resistance, 144-Pin TQFP	θ_{JA}	46.1	°C/W
I/O Pin Power Dissipation	$P_{I/O}$	User Determined	W
Power Dissipation ⁽¹⁾	P_D	$P_D = (I_{DD} \times V_{DD}) + P_{I/O} = K/(T_J + 273 \text{ °C})$	W
Constant ⁽²⁾	K	$P_D \times (T_A + 273 \text{ °C}) + P_D^2 \times \theta_{JA}$	W/°C
Average Junction Temperature	T_J	$T_A + (P_D \times \theta_{JA})$	°C
Maximum Junction Temperature	T_{JM}	100	°C

1. Power Dissipation is a function of temperature

2. K is a constant unique to the device. K can be determined for a known T_A and measured P_D . With this value of K, P_D and T_J can be determined for any value of T_A .

22.5 DC Electrical Characteristics

Table 22-4. DC Electrical Characteristics ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$)(¹)

Characteristic	Symbol	Min	Typ ⁽²⁾	Max	Unit
Output High Voltage ($I_{LOAD} = -2.0 \text{ mA}$) All I/O pins	V_{OH}	$V_{DD} - 0.8$	—	—	V
Output Low Voltage ($I_{LOAD} = 1.6 \text{ mA}$) All I/O pins	V_{OL}	—	—	0.4	V
Input High Voltage All Ports, IRQs, RESET, OSC1	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Low Voltage All Ports, IRQs, RESET, OSC1	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
V_{DD} Supply Current			—		
Run ⁽³⁾		—	—	30	mA
Wait ⁽⁴⁾		—	—	12	mA
Stop ⁽⁵⁾	I_{DD}				
25 °C		—	—	5	μA
0 °C to 85 °C		—	—	15	μA
25 °C with LVI Enabled		—	—	320	μA
0 °C to 85 °C with LVI Enabled		—	—	380	μA
I/O Ports Hi-Z Leakage Current	I_{IL}	—	—	± 10	μA
Input Current	I_{IN}	—	—	± 1	μA
Capacitance Ports (As Input or Output)	C_{OUT} C_{IN}	— —	— —	12 8	pF
Low-Voltage Inhibit Reset	V_{LVR}	2.6	2.7	2.8	V
Low-Voltage Reset/Recover Hysteresis	H_{LVR}	60	80	100	mV
POR ReArm Voltage ⁽⁶⁾	V_{POR}	0	—	100	mV
POR Rise Time Ramp Rate ⁽⁷⁾	R_{POR}	0.035	—	—	V/ms
Monitor Mode Entry Voltage	V_{HI}	$1.4 \times V_{DD}$	—	$2 \times V_{DD}$	V

- $V_{DD} = 5.0 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H , unless otherwise noted.
- Typical values reflect average measurements at midpoint of voltage range, 25 °C only.
- Run (operating) I_{DD} measured using external square wave clock source ($f_{osc} = 8.2 \text{ MHz}$). All inputs 0.2 V from rail. No dc loads. Less than 100 pF on all outputs. $C_L = 20 \text{ pF}$ on OSC2. All ports configured as inputs. OSC2 capacitance linearly affects Run I_{DD} . Measured with all modules enabled.
- Wait I_{DD} measured using external square wave clock source ($f_{osc} = 8.2 \text{ MHz}$). All inputs 0.2 V from rail. No dc loads. Less than 100 pF on all outputs. $C_L = 20 \text{ pF}$ on OSC2. All ports configured as inputs. OSC2 capacitance linearly affects Wait I_{DD} . Measured with PLL, LCD, LVI, and TBM enabled.
- Stop I_{DD} measured with $OSC1 = V_{SS}$.
- Maximum is highest voltage that POR is guaranteed.
- If minimum V_{DD} is not reached before the internal POR reset is released, \overline{RST} must be driven low externally until minimum V_{DD} is reached.

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Table 22-5. DC Electrical Characteristics ($V_{DD} = 3.3 \text{ Vdc} \pm 10\%$)⁽¹⁾

Characteristic	Symbol	Min	Typ ⁽²⁾	Max	Unit
Output High Voltage ($I_{LOAD} = -2.0 \text{ mA}$) all ports	V_{OH}	$V_{DD} - 0.8$	—	—	V
Output Low Voltage ($I_{LOAD} = 1.6 \text{ mA}$) all ports	V_{OL}	—	—	0.4	V
Input High Voltage All ports, IRQs, RESET, OSC1	V_{IH}	$0.7 \times V_{DD}$	—	V_{DD}	V
Input Low Voltage All ports, IRQs, RESET, OSC1	V_{IL}	V_{SS}	—	$0.3 \times V_{DD}$	V
V_{DD} Supply Current			—		
Run ⁽³⁾		—	—	10	mA
Wait ⁽⁴⁾		—	—	6	mA
Stop ⁽⁵⁾	I_{DD}				
25 °C		—	—	3	μA
0 °C to 85 °C		—	—	10	μA
25 °C with LVI Enabled		—	—	200	μA
0 °C to 85 °C with LVI Enabled		—	—	250	μA
I/O Ports Hi-Z Leakage Current	I_{IL}	—	—	± 10	μA
Input Current	I_{IN}	—	—	± 11	μA
Capacitance	C_{OUT}	—	—	12	pF
Ports (as Input or Output)	C_{IN}	—	—	8	
Low Voltage Reset Inhibit	V_{LVII}	2.6	2.7	2.8	V
Low Voltage Reset Inhibit/Recover Hysteresis	H_{LVI}	60	80	100	mV
POR ReArm Voltage ⁽⁶⁾	V_{POR}	0	—	200	mV
POR Rise Time Ramp Rate ⁽⁷⁾	R_{POR}	.02	—	—	V/ms
Monitor Mode Entry Voltage	V_{HI}	$1.6 \times V_{DD}$	—	$2 \times V_{DD}$	V

- $V_{DD} = 3.3 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H , unless otherwise noted.
- Typical values reflect average measurements at midpoint of voltage range, 25 °C only.
- Run (operating) I_{DD} measured using external square wave clock source ($f_{osc} = 8.2 \text{ MHz}$). All inputs 0.2 V from rail. No dc loads. Less than 100 pF on all outputs. $C_L = 20 \text{ pF}$ on OSC2. All ports configured as inputs. OSC2 capacitance linearly affects Run I_{DD} . Measured with all modules enabled.
- Wait I_{DD} measured using external square wave clock source ($f_{osc} = 8.2 \text{ MHz}$). All inputs 0.2 V from rail. No dc loads. Less than 100 pF on all outputs. $C_L = 20 \text{ pF}$ on OSC2. All ports configured as inputs. OSC2 capacitance linearly affects Wait I_{DD} . Measured with PLL, LCD, LVI, and TBM enabled.
- Stop I_{DD} measured with $OSC1 = V_{SS}$.
- Maximum is highest voltage that POR is guaranteed.
- If minimum V_{DD} is not reached before the internal POR reset is released, \overline{RST} must be driven low externally until minimum V_{DD} is reached.

22.6 Control Timing

Table 22-6. Control Timing ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$)(¹)

Characteristic	Symbol	Min	Max	Unit
Frequency of Operation (²) Crystal Option External Clock Option(³)	f_{OSC}	32k dc(⁴)	100k 32M	Hz
Internal Operating Frequency	f_{OP}	—	8.0	MHz
\overline{RESET} input Pulse Width Low (⁵)	t_{IRL}	50	—	ns
\overline{IRQ} Interrupt Pulse Width Low (⁶)(Edge -Triggered)	t_{ILIH}	50	—	ns

1. $V_{SS} = 0 \text{ Vdc}$; timing shown with respect to 20% V_{DD} and 70% V_{SS} unless note
2. See [Table 22-13](#) and [Table 22-14](#) for more information
3. No more than 10% duty cycle deviation from 50%
4. Some modules may require a minimum frequency greater than dc for proper operation; see appropriate Table for this information
5. Minimum pulse width reset is guaranteed to be recognized; it is possible for a smaller pulse width to cause a reset.
6. Minimum pulse width is for guaranteed interrupt; it is possible for a smaller pulse width to be recognized

Table 22-7. Control Timing ($V_{DD} = 3.3 \text{ Vdc} \pm 10\%$)(¹)

Characteristic	Symbol	Min	Max	Unit
Frequency of Operation (²) Crystal Option External Clock Option(³)	f_{OSC}	32k dc(⁴)	100k 16M	Hz
Internal Operating Frequency	f_{OP}	—	4.0	MHz
\overline{RESET} input Pulse Width Low (⁵)	t_{IRL}	125	—	ns
\overline{IRQ} Interrupt Pulse Width Low(⁶) (Edge-Triggered)	t_{ILIH}	125	—	ns

1. $V_{SS} = 0 \text{ Vdc}$; timing shown with respect to 20% V_{DD} and 70% V_{SS} unless noted
2. See [Table 22-11](#) and [Table 22-12](#) for more information
3. No more than 10% duty cycle deviation from 50%
4. Some modules may require a minimum frequency greater than dc for proper operation; see appropriate Table for this information
5. Minimum pulse width reset is guaranteed to be recognized; it is possible for a smaller pulse width to cause a reset.
6. Minimum pulse width is for guaranteed interrupt; it is possible for a smaller pulse width to be recognized

22.7 Serial Peripheral Interface Characteristics

Table 22-8. Serial Peripheral Interface (SPI) Timing ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$) ⁽¹⁾

Diagram Number ⁽²⁾	Characteristic	Symbol	Min	Max	Unit
	Operating Frequency Master Slave	$f_{OP(M)}$ $f_{OP(S)}$	$f_{OP}/128$ DC	$f_{OP}/2$ f_{OP}	MHz
1	Cycle Time Master Slave	$t_{CYC(M)}$ $t_{CYC(S)}$	2 1	128 –	t_{CYC}
2	Enable Lead Time	$t_{LEAD(S)}$	15		ns
3	Enable Lag Time	$t_{LAG(S)}$	15		ns
4	Clock (SCK) High Time Master Slave	$t_{SCKH(M)}$ $t_{SCKH(S)}$	100 50	– –	ns
5	Clock (SCK) Low Time Master Slave	$t_{SCKL(M)}$ $t_{SCKL(S)}$	100 50	– –	ns
6	Data Setup Time (Inputs) Master Slave	$t_{SU(M)}$ $t_{SU(S)}$	45 5	– –	ns
7	Data Hold Time (Inputs) Master Slave	$t_{H(M)}$ $t_{H(S)}$	0 15	– –	ns
8	Access Time, Slave ⁽³⁾ CPHA = 0 CHPA = 1	$t_{A(CP0)}$ $t_{A(CP1)}$	0 0	40 20	ns
9	Disable Time, Slave ⁽⁴⁾	$t_{DIS(S)}$	–	25	ns
10	Data Valid Time (After enable edge) Master Slave ⁽⁵⁾	$t_{V(M)}$ $t_{V(S)}$	– –	10 40	ns
11	Data Hold Time (Outputs, after enable edge) Master Slave	$t_{HO(M)}$ $t_{HO(S)}$	0 5	– –	ns

1. All timing is shown with respect to 20% V_{DD} and 70% V_{DD} , unless noted; assumes 100 pF load on all SPI pins

2. Numbers refer to dimensions in [Figure 22-1](#) and [Figure 22-2](#)

3. Time to data active from high-impedance state

4. Hold time to high-impedance state

5. With 100 pF on all SPI pins

Table 22-9. Serial Peripheral Interface (SPI) Timing ($V_{DD} = 3.3 \text{ Vdc} \pm 10\%$) ⁽¹⁾

Diagram Number ⁽²⁾	Characteristic	Symbol	Min	Max	Unit
	Operating Frequency Master Slave	$f_{OP(M)}$ $f_{OP(S)}$	$f_{OP}/128$ DC	$f_{OP}/2$ f_{OP}	MHz
1	Cycle Time Master Slave	$t_{CYC(M)}$ $t_{CYC(S)}$	2 1	128 –	t_{CYC}
2	Enable Lead Time	$t_{LEAD(S)}$	30		ns
3	Enable Lag Time	$t_{LAG(S)}$	30		ns
4	Clock (SCK) High Time Master Slave	$t_{SCKH(M)}$ $t_{SCKH(S)}$	200 100	– –	ns
5	Clock (SCK) Low Time Master Slave	$t_{SCKL(M)}$ $t_{SCKL(S)}$	200 100	– –	ns
6	Data Setup Time (Inputs) Master Slave	$t_{SU(M)}$ $t_{SU(S)}$	90 10	– –	ns
7	Data Hold Time (Inputs) Master Slave	$t_{H(M)}$ $t_{H(S)}$	0 30	– –	ns
8	Access Time, Slave ⁽³⁾ CPHA = 0 CHPA = 1	$t_{A(CP0)}$ $t_{A(CP1)}$	0 0	80 40	ns
9	Disable Time, Slave ⁽⁴⁾	$t_{DIS(S)}$	–	50	ns
10	Data Valid Time (After enable edge) Master Slave ⁽⁵⁾	$t_{V(M)}$ $t_{V(S)}$	– –	20 80	ns
11	Data Hold Time (Outputs, after enable edge) Master Slave	$t_{HO(M)}$ $t_{HO(S)}$	0 10	– –	ns

1. All timing is shown with respect to 20% V_{DD} and 70% V_{DD} , unless noted; assumes 100 pF load on all SPI pins

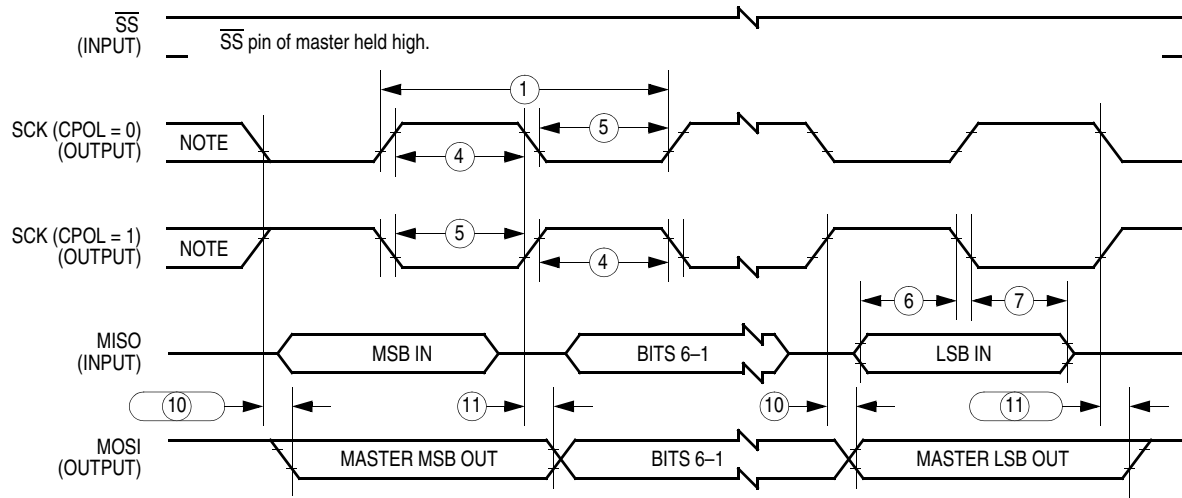
2. Numbers refer to dimensions in [Figure 22-1](#) and [Figure 22-2](#)

3. Time to data active from high-impedance state

4. Hold time to high-impedance state

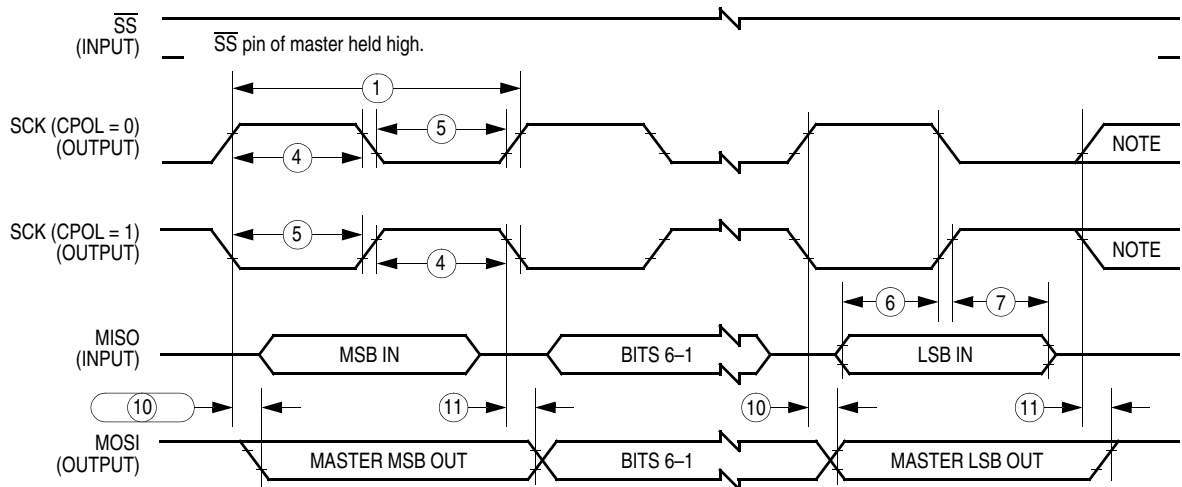
5. With 100 pF on all SPI pins

Preliminary Electrical Specifications



NOTE: This first clock edge is generated internally, but is not seen at the SCK pin.

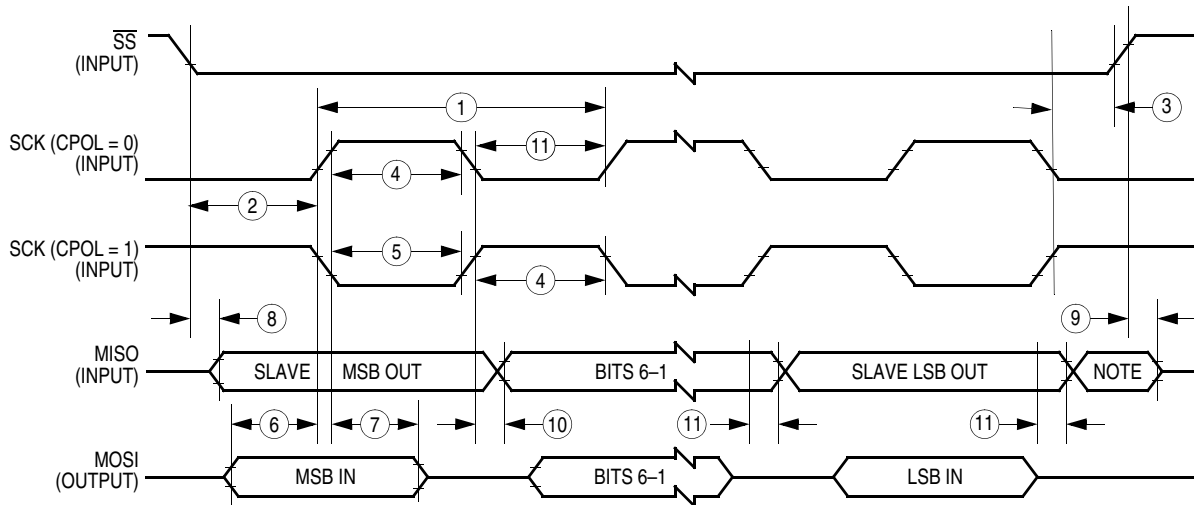
a) SPI Master Timing (CPHA = 0)



NOTE: This last clock edge is generated internally, but is not seen at the SCK pin.

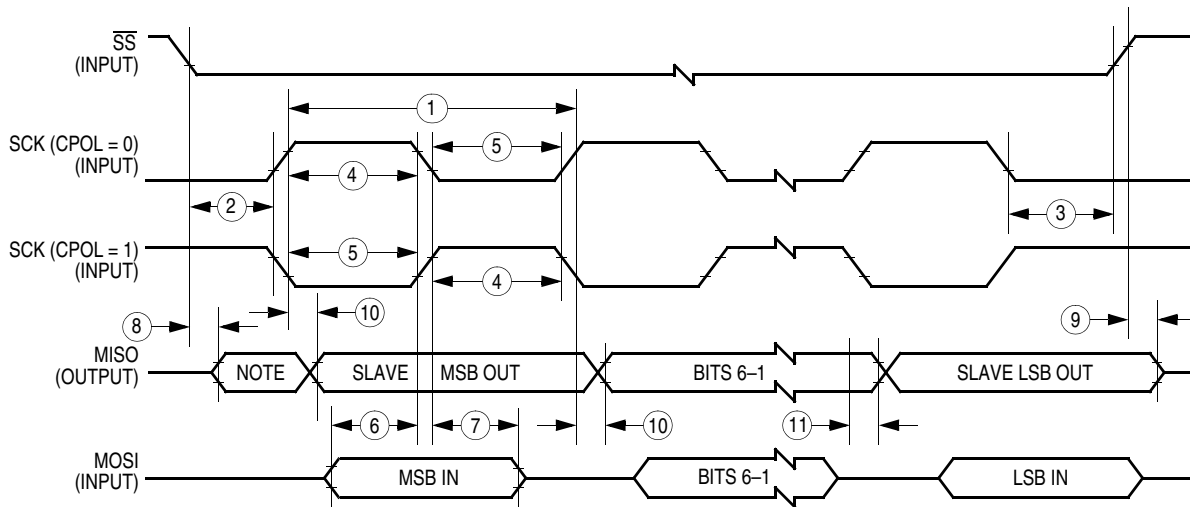
b) SPI Master Timing (CPHA = 1)

Figure 22-1. SPI Master Timing



NOTE: Not defined but normally MSB of character just received.

a) SPI Slave Timing (CPHA = 0)



NOTE: Not defined but normally LSB of character previously transmitted.

b) SPI Slave Timing (CPHA = 1)

Figure 22-2. SPI Slave Timing

22.8 Timer Interface Module Characteristics

Table 22-10. TIM Timing

Characteristic	Symbol	Min	Max	Unit
Input Capture Pulse Width	t_{TIH}, t_{TIL}	125	—	ns
Input Clock Pulse Width	t_{TCH}, t_{TCL}	$(1/f_{OP}) + 5$	—	ns

22.9 Clock Generation Module Electrical Characteristics

Table 22-11. CGM Component Specifications

Characteristic	Symbol	Min	Typ	Max	Notes
Crystal Load Capacitance	C_L	—	—	—	Consult Crystal Mfg. Data
Crystal Fixed Capacitance	C_1	—	$2 \cdot C_L$	—	Consult Crystal Mfg. Data
Crystal Tuning Capacitance	C_2	—	$2 \cdot C_L$	—	Consult Crystal Mfg. Data
Filter Capacitor	C_F	—	C_{FACT}^* (V_{DDA}/f_{XCLK})	—	
Bypass Capacitor	C_{BYP}	—	0.1 μF	—	C_{BYP} must provide low AC impedance from $f = f_{XCLK}/100$ to $100 \cdot f_{VCLK}$, so series resistance must be considered.

Table 22-12. CGM Operating Conditions

Characteristic	Symbol	Min	Typ	Max	Notes
Crystal Reference Frequency	f_{XCLK}	32.0 kHz	38.4 kHz	100 kHz	
Range Nominal Multiplier	f_{NOM}	—	38.4 kHz	—	
VCO Center-of-Range Frequency	f_{VRS}	38.4 kHz	—	40.0 MHz	4.0–5.5 V V_{DD} only
Medium Voltage VCO Center-of-Range Frequency		38.4 kHz	—	20.0 MHz	2.7–4.0 V V_{DD} only
VCO Power-of-Two Range Multiplier	2^E	1	1	8	
VCO Prescale Multiplier	2^P	1	1	8	
Reference Divider Factor	R	1	1	15	
VCO Operating Frequency	f_{VCLK}	f_{VRSMIN}	—	f_{VRSMAX}	

Table 22-13. CGM Acquisition/Lock Time Specifications

Description	Symbol	Min	Typ	Max	Notes
Manual Mode Time to Stable	t_{ACQ}	—	$(8 \cdot V_{DDA}) / (f_{X\ CLK} \cdot K_{ACQ})$	—	If C_F chosen correctly.
Manual Stable to Lock Time	t_{AL}	—	$(4 \cdot V_{DDA}) / (f_{X\ CLK} \cdot K_{TRK})$	—	If C_F chosen correctly.
Manual Acquisition Time	t_{LOCK}	—	$t_{ACQ} + t_{AL}$	—	
Tracking Mode Entry Frequency Tolerance	Δ_{TRK}	0	—	$\pm 3.6\%$	
Acquisition Mode Entry Frequency Tolerance	Δ_{ACQ}	$\pm 6.3\%$	—	$\pm 7.2\%$	
LOCK Entry Freq. Tolerance	Δ_{LOCK}	0	—	$\pm 0.9\%$	
LOCK Exit Freq. Tolerance	Δ_{UNL}	$\pm 0.9\%$	—	$\pm 1.8\%$	
Reference cycles per Acquisition Mode Measurement	n_{ACQ}	—	32	—	
Reference cycles per Tracking Mode Measurement	n_{TRK}	—	128	—	
Automatic Mode Time to Stable	t_{ACQ}	n_{ACQ} / f_{XCLK}	$(8 \cdot V_{DDA}) / (f_{X\ CLK} \cdot K_{ACQ})$	—	If C_F chosen correctly.
Automatic Stable to Lock Time	t_{AL}	n_{TRK} / f_{XCLK}	$(4 \cdot V_{DDA}) / (f_{X\ CLK} \cdot K_{TRK})$	—	If C_F chosen correctly.
Automatic Lock Time	t_{LOCK}	—	$t_{ACQ} + t_{AL}$	—	
PLL Jitter (deviation of average bus frequency over 2 ms)	f_J	0	—	$\pm (f_{CRYST}) \cdot (.025\%) \cdot ((2^P N/R)/4)$	N = VCO frequency multiplier(GBNT)

22.10 Analog-to-Digital Converter (ADC) Characteristics

Table 22-14. ADC Characteristics

Characteristic	Symbol	Min	Max	Unit	Notes
Supply Voltage	AV_{DD}	3.0	5.5	V	AV_{DD} should be tied to the same potential as V_{DD} via separate traces.
Input Voltages	V_{ADIN} V_{REFH}	0 1.5	AV_{DD} AV_{DD}	V	$V_{ADIN} \leq V_{RH}$
Resolution	B_{AD}	8	8	Bits	
Absolute Accuracy ($V_{REFL} = 0$ V, $V_{ADCAP} = 2 \times V_{DDA}$)	A_{AD}	$\pm 1/2$	± 1	LSB	Includes Quantization
ADC Internal Clock	f_{ADIC}	500k	1.048M	Hz	$t_{AIC} = 1/f_{ADIC}$
Conversion Range	R_{AD}	AV_{SS}	V_{RH}	V	
Power-up Time	t_{ADPU}	16		t_{AIC} cycles	
Conversion Time	t_{ADC}	16	17	t_{AIC} cycles	
Sample Time	t_{ADS}	5	—	t_{AIC} cycles	
Monotonicity	M_{AD}	Guaranteed			
Zero Input Reading	Z_{ADI}	00		Hex	$V_{IN} = AV_{SS}$
Full-scale Reading	F_{ADI}		FF	Hex	$V_{IN} = V_{RH}$
Input Capacitance	C_{ADI}	—	20	pf	Not tested

22.11 Memory Characteristics

Table 22-15. Memory Characteristics

Characteristic	Symbol	Min	Typ	Max	Unit
EPROM Programming Voltage	V_{EPGM}	—	13.5	—	V
EPROM Data Retention Time	t_{EDR}	—	10.0	—	years
EPROM Programming Time	t_{EPGM}	—	1	—	ms/byte
RAM Data Retention Voltage	V_{RDR}	.7	—	—	V

22.12 Liquid Crystal Display Driver Characteristics

Table 22-16. LCD Driver Characteristics

Characteristic	Min	Typ	Max	Unit
V_{LL7} Average ⁽¹⁾	6.93	7.0	7.07	V
V_{LL6} Average	5.93	6.0	6.07	V
V_{LL5} Average	4.93	5.0	5.07	V
V_{LL2} Average	1.93	2.0	2.07	V
V_{LL1} Average	0.93	1.0	1.07	V
V_{LL7} Ripple	0	—	± 100	mV
V_{LL6} Ripple	0	—	± 250	mV
V_{LL5} Ripple	0	—	± 250	mV
V_{LL2} Ripple	0	—	± 250	mV
V_{LL1} Ripple	0	—	± 250	mV
LCD Contrast Control Voltage Range V_{LL7}	6.3	—	7.0	V
LCD Contrast Control Voltage Range V_{LL6}	5.4	—	6.0	V
LCD Contrast Control Voltage Range V_{LL5}	4.5	—	5.0	V
LCD Contrast Control Voltage Range V_{LL2}	1.8	—	2.0	V
LCD Contrast Control Voltage Range V_{LL1}	0.9	—	1.0	V

1. Average V_{LLX} for contrast control set to nominal 7.0

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