

M68300 Family

MC68331

USER'S
MANUAL




MOTOROLA

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MC68331

USER'S MANUAL

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PREFACE

The MC68331 microcontroller unit (MCU) is an integral module of Motorola's M68300 Family of 32-bit MCUs. The *MC68331 User's Manual* describes the capabilities, operation, and functions of the MC68331 MCU.

This user's manual is organized as follows:

Section 1	Device Overview
Section 2	Signal Descriptions
Section 3	System Integration Module (SIM)
Section 4	CPU32 Overview
Section 5	Queued Serial Module (QSM)
Section 6	General Purpose Timer (GPT) Overview
Section 7	Emulation Overview
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For additional information pertaining to the CPU32 processor used in the MC68331, refer to the *CPU32 Central Processor Unit Reference Manual*, Motorola document number CPU32RM/AD. For information pertaining to the timer system used in the MC68331, refer to the *GPT General Purpose Timer Reference Manual*, Motorola document number GPTRM/AD.

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SECTION 1 DEVICE OVERVIEW

The MC68331 is a 32-bit integrated microcontroller, combining high-performance data manipulation capabilities with powerful peripheral subsystems. The MC68331 is a member of the M68300 Family of modular embedded controllers featuring fully static, high-speed complementary metal-oxide semiconductor (CMOS) technology. Based on the powerful MC68020, the CPU32 instruction processing module provides enhanced system performance and utilizes the extensive software base for the Motorola M68000 Family. Figure 1-1 shows the major components of the MC68331.

The MC68331 contains four peripheral modules: a central processing unit (CPU32), a general-purpose timer (GPT), a queued serial module (QSM), and a system integration module (SIM). These modules are connected on-chip via the intermodule bus (IMB).

The major features of the MC68331 are as follows:

- Modular Architecture
- 32-Bit MC68000 Family CPU (CPU32):
 - Upward Object Code Compatible
 - New Instructions for Controller Applications
 - Virtual Memory Implementation
 - Loop Mode of Instruction Execution
 - Improved Exception Handling for Controller Applications
 - Trace on Change of Flow
 - Table Lookup and Interpolate Instruction
 - Hardware Breakpoint Signal, Background Mode
 - Fully Static Implementation
- General-Purpose Timer (GPT) Module:
 - Two 16-Bit Free-Running Counters with One Nine-Stage Prescaler
 - Three Input Capture Channels
 - Four Output Compare Channels
 - One Input Capture/Output Compare Channel
 - One Pulse Accumulator/Event Counter Input
 - Two Pulse-Width Modulation Outputs
 - Optional External Clock Input

- Two Serial Input/Output (I/O) Subsystems (QSM):
 - Enhanced Serial Communications Interface (SCI), Universal Asynchronous Receiver Transmitter (UART): Modulus Baud Rate, Parity
 - Queued Serial Peripheral Interface (SPI): 80-Byte Ram, Up to 16 Automatic Transfers
 - Continuous Cycling, 8–16 Bits per Transfer
 - Dual Function I/O Ports
- System Integration Module (SIM)
 - External Bus Support
 - Twelve Programmable Chip-Select Outputs
 - System Protection Logic
 - System Clock Based on 32.768-kHz Crystal for Low Power Operation
 - Watchdog Timer, Clock Monitor, and Bus Monitor
 - Test/Debug Submodule for Factory/User Test and Development

1.1 Central Processor Unit

The CPU32 is upward compatible with the M68000 Family, which excels at processing calculation-intensive algorithms and supporting high-level languages. All of the MC68010 and most of the MC68020 enhancements, such as virtual memory support, loop mode operation, instruction pipeline, and 32-bit mathematical operations, are supported. Powerful addressing modes provide compatibility with existing software programs and increase the efficiency of high-level language compilers. New instructions, such as table lookup and interpolate and low power stop, support the specific requirements of controller applications.

1.2 Peripheral Modules

To improve total system throughput, the MC68331 features stand-alone subsystems. These subsystems include the GPT, the QSM, and the system integration module (SIM). These modules work together with the CPU32 to reduce part count, size, and cost of system implementation.

1.2.1 General-Purpose Timer (GPT)

The GPT is a simple yet flexible 11-channel timer for use in systems where a moderate degree of external visibility and control is required. The GPT can be broken into nearly independent submodules: the compare/capture unit, the pulse-width modulation unit and the pulse accumulator.

The compare/capture unit features three input capture channels, four output compare channels, and one input capture/output compare channel. These channels share a 16-bit free-running counter (TCNT) which derives its clock from a nine-stage prescaler or from the external clock input pin (PCLK).

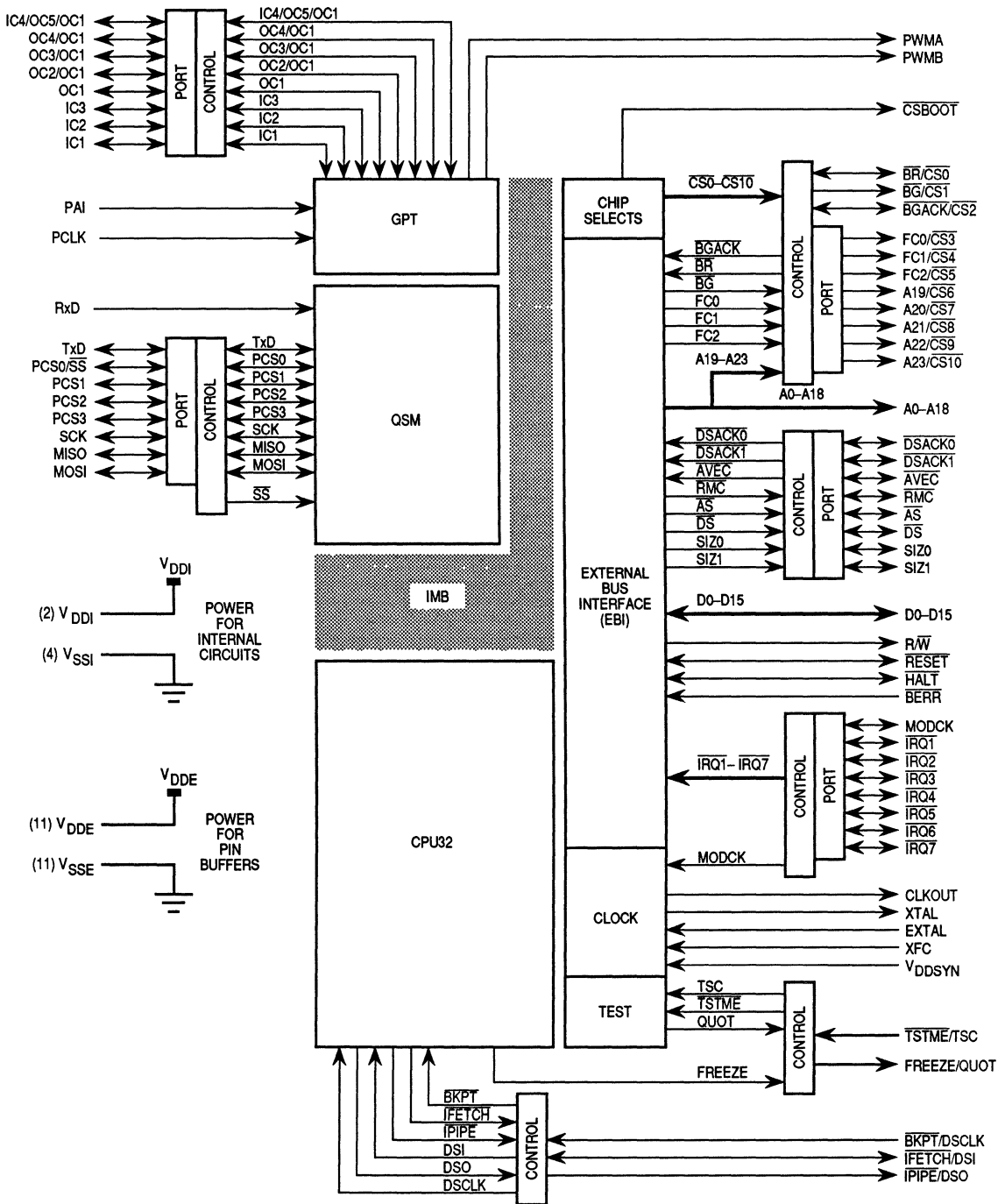


Figure 1-1. Block Diagram of MC68331

The pulse-width modulation submodule is associated with two output pins. The outputs are periodic waveforms whose duty cycle may be independently selected and modified by user software. The PWM unit has its own 16-bit free-running counter which is clocked by an output of the nine-stage prescaler (the same prescaler used by the compare/capture unit) or by the clock input pin, PCLK.

The pulse accumulator logic includes its own 8-bit counter and can operate in either event counting mode or gated time accumulation mode.

If not needed for timing functions, any of the pins associated with the GPT may be used for general-purpose input/output. The input capture and output compare pins are bidirectional and may be used to form an 8-bit parallel port. The PWM pins are outputs only. The pulse accumulator input (PAI) and PCLK are inputs only.

1.2.2 Queued Serial Module (QSM)

The QSM contains two serial ports. The QSPI provides easy peripheral expansion or inter-processor communications via a full-duplex, synchronous, three-line bus: data in, data out, and a serial clock. Four programmable peripheral-select pins provide addressability for up to 16 peripheral devices. The QSPI is enhanced with the addition of a queue contained in a small RAM. This allows the QSPI to handle up to 16 serial transfers of 8–16 bits each or to transmit a stream of data up to 256 bits long without CPU intervention. A special wraparound mode allows the user to do continuous sampling of a serial peripheral, automatically updating the QSPI RAM for efficient interfacing to serial analog-to-digital (A/D) converters.

The SCI provides a standard nonreturn to zero (NRZ) (mark/space) format. Advanced error detection circuitry catches noise glitches to 1/16 of a bit-time in duration. Word length is software selectable between 8 or 9 bits, and the modulus-type baud rate generator provides baud rates from 64 to 524 kbaud based on a 16.78-MHz system clock. The SCI features full- or half-duplex operation, with separate transmitter and receiver enable bits and double buffering of data. Optional parity generation and detection provide either even or odd parity check capability. Wakeup functions allow the CPU to run uninterrupted until either a true idle line is detected or a new address byte is received.

1.2.3 System Integration Module (SIM)

The SIM includes an external interface and various functions that reduce the need for external glue logic. The SIM contains the external bus interface (EBI), 12 chip-selects, system protection, test, and clock submodules.

1.2.4 External Bus Interface (EBI)

Based on the MC68020 bus, the external bus provides 24 address lines and a 16-bit data bus. The data bus allows dynamic sizing between 8- and 16-bit data accesses. Read-modify-write cycles are provided for via the RMC signal. External bus arbitration is accomplished by a three-line handshaking interface.

1.2.4.1 Chip-Selects

Twelve independent programmable chip-selects provide fast, two-cycle external memory or peripheral access. Block size is programmable from a minimum of 2 Kbytes to 1 Mbyte in length. Accesses can be preselected for either 8- or 16-bit transfers. Up to 13 wait states can be programmed for insertion during the access. All bus interface signals are automatically handled by the chip-select logic.

1.2.4.2 System Protection Submodule

System protection is provided on the MC68331 by various monitors and timers, including the bus monitor, HALT monitor, spurious interrupt monitor, software watchdog timer, and the periodic interrupt timer. These system functions are integrated on the microcontroller to reduce board size and the cost required by external components.

1.2.4.3 Test Submodule

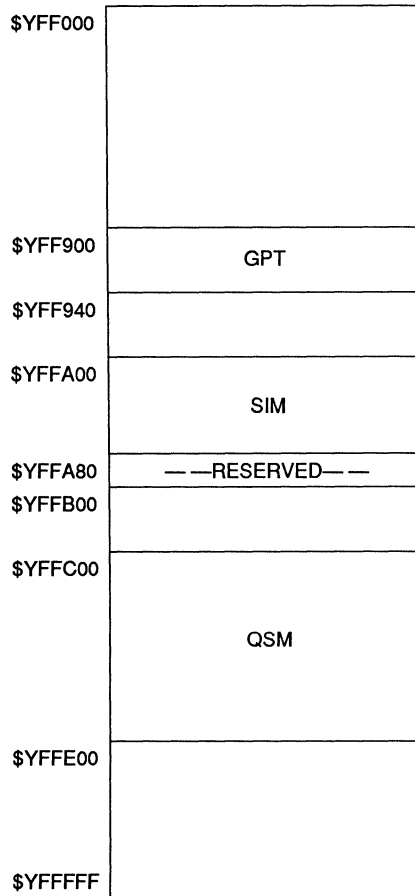
The test module consolidates the microcontroller test logic into a single block to facilitate production testing. Scan paths throughout the MC68331 provide signature analysis checks on internal logic.

1.2.4.4 System Clock

The system clock is generated by an on-chip phase-locked loop circuit to run the device up to 16.78 MHz from a 32.768-kHz crystal. The system speed can be changed dynamically, providing either high performance or low power-consumption under software control. With its fully static CMOS design, it is possible to completely stop the system clock using a low-power stop instruction, while still retaining the contents of the registers and on-board RAM.

1.3 Module Memory Map

Figure 1-2 illustrates the memory map of the MC68331. Unimplemented blocks are mapped externally.



Module	Size (Bytes)	Address Bus Decoding						Base Address
		A23	—	—	—	—	A0	
GPT	64	M111	1111	1111	1001	00XX	XXXX	\$YFF900
SIM	128	M111	1111	1111	1010	0XXX	XXXX	\$YFFA00
QSM	512	M111	1111	1111	110X	XXXX	XXXX	\$YFFC00

Figure 1-2. Module Memory Map

SECTION 2 SIGNAL DESCRIPTIONS

This section contains brief descriptions of the MC68331 input and output signals in their functional groups.

2.1 Signal Index

The input and output signals for the MC68331 are listed in Table 2-1. (Refer to Figure 2-1 for a block diagram of the function signal groups.) Both the names and mnemonics are shown, along with brief descriptions of the signals. For more detail on each signal, refer to the paragraph in this section named for the signal, and the reference in that paragraph to a description of the related operations. Guaranteed timing specifications for the SIM and EBI signals listed in Table 2-1 can be found in **SECTION 8 ELECTRICAL CHARACTERISTICS**.

2.2 Address Bus (A23–A0)

These three-state outputs provide the address for the current bus cycle, except in the CPU32 address space. Refer to **3.7 CPU Space Cycles** for more information on the CPU32 address space. A23 is the most significant address signal. Refer to **3.4.7.3 Address Bus** for information on the address bus and its relationship to bus operation.

2.3 Data Bus (D15–D0)

These three-state bidirectional signals provide the general-purpose data path between the MC68331 and all other devices. The data path is a maximum of 16 bits wide, but can be dynamically sized to support 8-bit or 16-bit transfers. D15 is the most significant bit of the data bus. Refer to **3.4.7.5 Data Bus** for information on the data bus and its relationship to bus operation. The data bus also serves as the mode-select pins during reset as described in **3.10 Reset Operation**.

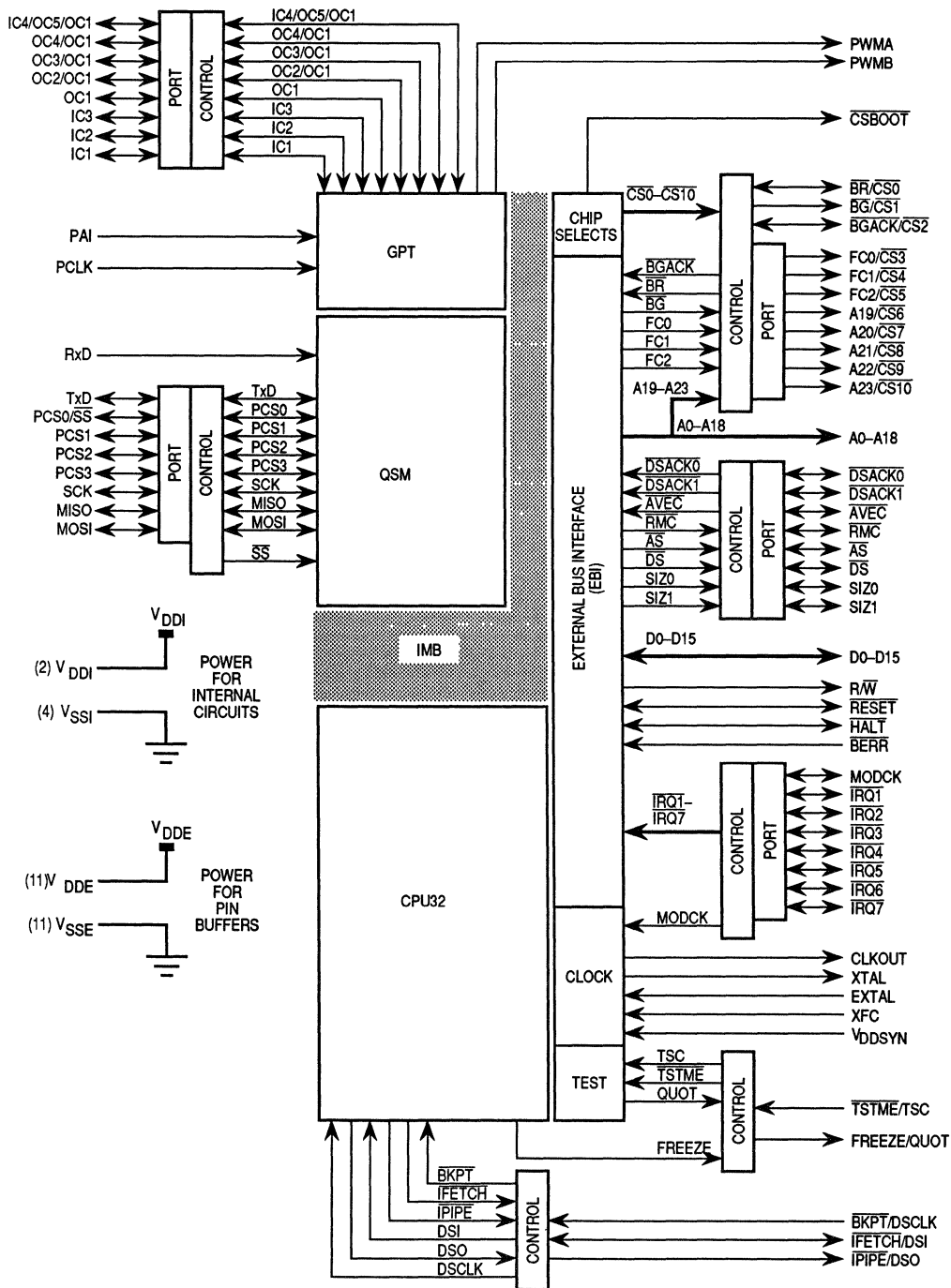


Figure 2-1. MC68331 Signals

Table 2-1. Signal Index (Sheet 1 of 2)

Signal Name	Mnemonic	Function
Address Bus	A23–A0	24-bit address bus
Data Bus	D15–D0	16-bit data bus used to transfer byte or word data per bus cycle
Function Codes	FC2–FC0	Identify the processor state and the address space of the current bus cycle
Boot Chip-Select	$\overline{\text{CSBOOT}}$	Chip-select boot startup ROM containing user's reset vector and initialization program
Chip-Selects	$\overline{\text{CS10}}\text{--}\overline{\text{CS0}}$	Enables peripherals at programmed addresses
Bus Request	$\overline{\text{BR}}$	Indicates that an external device requires bus mastership
Bus Grant	$\overline{\text{BG}}$	Indicates that the current bus cycle is complete and the MC68331 has relinquished the bus
Bus Grant Acknowledge	$\overline{\text{BGACK}}$	Indicates that an external device has assumed bus mastership
Data and Size Acknowledge	$\overline{\text{DSACK1}}$ $\overline{\text{DSACK0}}$	Provides asynchronous data transfers and dynamic bus sizing
Autovector	$\overline{\text{AVEC}}$	Requests an automatic vector during an interrupt acknowledge cycle
Read-Modify-Write Cycle	$\overline{\text{RMC}}$	Identifies the bus cycle as part of an indivisible read-modify-write operation
Address Strobe	$\overline{\text{AS}}$	Indicates that a valid address is on the address bus
Data Strobe	$\overline{\text{DS}}$	During a read cycle, DS indicates that an external device should place valid data on the data bus. During a write cycle, DS indicates that valid data is on the data bus.
Size	SIZ1–SIZ0	Indicates the number of bytes remaining to be transferred for this cycle
Read/Write	$\overline{\text{RW}}$	Indicates the direction of data transfer on the bus
Interrupt Request Level	$\overline{\text{IRQ7}}\text{--}\overline{\text{IRQ1}}$	Provides an interrupt priority level to the CPU
Reset	$\overline{\text{RESET}}$	System reset
Halt	$\overline{\text{HALT}}$	Suspends external bus activity
Bus Error	$\overline{\text{BERR}}$	Indicates that an erroneous bus operation is being attempted
System Clock Out	CLKOUT	Internal system clock
Crystal Oscillator	EXTAL, XTAL	Connections for an external crystal to the internal oscillator circuit
External Filter Capacitor	XFC	Connection pin for an external capacitor to filter the circuit of the phase-locked loop
Clock Mode Select	MODCK	Selects the source of the internal system clock
Instruction Fetch	$\overline{\text{IFETCH}}$	Indicates when the CPU is performing an instruction word prefetch and when the instruction pipeline has been flushed
Instruction Pipe	$\overline{\text{IPIPE}}$	Used to track movement of words through the instruction pipeline
Breakpoint	$\overline{\text{BKPT}}$	Signals a hardware breakpoint to the CPU
Freeze	FREEZE	Indicates that the CPU has acknowledged a breakpoint
Quotient Out	QUOT	Furnishes the quotient bit of the polynomial divider for test purposes
Test Mode Enable	$\overline{\text{TSTME}}$	Hardware enable for test mode

Table 2-1. Signal Index (Sheet 2 of 2)

Signal Name	Mnemonic	Function
Three-State Control	TSC	Places all output drivers in a high-impedance state
Development Serial In, Out, Clock	DSI, DSO, DSCLK	Serial I/O and clock for background debug mode
GPT Input Captures	IC1, IC2, IC3	Input capture channels
GPT Input Capture/Output Compare	IC4/OC5	Input capture 4/Output compare 5
GPT Output Compares	OC1–OC4	Output compare channels, OC1 alternately outputs timer counter prescaler
GPT PWM	PWMA,PWMB	Pulse width modulation channels, PWMA alternately outputs PWM prescaler
GPT Pulse Accumulator	PAI	Pulse accumulator input
GPT Auxiliary Input	PCLK	External GPT clock input
SCI Receive Data	RXD	Serial input to the SCI
SCI Transmit Data	TXD	Serial output from the SCI
Peripheral Chip-Select	$\overline{\text{PCS3}}\text{--}\overline{\text{PCS0}}$	QSPI peripheral chip-selects
Slave Select	$\overline{\text{SS}}$	Places the QSPI in slave mode
QSPI Serial Clock	SCK	Furnishes the clock from the QSPI in master mode or to the QSPI in slave mode
Master In Slave Out	MISO	Furnishes serial input to the QSPI in master mode, and serial output from the QSPI in slave mode
Master Out Slave In	MOSI	Furnishes serial output from the QSPI in master mode, and serial input to the QSPI in slave mode
Synthesizer Power	VDDSYN	Power supply to VCO
System Power Supply and Return	V _{DDE} , V _{SSE}	Power supply and return to the MCU for pin buffers
System Power Supply and Return	V _{DDI} , V _{SSI}	Power supply and return to the MCU for internal circuits

2

2.4 Function Codes (FC2–FC0)

These three-state outputs identify the processor state and the address space of the current bus cycle. Refer to **3.7 CPU Space Cycles** for more information.

2.5 Chip-Selects ($\overline{\text{CS10}}$ – $\overline{\text{CS0}}$, CSBOOT)

These output signals enable peripherals at programmed addresses. $\overline{\text{CSBOOT}}$ is the dedicated chip-select for a boot ROM containing the user's reset vector and initialization program. Refer to **3.3 Chip-Select Submodule** for more information on chip-selects.

2.6 Bus Control Signals

These signals control the bus transfer operations of the MC68331.

2.6.1 Data and Size Acknowledge ($\overline{\text{DSACK1}}$, $\overline{\text{DSACK0}}$)

These two active-low input signals allow asynchronous data transfers and dynamic data bus sizing between the MC68331 and external devices. Refer to **3.4.7.7 Bus Cycle Termination Signals** for more information on these signals and their relationship to dynamic bus sizing.

2.6.2 Autovector ($\overline{\text{AVEC}}$)

This active-low input signal requests an automatic vector during an interrupt acknowledge cycle. Refer to **3.7.3.2 Autovector Interrupt Acknowledge Cycle** for additional information on autovector.

2.6.3 Read-Modify-Write Cycle ($\overline{\text{RMC}}$)

This output signal identifies the bus cycle as part of an indivisible read-modify-write operation; it remains asserted during all bus cycles of the read-modify-write operation. Refer to **3.6.3 Read-Modify-Write Cycle** for additional information.

2.6.4 Address Strobe ($\overline{\text{AS}}$)

This output signal is driven by the bus master to indicate that a valid address is on the address bus. The function code, size, and read/write signals are also valid when $\overline{\text{AS}}$ is asserted. Refer to **3.4.7.4 Address Strobe** for information about the relationship of $\overline{\text{AS}}$ to bus operation.

2.6.5 Data Strobe ($\overline{\text{DS}}$)

During a read cycle, this output signal is driven by the bus master to indicate that an external device should place valid data on the data bus. During a write cycle, the data strobe indicates that valid data is on the data bus. Refer to **3.4.7.6 Data Strobe** for information about the relationship of $\overline{\text{DS}}$ to bus operation.

2.6.6 Transfer Size (SIZ0 , SIZ1)

These active-low output signals are driven by the bus master to indicate the number of operand bytes remaining to be transferred in the current bus cycle. Refer to **3.5.1 Dynamic Bus Sizing** for more information.

2.6.7 Read/Write ($\overline{\text{R/W}}$)

This active-high input/output signal is driven by the bus master to indicate the direction of data transfer on the bus. A logic one indicates a read from a slave device; a logic zero indicates a write to a slave device. Refer to **3.4.7.1 Bus Control Signals** for more information.

2.7 Bus Arbitration Signals

The following signals are the three bus arbitration control signals used to determine the bus master.

2.7.1 Bus Request ($\overline{\text{BR}}$)

This active-low input signal indicates that an external device needs to become the bus master. Refer to **3.9 Bus Arbitration** for more information.

2.7.2 Bus Grant ($\overline{\text{BG}}$)

Assertion of this active-low output signal indicates that the bus master has relinquished the bus. Refer to **3.9.2 Bus Grant** for more information.

2.7.3 Bus Grant Acknowledge ($\overline{\text{BGACK}}$)

Assertion of this active-low input indicates that an external device has become the bus master. Refer to **3.9.3 Bus Grant Acknowledge** for more information.

2.8 Interrupt Request Level ($\overline{\text{IRQ7}}\text{--}\overline{\text{IRQ1}}$)

These active-low input signals are prioritized interrupt request lines. $\overline{\text{IRQ7}}$ is the highest priority. $\overline{\text{IRQ6}}\text{--}\overline{\text{IRQ1}}$ are internally maskable interrupts and $\overline{\text{IRQ7}}$ is nonmaskable. Refer to interrupts in the CPU32 manual for more information.

2.9 Exception Control Signals

These signals are used by the microcontroller unit (MCU) to recover from an exception encountered by the system.

2.9.1 Reset ($\overline{\text{RESET}}$)

This active-low open-drain bidirectional signal is used to initiate a system reset. An external reset signal (as well as a reset from the SIM) resets the MCU as well as all external devices. A reset signal from the CPU32 (asserted as part of the $\overline{\text{RESET}}$ instruction) resets external devices only; the internal state of the CPU32 and other on-chip modules is not altered. When asserted by the MCU, it is guaranteed to be asserted for a minimum of 512 clock cycles. Refer to **3.10 Reset Operation** for a description of reset bus operation and reset in the CPU32 manual for information about the reset exception.

2.9.2 Halt ($\overline{\text{HALT}}$)

This active-low open-drain bidirectional signal is asserted to suspend external bus activity, to request a retry when used with $\overline{\text{BERR}}$, or for single-step operation. As an output, $\overline{\text{HALT}}$ indicates a double bus fault by the CPU. Refer to **3.8 Bus Exception Control Cycles** for a description of the effects of $\overline{\text{HALT}}$ bus operation.

2.9.3 Bus Error ($\overline{\text{BERR}}$)

This active-low input signal indicates that an invalid bus operation is being attempted or, when used with $\overline{\text{HALT}}$, that the processor should retry the current cycle. Refer to **3.8 Bus Exception Control Cycles** for a description of the effects of $\overline{\text{BERR}}$ bus operation.

2.10 Clock Signals

These signals are used by the MCU for controlling or generating the system clocks. Refer to **3.2 Clock Synthesizer** for more information on the various clock signals.

2.10.1 System Clock (CLKOUT)

This output signal is the internal system clock and is used as the bus timing reference by external devices. CLKOUT can be turned off or slowed in low-power stop mode. See **3.1.1 Module Configuration Register** for more information.

2.10.2 Crystal Oscillator (EXTAL, XTAL)

These two pins are the connections for an external crystal to the internal oscillator circuit. An external oscillator should serve as input to the EXTAL pin, when used. See **3.2 Clock Synthesizer** for more information.

2.10.3 External Filter Capacitor (XFC)

This pin is used to add an external capacitor to the filter circuit of the phase-locked loop. The capacitor should be connected between XFC and VDDSYN.

2.10.4 Clock Mode Select (MODCK)

The state of this input signal during reset selects the source of the internal system clock. If MODCK is high during reset, the internal voltage-controlled oscillator (VCO) furnishes the system clock. If MODCK is low during reset, an external frequency appearing at the EXTAL pin furnishes the system clock.

2.11 Instrumentation and Test Signals

These signals are used for test or software debugging.

2.11.1 Instruction Fetch ($\overline{\text{IFETCH}}$)

This active-low output signal indicates when the CPU is performing an instruction word prefetch and when the instruction pipeline has been flushed. Refer to instruction fetch in the CPU32 manual for information about $\overline{\text{IFETCH}}$.

2.11.2 Instruction Pipe ($\overline{\text{IPIPE}}$)

This active-low output signal is used to track movement of words through the instruction pipeline. Refer to instruction pipe in the CPU32 manual for information about $\overline{\text{IPIPE}}$.

2.11.3 Breakpoint ($\overline{\text{BKPT}}$)

This active-low input signal is used to signal a hardware breakpoint to the CPU. Refer to hardware breakpoints in the CPU32 manual for information about $\overline{\text{BKPT}}$.

2.11.4 Freeze ($\overline{\text{FREEZE}}$)

Assertion of this active-high output signal indicates that the CPU has acknowledged a breakpoint and has initiated background mode operation. Refer to development support in the CPU32 manual for more information about $\overline{\text{FREEZE}}$ and background mode.

2.11.5 Quotient Out ($\overline{\text{QUOT}}$)

This active-high output furnishes the quotient bit of the polynomial divider for test purposes.

2.11.6 Test Mode Enable ($\overline{\text{TSTME}}$)

This active-low input signal is a hardware enable required to enter test mode. Refer to **3.11.1 Entering Test Mode** for information about $\overline{\text{TSTME}}$.

2.11.7 Three-State Control ($\overline{\text{TSC}}$)

When this input signal is driven to 1.6 times V_{DD} , the MCU places all of its output drivers in a high-impedance state.

2.11.8 Development Serial In, Out, Clock ($\overline{\text{DSI}}$, $\overline{\text{DSO}}$, $\overline{\text{DSCLK}}$)

These signals provide serial communications for background debug mode. Refer to development support in the CPU manual for more information on background debug mode.

2.12 General-Purpose Timer (GPT) Signals

These signals are used by the general-purpose timer for its eleven timer functions.

2.12.1 Input Capture 1–3 ($\overline{\text{IC1}}$ – $\overline{\text{IC3}}$)

These three signals are the inputs for three of the input capture functions.

2.12.2 Input Capture 4/Output Compare 5 (IC4/OC5)

This signal can be used as an input for the input capture 4 function or as an output for the output compare 5 function.

2.12.3 Output Compare 1–4 (OC1–OC4)

These signals are the outputs for the associated output compare functions.

2.12.4 Pulse-Width Modulation A–B (PWMA–PWMB)

These two signals are outputs for the pulse-width modulation functions. PWMA can also be used to output the clock for the PWM function. The pulse-width modulation submodule has two outputs that are periodic waveforms whose duty cycles may be independently selected and modified by user software.

2.12.5 Pulse Accumulator Input (PAI)

This input is used for the pulse accumulator function. The pulse accumulator channel logic includes its own 8-bit counter and can operate in either event counting mode or gated time accumulation mode.

2.12.6 Auxiliary Input (PCLK)

This input is used to supply an external clock signal to the GPT.

2.13 Queued Serial Module Signals

The following signals are used by the queued serial module (QSM) for data and clock signals. All of these pins (except RXD) can be used for discrete input/output if they are not being used for serial communications interface (SCI) or queued serial peripheral interface (QSPI) functions. Refer to **5.3 QSM Pins** for a general discussion on the QSM signals.

2.13.1 SCI Receive Data (RXD)

This input signal furnishes serial data input to the SCI. It may not be used as discrete input/output. Refer to **5.6.5 Receiver Operation** for more information on the SCI signals.

2.13.2 SCI Transmit Data (TXD)

This signal is the serial data output from the SCI. Refer to **5.6.4 Transmitter Operation** for more information on the SCI signals.

2.13.3 Peripheral Chip-Selects ($\overline{\text{PCS3}}$ – $\overline{\text{PCS0}}$)

These bidirectional signals provide four QSPI peripheral chip-selects. Refer to **5.4.3.2 QSM Pin Assignment Register (QPAR)** for more information.

2.13.4 Slave Select ($\overline{\text{SS}}$)

Assertion of this bidirectional signal places the QSPI in slave mode. Refer to **5.5.5.2 Slave Mode** for more information.

2.13.5 QSPI Serial Clock (SCK)

This bidirectional signal furnishes the clock from the QSPI in master mode or furnishes the clock to the QSPI in slave mode. Refer to **5.5.5 Operating Modes and Flowcharts** for more information.

2.13.6 Master In Slave Out (MISO)

This bidirectional signal furnishes serial data input to the QSPI in master mode, and serial data output from the QSPI in slave mode. Refer to **5.5.5 Operating Modes and Flowcharts** for more information.

2.13.7 Master Out Slave In (MOSI)

This bidirectional signal furnishes serial data output from the QSPI in master mode, and serial data input to the QSPI in slave mode. Refer to **5.5.5 Operating Modes and Flowcharts** for more information.

2.14 Synthesizer Power (V_{DDSYN})

This pin supplies a quiet power source to the VCO to provide greater frequency stability.

2.15 System Power and Ground (V_{DDE} and V_{SSE})

These pins provide system power and return to the MCU for the pin buffer circuitry. Multiple pins are provided for adequate current capability. All power supply pins must be connected and also have adequate bypass capacitance for high-frequency noise suppression.

2.16 System Power and Ground (V_{DDI} and V_{SSI})

These pins provide system power and return to the MCU for the internal circuitry. Multiple pins are provided for adequate current capability. All power supply pins must be connected and also have adequate bypass capacitance for high-frequency noise suppression.

Table 2-2. Signal Summary

Signal Name	Mnemonic	Input/Output	Active State	Three-State
Address Bus	A23–A0	Output	High	Yes
Data Bus	D15–D0	Input/Output	High	Yes
Function Codes	FC2–FC0	Output	High	Yes
Boot Chip-Select	CSBOOT	Output	Low	No
Chip-Selects	CS10–CS0	Output	Low	No
Bus Request	BR	Input	Low	No
Bus Grant	BG	Output	Low	No
Bus Grant Acknowledge	BGACK	Input	Low	—
Data and Size Acknowledge	DSACK1/DSACK0	Input	Low	—
Autovector	AVEC	Input	Low	—
Read-Modify-Write Cycle	RMC	Output	Low	Yes
Address Strobe	AS	Output	Low	Yes
Data Strobe	DS	Output	Low	Yes
Size	SIZ1/SIZ0	Output	High	Yes
Read/Write	R/W	Output	High/Low	Yes
Interrupt Request Level	IRQ7–IRQ1	Input	Low	—
Reset	RESET	Input/Output	Low	No
Halt	HALT	Input/Output	Low	—
Bus Error	BERR	Input	Low	—
System Clock Out	CLKOUT	Input	—	—
Crystal Oscillator	EXTAL, XTAL	Input	—	—
External Filter Capacitor	XFC	Input	—	—
Clock Mode Select	MODCK	Input	High	—
Instruction Fetch	IFETCH	Output	Low	—
Instruction Pipe	IPIPE	Output	Low	—
Breakpoint	BKPT	Input	Low	—
Freeze	FREEZE	Output	High	—
Quotient Out	QUOT	Output	High	—
Test Mode Enable	TSTME	Input	Low	—
Three-State Control	TSC	Input	High	—
Development Serial In, Out, Clock	DSI, DSO, DSCLK	Input/Output	—	—
GPT Input Capture	IC1, IC2, IC3	Input/Output	High/Low	—
Input Capture/Output Compare	IC4/OC5	Input/Output	High/Low	—
Output Compare	OC1–OC4	Input/Output	High/Low	—
Pulse Accumulator Input	PAI	Input	High/Low	—
Pulse Width Modulation	PWMA, PWMB	Output	—	—
Auxiliary Timer Clock Input	PCLK	Input	—	—
SCI Receive Data	RXD	Input	High	—
SCI Transmit Data	TXD	Output	High	—
Peripheral Chip-Select	PCS3–PCS0	Input/Output	Low	—
Slave Select	SS	Input/Output	Low	—
QSPI Serial Clock	SCK	Input/Output	—	—
Master In Slave Out	MISO	Input/Output	High	—
Master Out Slave In	MOSI	Input/Output	High	—
Synthesizer Power	V _{DDSYN}	Input	—	—
System Power Supply and Return	V _{DDI} , V _{SSI}	Input	—	—
System Power Supply and Return	V _{DDE} , V _{SSE}	Input	—	—

SECTION 3 SYSTEM INTEGRATION MODULE (SIM)

The MC68331 system integration module (SIM) consists of five submodules that control the microcontroller unit (MCU) system startup, initialization, configuration, and external bus with a minimum of external devices. The five submodules that make up the SIM, shown in Figure 3-1, are as follows:

- System Configuration and Protection
- Clock Synthesizer
- Chip-Selects
- External Bus Interface
- System Test

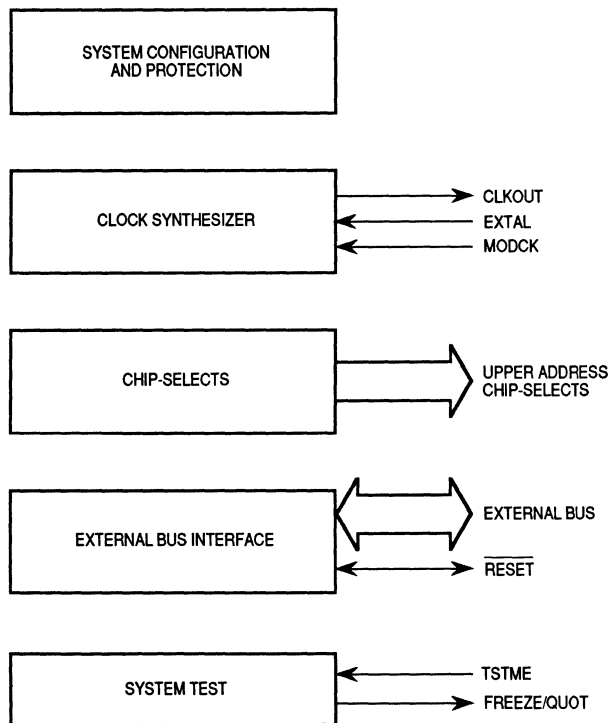


Figure 3-1. System Integration Module Block Diagram

The system configuration and protection submodule, described in **3.1 System Configuration and Protection Submodule**, controls system configuration and provides bus monitors and a software watchdog monitor for system protection.

The clock synthesizer, described in **3.2 Clock Synthesizer**, generates the clock signals used by the SIM as well as other modules and external devices.

The programmable chip-select submodule, described in **3.3 Chip-Select Submodule**, provides 12 chip-select signals. Each chip-select signal has an associated base register and option register that contain the programmable characteristics of that chip-select.

The external bus interface (EBI), described in **3.4 External Bus Interface**, handles the transfer of information between the internal CPU and memory, peripherals, or other processing elements in the external address space.

The system test submodule, described in **3.11 Test Submodule**, incorporates all the hardware necessary for testing the MCU, using scan-based testing. The system test submodule is used to perform factory tests, and its use in normal applications is not supported.

Figure 3-2 is a map of all registers in the SIM, and corresponding function codes (FC) that select user and supervisor data spaces.

FC	ADDRESS	15	8	7	0	
101	YFFA00	MODULE CONFIGURATION (MCR)				
101	YFFA02	MODULE TEST (SIMTR)				
101	YFFA04	CLOCK SYNTHESIZER CONTROL (SYNCR)				TEST CLOCK
101	YFFA06	UNUSED	RESET STATUS REGISTER (RSR)			
101	YFFA08	MODULE TEST E (SIMTRE)				EBI
101	YFFA0A	UNUSED	UNUSED			
101	YFFA0C	UNUSED	UNUSED			
101	YFFA0E	UNUSED	UNUSED			
X01	YFFA10	UNUSED	PORTE DATA (PORTE)			EBI
X01	YFFA12	UNUSED	PORTE DATA (PORTE)			
X01	YFFA14	UNUSED	PORTE DATA DIRECTION (DDRE)			
101	YFFA16	UNUSED	PORTE PIN ASSIGNMENT (PEPAR)			
X01	YFFA18	UNUSED	PORTF DATA (PORTF)			EBI
X01	YFFA1A	UNUSED	PORTF DATA (PORTF)			EBI
X01	YFFA1C	UNUSED	PORTF DATA DIRECTION (DDRF)			
101	YFFA1E	UNUSED	PORTF PIN ASSIGNMENT (PFPAR)			EBI
101	YFFA20	UNUSED	SYSTEM PROTECTION CONTROL (SYPCR)			SYS-PROTECT
101	YFFA22	PERIODIC INTERRUPT CONTROL (PICR)				MOD CONF
101	YFFA24	PERIODIC INTERRUPT TIMING (PITR)				MOD CONF

Figure 3-2. SIM Register Map (Sheet 1 of 2)

FC	ADDRESS	15	8	7	0	
101	YFFA26	UNUSED		SOFTWARE SERVICE (SWSR)		SYS-PROTECT
101	YFFA28	UNUSED		UNUSED		
101	YFFA30	TEST MODULE MASTER SHIFT A (TSTMSRA)				TEST
101	YFFA32	TEST MODULE MASTER SHIFT B (TSTMSRB)				
101	YFFA34	TEST MODULE SHIFT COUNT.A.(TSTSCA)		TEST MODULE SHIFT COUNT.B.(TSTSCB)		
101	YFFA36	TEST MODULE REPETITION COUNTER (TSTRC)				
101	YFFA38	TEST MODULE CONTROL (CREG)				
X01	YFFA3A	TEST MODULE DISTRIBUTED REGISTER (DREG)				TEST
	YFFA3C	UNUSED		UNUSED		
	YFFA3E	UNUSED		UNUSED		
X01	YFFA40	UNUSED		PORT C DATA (CSPDR)		CHIP-SELECT
X01	YFFA42	UNUSED		UNUSED		
101	YFFA44	CHIP-SELECT PIN ASSIGNMENT (CSPAR0)				
101	YFFA46	CHIP-SELECT PIN ASSIGNMENT (CSPAR1)				
101	YFFA48	CHIP-SELECT BASE BOOT (CSBARBT)				
101	YFFA4A	CHIP-SELECT OPTION BOOT (CSORBT)				
101	YFFA4C	CHIP-SELECT BASE 0 (CSBAR0)				
101	YFFA4E	CHIP-SELECT OPTION 0 (CSOR0)				
101	YFFA50	CHIP-SELECT BASE 1 (CSBAR1)				
101	YFFA52	CHIP-SELECT OPTION 1 (CSOR1)				
101	YFFA54	CHIP-SELECT BASE 2 (CSBAR2)				
101	YFFA56	CHIP-SELECT OPTION 2 (CSOR2)				
101	YFFA58	CHIP-SELECT BASE 3 (CSBAR3)				
101	YFFA5A	CHIP-SELECT OPTION 3 (CSOR3)				
101	YFFA5C	CHIP-SELECT BASE 4 (CSBAR4)				
101	YFFA5E	CHIP-SELECT OPTION 4 (CSOR4)				
101	YFFA60	CHIP-SELECT BASE 5 (CSBAR5)				
101	YFFA62	CHIP-SELECT OPTION 5 (CSOR5)				
101	YFFA64	CHIP-SELECT BASE 6 (CSBAR6)				
101	YFFA66	CHIP-SELECT OPTION 6 (CSOR6)				
101	YFFA68	CHIP-SELECT BASE 7 (CSBAR7)				
101	YFFA6A	CHIP-SELECT OPTION 7 (CSOR7)				
101	YFFA6C	CHIP-SELECT BASE 8 (CSBAR8)				
101	YFFA6E	CHIP-SELECT OPTION 8 (CSOR8)				
101	YFFA70	CHIP-SELECT BASE 9 (CSBAR9)				
101	YFFA72	CHIP-SELECT OPTION 9 (CSOR9)				
101	YFFA74	CHIP-SELECT BASE 10 (CSBAR10)				
101	YFFA76	CHIP-SELECT OPTION 10 (CSOR10)				CHIP-SELECT
	YFFA78	UNUSED		UNUSED		
	YFFA7A	UNUSED		UNUSED		
	YFFA7C	UNUSED		UNUSED		
	YFFA7E	UNUSED		UNUSED		

X = Depends on state of SUPV bit in SIM MCR

Y = m111, where m is the modmap bit in the SIM MCR (Y = \$7or \$F)

Figure 3-2. SIM Register Map (Sheet 2 of 2)

3.1 System Configuration and Protection Submodule

The SIM module allows the user to control some features of system configuration by writing bits in the module configuration register, described in **3.1.1 Module Configuration Register (MCR)**. This register also contains read-only status bits that show the state of some of the SIM features.

This MCU is designed with the concept of providing maximum system safeguards. Many of the functions that normally must be provided in external circuits are incorporated into this MCU. The features provided in the system configuration and protection submodule are as follows:

System Configuration

The module configuration register allows the user to configure the system according to the particular system requirements.

Internal Bus Monitor

The MCU provides an internal bus monitor to monitor the \overline{DSACKx} response time for all internal bus accesses. An option allows the monitoring of internal to external bus accesses. There are four selectable response times that allow for the response speed of peripherals used in the system. A bus error (\overline{BERR}) signal is asserted internally if the \overline{DSACKx} response time is exceeded. When operating as a bus master, the \overline{BERR} signal is not asserted externally.

Halt Monitor

A halt monitor causes a reset to occur if the internal halt (\overline{HALT}) is asserted by the CPU.

Spurious Interrupt Monitor

If no interrupt arbitration occurs during an interrupt acknowledge (IACK) cycle, the \overline{BERR} signal is asserted internally.

Software Watchdog

The watchdog asserts reset if the software fails to service the software watchdog for a designated period of time (presumably because it is trapped in a loop or lost). There are four selectable timeout periods, and a prescaler may be used for long timeout periods.

Periodic Interrupt Timer

The MCU provides a timer to generate periodic interrupts. The periodic interrupt time period can vary from 122 μ s to 15.94 s (with a 32.768-kHz crystal used to generate the system clock).

Figure 3-3 shows a block diagram of the system configuration and protection submodule.

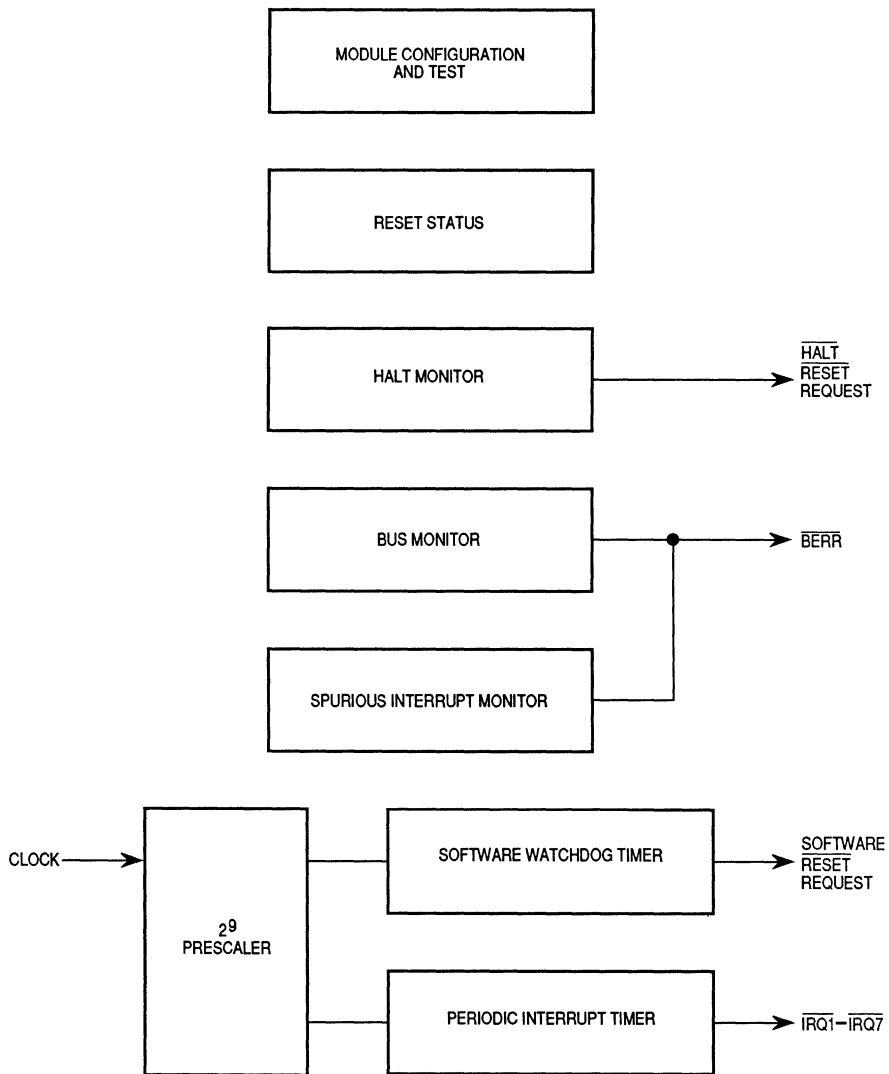


Figure 3-3. System Configuration and Protection Submodule

NOTE

In the registers discussed in the following paragraphs, the numbers in the top line of the register description represent the bit number in the register. The second line contains the mnemonic for the bit. The values shown under the mnemonic in the register diagram are the values of those register bits after reset.

3.1.1 Module Configuration Register (MCR)

The module configuration register controls the SIM configuration. Refer to Figure 3-4. The register can be both read and written at any time, except for module mapping (MM) (bit 6), which can only be written once.

MCR — Module Configuration Register

\$YFFFA00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXOFF	FRZSW	FRZBM	0	SLVEN	0	SHEN1	SHEN0	SUPV	MM	0	0	IARB3	IARB2	IARB1	IARB0
RESET:															
0	1	1	0	DB11	0	0	0	1	1	0	0	1	1	1	1

Figure 3-4. Module Configuration Register

EXOFF — External Clock Off

- 1 = The CLKOUT pin is placed in a high-impedance state.
- 0 = The CLKOUT pin is driven from an internal clock source.

FRZSW — Freeze Software Enable

- 1 = When FREEZE is asserted, the software watchdog and periodic interrupt timer counters are disabled, preventing interrupts from occurring during software debug.
- 0 = When FREEZE is asserted, the software watchdog and periodic interrupt timer counters continue to run. Refer to **3.1.9 Freeze Operation** for more information on freeze operation.

FRZBM — Freeze Bus Monitor Enable

- 1 = When FREEZE is asserted, the bus monitor is disabled.
- 0 = When FREEZE is asserted, the bus monitor continues to operate as programmed.

SLVEN — Slave Mode Enabled

- 1 = Any external master winning control of the external bus also gains direct access to the internal peripherals.
- 0 = The internal peripherals are not available to an external master. This bit is a read-only status bit that reflects the state of the data bus bit 11 (DB11) during reset.

SHEN1–0 — Show Cycle Enable

These two control bits determine what the EBI does with the external bus during internal transfer operations. A show cycle allows internal transfers to be externally monitored. Table 3-1 shows for all SHEN bit combinations whether show cycle data is driven externally or not, and also whether external bus arbitration can occur. External peripherals must not be enabled during show cycles to prevent bus conflicts.

Table 3-1. Show Cycle Control Bits

SHEN1	SHEN0	Action
0	0	Show cycles disabled, external arbitration enabled.
0	1	Show cycles enabled, external arbitration disabled.
1	0	Show cycles enabled, external arbitration enabled.
1	1	Show cycles enabled, external arbitration enabled; internal activity is halted by a bus grant.

SUPV — Supervisor/Unrestricted Data Space

The SUPV bit defines the SIM global registers as either supervisor data space or user (unrestricted) data space.

- 1 = Registers with access controlled by the SUPV bit are restricted to supervisor access only (FC2 must be a one).
- 0 = Registers with access controlled by the SUPV bit are unrestricted (FC2 is a don't care).

MM — Module Mapping

- 1 = Internal modules are addressed from \$FFF000–\$FFFFFF, which is in the absolute short addressing range.
- 0 = Internal modules are addressed from \$7FF000–\$7FFFFFF.

IARB3–IARB0 — Interrupt Arbitration Bits

Each module that generates interrupts, including the SIM, has an IARB field. The value of the IARB field allows arbitration during an IACK cycle among modules that simultaneously generate the same interrupt level. No two modules can share the same IARB value. The reset value of IARB is \$F, allowing the SIM to arbitrate during an IACK cycle. The system software must initialize the IARB field to a value from \$F (highest priority) to \$1 (lowest priority). A zero value prevents the SIM from arbitrating for the interrupt and causes interrupts generated by the SIM to be treated as spurious.

3.1.2 System Integration Module Test Registers

The following paragraphs describe registers in the SIM used only for factory test purposes.

3.1.2.1 System Integration Module Test Register (SIMTR)

The system integration module test register bits are reserved for factory testing. This register can only be accessed in test mode, and *user access is strongly discouraged*. The mask number is accessible at any time. Refer to Figure 3-5.

SIMTR — System Integration Module Test Register

\$YFFA02

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MASK						0	0	SOSEL1	SOSEL0	SHIRQ1	SHIRQ0	FBIT1	FBIT0	BWC1	BWC0

RESET:

* * * * * 0 0 0 0 0 0 0 0 0 0

*At Reset this is the Mask number.

Figure 3-5. System Integration Module Test Register

3

Mask — Revision Number for this Part

Bits 15–10 indicate a mask number for each specific revision or derivative of this part. These bits are read-only; a write has no effect.

SOSEL1–SOSEL0 — Scan-Out Select

These bits define the output scan path or monitor point connected to master shift register B via the SCANB line, as shown in the following table.

Table 3-2. Scan-Out Select

SOSEL1	SOSEL0	Function
0	0	Internal IRQ6 (Scan In)
0	1	External IRQ6 (External Scan In)
1	0	Periodic Interrupt Zero Detect
1	1	Modulo Counter Clock Output

SHIRQ1–SHIRQ0 — Show Interrupt Request

These bits are used to force internal information to appear externally, as listed in the following table.

Table 3-3. Show Interrupt Request

SHIRQ1	SHIRQ0	Function
0	0	Off
0	1	Reserved
1	0	Show Internal IRQ
1	1	Show Internal Bus Signals

FBIT1–FBIT0 — Force Bits

These bits force selected test conditions, as listed in the following table.

Table 3-4. Force Bits

FBIT1	FBIT0	Function
0	0	Off
0	1	Software Watchdog Bypass
1	0	Software Watchdog Reset
1	1	Loss of Clock Reset

BWC1–BWC0 — Bandwidth Control Bits

These bits force selected test conditions for the phase locked loop, as listed in the following table.

Table 3-5. Bandwidth Control Bits

BWC1	BWC0	Function
0	0	Off
0	1	Narrow Bandwidth
1	0	Wide Bandwidth
1	1	Disable Filter

3.1.2.2 System Integration Module Test Register (E Clock) (SIMTRE)

This write-only register is reserved for factory testing. A write to this register in test mode forces the E-clock phase to synchronize with the system clock.

3.1.3 Reset Status Register (RSR)

The reset status register contains a bit for each reset source in the MCU. A bit set to one indicates the last type of reset that occurred, and only one bit can be set in the register. The reset status register is updated by the reset control logic when the MCU comes out of reset. This register can be read at any time; a write has no effect. For more information refer to **3.10 Reset Operation**.

RSR — Reset Status Register

\$YFFA07

7	6	5	4	3	2	1	0
EXT	POW	SW	HLT	0	LOC	SYS	TST

Figure 3-6. Reset Status Register

EXT — External Reset

1 = The last reset was caused by an external signal.

POW — Power-Up Reset

1 = The last reset was caused by the power-up reset circuit.

SW — Software Watchdog Reset

1 = The last reset was caused by the software watchdog circuit.

HLT — Halt Monitor Reset

1 = The last reset was caused by the system protection submodule halt monitor.

LOC — Loss of Clock Reset

1 = The last reset was caused by a loss of frequency reference to the clock submodule. This reset can only occur if the reset enable (RSTEN) bit in the clock submodule is set and the voltage-controlled oscillator (VCO) is enabled.

SYS — System Reset

1 = The last reset was caused by the CPU executing a reset instruction. The system reset does not load a reset vector or affect any internal CPU registers or SIM configuration registers, but does reset external devices and other internal modules.

TST — Test Submodule Reset

1 = The last reset was caused by the test submodule.

3.1.4 System Protection Control Register (SYPCR)

The system protection control register controls the system monitors, the prescaler for the software watchdog clock, and the bus monitor timing.

In operating mode, this register may be written only once following a power-on or external reset, but can be read at any time. In test mode, this register is writable at any time.

SYPCR — System Protection Control Register**\$YFFA21**

7	6	5	4	3	2	1	0
SWE	SWP	SWT1	SWT0	HME	BME	BMT1	BMT0

RESET:

1 $\overline{\text{MODCK}}$ 0 0 0 0 0 0

Figure 3-7. System Protection Control Register

- SWE — Software Watchdog Enable
 1 = Software watchdog enabled
 0 = Software watchdog disabled

Refer to **3.1.6 Software Watchdog** for more information on the software watchdog.

- SWP — Software Watchdog Prescale
 1 = Software watchdog clock prescaled by 512
 0 = Software watchdog clock not prescaled

This bit controls the value of the software watchdog prescaler as shown below. The reset value of this bit is affected by the state of the MODCK pin on the rising edge of reset, as shown in Table 3-6. System software, when writing to the SYPCR, can change the value of this bit.

The MODCK pin also controls the clock source for the MCU. If the MODCK pin is high during reset the internal VCO provides the system clock. When it is low at reset, an external frequency appearing at the EXTAL pin furnishes the system clock.

Table 3-6. MODCK Pin and SWP Bit at Reset

MODCK	SWP
0 (External Clock)	1 (+ 512)
1 (Internal Clock)	0 (+ 1)

SWT1–SWT0 — Software Watchdog Timing

These bits control the divide ratio used to establish the timeout period for the software watchdog timer. The software timeout period is given by the following equation.

$$\text{Timeout Period} = 1/(\text{EXTAL Frequency}/\text{Divide Count}) \quad (3-1)$$

or

$$\text{Timeout Period} = \text{Divide Count}/\text{EXTAL Frequency} \quad (3-2)$$

The software timeout period shown in Table 3-7 gives the equation to derive the software watchdog timeout for any clock frequency, and the timeout periods are listed for a 32.768-kHz crystal used with the VCO and a 16.718-MHz external oscillator.

Table 3-7. Software Timeout Periods for Watchdog Timeout

Bits 6–4	Software Timeout Period	32.768-kHz Crystal Period	16.718-MHz External Clock Period
000	2^9 /EXTAL Input Frequency	15.6 Milliseconds	30.6 Microseconds
001	2^{11} /EXTAL Input Frequency	62.5 Milliseconds	122.5 Microseconds
010	2^{13} /EXTAL Input Frequency	250 Milliseconds	490 Microseconds
011	2^{15} /EXTAL Input Frequency	1 Second	1.96 Microseconds
100	2^{18} /EXTAL Input Frequency	8 Seconds	15.6 Milliseconds
101	2^{20} /EXTAL Input Frequency	32 Seconds	62.7 Milliseconds
110	2^{22} /EXTAL Input Frequency	128 Seconds	250 Milliseconds
111	2^{24} /EXTAL Input Frequency	512 Seconds	1 Second

CAUTION

When the SWT1–SWT0 bits are modified to select a software timeout other than the default, the software service sequence (\$55 followed by \$AA written to the software service register) must be performed before the new timeout period takes effect.

Refer to **3.1.6 Software Watchdog** for more information.

HME — Halt Monitor Enable

1 = Enable halt monitor function

0 = Disable halt monitor function

For more information refer to **3.1.5.2 Halt Monitor**.

BME — Bus Monitor External Enable

1 = Enable bus monitor function for an internal to external bus cycle

0 = Disable bus monitor function for an internal to external bus cycle

For more information refer to **3.1.5.1 Internal Bus Monitor**.

BMT — Bus Monitor Timing

These bits select the timeout period for the bus monitor according to the following table.

Table 3-8. Bus Monitor Timing

Bits 1–0	Bus Monitor Timeout Period
00	64 System Clocks (CLK)
01	32 System Clocks (CLK)
10	16 System Clocks (CLK)
11	8 System Clocks (CLK)

3.1.5 Bus Monitors

The SIM provides a bus monitor that monitors all internal bus accesses and optionally monitors internal to external bus accesses for excessive response times.

3.1.5.1 Internal Bus Monitor

The internal bus monitor continually checks for the $\overline{\text{DSACKx}}$ response time during a normal bus cycle or the $\overline{\text{AVEC}}$ response time during an interrupt acknowledge (IACK) bus cycle. The monitor initiates $\overline{\text{BERR}}$ if the response time is excessive. The internal bus monitor does not check $\overline{\text{DSACKx}}$ response on the external bus unless it initiates the bus cycle. If the system contains external bus masters, an external bus monitor must also be implemented, and the internal to external bus monitor option disabled.

The $\overline{\text{DSACKx}}$ or $\overline{\text{AVEC}}$ response time is measured in clock cycles, and the maximum allowable response time is programmable. Four selectable response time periods for the bus monitor are listed in **3.1.4 System Protection Control Register (SYPCR)** under the BMT bit description. These are provided to allow for the different response times of peripherals that might be used in the system.

The BME bit in the SYPCR enables the internal bus monitor for internal to external bus cycles.

3.1.5.2 Halt Monitor

The halt monitor responds to an assertion of $\overline{\text{HALT}}$ on the internal bus. Refer to **3.8.4 Double Bus Fault** for more information. A flag in the reset status register (RSR) indicates that the last reset was caused by the halt monitor. The halt monitor reset can be inhibited by the HME bit in the SYPCR.

3.1.5.3 Spurious Interrupt Monitor

The spurious interrupt monitor issues $\overline{\text{BERR}}$ if no interrupt arbitration occurs during an IACK cycle. This causes the processor to take a spurious interrupt exception. Normally during an IACK cycle, one or more internal submodules recognize that the CPU is responding to their own interrupt and arbitrate for the privilege of returning a vector or asserting $\overline{\text{AVEC}}$. *This feature cannot be disabled.*

3.1.6 Software Watchdog

Once enabled, the software watchdog requires a special service sequence to be executed on a periodic basis. If this periodic servicing action does not take place, the software watchdog times out and issues a reset. This protects the system against the possibility of the software becoming trapped in loops or running away. There are selectable watchdog timeout periods that are tabulated

in the SYPCR description. The watchdog clock rate is affected by the SWP and SWT bits in the SYPCR, described in the SYPCR bit descriptions.

Figure 3-8 shows a block diagram of the watchdog timer and the clock control for the periodic interrupt timer.

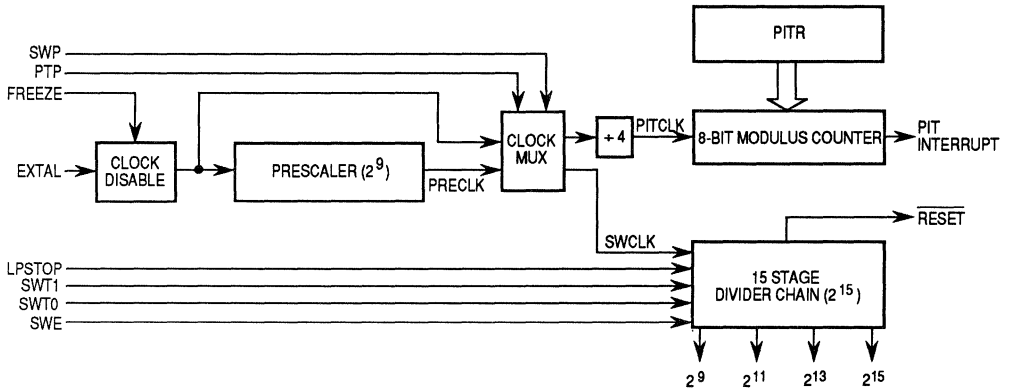


Figure 3-8. Watchdog Timer

The software watchdog service sequence consists of the following two steps:

1. Write \$55 to the software service register (SWSR). (Refer to Figure 3-9.)
2. Write \$AA to the SWSR.

Both writes must occur in the order listed prior to the watchdog timeout, but any number of instructions can be executed between the two writes.

SWSR — Software Service Register

\$YFFA27

7	6	5	4	3	2	1	0
SWSR7	SWSR6	SWSR5	SWSR4	SWSR3	SWSR2	SWSR1	SWSR0

RESET:

0 0 0 0 0 0 0 0

Figure 3-9. Software Service Register

The SWSR is the location to which the watchdog timer servicing sequence is written. This register can be written at any time, but returns all zeros when read.

The software watchdog can be enabled or disabled by the SWE bit in the SYPCR.

3.1.7 Periodic Interrupt Timer (PITR)

The periodic interrupt timer consists of an 8-bit modulus counter that is loaded with the value contained in the PITR, described below.

PITR — Periodic Interrupt Timing Register **\$YFFA24**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	PTP	PITR7	PITR6	PITR5	PITR4	PITR3	PITR2	PITR1	PITR0

RESET:

0	0	0	0	0	0	0	MODCK	0	0	0	0	0	0	0	0
---	---	---	---	---	---	---	-------	---	---	---	---	---	---	---	---

Figure 3-10. Periodic Interrupt Timing Register

PTP — Periodic Timer Prescaler Control

The periodic timer prescale bit (PTP) contains the prescaler control for the periodic timer.

- 1 = Periodic timer clock prescaled by a value of 512
- 0 = Periodic timer clock not prescaled

The reset value of this bit is affected by the state of the clock mode select (MODCK) pin on the rising edge of reset, as shown in the following table.

Table 3-9. MODCK Pin and PTP Bit at Reset

MODCK	PTP
0 (External Clock)	1 (+ 512)
1 (Internal Clock)	0 (+ 1)

PITR7–PITR0 — PITM Field (Periodic Interrupt Timing Modulus)

The periodic interrupt timing register (PITR) contains the count value for the periodic timer. A zero value turns off the periodic timer. This register can be read or written at any time.

Figure 3-8 shows a block diagram of the clock control circuits for the periodic interrupt timer as well as the watchdog timer. The modulus counter is clocked by a signal derived from the buffered crystal oscillator (EXTAL) input pin unless an external frequency source is used. When an external frequency source is used (MODCK low at the end of reset), the default state of the prescaler control bits (SWP and PTP) is changed to enable both prescalers.

Either clock source (EXTAL or EXTAL + 512) is divided by four before driving the modulus counter (PITCLK). When the modulus counter value reaches zero, an

interrupt is generated. The value in the PITR (the PITM field) is then loaded again into the modulus counter and the counting process starts over. If a new value is written to the PITR, this value is loaded into the modulus counter when the current count is completed.

This register can be read or written at any time. Bits 15–9 are not implemented, and always return zero when read. A write does not affect these bits.

3.1.7.1 Periodic Interrupt Control Register (PICR)

The periodic interrupt control register sets up the interrupt request level for the interrupt periodic timer and also contains the interrupt vector generated during an IACK cycle in response to an interrupt from the periodic timer.

PICR — Periodic Interrupt Control Register

\$YFFA22

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
0	0	0	0	0	PIRQL2	PIRQL1	PIRQL0	PIV7	PIV6	PIV5	PIV4	PIV3	PIV2	PIV1	PIV0	
RESET:																
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

Figure 3-11. Periodic Interrupt Control Register

PIRQL2–PIRQL0 — Periodic Interrupt Request Level

These bits contain the periodic interrupt request level. Table 3-10 shows what interrupt request level is asserted. The periodic timer continues to run when the interrupt is disabled.

Table 3-10. Periodic Interrupt Request Level

Bits 10–8	Interrupt Request Level
000	Periodic Interrupt Disabled
001	Interrupt Request Level 1
010	Interrupt Request Level 2
011	Interrupt Request Level 3
100	Interrupt Request Level 4
101	Interrupt Request Level 5
110	Interrupt Request Level 6
111	Interrupt Request Level 7

PIV7–PIV0 — Periodic Interrupt Vector

These bits contain the value of the vector generated during an IACK cycle in response to an interrupt from the periodic timer. When the SIM responds to the IACK cycle, the periodic interrupt vector from the PICR is placed on the bus. This vector number is multiplied by four to form the vector offset, which is added to the vector base register to obtain the address of the vector.

Bits 10–0 can be read or written at any time. Bits 15–11 are unimplemented and always return zero. A write to these bits has no effect.

3.1.7.2 Periodic Timer Period Calculation

The period of the periodic timer can be calculated using the following equation:

$$\text{PIT Period} = \text{PITM}/(\text{EXTAL}/\text{Prescaler})/4 \quad (3-3)$$

where:

PIT Period = Periodic Interrupt Timer Period

PITM = Periodic Interrupt Timer Register Modulus (PITR7–PITR0)

EXTAL = Crystal Frequency

Prescaler = 512 or 1 depending on the state of the PTP bit in the PITR

Solving the equation using a crystal frequency of 32.768 kHz with the prescaler disabled (PTP = 0) gives:

$$\begin{aligned} \text{PIT Period} &= \text{PITM}/(32768/1)/4 \\ &= \text{PITM}/8192 \end{aligned} \quad (3-4)$$

This gives a range from 122 μ s with a PITM of \$01 (00000001 binary) to 31.128 ms with a PITM of \$FF (11111111 binary).

Solving the equation with the prescaler enabled (PTP = 1) gives the following values:

$$\begin{aligned} \text{PIT Period} &= \text{PITM}/(32768/512)/4 \\ &= \text{PITM}/16 \end{aligned} \quad (3-5)$$

This gives a range from 62.5 ms with a PITM value of \$01 (00000001 binary) to 15.94 s with a PITM of \$FF (11111111 binary).

Table 3-11 lists some of the periods available using a 32.768-kHz clock:

**Table 3-11. PIT Periods for 32.768-kHz
Clock**

PITR	PIT Period
\$0000	Periodic Interrupt Timer Off
\$0001	122 Microseconds
\$0002	244 Microseconds
\$0004	488 Microseconds
\$0008	977 Microseconds
\$000F	1.83 Milliseconds
\$0020	3.90 Milliseconds
\$0040	7.88 Milliseconds
\$0080	15.6 Milliseconds
\$00A0	19.5 Milliseconds
\$00FF	31.1 Milliseconds
\$0100	Periodic Interrupt Timer Off
\$0101	62.5 Milliseconds
\$0102	125 Milliseconds
\$0104	250 Milliseconds
\$0108	500 Milliseconds
\$0110	1 Second
\$0120	2 Seconds
\$0140	4 Seconds
\$0180	8 Seconds
\$01A0	10 Seconds
\$01FF	15.9 Seconds

For fast calculation of periodic timer period using a 32.768-kHz clock, the following equations can be used:

With prescaler disabled:

$$\text{PIT Period} = \text{PITM} (122 \mu\text{s}) \quad (3-6)$$

With prescaler enabled:

$$\text{PIT Period} = \text{PITM} (62.5 \text{ ms}) \quad (3-7)$$

3.1.7.3 Using The Periodic Timer as a Real-Time Clock

The periodic interrupt timer can be used as a real-time clock interrupt by setting it up to generate an interrupt with a 1-s period. Rearranging the periodic timer period equation to solve for the desired count value,

$$\begin{aligned} \text{PITM} &= (\text{PIT Period})(\text{EXTAL})/(\text{Prescaler})(4) && (3-8) \\ &= (1)(32768)/(512)(4) \\ &= 16 \text{ (decimal)} \end{aligned}$$

Therefore, the PITR should be loaded with a value of \$10, with the prescaler enabled, to generate interrupts at a 1-s rate.

3.1.8 Low Power STOP Operation (LPSTOP)

Execution of the LPSTOP instruction disables the clock to the software watchdog timer in the low state. The software watchdog timer remains stopped until the LPSTOP state is ended and then begins to run again on the next rising clock edge.

NOTE

When the CPU executes the STOP instruction (as opposed to LPSTOP), the software watchdog timer continues to run. If the software watchdog is enabled, it resets the MCU when timeout occurs.

The periodic interrupt timer does not respond to an LPSTOP instruction so that it can be used to bring the MCU out of the LPSTOP condition as long as the interrupt request level is higher than the CPU interrupt mask level. The periodic interrupt timer is clocked by the EXTAL clock, and so runs at the same frequency as the EXTAL pin during LPSTOP.

To stop the periodic interrupt timer while in LPSTOP, the PITR must be loaded with a zero value before LPSTOP is executed.

The bus monitor, halt monitor, and spurious interrupt monitor are all inactive during LPSTOP.

3.1.9 Freeze Operation

FREEZE is asserted by the CPU if a breakpoint is encountered with background mode enabled. When FREEZE is asserted, only the bus monitor, software watchdog, and periodic interrupt timer are affected. The halt monitor and spurious interrupt monitor continue to operate normally. Setting the FRZBM bit disables the bus monitor when FREEZE is asserted, and setting the FRZSW bit disables the software watchdog and the periodic interrupt timer when FREEZE is asserted. The FRZBM and FRZSW bits are located in the MCR.

3.2 Clock Synthesizer

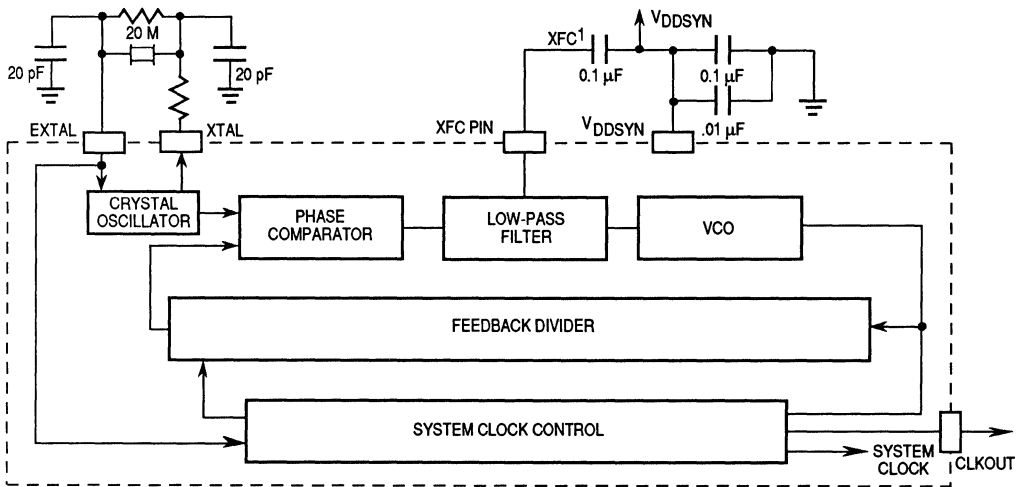
3

The clock synthesizer can operate from an on-chip phase-locked loop (PLL) using an external crystal connected between the EXTAL and XTAL pins as a reference frequency source. A 32.768-kHz crystal provides an inexpensive reference, but the reference crystal frequency can be any frequency from 25 to 50 kHz. Outside of this range, an external oscillator can be used with the on-chip frequency synthesizer and VCO, or the system clock frequency can be driven directly into the EXTAL pin (the XTAL pin should be left floating for this case).

With a 32.768-kHz crystal the system clock frequency is programmable from 131 kHz to the maximum clock frequency, specified in **SECTION 8 ELECTRICAL CHARACTERISTICS**, with a resolution of 131 kHz. The minimum VCO frequency is always four times the crystal frequency. This is also the resolution.

A separate power pin (V_{DDSYN}) is used to allow the clock circuits to run with the rest of the MCU powered down and to provide increased noise immunity for the clock circuits. The source for V_{DDSYN} should be a quiet power supply with adequate external bypass capacitors placed as close as possible to the V_{DDSYN} pin to ensure a stable operating frequency. Figure 3-12 shows a block diagram of the clock submodule and suggested values for the bypass and PLL external capacitors.

The PLL requires an external low-leakage filter capacitor, typically in the range from 0.01 to 0.1 μF , connected between the external filter capacitor (XFC) and V_{DDSYN} pins. Smaller values of the external filter capacitor provide a faster response time for the PLL, and larger values provide greater frequency stability.



- NOTES:
1. Must be low-leakage capacitor.
 2. EXTAL can be driven with an external oscillator.

Figure 3-12. Clock Submodule Block Diagram

3.2.1 Clock Synthesizer Control Register (SYNCR)

The clock synthesizer control register can be read or written only in supervisor mode. The reset state of SYNCR produces an operating frequency of 8.38 MHz when the PLL is referenced to a 32.768-kHz crystal. The system frequency is controlled by the frequency control bits in the upper byte of the SYNCR as follows:

SYNCR — Clock Synthesizer Control Register **\$YFFA04**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
W	X	Y5	Y4	Y3	Y2	Y1	Y0	EDIV	0	0	SLIMP	SLOCK	RSTEN	STSIM	STEXT

RESET:

0	0	1	1	1	1	1	1	0	0	0	U	U	0	0	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

U = Unaffected by reset

Figure 3-13. Clock Synthesizer Control Register

W — Frequency Control Bit

This bit controls the prescaler tap in the synthesizer feedback loop. Setting the bit increases the VCO speed by a factor of four, as specified in equation 3-9, which requires time for the VCO to relock.

X — Frequency Control Bit

This bit controls a divide by two prescaler that is not in the synthesizer feedback loop. Setting the bit bypasses the prescaler and therefore doubles the system clock speed without changing the VCO speed, as specified in equation 3-9 for determining system frequency, and so no delay is incurred to relock the VCO.

Y5–Y0 — Frequency Control Bits

The Y bits, with a value from 0 to 63, control the modulus down counter in the synthesizer feedback loop, causing it to divide by the value of Y+1. (Refer to equation 3-9 for determining system frequency). Changing these bits requires a time delay for the VCO to relock.

EDIV — E-Clock Divide Rate

1 = E-clock = system clock divided by 16.

0 = E-clock = system clock divided by 8.

SLIMP — Limp Mode

1 = A loss of crystal reference has been detected and the VCO is running at approximately half of maximum speed, determined from an internal voltage reference.

0 = External crystal frequency is VCO reference.

SLOCK — Synthesizer Lock

1 = VCO has locked on the desired frequency (or system clock is driven externally).

0 = VCO is enabled, but has not yet locked.

The MCU maintains the reset state until the synthesizer locks, but the SLOCK bit does not indicate synthesizer lock status until after the user writes to SYNCR.

RSTEN — Reset Enable

1 = Loss of crystal causes a system reset.

0 = Loss of crystal causes the VCO to operate at a nominal speed without external reference (limp mode), and the MCU continues to operate at that speed.

Note: The LOC detection circuitry is disabled in low-power stop. If a loss of clock occurs during LPSTOP, power must be recycled to remove the device from this mode.

STSIM — Stop System Integration Module Clock

1 = When the LPSTOP instruction is executed, the SIM clock is driven from the VCO.

0 = When the LPSTOP instruction is executed, the SIM clock is driven from the crystal oscillator and the VCO is turned off to conserve power.

STEXT — Stop External Clock

- 1 = When the LPSTOP instruction is executed, the external clock pin (CLKOUT) is driven from the SIM clock, as determined by the STSIM bit.
- 0 = When the LPSTOP instruction is executed, the external clock is held low to conserve power.

3.2.2 Phase Comparator and Filter

The phase comparator takes the output of the frequency divider and compares it to a reference signal from an external crystal. The result of this compare is low-pass filtered and used to control the VCO. The comparator also detects when the crystal oscillator stops running to initiate the limp mode for the system clock.

3.2.3 Frequency Divider

The frequency divider circuits divide the VCO frequency down to the reference frequency for the phase comparator. The frequency divider consists of the following elements:

- 3-bit prescaler controlled by the W bit in SYNCR
- 6-bit modulo down counter controlled by the Y bits in the SYNCR

Several factors are important to the design of the system clock. The resulting system clock frequency must be within the limits specified for the MCU. The frequency of the system clock is given by the following equation:

$$F_{\text{SYSTEM}} = F_{\text{CRYSTAL}} [4(Y+1)2^{2W+X}] \quad (3-9)$$

The maximum VCO frequency limit must also be observed. The VCO frequency is given by the following equation:

$$F_{\text{VCO}} = F_{\text{SYSTEM}}(2 - X) \quad (3-10)$$

Clearing the X bit causes the VCO output to be divided by two. This causes the VCO to operate at twice the system frequency. The VCO upper-frequency limit must be considered when programming the SYNCR. Both the system clock and VCO frequency limits are given in **SECTION 8 ELECTRICAL CHARACTERISTICS**.

Table 3-12 lists the frequencies available from various combinations of SYNCR bits with a reference frequency of 32.768 kHz.

Table 3-12. System Frequencies from 32.768-kHz Reference (Sheet 1 of 2)

Y	W = 0 X = 0	W = 0 X = 1	W = 1 X = 0	W = 1 X = 1
0 = 000000	131	262	524	1049
1 = 000001	262	524	1049	2097
2 = 000010	393	786	1573	3146
3 = 000011	524	1049	2097	4194
4 = 000100	655	1311	2621	5243
5 = 000101	786	1573	3146	6291
6 = 000110	918	1835	3670	7340
7 = 000111	1049	2097	4194	8389
8 = 001000	1180	2359	4719	9437
9 = 001001	1311	2621	5243	10486
10 = 001010	1442	2884	5767	11534
11 = 001011	1573	3146	6291	12583
12 = 001100	1704	3408	6816	13631
13 = 001101	1835	3670	7340	14680
14 = 001110	1966	3932	7864	15729
15 = 001111	2097	4194	8389	16777
16 = 010000	2228	4456	8913	
17 = 010001	2359	4719	9437	
18 = 010010	2490	4981	9961	
19 = 010011	2621	5243	10486	
20 = 010100	2753	5505	11010	
21 = 010101	2884	5767	11534	
22 = 010110	3015	6029	12059	
23 = 010111	3146	6291	12583	
24 = 011000	3277	6554	13107	
25 = 011001	3408	6816	13631	
26 = 011010	3539	7078	14156	
27 = 011011	3670	7340	14680	
28 = 011100	3801	7602	15204	
29 = 011101	3932	7864	15729	
30 = 011110	4063	8126	16253	
31 = 011111	4194	8389	16777	
32 = 100000	4325	8651		
33 = 100001	4456	8913		
34 = 100010	4588	9175		
35 = 100011	4719	9437		
36 = 100100	4850	9699		
37 = 100101	4981	9961		
38 = 100110	5112	10224		
39 = 100111	5243	10486		
40 = 101000	5374	10748		
41 = 101001	5505	11010		
42 = 101010	5636	11272		
43 = 101011	5767	11534		
44 = 101100	5898	11796		
45 = 101101	6029	12059		
46 = 101110	6160	12321		
47 = 101111	6291	12583		

Table 3-12. System Frequencies from 32.768-kHz Reference (Sheet 2 of 2)

Y	W = 0 X = 0	W = 0 X = 1	W = 1 X = 0	W = 1 X = 1
48 = 110000	6423	12845		
49 = 110001	6554	13107		
50 = 110010	6685	13369		
51 = 110011	6816	13631		
52 = 110100	6947	13894		
53 = 110101	7078	14156		
54 = 110110	7209	14418		
55 = 110111	7340	14680		
56 = 111000	7471	14942		
57 = 111001	7602	15204		
58 = 111010	7733	15466		
59 = 111011	7864	15729		
60 = 111100	7995	15991		
61 = 111101	8126	16253		
62 = 111110	8258	16515		
63 = 111111	8389	16777		

Note: All frequencies in kHz

3.2.4 Clock Control

The clock control circuits determine the source used for both internal and external clocks during special circumstances, such as an LPSTOP execution.

Table 3-13 summarizes the clock activity during LPSTOP, with MODCK = 1 and 0 during reset. Any clock in the off state is held low. In LPSTOP mode, SIMCLK runs the periodic interrupt $\overline{\text{RESET}}$ and $\overline{\text{IRQ}}$ pin synchronizers.

Table 3-13. Clock Control Signals

Inputs		Register Bits			Clocks	
MODCLK	EXTAL	STSIM	STEXT	LSTOP	SIMCLK	CLKOUT
0	Clock	X	X	No	EXTAL	EXTAL
0	Clock	0	0	Yes	EXTAL	Off
0	Clock	0	1	Yes	EXTAL	EXTAL
0	Clock	1	0	Yes	EXTAL	Off
0	Clock	1	1	Yes	EXTAL	EXTAL
1	Crystal	X	X	No	VCO	VCO
1	Crystal	0	0	Yes	Crystal	Off
1	Crystal	0	1	Yes	Crystal	Crystal
1	Crystal	1	0	Yes	VCO	Off
1	Crystal	1	1	Yes	VCO	VCO

3.3 Chip-Select Submodule

Typical microcomputer systems require external hardware to provide select signals to external peripherals. This MCU integrates these functions on-chip to provide the cost, speed, and reliability benefits at a higher level of integration. The chip-select signals can also be programmed as output enable, read or write strobe, or IACK signals.

Since initialization software would probably reside in a peripheral memory device controlled by the chip-select circuits, a $\overline{\text{CSBOOT}}$ register provides default reset values to support bootstrap operation.

The chip-select submodule supports the following programmable features:

- **Twelve Programmable Chip-Select Circuits** — There are twelve chip-select signals ($\overline{\text{CSBOOT}}$ and CS10–CS0) available to the programmer; which use the $\overline{\text{CSBOOT}}$ pin, bus arbitration pins $\overline{\text{BR}}$, $\overline{\text{BG}}$, and $\overline{\text{BGACK}}$, function code pins [FC2:FC0], and address pins [A23:A19]. The $\overline{\text{CSBOOT}}$ pin is dedicated to a single function because it must function after a reset with no initialization; the other chip-select circuits share functions on their output pins. All 12 chip-select circuits are independently programmable from the same list of selectable features. Each chip-select circuit has an individual base register and option register that contain the programmable characteristics of that chip-select. Using these address lines as chip-select signals does not restrict the large linear address space of the MCU since the chip-select logic always uses the internal address lines.
- **Variable Block Sizes** — The block size starting from the specified base address can be programmed as 2K, 8K, 16K, 64K, 128K, 256K, 512K, or 1 Mbyte.
- **Both 8-Bit and 16-Bit Ports Supported** — Eight-bit ports are accessible on both odd and even addresses when connected to data bus bits 15–8. Sixteen-bit ports can be accessed as odd bytes, even bytes, or words.
- **Read-Only, Write-Only, or Read/Write Capability** — Chip-selects can be asserted synchronized with read, write, or both read and write.
- **Address Strobe and Data Strobe Timing Option** — Chip-select signals can be synchronized with either address strobe or data strobe, so that control signals such as output enable or write enable can be easily generated.
- **Internal $\overline{\text{DSACK}}$ Generation with Wait States** — The port size programmed in the pin assignment register can be referenced for generating $\overline{\text{DSACK}}$, and the proper number of wait states for a particular device programmed by the user.

- Address Space Checking — Supervisor, user, and CPU space accesses can be optionally checked.
- Interrupt Priority Level Checking (IPL) — In the IACK cycle, the acknowledged interrupt level can be compared with the user-specified level programmed in the option field. If autovector option is selected, AVEC is internally asserted.
- Discrete Output — Port C pins A22–A19 and FC2–FC0 can be programmed for discrete output, with data stored in the pin data register (CSPDR).
- M6800-Type Peripheral Support — M6800-type peripherals that require an E clock for synchronization can be supported. Chip-select is asserted, synchronized with the E clock on pin A23, providing correct data bus timing for the MCU.

The pin assignment registers (CSPAR0, CSPAR1) determine the function of the pins that can be assigned to chip-selects. The initial pin assignment is determined by the state of the data bus pins when the MCU comes out of reset. Table 3-14 lists the allocation of chip-selects and discrete outputs on the pins of the MCU. The active states are defined as active low.

Table 3-14. Pin Allocation of Chip-Selects

Pin	Chip-Select	Discrete Outputs
CSBOOT	$\overline{\text{CSBOOT}}$	—
BR	$\overline{\text{CS0}}$	—
BG	$\overline{\text{CS1}}$	—
BGACK	$\overline{\text{CS2}}$	—
FC0	$\overline{\text{CS3}}$	DO0
FC1	$\overline{\text{CS4}}$	DO1
FC2	$\overline{\text{CS5}}$	DO2
A19	$\overline{\text{CS6}}$	DO3
A20	$\overline{\text{CS7}}$	DO4
A21	$\overline{\text{CS8}}$	DO5
A22	$\overline{\text{CS9}}$	DO6
A23	$\overline{\text{CS10}}$	E Clock

The CSPDR stores seven bits of data for the seven discrete outputs. A single $\overline{\text{DSACK}}$ generator is shared by all chip-select circuits. Figure 3-14 shows a block diagram of a single chip-select circuit.

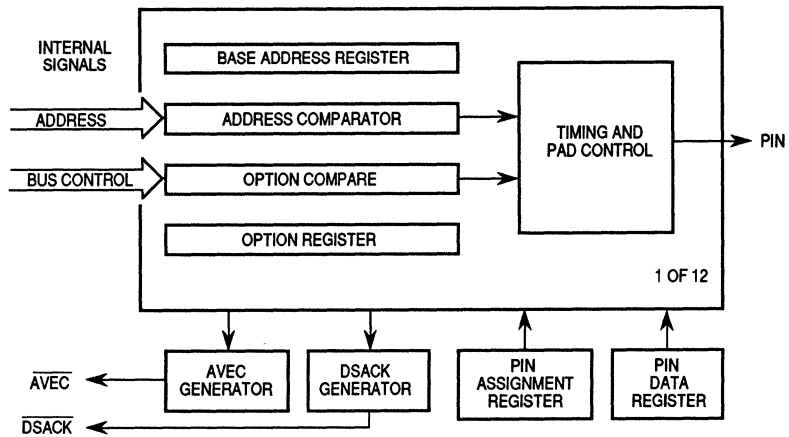


Figure 3-14. Chip-Select Circuit Block Diagram

3.3.1 Chip-Select Operation

Figure 3-16 is a flow diagram for the assertion of chip-select. Since there are no differences in flow for chip-selects between supervisor/user space and CPU space, the base and option registers must be properly programmed for each type of external bus cycle.

In CPU space, bits [15:3] of the base register must all be configured to match bits [23:11] of the address bus for a CPU space cycle, since the address is compared to a particular address generated by the CPU during a CPU space cycle.

Shown in Figure 3-15 is the CPU space cycle for the interrupt acknowledge cycle. [FC2:FC0] are set to \$7 indicating the CPU address space. [A3:A1] are set to the interrupt level and the CPU space type field ([A19:A16]) is set to \$F, the interrupt acknowledge code. The rest of the bits on the address bus are set to ones. **3.7.3 Interrupt Acknowledge Bus Cycles** provides additional information on the IACK cycle.

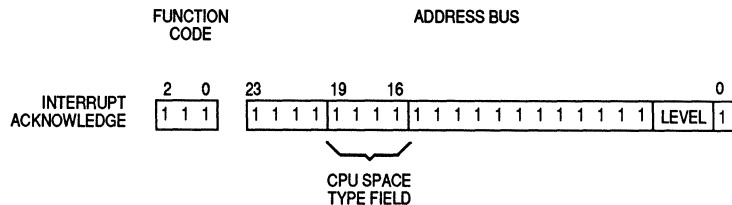


Figure 3-15. CPU Space Encoding for IACK

To use the chip-select as an IACK to an external device, the following conditions must be observed:

- The base address field must be programmed to all ones.
- The block size must be programmed to no more than 64 Kbytes to allow the address comparator to check more significant bits than A16 (since the CPU places the CPU space type on address lines [A19:A16]).
- The read/write field must be read-only since an IACK cycle is performed as a read cycle.
- The upper/lower byte field must be lower byte if assigned to a 16-bit port, since an external vector is fetched from the lower byte for a 16-bit port.

Whenever the MCU makes an access, the chip-select circuits compare the following items:

- Function codes with the address space field.
- Address lines with the base address and block size fields.
- Read/write with the read/write field.
- Enabled byte with the upper/lower field for 16-bit ports.
- If the access is an IACK cycle, the level number of the interrupt being acknowledged (placed on A3–A1) is compared to the interrupt priority level field.

When a match occurs, the chip-select is asserted synchronously with \overline{AS} or \overline{DS} in asynchronous mode or during the bus cycle of E clock in synchronous mode. In the asynchronous mode, the \overline{DSACK} field determines whether the need to generate \overline{DSACK} internally exists. If the peripheral device does not provide a \overline{DSACK} , an internal \overline{DSACK} can be generated. The speed of the external device determines if wait states are needed. Normally wait states are inserted into the bus cycle after S2 of the bus cycle until the peripheral asserts \overline{DSACK} . Since the peripheral does not generate a \overline{DSACK} when internal \overline{DSACK} is selected, the number of wait states needed (if any) must be determined before hand and programmed into the chip-select option register.

If the interrupting device does not provide a vector number, the bus cycle must be terminated by asserting \overline{AVEC} . This can be done by asserting the \overline{AVEC} pin or generating \overline{AVEC} internally by properly programming the chip-select option register.

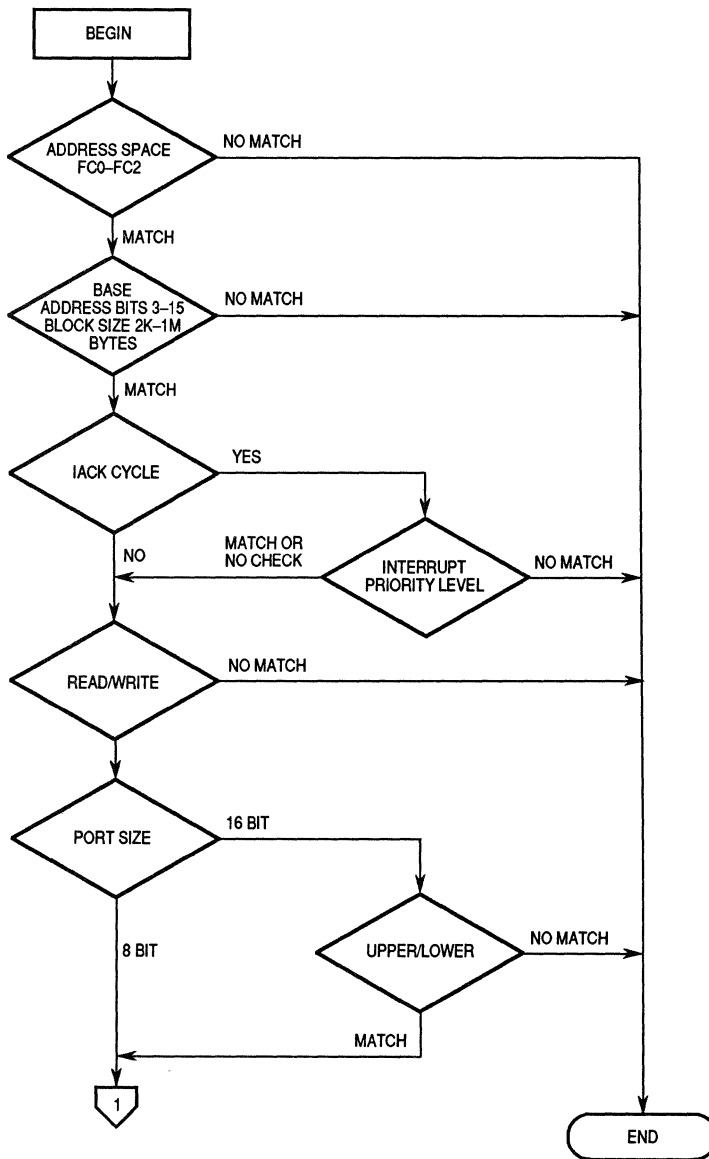


Figure 3-16. Flow Diagram for Chip-Select (Sheet 1 of 3)

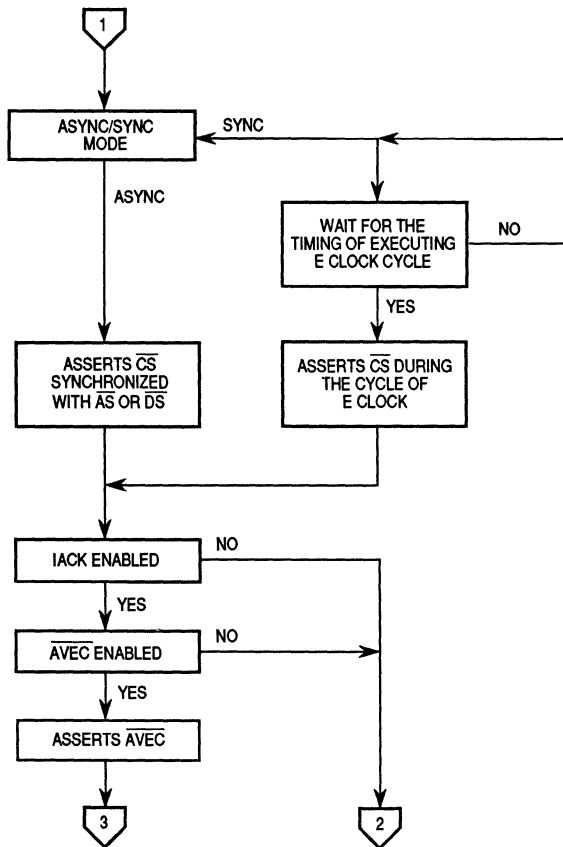


Figure 3-16. Flow Diagram for Chip-Select (Sheet 2 of 3)

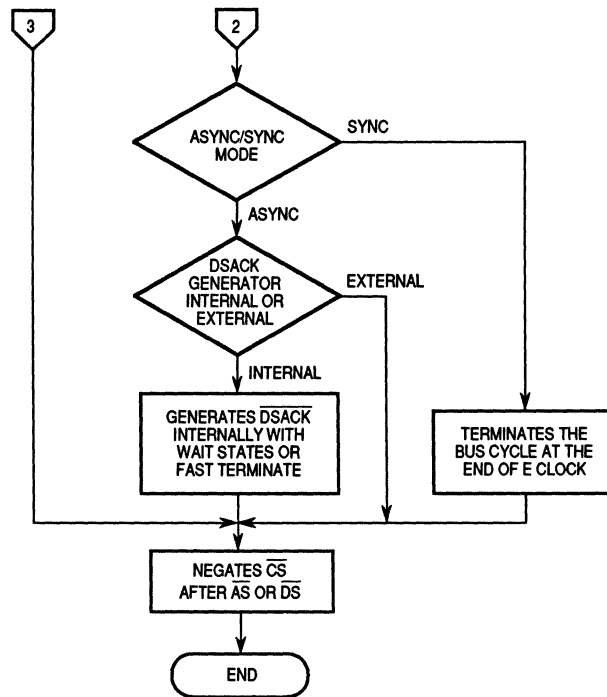


Figure 3-16. Flow Diagram for Chip-Select (Sheet 3 of 3)

3.3.2 Pin Assignment Registers Description (CSPAR0, CSPAR1)

Chip-select pin assignment registers 0 and 1 (CSPAR0, CSPAR1) contain pairs of bits in two-bit binary format that determine the function of pins in the other chip-select registers. Parenthetic mnemonics in these registers are alternate functions for the associated pins.

The notation of DB2 in the reset value for bit 13 means that bit 13 of CSPAR0 assumes the value present at data bus pin 2 after reset.

CSPAR0 — Chip-Select Pin Assignment Register 0

\$YFFA44

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	CS5 (FC2)		CS4 (FC1)		CS3 (FC0)		CS2 (BGACK)		CS1 (BG)		CS0 (BR)		CSBOOT	

RESET:

0 0 DB2 1 DB2 1 DB2 1 DB1 1 DB1 1 DB1 1 1 DB0

Bit 1 is always a one because CSBOOT has no alternate function.

Bits 15–14 — Not Used

These bits always read zero; write has no effect.

CSPAR1 — Chip-Select Pin Assignment Register 1

\$YFFA46

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0 0		0 0		CS10 (A23)		CS9 (A22)		CS8 (A21)		CS7 (A20)		CS6 (A19)	

RESET:

0 0 0 0 0 0 DB7 1 DB6 1 DB5 1 DB4 1 DB3 1

Bits 15–10 — Not Used

These bits always read zero; write has no effect.

Figure 3-17. CSPAR0 and CSPAR1 Registers

Table 3-15 shows the hierarchical selection method of CSPAR1 for the bits that are controlled by the state of the data bus pins during reset. Table 3-16 lists the encoding of the bits in the pin assignment registers. Refer to **3.3.6.1 Pin Assignment Registers Operation** for additional information on RESET mode selection.

Table 3-15. Hierarchical Selection Structure of CSPAR1

Data Bus Pins At Reset					Default/Alternate Function				
DB7	DB6	DB5	DB4	DB3	CS10/A23	CS9/A22	CS8/A21	CS7/A20	CS6/A19
1	1	1	1	1	CS10	CS9	CS8	CS7	CS6
1	1	1	1	0	CS10	CS9	CS8	CS7	A19
1	1	1	0	X	CS10	CS9	CS8	A20	A19
1	1	0	X	X	CS10	CS9	A21	A20	A19
1	0	X	X	X	CS10	A22	A21	A20	A19
0	X	X	X	X	A23	A22	A21	A20	A19

3

Table 3-16. Pin Assignment Register Bit Encoding

Bits	Description
00	Discrete Output (E Clock on A23)*
01	Alternate Function
10	Chip-Select (8-Bit Port)
11	Chip-Select (16-Bit Port)

*Except for BR, BG, BGACK

If a pin is programmed as a discrete output, the pin drives an external signal to the value specified in the pin data register, with the following exceptions:

- No discrete output function is available on pins \overline{BR} , \overline{BG} , or \overline{BGACK} . If these pins are programmed to discrete output, they still perform the function indicated by their pin names.
- Pin A23 provides E-clock on the output pin rather than a discrete output signal.

When a pin is programmed as a discrete output or alternate function, the internal chip-select logic still functions and can be used to generate \overline{DSACK} or \overline{AVEC} internally on an address match.

Port size must be determined when a pin is assigned as a chip-select. If a pin is assigned as chip-select 8-bit port, the chip-select is asserted at all addresses within the range of its block size. If a pin is assigned as chip-select 16-bit port, the upper/lower byte field of the option register determines with which byte the chip-select is associated.

3.3.3 Base Address Registers Description (CSBARBT, CSBAR0–CSBAR10)

The base address is the starting address for the block enabled by a given chip-select. The block size determines the extent of the block in the address space above the base address. Each chip-select has its own associated base register, so that an efficient address map can be constructed for each application. Refer to Figure 3-18 for the chip-select base address register boot (CSBARBT) and chip-select base address registers 0–10 (CSBAR0–CSBAR10) registers.

CSBARBT — Chip-Select Base Address Register Boot \$YFFFA48

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A23	A22	A21	A20	A19	A18	A17	A16	A15	A14	A13	A12	A11	BLKSZ		

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1

CSBAR0–CSBAR10 — Chip-Select Base Address Registers \$YFFFA4C–YFFFA74

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A23	A22	A21	A20	A19	A18	A17	A16	A15	A14	A13	A12	A11	BLKSZ		

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Figure 3-18. Base Address Registers

BLKSZ — Block Size Field

This field determines the size of the block above the base address that must be enabled by the chip-select. Table 3-17 lists the bit encoding for the base address registers block size field.

Table 3-17. Base Address Register Block Size Encoding

Block Size Field	Block Size	Address Lines Compared
000	2K	A23–A11
001	8K	A23–A13
010	16K	A23–A14
011	64K	A23–A16
100	128K	A23–A17
101	256K	A23–A18
110	512K	A23–A19
111	1M	A23–A20

NOTE

If a block size of 1 Mbyte is selected and an external device requires an address [A19:A0], pin A19 must be assigned as an address line and, therefore, cannot be used as a chip-select.

Bits 15–3 — Base Address Field

In supervisor/user space, this field sets the starting address of a particular address space. Since the address compare logic uses only the most significant bits to cause an address match within its block size, the value of the base address must be a multiple of the block size. For example, with a block size of 64 Kbytes, the compare logic only uses bits [15:8] of the base register, which corresponds to address [A23:A16]. The register illustration for the base address registers shows the address lines compared by each bit in the registers.

The base address of the different chip-selects can overlap.

3.3.4 Option Registers Description (CSORBT, CSOR0–CSOR10)

The option registers consist of eight fields that determine the timing and conditions for asserting the chip-select signals. Refer to Figures 3-18 and 3-19. These conditions make the chip-selects useful for generating a variety of control signals for peripherals used with the MCU.

The option register for $\overline{\text{CSBOOT}}$, called CSORBT, contains reset values that differ from the other option registers to support bootstrap operations from peripheral memory devices.

CSORBT — Chip-Select Option Register Boot **\$YFFA4A**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODE	BYTE	R/W	STRB	DSACK			SPACE	IPL		AVEC					
RESET:															
0	1	1	1	1	0	1	1	0	1	1	1	0	0	0	0

Figure 3-19. Chip-Select Option Register Boot for $\overline{\text{CSBOOT}}$

CSOR0–CSOR10 — Chip-Select Option Registers **\$YFFA4E–YFFA76**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODE	BYTE	R/W	STRB	DSACK			SPACE	IPL		AVEC					
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3-20. Chip-Select Option Registers 0–10

Table 3-18 provides a summary of the option register functions for quick reference.

Table 3-18. Option Register Functions Summary

Mode	Byte	R/W	STRB	DSACK	Space	IPL	AVEC
0 = ASYNC	00 = Off	00 = Rsvd	0 = \overline{AS}	0000 = 0 WAIT	00 = CPU SP	000 = All	0 = Off
1 = SYNC	01 = Lower	01 = Read	1 = \overline{DS}	0001 = 1 WAIT	01 = User SP	001 = Level 1	1 = On
	10 = Upper	10 = Write		0010 = 2 WAIT	10 = Supv SP	010 = Level 2	
	11 = Both	11 = Both		0011 = 3 WAIT	11 = S/U SP	011 = Level 3	
				0100 = 4 WAIT		100 = Level 4	
				0101 = 5 WAIT		101 = Level 5	
				0110 = 6 WAIT		110 = Level 6	
				0111 = 7 WAIT		111 = Level 7	
				1000 = 8 WAIT			
				1001 = 9 WAIT			
				1010 = 10 WAIT			
				1011 = 11 WAIT			
				1100 = 12 WAIT			
				1101 = 13 WAIT			
				1110 = F term			
				1111 = External			

The following bit descriptions apply to both the CSORBT and CSOR10–CSOR0 option registers.

MODE — Asynchronous/Synchronous Mode

1 = Synchronous mode selected

0 = Asynchronous mode selected

In asynchronous mode, the chip-select is asserted synchronized with \overline{AS} or \overline{DS} .

In synchronous mode, the \overline{DSACK} field is not used, since a bus cycle is only performed as a synchronous operation. When a match condition occurs on a chip-select programmed for synchronous operation, the chip-select signals the EBI that an E-clock cycle is pending. The chip-select is asserted with timing that meets the M6800 peripheral bus specification.

On a word or long-word transfer to an 8-bit port in synchronous mode, the MCU performs the consecutive cycles without inserting any E-clock cycles between the consecutive cycles. Refer to **SECTION 8 ELECTRICAL CHARACTERISTICS** for illustration of specific timing information.

In synchronous mode, the bus monitor timeout in the SYPCR must be programmed to a time longer than the number of clock cycles required for two E-clock cycles as programmed by the EDIV bit in the SYPCR.

BYTE — Upper/Lower Byte Option

This field is used only when the chip-select 16-bit port option is selected in the pin assignment register. These options are used to handle any bus transfer to a 16-bit port properly. Table 3-19 lists the upper/lower byte options.

Table 3-19. Byte Field

Bits	Description
00	Disable
01	Lower Byte
10	Upper Byte
11	Both Bytes

The disable option is used to disable chip-select logic. This option causes the associated pin to be driven high, and internally generated signals such as \overline{DSACK} or \overline{AVEC} are not asserted. This option can be used with both 8-bit and 16-bit port options.

For a single-byte transfer to an odd address, the chip-select logic can determine the byte accessed by the CPU by checking SIZ_1 – SIZ_0 and A_0 on the internal bus.

The both-bytes option is used to generate a control signal that enables both upper and lower bytes on an external device. In this case, the internal address and size lines are not checked.

If a MOVEP (move peripheral) instruction is used to access an 8-bit peripheral, the port size must be set to 16 bit, and either the upper or lower byte selected in the option fields to match the way the peripheral is connected to the data bus.

R/\overline{W} — Read/Write

Table 3-20 shows the options for this field. This option causes the chip-select to be asserted only for a read, only for a write, or for both read and write.

Table 3-20. R/\overline{W} Field

Bits	Description
00	Reserved
01	Read Only
10	Write Only
11	Read/Write

STRB — Address Strobe/Data Strobe

1 = Data strobe

0 = Address strobe

This option controls the timing for assertion of a chip-select in asynchronous mode. Selecting address strobe causes chip-select to be asserted synchronized with address strobe. Selecting data strobe causes chip-select to be asserted synchronized with data strobe.

This option is only used in asynchronous mode. In synchronous mode, this bit does not affect the timing of the chip-select.

DSACK — Data Strobe Acknowledge

This option field specifies the source of the DSACK (externally or internally generated) in asynchronous mode. Table 3-21 shows the options for this field. It also allows the user to adjust the bus timing with internal DSACK generation by controlling the number of wait states that are inserted to optimize the bus speed in a particular application. The following table shows the DSACK field encoding.

A wait state has a duration of one clock cycle. The wait states are inserted beginning with S2 of the external bus cycle. For example, with the DSACK field set to two wait states, the internal DSACK is generated after two clock cycles, which is counted from S2. The total bus cycle time is, therefore, five clock cycles. The cycle is terminated by the first DSACK that occurs, and so if the external DSACK occurs earlier than the internal DSACK, the external DSACK will terminate the bus cycle.

If an external device is fast enough, the bus cycle can be terminated at S3 by selecting the fast termination option (Refer to **3.5.6 Fast Termination Cycles**). For more specific timing information, refer to **SECTION 8 ELECTRICAL CHARACTERISTICS**.

Table 3-21. DSACK Field

Bits	Description
0000	No Wait States
0001	1 Wait State
0010	2 Wait States
0011	3 Wait States
0100	4 Wait States
0101	5 Wait States
0110	6 Wait States
0111	7 Wait States
1000	8 Wait States
1001	9 Wait States
1010	10 Wait States
1011	11 Wait States
1100	12 Wait States
1101	13 Wait States
1110	Fast Termination
1111	External <u>DSACK</u>

SPACE — Address Space

This option field is used to check the address spaces indicated by the function codes generated by the CPU. Table 3-22 lists the address space option field encoding.

Table 3-22. Space Field

Bits	Description
00	CPU Space
01	User Space
10	Supervisor Space
11	Supervisor/User Space

3

IPL — Interrupt Priority Level

In an IACK cycle, the chip-select logic checks the acknowledged interrupt priority level on address lines [A3:A1]. If that level matches the level set in the IPL field, then the chip-select can be asserted if the match conditions in the other fields are met. Table 3-23 lists the IPL field encoding.

Table 3-23. IPL Field

Bits	Description
000	Any Level
001	IPL1
010	IPL2
011	IPL3
100	IPL4
101	IPL5
110	IPL6
111	IPL7

Any level means that chip-select is asserted regardless of the interrupt priority level of the IACK cycle.

This option field only affects the response of chip-selects and does not affect interrupt recognition by the CPU.

AVEC — Autovector Enable

1 = Autovector enabled

0 = External interrupt vector enabled

This option field selects one of two methods of acquiring the interrupt vector during the IACK cycle.

If the chip-select is configured to trigger on an IACK cycle and the $\overline{\text{AVEC}}$ field is set to one, the chip-select automatically generates an $\overline{\text{AVEC}}$ in response to the IACK cycle. Otherwise, the vector must be supplied by the requesting device.

NOTE

When a chip-select is used to generate an internal AVEC during an IACK cycle, it cannot be used to select the peripheral device for reading or writing. The IACK cycle occurs in CPU space. I/O occurs in user/supervisor space. A separate chip-select is needed to access the peripheral. The chip-select used for the AVEC can, however, still be used for discrete I/O.

3.3.5 Chip-Select Pin Data Register Description (CSPDR)

The pin data register controls the state of pins programmed as discrete outputs. When a pin is assigned as a discrete output, the value in this register appears at the output. Data bits DO6–DO0 correspond to CS9–CS3 in order, as shown in Figure 3-21.

CSPDR — Chip-Select Pin Data Register **\$YFFA41**

7	6	5	4	3	2	1	0
0	DO6	DO5	DO4	DO3	DO2	DO1	DO0
RESET:							
0	1	1	1	1	1	1	1

Figure 3-21. Chip-Select Pin Data Register

This is a read/write register. Bit 7 is not used. Writing to this bit has no effect, and it always reads zero when read.

3.3.6 Reset Mode Selection

When the external reset pin is asserted (whether internally or from external logic), except from the CPU executing the RESET instruction, the MCU reads data bus pin information. The data bus is pulled high internally to cause a specific default pin configuration, but the user can pull bits low to achieve a desired alternate configuration. Table 3-24 shows which pins determine a given configuration when the reset pin is released. For more information on reset operation, refer to **3.10 Reset Operation**.

Table 3-24. Mode Selection during Reset

Group	Mode Select Pin	Default Function (Pin Left High)	Alternate Function (Pin Pulled Low)
1	DB0	$\overline{\text{CSBOOT}}$ 16-Bit	$\overline{\text{CSBOOT}}$ 8-Bit
2	DB1	$\overline{\text{CS0}}$ $\overline{\text{CS1}}$ $\overline{\text{CS2}}$	$\overline{\text{BR}}$ $\overline{\text{BG}}$ $\overline{\text{BGACK}}$
3	DB2	$\overline{\text{CS3}}$ $\overline{\text{CS4}}$ $\overline{\text{CS5}}$	FC0 FC1 FC2
4	DB3 DB4 DB5 DB6 DB7	$\overline{\text{CS6}}$ $\overline{\text{CS7}}\text{--}\overline{\text{CS6}}$ $\overline{\text{CS8}}\text{--}\overline{\text{CS6}}$ $\overline{\text{CS9}}\text{--}\overline{\text{CS6}}$ $\overline{\text{CS10}}\text{--}\overline{\text{CS6}}$	A19 A20–A19 A21–A19 A22–A19 A23–A19
E	DB8	Bus Control $\overline{\text{DSACK0}}$, $\overline{\text{DSACK1}}$, $\overline{\text{AVEC}}$, $\overline{\text{DS}}$, $\overline{\text{AS}}$, SIZE, $\overline{\text{RMC}}$	PORTE
F	DB9	$\overline{\text{IRQ7}}\text{--}\overline{\text{IRQ1}}$ MODCK	PORTF
	DB11	Slave Mode Disabled	Slave Mode Enabled
	MODCK	VCO = System Clock	EXTAL = System Clock
	BKPT	Background Mode Disabled	Background Mode Enabled

3

3.3.6.1 Pin Assignment Registers Operation

The $\overline{\text{CSBOOT}}$ register selects a boot ROM containing a reset vector and initialization firmware. To do this, bit one in CSPAR0 has a reset value of one to assign $\overline{\text{CSBOOT}}$ as a chip-select. Bit zero is set to the value of DB0 when the MCU comes out of reset and the port size of $\overline{\text{CSBOOT}}$ is determined to be 8 or 16 bits.

All of the least significant bits of CS10–CS0 in CSPAR0 and CSPAR1 have a reset value of one. All of the most significant bits are set according to levels on [DB7:DB1] at the end of reset. This determines whether the pins function as chip-selects or their alternate functions.

Although $\overline{\text{CSBOOT}}$ is enabled at reset, CS10–CS0 are disabled at reset, since they should not be active until an initialization program sets up the base and option registers.

The chip-select pins are grouped to allow the pins to be conveniently connected to assign their function at reset. Table 3-24 shows these pin groupings.

In group one, DB0 determines the port size of $\overline{\text{CSBOOT}}$. Pulling DB0 low sets the port size of $\overline{\text{CSBOOT}}$ to 8 bit, or, if DB0 is left open, internal connections pull DB0 high and set the port size to 16 bit.

In groups two and three, one pin selects the entire group. If DB1 or DB2 is pulled low, the group is assigned to the alternate functions. Otherwise, the group is assigned to chip-selects.

In group four, an address line is associated with one data pin. However, any data pin pulled low assigns its associated pin and all less significant address line pins as address lines. For example, if DB5 is pulled low during reset, pins A19, A20, and A21 are assigned as address lines, and pins A22 and A23 are assigned as chip-selects.

3.3.6.2 Base and Option Registers Operation

After reset, the MCU fetches the interrupt stack pointer and program counter from address \$0000 0000. To support bootstrap operation from reset, the base address field in chip-select base address register boot (CSBARBT) has a reset value of all zeros. This allows a ROM device, containing reset vectors at the top of its address space, to be enabled by $\overline{\text{CSBOOT}}$ after a reset. The block size field in CSBARBT has a reset value of 1 Mbyte.

The byte field in option register CSORBT has a reset value of both bytes, but CSOR10–CSOR0 have a reset value of disable, since they should not select external devices until an initial program sets up the base and option registers. Table 3-25 shows the reset values in the base and option registers for $\overline{\text{CSBOOT}}$.

Table 3-25. $\overline{\text{CSBOOT}}$ Base and Option Register Reset Values

Fields	Reset Values
Base Address	\$0000 0000
Block Size	\$1 MByte
Async/Sync Mode	Asynchronous Mode
Upper/Lower Byte	Both Bytes (CSORBT)
	Disable (CSOR10–CSOR0)
Read/Write	Read/Write
$\overline{\text{AS}}/\overline{\text{DS}}$	$\overline{\text{AS}}$
$\overline{\text{DSACK}}$	13 Wait States
Address Space	Supervisor/User Space
IPL	Any Level
Autovector	Interrupt Vector Externally

3.4 External Bus Interface

This section provides a functional description of the bus, the signals that control it, and the bus cycles provided for data transfer operations. It also describes the error and halt conditions, bus arbitration, and the reset operation. Operation of the bus is the same whether the MCU or an external device is the bus master; the names and descriptions of bus cycles are from the point of view of the bus master. For exact timing specifications, refer to **SECTION 8 ELECTRICAL CHARACTERISTICS**.

The MCU architecture supports byte, word, and long-word operands, allowing access to 8- and 16-bit data ports through the use of asynchronous cycles controlled by the data transfer (SIZ1 and SIZ0) and data size acknowledge pins (DSACK1 and DSACK0). The MCU requires word and long-word operands to be located in memory on word or long-word boundaries. The only type of transfer that can be misaligned is a single-byte transfer to an odd address, referred to as an odd-byte transfer. For an 8-bit port, multiple bus cycles may be required for an operand transfer due to either misalignment or a port width smaller than the operand size.

The chip-select pin assignment register 0–1 (CSPAR0–1) and the chip-select pin data register (CSPDR) control the alternate functions of the chip-select pins. There is another group of registers that set up operating conditions for the external bus control signals and external interrupt inputs.

These registers can configure each Port E and Port F pin to be a bus control/external interrupt input or an input/output. The state of DB8 during reset controls whether the port E pins are used as bus control signals or discrete I/O lines. If DB8 is low during reset, a value of \$00 is set in the port E pin assignment register. The reset state of DB9 controls whether the port F pins are used as external interrupt inputs or discrete I/O lines.

For a list of pin numbers used with port E and port F, see the MCU pinout diagram in **SECTION 9 ORDERING INFORMATION AND MECHANICAL DATA**. Refer to Figure 2-1 Function Signal Group for a block diagram of the port control circuits.

3.4.1 Port E Pin Assignment Register (PEPAR)

The bits in this register (Figure 3-22) control the function of each port E pin. Any bit set to one defines the corresponding pin to be a bus control signal, with the function defined in the register diagram. Any bit cleared to zero defines the corresponding pin to be an I/O pin, controlled by the port E data and data direction registers.

PEPAR — Port E Pin Assignment Register**\$YFFA17**

7	6	5	4	3	2	1	0
(PEPA7) SIZ1	(PEPA6) SIZ0	(PEPA5) \overline{AS}	(PEPA4) \overline{DS}	(PEPA3) \overline{RMC}	(PEPA2) \overline{AVEC}	(PEPA1) $\overline{DSACK1}$	(PEPA0) $\overline{DSACK0}$

RESET:

DB8	DB8	DB8	DB8	DB8	DB8	DB8	DB8
-----	-----	-----	-----	-----	-----	-----	-----

Figure 3-22. Port E Pin Assignment Register

The state of data bus bit 8 (DB8) controls the state of this register following reset. If DB8 is high during reset, the register is set to \$FF, which defines all port E pins to be bus control signals. If DB8 is low during reset, this register is set to \$00, defining all port E pins to be I/O pins.

3.4.2 Port E Data Direction Register (DDRE)

The bits in this register (Figure 3-23) control the direction of the pin drivers when the pins are configured as I/O. Any bit in this register set to one configures the corresponding pin as an output. Any bit in this register cleared to zero configures the corresponding pin as an input.

This register can be read or written at any time.

DDRE — Port E Data Direction Register**\$YFFA15**

7	6	5	4	3	2	1	0
DDE7	DDE6	DDE5	DDE4	DDE3	DDE2	DDE1	DDE0

RESET:

0	0	0	0	0	0	0	0
---	---	---	---	---	---	---	---

Figure 3-23. Port E Data Direction Register**3.4.3 Port E Data Register (PORTE)**

A write to the port E data register (Figure 3-24) is stored in the internal data latch, and if any port E pin is configured as an output, the value stored for that bit is driven on the pin. A read of PORTE returns the value at the pin only if the pin is configured as a discrete input. Otherwise, the value read is the value stored in the register.

PORTE — Port E Data Register**\$YFFA11, YFFA13**

7	6	5	4	3	2	1	0
PE7	PE6	PE5	PE4	PE3	PE2	PE1	PE0
RESET:							
U	U	U	U	U	U	U	U

Figure 3-24. Port E Data Register

Port E is a single register that can be accessed in two locations. These registers can be read or written at any time.

3.4.4 Port F Pin Assignment Register (PFPAR)

The bits in this register (Figure 3-25) control the function of each port F pin. Any bit set to one defines the corresponding pin to be an interrupt request input as defined in the register diagram. Any bit cleared to zero defines the corresponding pin to be an I/O pin, controlled by the port F data and data direction registers. The MODCK signal has no function after reset.

PFPAR — Port F Pin Assignment Register**\$YFFA1F**

7	6	5	4	3	2	1	0
(PFFPA7) $\overline{\text{IRQ7}}$	(PFFPA6) $\overline{\text{IRQ6}}$	(PFFPA5) $\overline{\text{IRQ5}}$	(PFFPA4) $\overline{\text{IRQ4}}$	(PFFPA3) $\overline{\text{IRQ3}}$	(PFFPA2) $\overline{\text{IRQ2}}$	(PFFPA1) $\overline{\text{IRQ1}}$	(PFFPA0) MODCK
RESET:							
DB9	DB9	DB9	DB9	DB9	DB9	DB9	DB9

Figure 3-25. Port F Pin Assignment Register

The state of data bus bit 9 controls the state of this register following reset. If DB9 is high during reset, the register is set to \$FF, which defines all port F pins to be interrupt request inputs. If DB9 is low during reset, this register is set to \$00, defining all port F pins to be I/O pins.

3.4.5 Port F Data Direction Register (DDRF)

The bits in this register (Figure 3-26) control the direction of the pin drivers when the pins are configured as I/O. Any bit in this register set to one configures the corresponding pin as an output. Any bit in this register cleared to zero configures the corresponding pin as an input.

DDRF — Port F Data Direction Register**\$YFFA1D**

7	6	5	4	3	2	1	0
DDF7	DDF6	DDF5	DDF4	DDF3	DDF2	DDF1	DDF0

RESET:

0	0	0	0	0	0	0	0
---	---	---	---	---	---	---	---

Figure 3-26. Port F Data Direction Register**3.4.6 Port F Data Register (PORTF)**

The write to the port F data register (Figure 3-27) is stored in the internal data latch, and if any port F pin is configured as an output, the value stored for that bit is driven on the pin. A read of PORTF returns the value at the pin only if the pin is configured as a discrete input. Otherwise, the value read is the value stored in the register.

PORTF — Port F Data Register**\$YFFA19, YFFA1B**

7	6	5	4	3	2	1	0
PF7	PF6	PF5	PF4	PF3	PF2	PF1	PF0

RESET:

U	U	U	U	U	U	U	U
---	---	---	---	---	---	---	---

Figure 3-27. Port F Data Register

Port F is a single register that can be accessed in two locations. These registers can be read or written at any time.

3.4.7 Bus Transfer Signals

The bus transfers information between the MCU and an external memory or peripheral device. External devices can accept or provide 8 bits or 16 bits in parallel and must follow the handshake protocol described in this section. The maximum number of bits accepted or provided during a bus transfer is defined as the port width. The MCU contains an address bus that specifies the address for the transfer and a data bus that transfers the data. Control signals indicate the beginning of the cycle, the address space and size of the transfer, and the type of cycle. The selected device then controls the length of the cycle with the signal(s) used to terminate the cycle. Strobe signals, one for the address bus and another for the data bus, indicate the validity of the address and provide timing information for the data. The bus operates in an asynchronous mode for any port

width. The bus and control input signals are internally synchronized to the MCU clock, introducing a delay. This delay is the time period required for the MCU to sample an input signal, synchronize the input to the internal clocks, and determine whether it is high or low.

Furthermore, for all inputs, the MCU latches the level of the input during a sample window around the falling edge of the clock signal. This window is illustrated in Figure 3-28. To ensure that an input signal is recognized on a specific falling edge of the clock, that input must be stable during the sample window. If an input makes a transition during the window time period, the level recognized by the MCU is not predictable; however, the MCU always resolves the latched level to either a logic high or low before using it. In addition to meeting input setup and hold times for deterministic operation, all input signals must obey the protocols described in this section.

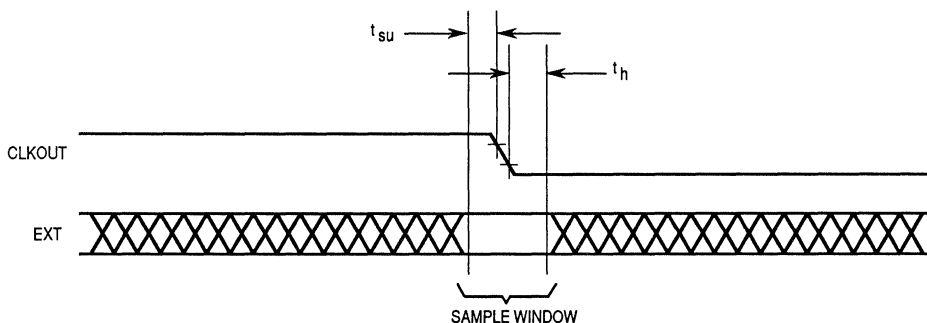


Figure 3-28. Input Sample Window

3.4.7.1 Bus Control Signals

The MCU initiates a bus cycle by driving the address, size, function code, and read/write outputs. At the beginning of a bus cycle, the size signals (SIZ1, SIZ0) are driven along with the function code signals. SIZ1 and SIZ0 indicate the number of bytes remaining to be transferred during an operand cycle (consisting of one or more bus cycles). Table 3-26 shows the encoding of SIZ1 and SIZ0. These signals are valid while address strobe (\overline{AS}) is asserted. The read/write (R/\overline{W}) signal determines the direction of the transfer during a bus cycle. This signal changes state, when required, at the beginning of a bus cycle, and is valid while \overline{AS} is asserted. R/\overline{W} only transitions when a write cycle is preceded by a read cycle or vice versa. The signal may remain low for two consecutive write cycles. The read-modify-write cycle signal (\overline{RMC}) is asserted at the beginning of the first bus cycle of a read-modify-write operation, and remains asserted until completion of the final bus cycle of the operation.

Table 3-26. Size Signal Encoding

SIZ1	SIZ0	Transfer Size
0	1	Byte
1	0	Word
1	1	3 Byte
0	0	Long Word

3.4.7.2 Function Codes

The function code signals [FC2:FC0] select one of eight address spaces to which the address applies. These spaces are designated as either user or supervisor, and program or data spaces. One other address space is designated as CPU space to allow the CPU to acquire specific control information not normally associated with read or write bus cycles. The function code signals are valid while \overline{AS} is asserted.

Table 3-27 Address Space

[FC2:FC0]	Address Space
000	Undefined Reserved
001	User Data Space
010	User Program Space
011	Undefined Reserved
100	Undefined Reserved
101	Supervisor Data Space
110	Supervisor Program Space
111	CPU Space

Function codes can be considered as extensions of the 24-bit linear address that can provide up to eight 16 Mbyte address spaces. Function codes are automatically generated by the CPU to select address spaces for data and program at the user and supervisor privilege levels, and a CPU address space used for processor functions. User programs can access only their own program and data areas to increase protection of system integrity, and can be restricted from accessing other information. The S bit in the CPU status bit is set for supervisor accesses and cleared for user accesses to provide supervisor/user differentiation. Refer to **3.7 CPU Space Cycles** for more information.

3.4.7.3 Address Bus

The address bus signals [A23:A0] define the address of the byte (or the most significant byte) to be transferred during a bus cycle. The MCU places the address on the bus at the beginning of a bus cycle. The address is valid while \overline{AS} is asserted.

3.4.7.4 Address Strobe

The \overline{AS} is a timing signal that indicates the validity of an address on the address bus and of many control signals. It is asserted one-half clock after the beginning of a bus cycle.

3.4.7.5 Data Bus

The data bus signals [D15:D0] comprise a bidirectional, nonmultiplexed parallel bus that contains the data being transferred to or from the MCU. A read or write operation may transfer 8 or 16 bits of data (1 or 2 bytes) in one bus cycle. During a read cycle, the data is latched by the MCU on the last falling edge of the clock for that bus cycle. For a write cycle, all 16 bits of the data bus are driven, regardless of the port width or operand size. The MCU places the data on the data bus one-half clock cycle after \overline{AS} is asserted in a write cycle.

3.4.7.6 Data Strobe

The data strobe (\overline{DS}) is a timing signal that applies to the data bus. For a read cycle, the MCU asserts \overline{DS} to signal the external device to place data on the bus. It is asserted at the same time as \overline{AS} during a read cycle. For a write cycle, \overline{DS} signals to the external device that the data to be written is valid on the bus. The MCU asserts \overline{DS} one full clock cycle after the assertion of \overline{AS} during a write cycle.

3.4.7.7 Bus Cycle Termination Signals

During bus cycles, external devices assert the data transfer and size acknowledge signals ($\overline{DSACK1}$ and/or $\overline{DSACK0}$) as part of the bus protocol. During a read cycle, this signals the MCU to terminate the bus cycle and to latch the data. During a write cycle, this indicates that the external device has successfully stored the data and that the cycle may terminate. These signals also indicate to the MCU the size of the port for the bus cycle just completed, as shown in Table 3-2. Refer to **3.6.1 Read Cycle** for the timing of $\overline{DSACK1}$ and $\overline{DSACK0}$.

The bus error (\overline{BERR}) signal is also a bus cycle termination indicator and can be used in the absence of \overline{DSACKx} to indicate a bus error condition. It can also be asserted in conjunction with \overline{DSACKx} to indicate a bus error condition, provided it meets the appropriate timing described in this section and in **SECTION 8 ELECTRICAL CHARACTERISTICS**. Additionally, the \overline{BERR} and \overline{HALT} signals can be asserted together to indicate a retry termination. Again, the \overline{BERR} and \overline{HALT} signals can be asserted simultaneously, in lieu of, or in conjunction with, the \overline{DSACKx} signals.

The internal bus monitor can be used to generate the \overline{BERR} signal for internal and internal-to-external transfers in all the following descriptions. (Refer to **3.1.5**

Bus Monitors for information on the functions of the bus monitor.) An external bus master must provide its own $\overline{\text{BERR}}$ generation and drive the $\overline{\text{BERR}}$ pin, since the internal $\overline{\text{BERR}}$ monitor has no information about transfers initiated by an external bus master.

Finally, the autovector ($\overline{\text{AVEC}}$) signal can be used to terminate interrupt acknowledge cycles, indicating that the MCU should internally generate a vector number to locate an interrupt handler routine. $\overline{\text{AVEC}}$ is ignored during all other bus cycles.

3.5 Data Transfer Mechanism

The MCU architecture supports byte, word, and long-word operands, allowing access to 8- and 16-bit data ports through the use of asynchronous cycles controlled by the data transfer and size acknowledge inputs ($\overline{\text{DSACK1}}$ and $\overline{\text{DSACK0}}$).

3.5.1 Dynamic Bus Sizing

The MCU dynamically interprets the port size of the addressed device during each bus cycle, allowing operand transfers to or from 8- and 16-bit ports. During an operand transfer cycle, the slave device signals its port size (byte or word) and indicates completion of the bus cycle to the MCU through the use of the $\overline{\text{DSACKx}}$ inputs. Refer to Table 3-28 $\overline{\text{DSACKx}}$ Codes and Results.

Table 3-28. $\overline{\text{DSACK}}$ Codes and Results

$\overline{\text{DSACK1}}$	$\overline{\text{DSACK0}}$	Result
1 (Negated)	1 (Negated)	Insert Wait States in Current Bus Cycle
1 (Negated)	0 (Asserted)	Complete Cycle — Data Bus Port Size is 8 Bits
0 (Asserted)	1 (Negated)	Complete Cycle — Data Bus Port Size is 16 Bits
0 (Asserted)	0 (Asserted)	Reserved

For example, if the MCU is executing an instruction that reads a long-word operand from a 16-bit port, the MCU latches the 16 bits of valid data and runs another bus cycle to obtain the other 16 bits. The operation for an 8-bit port is similar, but requires four read cycles. The addressed device uses the $\overline{\text{DSACKx}}$ signals to indicate the port width. For instance, a 16-bit device always returns $\overline{\text{DSACK0}}$ for a 16-bit port (regardless of whether the bus cycle is a byte or word operation).

Dynamic bus sizing requires that the portion of the data bus used for a transfer to or from a particular port size be fixed. A 16-bit port must reside on data bus bits [15:0], and an 8-bit port must reside on data bus bits [15:8]. This requirement minimizes the number of bus cycles needed to transfer data to 8- and 16-bit ports and ensures that the MCU correctly transfers valid data.

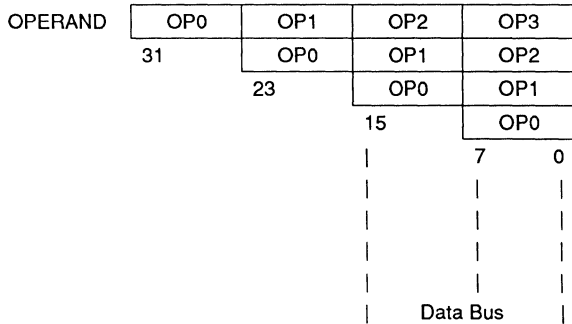
The MCU always attempts to transfer the maximum amount of data on all bus cycles; for a word operation, it always assumes that the port is 16 bits wide when beginning the bus cycle. Operand bytes are designated as shown in Figure 3-2. The most significant byte of a long-word operand is OP0, and OP3 is the least significant byte. The two bytes of a word-length operand are OP0 (most significant) and OP1. The single byte of a byte-length operand is OP0. These designations are used in the figures and descriptions that follow.

Figure 3-29 shows the required organization of data ports on the MCU bus for both 8- and 16-bit devices. The four bytes shown in Figure 3-29 are connected through the internal data bus and data multiplexer to the external data bus. The data multiplexer establishes the necessary connections for different combinations of address and data sizes. The multiplexer takes the two bytes of the 16-bit bus and routes them to their required positions. The positioning of bytes is determined by the size (SIZ1 and SIZ0) and address (A0) outputs. The SIZ1 and SIZ0 outputs indicate the remaining number of bytes to be transferred during the current bus cycle, as shown in Table 3-26. The number of bytes transferred during a write or read bus cycle is equal to or less than the size indicated by the SIZ1 and SIZ0 outputs, depending on port width. For example, during the first bus cycle of a long-word transfer to a word port, the size outputs indicate that four bytes are to be transferred, although only two bytes are transferred on that bus cycle.

The address line A0 also affects the operation of the data multiplexer. During an operand transfer, [A23:A1] indicate the word base address of that portion of the operand to be accessed, and A0 indicates the byte offset from the base. Figure 3-2 lists the bytes required on the data bus for read cycles. The entries shown as OPn are portions of the requested operand that are read or written during that bus cycle and are defined by SIZ1, SIZ0, and A0 for the bus cycle. The transfer cases marked misaligned are not allowed in this MCU.

3.5.2 Misaligned Operands

In this architecture, the basic operand size is 16 bits. Operand misalignment refers to whether an operand is aligned on a word boundary or overlaps the word boundary. This is determined by address line A0. When A0 is low, the address is even and is a word and byte boundary. When A0 is high, the address is odd and is a byte boundary only. A byte operand is properly aligned at any address; a word or long-word operand is misaligned at an odd address.



Case	Transfer Case	SIZ1	SIZ0	A0	DSACK1	DSACK0	D15 D8	D7 D0
a)	Byte to Byte	0	1	X	1	0	OP0	(OP0)
b)	Byte to Word (Even)	0	1	0	0	X	OP0	(OP0)
c)	Byte to Word (Odd)	0	1	1	0	X	(OP0)	OP0
d)	Word to Byte (Aligned)	1	0	0	1	0	OP0	(OP1)
e)	Word to Byte (Misaligned)*	1	0	1	1	0	OP0	(OP0)
f)	Word to Word (Aligned)	1	0	0	0	X	OP0	OP1
g)	Word to Word (Misaligned)*	1	0	1	0	X	(OP0)	OP0
h)	3 Byte to Byte (Aligned)*†	1	1	0	1	0	OP0	(OP1)
i)	3 Byte to Byte (Misaligned)†	1	1	1	1	0	OP0	(OP0)
j)	3 Byte to Word (Aligned)*†	1	1	0	0	X	OP0	OP1
k)	3 Byte to Word (Misaligned)*†	1	1	1	0	X	(OP0)	OP0
l)	Long Word to Byte (Aligned)	0	0	0	1	0	OP0	(OP1)
m)	Long Word to Byte (Misaligned)*	0	0	1	1	0	OP0	(OP0)
n)	Long Word to Word (Aligned)	0	0	0	0	X	OP0	OP1
o)	Long Word to Word (Misaligned)*	0	0	1	0	X	(OP0)	OP0

NOTES:

Operands in parentheses are ignored by the MC68331 during read cycles.

Misaligned transfer cases, identified by an asterisk (*), are not supported by the MC68331.

†Three-byte transfer cases occur only as a result of a long word to byte transfer.

Figure 3-29. MCU Interface to Various Port Sizes

Each bus cycle can transfer at most a word of data aligned on a word boundary. If the MCU transfers a long-word operand over a 16-bit port, the most significant operand word is transferred on the first bus cycle and the least significant operand word on a following bus cycle.

The CPU restricts alignment of all operands (both data and instruction). That is, both word and long-word operands must be located on a word or long-word boundary. The only type of transfer that can be misaligned is a single-byte transfer to an odd address, referred to as an odd-byte transfer.

3.5.3 Operand Transfer Cases

The following cases are examples of all the allowable alignments of operands to ports.

3.5.3.1 Byte Operand to 8-Bit Port, Even ($A0 = 0$)

The MCU drives the address bus with the desired address and the size pins to indicate a single-byte operand. Refer to Figure 3-30.

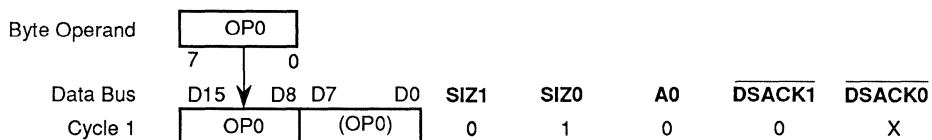


Figure 3-30. Byte Operand to 8-Bit Port, Even ($A0 = 0$)

For a read operation, the slave responds by placing data on bits [15:8] of the data bus, asserting $\overline{DSACK0}$, and negating $\overline{DSACK1}$ to indicate an 8-bit port. The MCU then reads the operand byte from bits [15:8] and ignores bits [7:0].

For a write operation, the MCU drives the single-byte operand on both bytes of the data bus because it does not know the size of the port until the \overline{DSACKx} signals are read. The slave device must recognize the size of the operand and use the address to place the operand in the specified location. The slave then asserts $\overline{DSACK0}$ to terminate the bus cycle.

3.5.3.2 Byte Operand to 16-Bit Port, Even ($A0 = 0$)

The MCU drives the address bus with the desired address and the size pins to indicate a single-byte operand. Refer to Figure 3-31.

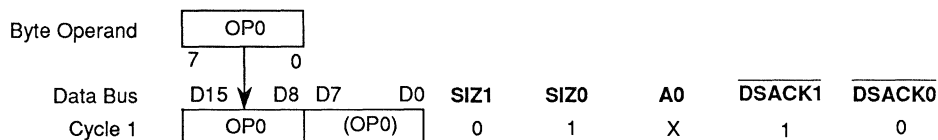


Figure 3-31. Byte Operand to 16-Bit Port, Even ($A0 = 0$)

For a read operation, the slave responds by placing data on bits [15:8] of the data bus, asserting $\overline{DSACK1}$, and negating $\overline{DSACK0}$ to indicate a 16-bit port. The MCU then reads the operand byte from bits [15:8] and ignores bits [7:0].

For a write operation, the MCU drives the single-byte operand on both bytes of the data bus because it does not know the size of the port until the \overline{DSACKx} signals are read. The slave device then reads the operand from bits [15:8] of the data bus and uses the address to place the operand in the specified location. The slave then asserts $\overline{DSACK1}$ to terminate the bus cycle.

3.5.3.3 Byte Operand to 16-Bit Port, Odd (A0 = 1)

The MCU drives the address bus with the desired address and the size pins to indicate a single-byte operand. Refer to Figure 3-32.

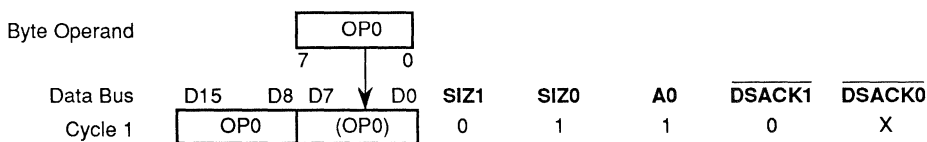


Figure 3-32. Byte Operand to 16-Bit Port, Odd (A0 = 1)

For a read operation, the slave responds by placing data on bits [7:0] of the data bus, asserting $\overline{DSACK1}$, and negating $\overline{DSACK0}$ to indicate a 16-bit port. The MCU then reads the operand byte from bits [7:0] and ignores bits [15:8].

For a write operation, the MCU drives the single-byte operand on both bytes of the data bus because it does not know the size of the port until the \overline{DSACKx} signals are read. The slave device then reads the operand from bits [7:0] of the data bus and uses the address to place the operand in the specified location. The slave then asserts $\overline{DSACK1}$ to terminate the bus cycle.

3.5.3.4 Word Operand to 8-Bit Port, Aligned

The MCU drives the address bus with the desired address and the size pins to indicate a word operand. Refer to Figure 3-33.

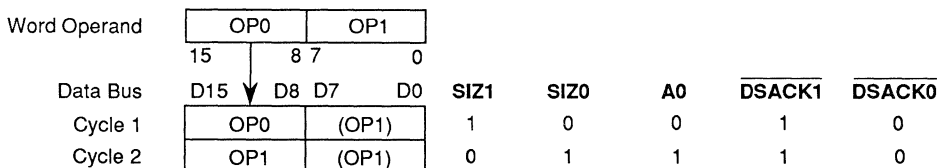


Figure 3-33. Word Operand to 8-Bit Port, Aligned

For a read operation, the slave responds by placing the most significant byte of the operand on bits [15:8] of the data bus and asserting $\overline{\text{DSACK0}}$ to indicate an 8-bit port. The MCU reads the most significant byte of the operand from bits [15:8] and ignores bits [7:0]. The MCU then decrements the transfer size counter, increments the address, and reads the least significant byte of the operand from bits [15:8] of the data bus.

For a write operation, the MCU drives the word operand on bits [15:0] of the data bus. The slave device then reads the most significant byte of the operand from bits [15:8] of the data bus and asserts $\overline{\text{DSACK0}}$ to indicate that it received the data but is an 8-bit port. The MCU then decrements the transfer size counter, increments the address, and writes the least significant byte of the operand to bits [15:8] of the data bus.

3.5.3.5 Word Operand to 16-Bit Port, Aligned

The MCU drives the address bus with the desired address and the size pins to indicate a word operand. Refer to Figure 3-34.

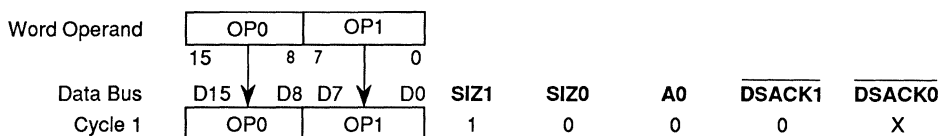


Figure 3-34. Word Operand to 16-Bit Port, Aligned

For a read operation, the slave responds by placing the data on bits [15:0] of the data bus and asserting $\overline{\text{DSACK1}}$ to indicate a 16-bit port. When $\overline{\text{DSACK1}}$ is asserted, the MCU reads the data on the data bus and terminates the cycle.

For a write operation, the MCU drives the word operand on bits [15:0] of the data bus. The slave device then reads the entire operand from bits [15:0] of the data bus and asserts $\overline{\text{DSACK1}}$ to terminate the bus cycle.

3.5.3.6 Long-Word Operand to 8-Bit Port, Aligned

The MCU drives the address bus with the desired address and the size pins to indicate a long word operand. Refer to Figure 3-35.

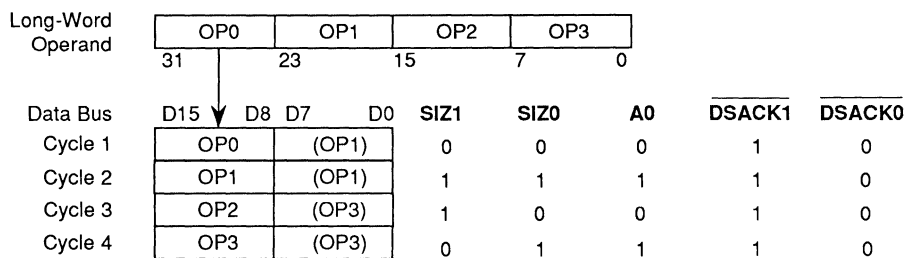


Figure 3-35. Long-Word Operand to 8-Bit Port, Aligned

For a read operation (Figure 3-36), the slave places the most significant byte of the operand on bits [15:8] of the data bus and asserts $\overline{\text{DSACK0}}$ to indicate an 8-bit port. The MCU reads the most significant byte of the operand (byte 0) from bits [15:8] and ignores bits [7:0]. The MCU then decrements the transfer size counter, increments the address, initiates a new cycle, and reads byte 1 of the operand from bits [15:8] of the data bus. The MCU repeats the process of decrementing the transfer size counter, incrementing the address, initiating a new cycle, and reading a byte to transfer the remaining two bytes.

For a write operation (Figure 3-37), the MCU drives the two most significant bytes of the operand on bits [15:0] of the data bus. The slave device then reads only the most significant byte of the operand (byte 0) from bits [15:8] of the data bus and asserts $\overline{\text{DSACK0}}$ but not $\overline{\text{DSACK1}}$ to indicate that it received the data but is an 8-bit port. The MCU then decrements the transfer size counter, increments the address, and writes byte 1 of the operand to bits [15:8] of the data bus. The MCU continues to decrement the transfer size counter, increment the address, and write a byte to transfer the remaining two bytes to the slave device.

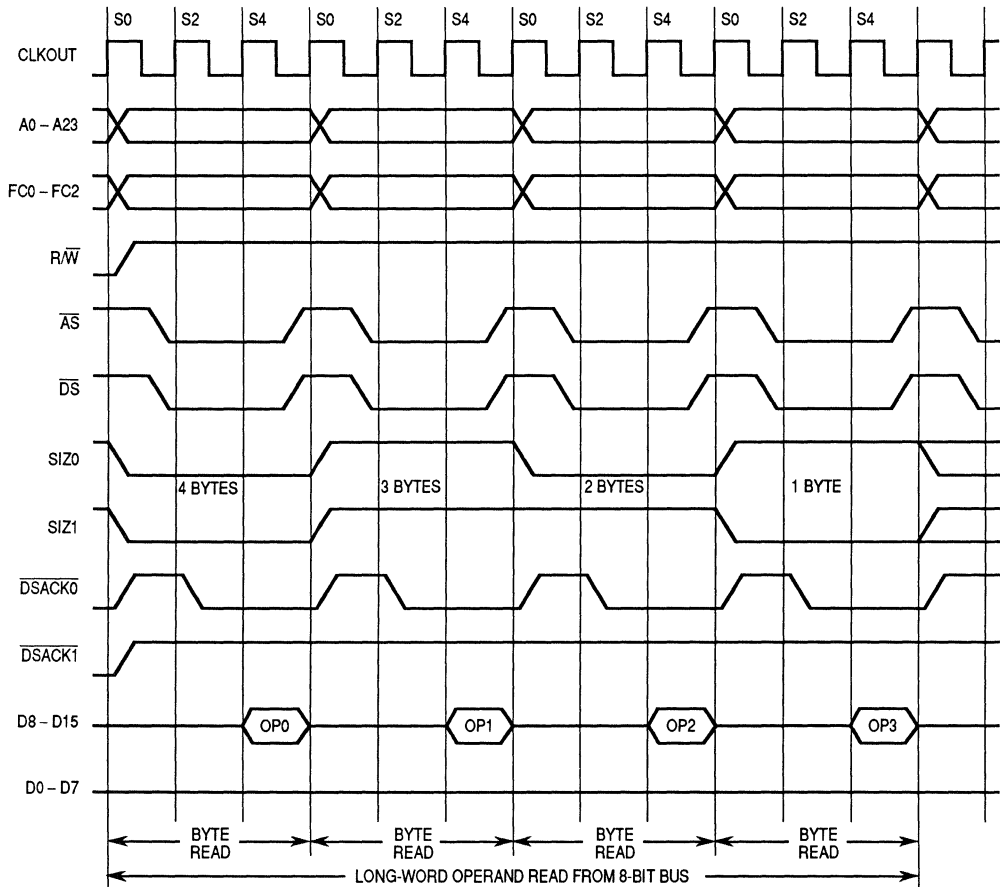


Figure 3-36. Long-Word Operand Read Timing from 8-Bit Data Port

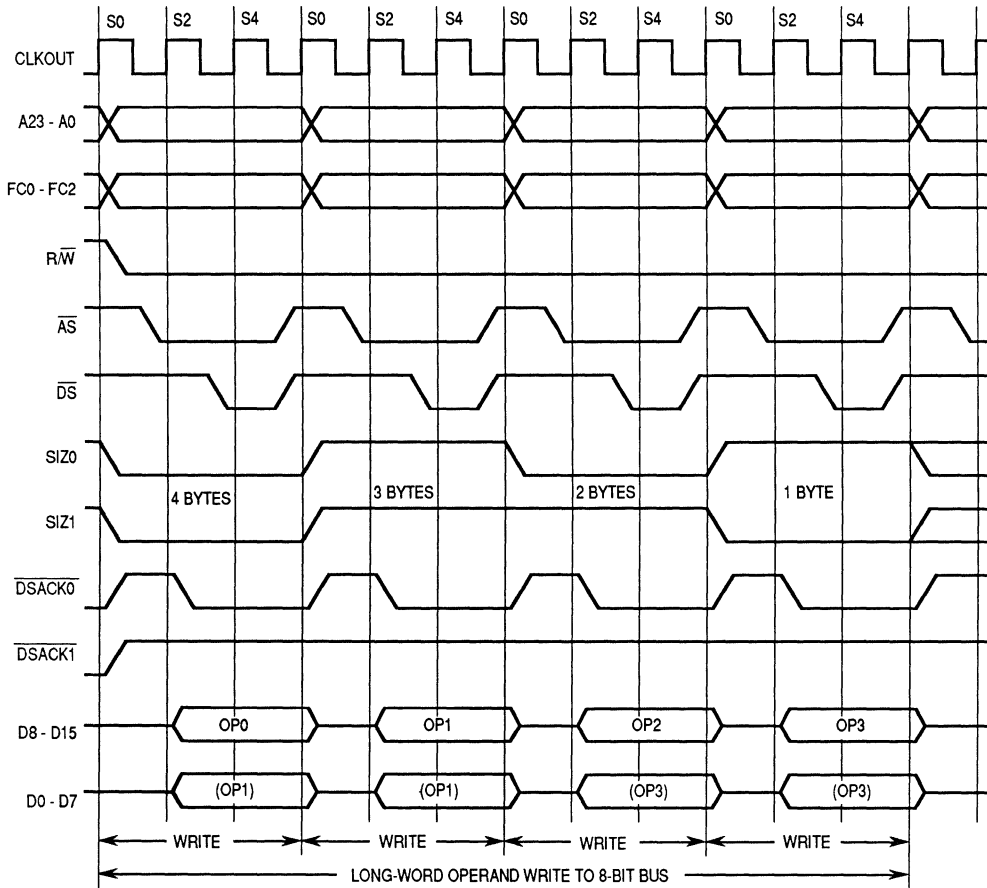


Figure 3-37. Long Word Operand Write Timing from 8-Bit Port

3.5.3.7 Long-Word Operand to 16-Bit Port, Aligned

Figure 3-38 shows both long-word and word read and write timing to a 16-bit port. The MCU drives the address bus with the desired address and drives the size pins to indicate a long-word operand.

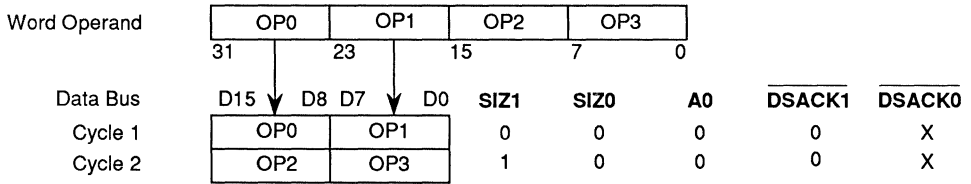


Figure 3-38. Long-Word Operand to 16-Bit Port, Aligned

For a read operation, the slave responds by placing the two most significant bytes of the operand on bits [15:0] of the data bus, and asserting $\overline{\text{DSACK1}}$ to indicate a 16-bit port. The MCU reads the two most significant bytes of the operand (bytes 0 and 1) from bits [15:0]. The MCU then decrements the transfer size counter, increments the address, initiates a new cycle, and reads bytes 2 and 3 of the operand from bits [15:0] of the data bus.

For a write operation, the MCU drives the two most significant bytes of the operand on bits [15:0] of the data bus. The slave device then reads the two most significant bytes of the operand (bytes 0 and 1) from bits [15:0] of the data bus and asserts $\overline{\text{DSACK1}}$ to indicate that it received the data and is a 16-bit port. The MCU then decrements the transfer size counter by 2, increments the address by 2, and writes bytes 2 and 3 of the operand to bits [15:0] of the data bus.

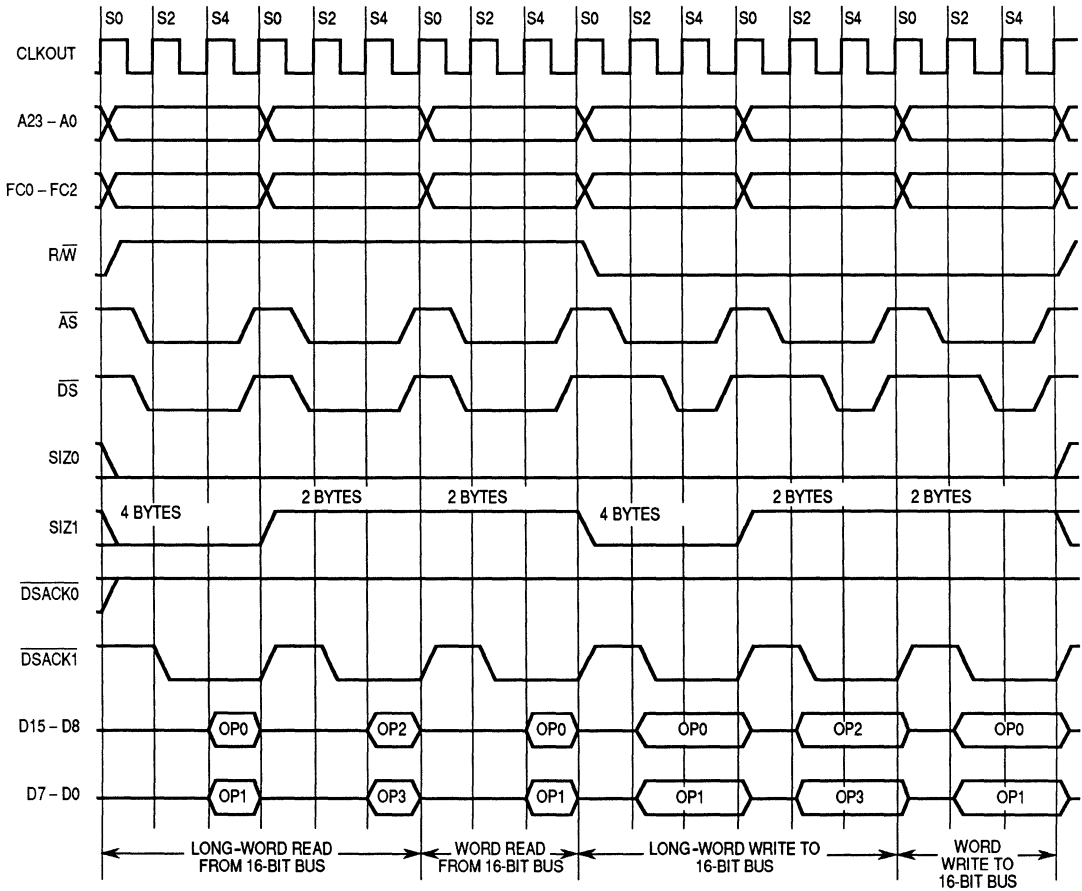


Figure 3-39. Long-Word and Word Read and Write Timing — 16-Bit Port

3.5.4 Bus Operation

The MCU bus is used in an asynchronous manner. The external devices connected to the bus can operate at clock frequencies different from the clock for the MCU. Bus operation uses handshake lines \overline{AS} , \overline{DS} , $\overline{DSACK1}$, $\overline{DSACK0}$, \overline{BERR} , and \overline{HALT} to control data transfers. \overline{AS} signals the start of a bus cycle, and \overline{DS} is used as a condition for valid data on a write cycle. Decoding the size outputs and lower address line A0 provides strobes that select the active portion of the data bus. The slave device (memory or peripheral) then responds by placing the requested data on the correct portion of the data bus for a read cycle or latching the data on a write cycle, and asserting the $\overline{DSACK1}/\overline{DSACK0}$ combination that corresponds to the port size to terminate the cycle. If no slave responds or the access is invalid, external control logic asserts the \overline{BERR} , or \overline{BERR} and \overline{HALT} signal(s) to abort or retry the bus cycle, respectively. The \overline{DSACKx} signals can be asserted before the data from a slave device is valid on a read cycle. The length of time that \overline{DSACKx} may precede data must not exceed a specified value in any asynchronous system to ensure that valid data is latched into the MCU. (Refer to **SECTION 8 ELECTRICAL CHARACTERISTICS** for timing parameters.) Notice that no maximum time is specified from the assertion of \overline{AS} to the assertion of \overline{DSACKx} . Although the MCU can transfer data in a minimum of three clock cycles when the cycle is terminated with \overline{DSACKx} , the MCU inserts wait cycles in clock period increments until \overline{DSACKx} is recognized. The \overline{BERR} and/or \overline{HALT} signals can be asserted after a \overline{DSACK} signal is asserted. \overline{BERR} and/or \overline{HALT} must be asserted within the time specified after \overline{DSACKx} is asserted in any asynchronous system. **Warning:** *If this maximum delay time is violated, the MCU may exhibit erratic behavior.*

3.5.5 Synchronization of Asynchronous Inputs to CLKOUT

Although cycles terminated with \overline{DSACKx} signals are classified as asynchronous, cycles terminated with \overline{DSACKx} can also operate synchronously in that signals are interpreted relative to clock edges. The devices that use these cycles must synchronize the response to the MCU clock (CLKOUT) in order to be synchronous. Since they terminate bus cycles with the data transfer and size acknowledge signals (\overline{DSACKx}), the dynamic bus-sizing capabilities of the MCU are available. The minimum cycle time for these cycles is also three clocks. To support those systems that use the system clock to generate \overline{DSACKx} and other asynchronous inputs, the asynchronous input setup time and the asynchronous input hold time are given. If the setup and hold times are met for the assertion or negation of a signal, such as \overline{DSACKx} , the MCU can be guaranteed to recognize that signal level on that specific falling edge of the system clock. If the assertion of \overline{DSACKx} is recognized on a particular falling edge of the clock, valid data is latched into the MCU (for a read cycle) on the next falling clock edge, provided that the data meets the data setup time. In this case, the parameter for

asynchronous operation can be ignored. The timing parameters referred to are described in **SECTION 8 ELECTRICAL CHARACTERISTICS**. Note that if a system asserts $\overline{\text{DSACKx}}$ for the required window around the falling edge of S2 and obeys the proper bus protocol by maintaining $\overline{\text{DSACKx}}$ (and/or $\overline{\text{BERR/HALT}}$) until and throughout the clock edge that negates $\overline{\text{AS}}$ (with the appropriate asynchronous input hold time), no wait states are inserted. The bus cycle runs at its maximum speed for bus cycles terminated with $\overline{\text{DSACKx}}$ of three clocks per cycle. To assure proper operation in a synchronous system when $\overline{\text{BERR}}$ or $\overline{\text{BERR}}$ and $\overline{\text{HALT}}$ is asserted after $\overline{\text{DSACKx}}$, $\overline{\text{BERR}}$ (and $\overline{\text{HALT}}$) must meet the appropriate setup time prior to the falling clock edge one clock cycle after $\overline{\text{DSACKx}}$ is recognized. **Warning:** *This setup time is critical, and the MCU may exhibit erratic behavior if it is violated.* When operating synchronously, the data-in setup and hold times for synchronous cycles may be used instead of the timing requirements for data relative to the $\overline{\text{DS}}$ signal.

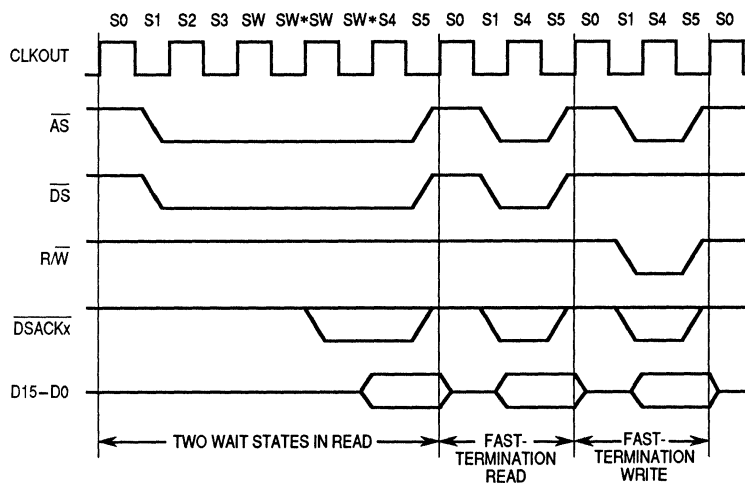
3.5.6 Fast Termination Cycles

With an external device that has a fast access time, the chip-select circuit fast-termination option can provide a two-cycle external bus transfer. Since the chip-select circuits are driven from the system clock, the bus cycle termination is inherently synchronized with the system clock.

The $\overline{\text{DSACK}}$ option in the chip-select option registers determine whether internally generated $\overline{\text{DSACKx}}$ or externally generated $\overline{\text{DSACKx}}$ is used. To use the fast-termination option, an external device should be fast enough to have data ready, within the specified setup time, by the falling edge of S4. Figure 3-40 shows the $\overline{\text{DSACK}}$ timing for two wait states in read, and a fast-termination read and write.

When using the fast-termination option, data strobe is asserted only in a read cycle and not in a write cycle. The STRB field in the option register used must be programmed to address strobe in order to assert the chip-select when it is used for a fast-termination write (refer to **3.3.4 Option Registers Description (CSORBT, CSOR0–CSOR10)** for more information).

If several chip-selects are used to provide control signals to a single device and the match condition occurs simultaneously, the $\overline{\text{DSACK}}$ fields should be programmed to the external $\overline{\text{DSACK}}$ or to the same number of wait states with one $\overline{\text{DSACK}}$ field programmed to the internal $\overline{\text{DSACK}}$ option. This prevents a conflict on the internal bus when the wait states are loaded into the $\overline{\text{DSACK}}$ counter, which is shared by all chip-selects. Refer to **3.3 Chip-Select Submodule** for more information on chip-selects.



* \overline{DSACKx} only internally asserted for fast-termination cycles

Figure 3-40. Fast-Termination Timing

3.6 Data Transfer Cycles

The transfer of data between the MCU and other devices involves the following signals:

- Address Bus [A23:A0]
- Data Bus [D15:D0]
- Control Signals

The address and data buses are both parallel, nonmultiplexed buses. The bus master transfers data on the bus by issuing control signals, and the bus uses a handshake protocol to ensure correct movement of the data. In all bus cycles, the bus master is responsible for deskewing all signals it issues at both the start and the end of the cycle. In addition, the bus master is responsible for deskewing the acknowledge and data signals from the slave devices. The following paragraphs define read, write, and read-modify-write cycle operations. Each of the bus cycles is defined as a succession of states. These states apply to the bus operation and are different from the MCU states described for the CPU. The clock cycles used in the descriptions and timing diagrams of data transfer cycles are independent of the clock frequency. Bus operations are described in terms of external bus states.

3.6.1 Read Cycle

During a read cycle, the MCU receives data from a memory or peripheral device. If the instruction specifies a long-word or word operation, the MCU attempts to read two bytes at once. For a byte operation, the MCU reads one byte. The section of the data bus from which each byte is read depends on the operand size, address signal A0, and the port size. Refer to **3.5.1 Dynamic Bus Sizing** and **3.5.2 Misaligned Operands** for more information on dynamic bus sizing and misaligned operands. Figure 3-41 is a flowchart of a word read cycle.

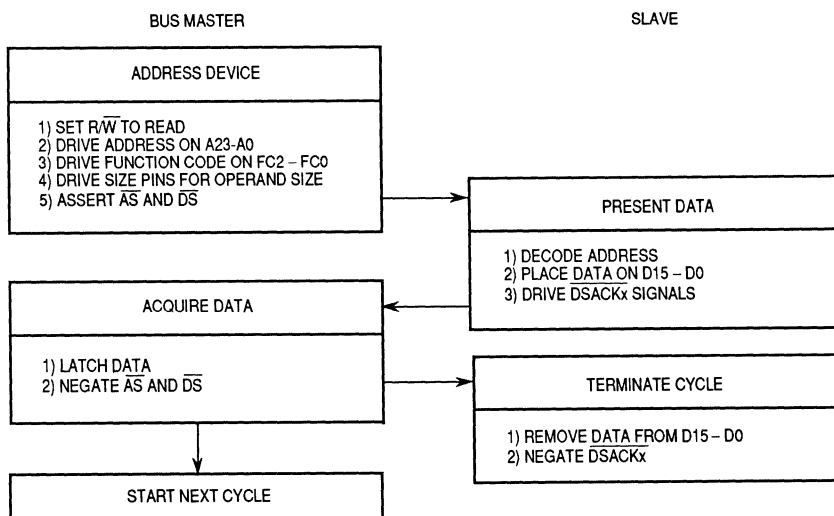


Figure 3-41. Word Read Cycle Flowchart

State 0 — The read cycle starts in state 0 (S0). During S0, the MCU places a valid address on [A23:A0] and valid function codes on [FC2:FC0]. The function codes select the address space for the cycle. The MCU drives $\overline{R/W}$ high for a read cycle. Size signals SIZ1 and SIZ0 become valid, indicating the number of bytes requested to be transferred.

State 1— One-half clock later in state 1 (S1), the MCU asserts the \overline{AS} indicating that the address on the address bus is valid. The MCU also asserts the \overline{DS} during S1.

State 2 — The selected device uses $\overline{R/W}$, SIZ1–SIZ0, A0, and \overline{DS} to place its information on the data bus. One or both of the bytes [D15:D8] and [D7:D0] are selected by the size signals and A0. Concurrently, the selected device asserts the \overline{DSACKx} signals.

State 3 — As long as at least one of the \overline{DSACKx} signals is recognized by the end of S2 (meeting the asynchronous input setup time requirement), data is latched on the next falling edge of the clock, and the cycle terminates. If \overline{DSACKx} is not recognized by the start of S3, the MCU inserts wait states instead of proceeding to states 4 and 5. To ensure that wait states are inserted, both $\overline{DSACK1}$ and $\overline{DSACK0}$ must remain negated throughout the asynchronous input setup and hold times around the end of S2. If wait states are added, the MCU continues to sample the \overline{DSACKx} signals on the falling edges of the clock until one is recognized.

State 4 — At the end of S4, the MCU latches the incoming data.

State 5 — The MCU negates \overline{AS} and \overline{DS} during S5. It holds the address valid during S5 to provide address hold time for memory systems. R/\overline{W} , $SIZ1$ and $SIZ0$, and $[FC2:FC0]$ also remain valid throughout S5. The external device keeps its data and \overline{DSACKx} signals asserted until it detects the negation of \overline{AS} or the negation of \overline{DS} (whichever it detects first). The device must remove its data and negate \overline{DSACKx} within approximately one clock period after sensing the negation of \overline{AS} or \overline{DS} . **Warning:** *\overline{DSACKx} signals that remain asserted beyond this limit may be prematurely detected for the next bus cycle.*

3.6.2 Write Cycle

During a write cycle, the MCU transfers data to memory or a peripheral device. Figure 3-42 is a flowchart of a write-cycle operation for a word transfer.

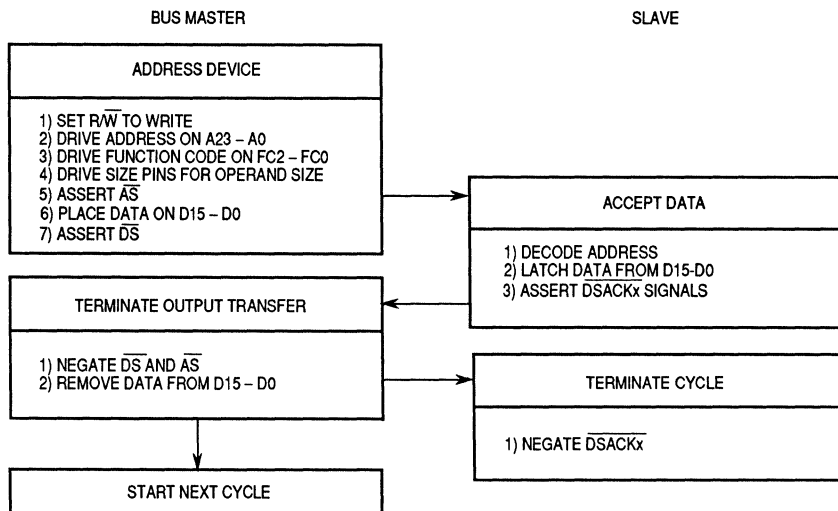


Figure 3-42. Write Cycle Flowchart

State 0 — The write cycle starts in S0. During S0, the MCU places a valid address on [A23:A0] and valid function codes on [FC2:FC0]. The function codes select the address space for the cycle. The MCU drives $\overline{R/W}$ low for a write cycle. Size signals SIZ1 and SIZ0 become valid, indicating the number of bytes to be transferred.

State 1 — One-half clock later in S1, the MCU asserts the \overline{AS} indicating that the address on the address bus is valid.

State 2 — During S2, the MCU places the data to be written onto the data bus [D15:D0] and samples the \overline{DSACKx} at the end of S2.

State 3 — The MCU asserts \overline{DS} during S3. This indicates that the data is stable on the data bus. As long as at least one of the \overline{DSACKx} signals is recognized by the end of S2 (meeting the asynchronous input setup time requirement), the cycle terminates one clock later. If \overline{DSACKx} is not recognized by the start of S3, the MCU inserts wait states instead of proceeding to states 4 and 5. To ensure that wait states are inserted, both $\overline{DSACK1}$ and $\overline{DSACK0}$ must remain negated throughout the asynchronous input setup and hold times around the end of S2. If wait states are added, the MCU continues to sample the \overline{DSACKx} signals on the falling edges of the clock until one is recognized. The selected device uses $\overline{R/W}$, SIZ1–SIZ0, and A0 to latch data from the appropriate byte(s) of the data bus [D15:D8] and [D7:D0]. The size signals and A0 select the bytes of the data bus. If \overline{DSACKx} is not already asserted, the device asserts \overline{DSACKx} to signal that it has successfully stored the data.

State 4 — The MCU issues no new control signals during S4.

State 5 — The MCU negates \overline{AS} and \overline{DS} during S5. It holds the address and data valid during S5 to provide address hold time for memory systems. $\overline{R/W}$, SIZ1 and SIZ0, and [FC2:FC0] also remain valid throughout S5. The external device must keep \overline{DSACKx} asserted until it detects the negation of \overline{AS} or \overline{DS} (whichever it detects first). The device must negate \overline{DSACKx} within approximately one clock period after sensing the negation of \overline{AS} or \overline{DS} .

Warning: *\overline{DSACKx} signals that remain asserted beyond this limit may be prematurely detected for the next bus cycle.*

3.6.3 Read-Modify-Write Cycle

The read-modify-write cycle performs a read, conditionally modifies the data in the arithmetic logic unit, and may write the data out to memory. In this MCU, this operation is indivisible, providing semaphore capabilities for multiprocessor systems. During the entire read-modify-write sequence, the MCU asserts the \overline{RMC} signal to indicate that an indivisible operation is occurring. The MCU does not issue a bus grant (\overline{BG}) signal in response to a bus request (\overline{BR}) signal during

this operation. Figure 3-43 is an example of a functional timing diagram of a read-modify-write instruction specified in terms of clock periods.

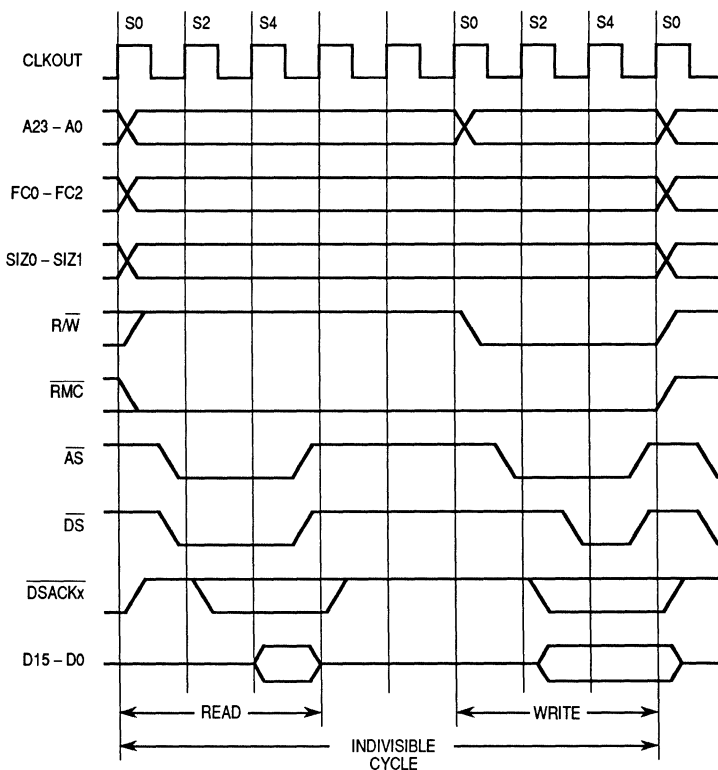


Figure 3-43. Read-Modify-Write Cycle Timing

State 0 — The MCU asserts \overline{RMC} in S0 to identify a read-modify-write cycle. The MCU places a valid address on [A23:A0] and valid function codes on [FC2:FC0]. The function codes select the address space for the operation. Size signals SIZ1–SIZ0 become valid in S0 to indicate the operand size. The MCU drives R/W high for the read cycle.

State 1 — One-half clock later in S1, the MCU asserts \overline{AS} indicating that the address on the address bus is valid. The MCU also asserts \overline{DS} during S1.

State 2 — The selected device uses $\overline{R/W}$, SIZ1–SIZ0, A0, and \overline{DS} to place information on the data bus. Either or both of the bytes [D15:D8] and [D7:D0] are

selected by the size signals and A0. Concurrently, the selected device may assert the \overline{DSACKx} signals.

State 3 — As long as at least one of the \overline{DSACKx} signals is recognized by the end of S2 (meeting the asynchronous input setup time requirement), data is latched on the next falling edge of the clock, and the cycle terminates. If \overline{DSACKx} is not recognized by the start of S3, the MCU inserts wait states instead of proceeding to states 4 and 5. To ensure that wait states are inserted, both $\overline{DSACK1}$ and $\overline{DSACK0}$ must remain negated throughout the asynchronous input setup and hold times around the end of S2. If wait states are added, the MCU continues to sample the \overline{DSACKx} signals on the falling edges of the clock until one is recognized.

State 4 — At the end of S4, the MCU latches the incoming data.

State 5 — The MCU negates \overline{AS} and \overline{DS} during S5. If more than one read cycle is required to read in the operand(s), S0–S5 are repeated for each read cycle. When finished reading, the MCU holds the address, R/W, and [FC2:FC0] valid in preparation for the write portion of the cycle. The external device keeps its data and \overline{DSACKx} signals asserted until it detects the negation of \overline{AS} or \overline{DS} (whichever it detects first). The device must remove the data and negate \overline{DSACKx} within approximately one clock period after sensing the negation of \overline{AS} or \overline{DS} . **Warning:** *\overline{DSACKx} signals that remain asserted beyond this limit may be prematurely detected for the next portion of the operation.*

Idle States — The MCU does not assert any new control signals during the idle states, but it may internally begin the modify portion of the cycle at this time. States 0–5 are omitted if no write cycle is required. If a write cycle is required, the R/W signal remains in the read mode until state 0 to prevent bus conflicts with the preceding read portion of the cycle; the data bus is not driven until state 2.

State 0 — The MCU drives R/W low for a write cycle. Depending on the write operation to be performed, the address lines may change during state 0.

State 1 — In S1, the MCU asserts \overline{AS} , indicating that the address on the address bus is valid.

State 2 — During S2, the MCU places the data to be written onto the data bus [D15:D0].

State 3 — The MCU asserts the \overline{DS} during S3. This indicates that the data is stable on the data bus. As long as at least one of the \overline{DSACKx} signals is recognized by the end of S2 (meeting the asynchronous input setup time requirement), the cycle terminates one clock later. If \overline{DSACKx} is not recognized by the start of S3, the MCU inserts wait states instead of proceeding to states 4 and 5. To ensure that wait states are inserted, both $\overline{DSACK1}$ and $\overline{DSACK0}$ must

3.7.1 Breakpoint Acknowledge Cycle

The breakpoint acknowledge cycle allows external hardware to insert an instruction directly into the instruction pipeline as the program executes.

When a breakpoint instruction (BKPT) is executed, the MC68331 performs a word read from CPU space, type 0, at an address corresponding to the breakpoint number (bits [2:0] of the BKPT opcode) on address lines [A4:A2] and the T-bit (A1) set to zero. If this bus cycle is terminated by $\overline{\text{BERR}}$, the MCU then proceeds to perform illegal instruction exception processing. If the bus cycle is terminated by $\overline{\text{DSACKx}}$, the MCU uses the data on [D15:D0] (for 16-bit ports) or two reads from [D15:D8] (for 8-bit ports) to replace the BKPT instruction in the internal instruction pipeline, and begins execution of that instruction.

When the assertion of the BKPT pin is acknowledged by the CPU while background mode is not enabled, the MC68331 performs a word read from CPU space, type 0, at an address corresponding to all ones being set on address lines [A4:A2] (BKPT #7) and the T-bit (A1) being set to one. If this bus cycle is terminated by $\overline{\text{BERR}}$, the MCU then proceeds to perform hardware breakpoint exception processing. If the bus cycle is terminated by $\overline{\text{DSACKx}}$, the MCU ignores any data on the data bus and continues execution of the next instruction.

NOTE:

The BKPT pin is sampled on the same clock phase as data and is latched with data as it enters the CPU pipeline. If BKPT is asserted for only one bus cycle and a pipe flush occurs before BKPT is detected by the CPU, BKPT will be ignored. To ensure detection of BKPT by the CPU, BKPT can be asserted until a breakpoint acknowledge cycle is recognized.

The breakpoint operation flow is shown in Figure 3-45. Figures 3-46 and 3-47 show the timing diagrams for the breakpoint acknowledge cycle with instruction opcodes supplied on the cycle and with an exception signaled, respectively.

BREAKPOINT OPERATION FLOW

PROCESSOR

EXTERNAL DEVICE

ACKNOWLEDGE BREAKPOINT

IF BREAKPOINT INSTRUCTION EXECUTED:
 1) SET $\overline{R/W}$ TO READ
 2) SET FUNCTION CODE TO CPU SPACE
 3) PLACE CPU SPACE TYPE 0 ON A19 – A16
 4) PLACE BREAKPOINT NUMBER ON A4 – A2
 5) SET T-BIT (A1), TO ZERO
 6) SET SIZE TO WORD
 7) ASSERT \overline{AS} AND \overline{DS}

IF BKPT PIN ASSERTED:
 1) SET $\overline{R/W}$ TO READ
 2) SET FUNCTION CODE TO CPU SPACE
 3) PLACE CPU SPACE TYPE 0 ON A19 – A16
 4) PLACE ALL ONES ON A4 – A2
 5) SET T-BIT (A1), TO ONE
 6) SET SIZE TO WORD
 7) ASSERT \overline{AS} AND \overline{DS}

IF BKPT INSTRUCTION EXECUTED:
 1) PLACE REPLACEMENT OPCODE ON DATA BUS
 2) ASSERT \overline{DSACKx}
 OR:
 1) ASSERT \overline{BERR} TO INITIATE EXCEPTION PROCESSING

IF BKPT ASSERTED:
 1) ASSERT \overline{DSACKx}
 OR:
 1) ASSERT \overline{BERR} TO INITIATE EXCEPTION PROCESSING

IF BREAKPOINT INSTRUCTION EXECUTED AND \overline{DSACKx} IS ASSERTED:
 1) LATCH DATA
 2) NEGATE \overline{AS} AND \overline{DS}
 3) GO TO (A)

IF BKPT PIN ASSERTED AND \overline{DSACKx} IS ASSERTED:
 1) NEGATE \overline{AS} AND \overline{DS}
 2) GO TO (A)

IF \overline{BERR} ASSERTED:
 1) NEGATE \overline{AS} AND \overline{DS}
 2) GO TO (B)

IF BKPT INSTRUCTION EXECUTED:
 1) PLACE LATCHED DATA IN INSTRUCTION PIPELINE
 2) CONTINUE PROCESSING

IF BKPT PIN ASSERTED:
 1) CONTINUE PROCESSING

1) NEGATE \overline{DSACKx} or \overline{BERR}

IF BKPT INSTRUCTION EXECUTED:
 1) INITIATE ILLEGAL INSTRUCTION PROCESSING

IF BKPT PIN ASSERTED:
 1) INITIATE HARDWARE BREAKPOINT PROCESSING

3

Figure 3-45. Breakpoint Operation Flow

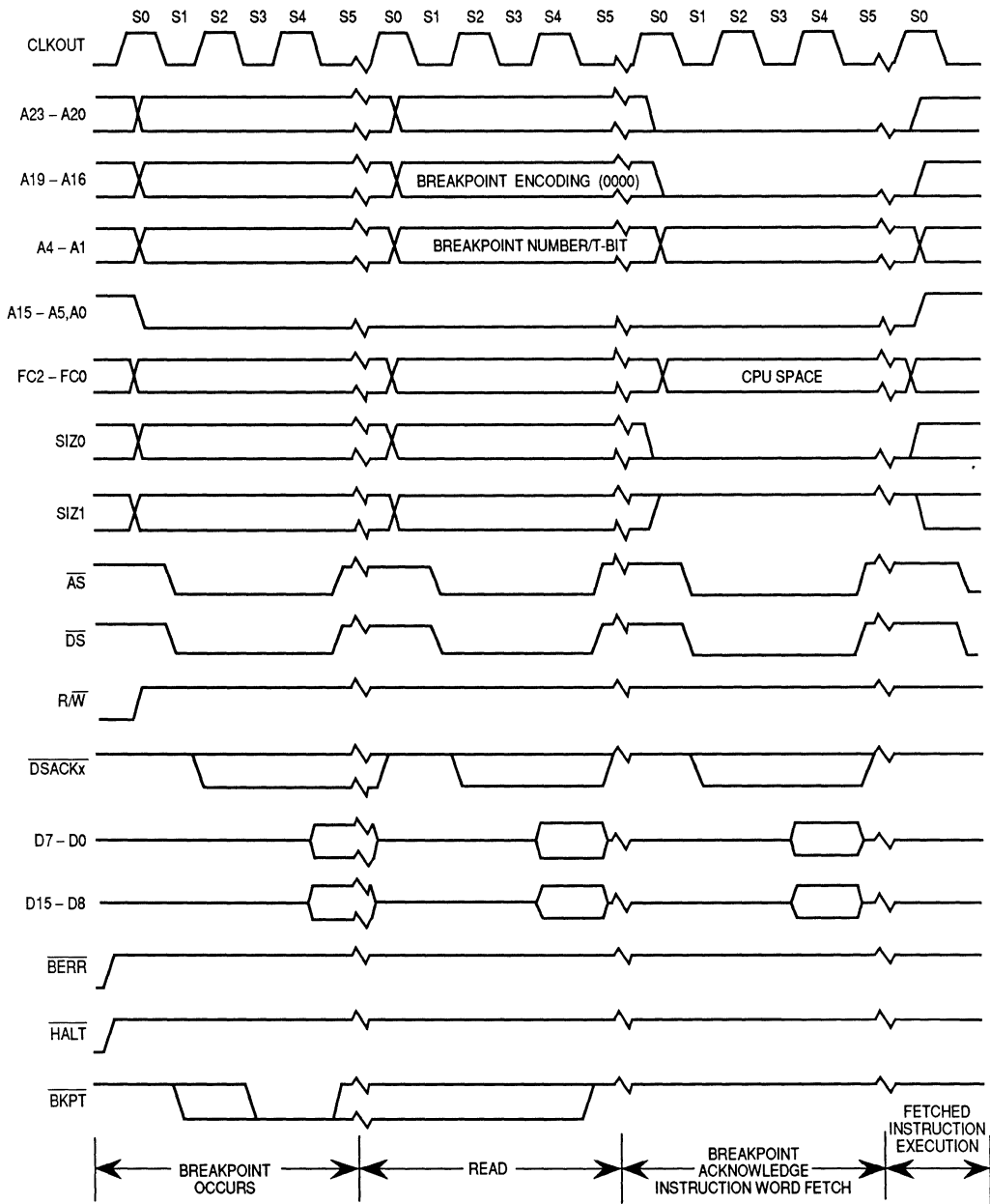
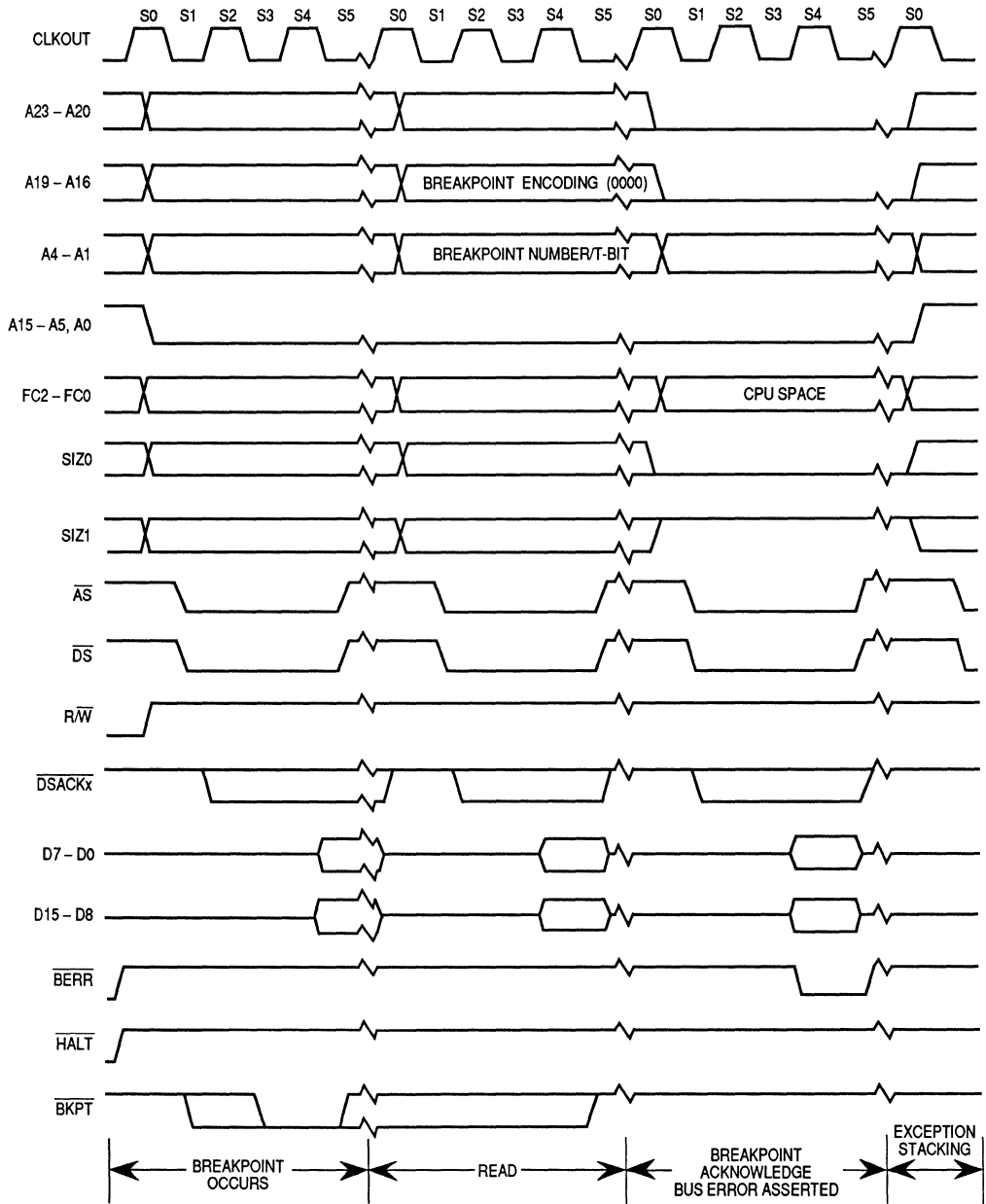


Figure 3-46. Breakpoint Acknowledge Cycle Timing (Opcode Returned)



**Figure 3-47. Breakpoint Acknowledge Cycle Timing
(Exception Signaled)**

3.7.2 LPSTOP Broadcast Cycle

The LPSTOP broadcast cycle is generated by the CPU executing the LPSTOP instruction. The external bus interface must get a copy of the interrupt mask level from the CPU, so the CPU performs a CPU space type three write at address \$3FFFE. The mask level (bits [2:0]) is encoded on the data bus as shown in Figure 3-48. The CPU space type three cycle is shown externally if the bus is available as an indication to external devices that the MCU is going into low power stop mode. The SIM provides an internally generated DSACK response to this cycle. The timing of this bus cycle is as shown in Figure 10-8 Synchronous Write Cycle Timing Diagram.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	12	11	10

Figure 3-48. LPSTOP Interrupt Mask Level

3.7.3 Interrupt Acknowledge Bus Cycles

When a peripheral device signals the MCU (with the $\overline{\text{IRQ7}}\text{--}\overline{\text{IRQ1}}$ signals) that the device requires service, and the internally synchronized value on these signals indicates a higher priority than the interrupt mask in the status register (or that a transition has occurred in the case of a level 7 interrupt), the MCU makes the interrupt a pending interrupt. The MCU takes an interrupt exception for a pending interrupt within one instruction boundary (after processing any other pending exception with a higher priority). The following paragraphs describe the various kinds of interrupt acknowledge bus cycles that can be executed as part of interrupt exception processing.

3.7.3.1 Interrupt Acknowledge Cycle — Terminated Normally

When the MCU processes an interrupt exception, it performs an interrupt acknowledge cycle to obtain the number of the vector that contains the starting location of the interrupt service routine. Some interrupting devices have programmable vector registers that contain the interrupt vectors for the routines they use. The following paragraphs describe the interrupt acknowledge cycle for these devices. Other interrupting conditions or devices cannot supply a vector number and use the autovector cycle described in **3.7.3.2 Autovector Interrupt Acknowledge Cycle**. The interrupt acknowledge cycle is a read cycle. It differs from the read cycle described in **3.6.1 Read Cycle** in that it accesses the CPU address space. Specifically, the differences are as follows:

- a. [FC2:FC0] are set to \$7 (111 binary) for CPU address space.
- b. Address bits [A3:A1] are set to the interrupt request level.

- c. The CPU space type field (address bits [A19:A16]) is set to \$F, the interrupt acknowledge code.
- d. The SIZ_0 , SIZ_1 , and R/\overline{W} signals are driven to indicate a single-byte read cycle. The responding device places the vector number on the least significant byte of its data port (for an 8-bit port, the vector number must be on [D15:D8]; for a 16-bit port the vector must be on [D7:D0]) during the interrupt acknowledge cycle. Beyond this, the cycle is terminated normally with \overline{DSACK}_x . Figure 3-48 is the flowchart of the interrupt acknowledge cycle. Figure 3-49 shows the timing for an interrupt acknowledge terminated with \overline{DSACK}_x .

Interrupting devices decode the above information to decide which one should put its interrupt vector on the bus and drive \overline{DSACK}_x to terminate the bus cycle. The chip-select logic can be programmed to decode this CPU space bus cycle and generate a chip-select signal to the device. The device would respond by putting its vector on the data bus.

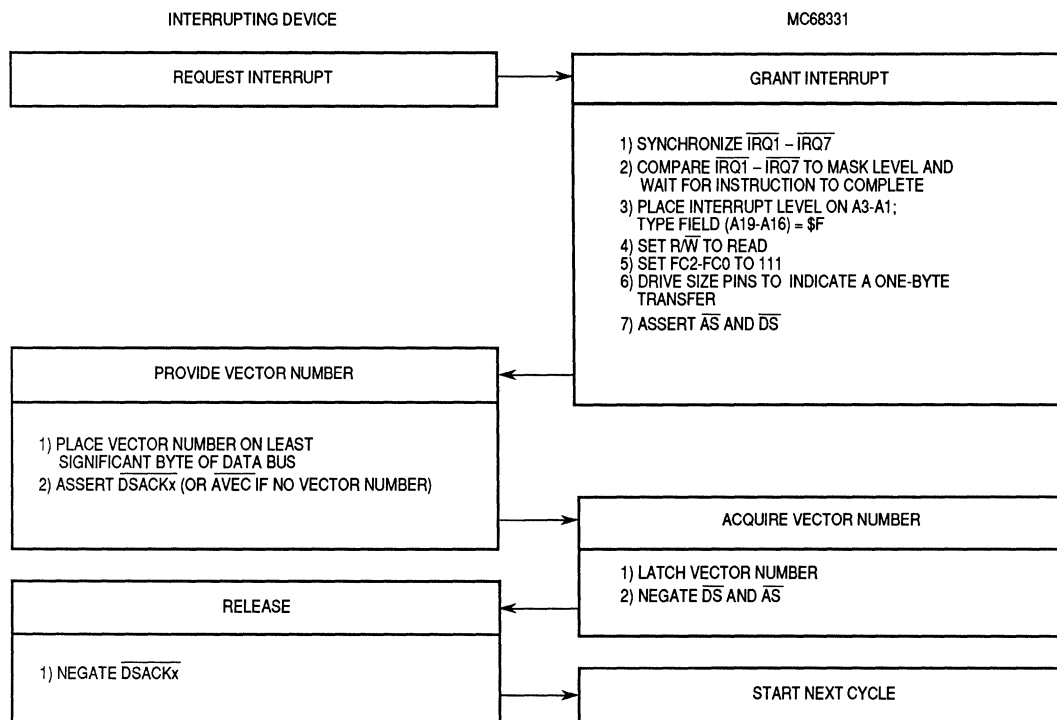


Figure 3-49. Interrupt Acknowledge Cycle Flowchart

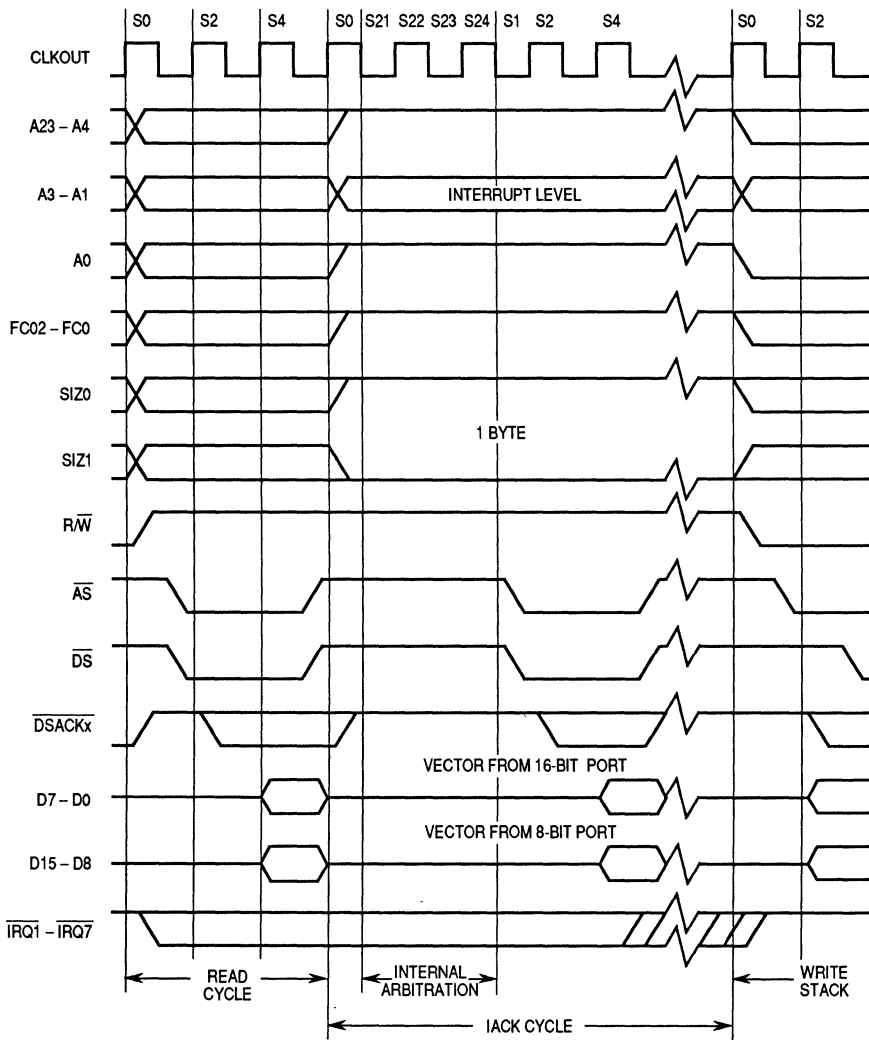


Figure 3-50. Interrupt Acknowledge Cycle Timing

3.7.3.2 Autovector Interrupt Acknowledge Cycle

When the interrupting device cannot supply a vector number, it requests an automatically generated vector, or autovector. Instead of placing a vector number on the data bus and asserting \overline{DSACKx} , the device asserts \overline{AVEC} to terminate the cycle. The \overline{DSACKx} signals may not be asserted during an interrupt acknowledge cycle terminated by \overline{AVEC} . The vector number supplied in an autovector operation is derived from the interrupt level of the current interrupt. When the \overline{AVEC} signal is asserted instead of \overline{DSACK} during an interrupt acknowledge cycle, the MCU ignores the state of the data bus and internally

generates the vector number, the sum of the interrupt level plus 24 (\$18). There are seven distinct autovectors that can be used, corresponding to the seven levels of interrupts available with signals IRQ7–IRQ1. Figure 3-50 shows the timing for an autovector operation.

The chip-select logic can be programmed to decode this CPU space bus cycle and automatically generate an \overline{AVEC} response internally. The device does not have to return any kind of response in this case. Refer to **3.3.1 Chip-Select Operation** for more information on programming the chip-select logic to provide an autovector response.

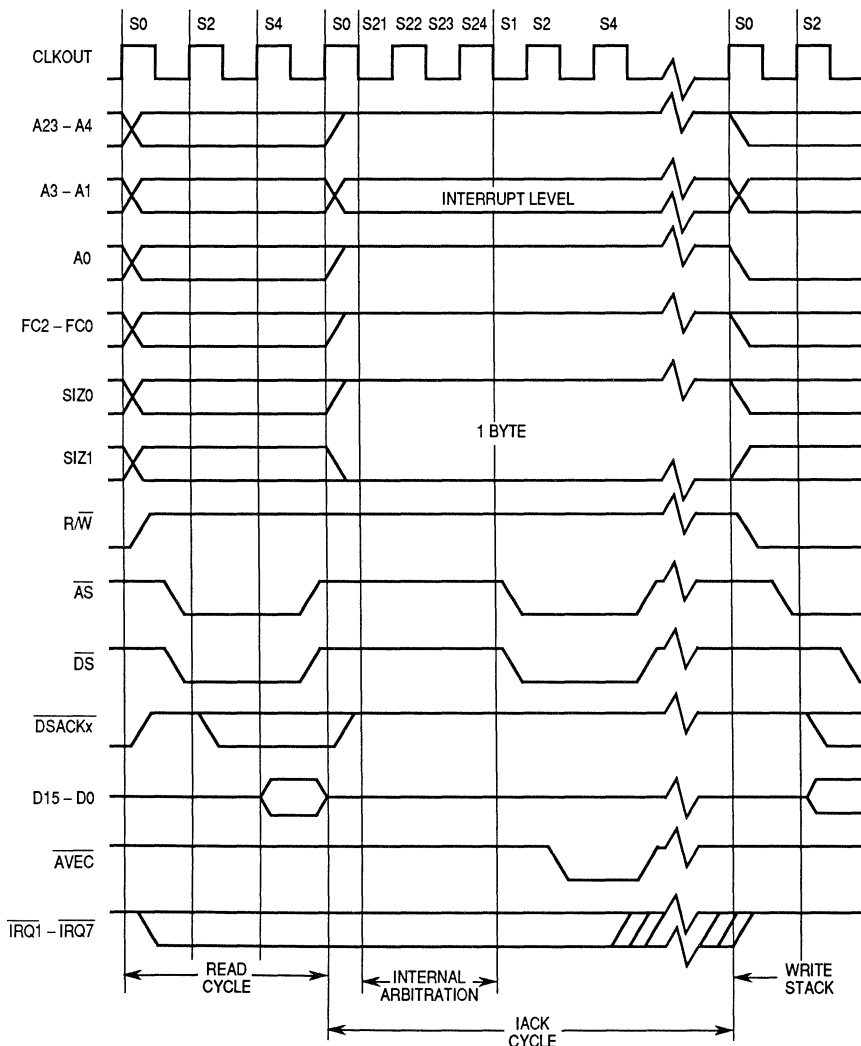


Figure 3-51. Autovector Operation Timing

3.7.3.3 Spurious Interrupt Cycle

When a device (including the system integration module (SIM), which responds for external requests), does not respond during an interrupt acknowledge cycle by arbitrating for the interrupt acknowledge cycle, the spurious interrupt monitor generates an internal bus error signal to terminate the vector acquisition. The MCU automatically generates the spurious interrupt vector number 24 (\$18) instead of the interrupt vector number in this case. When a device does not respond to an interrupt acknowledge cycle with \overline{AVEC} or \overline{DSACKx} , a bus monitor must assert \overline{BERR} , which results in the CPU taking the spurious interrupt vector. If the halt signal \overline{HALT} is also asserted, the MCU retries the interrupt acknowledge cycle instead of using the spurious interrupt vector.

3.8 Bus Exception Control Cycles

The bus architecture requires assertion of \overline{DSACKx} from an external device to signal that a bus cycle is complete. \overline{DSACKx} or \overline{AVEC} is not asserted in the following cases:

- The external device does not respond.
- No interrupt vector is provided.
- Various other application-dependent errors occur.

This MCU has a bus error input when no device responds by asserting \overline{DSACKx} or \overline{AVEC} within an appropriate period of time after the MCU asserts the \overline{AS} . This allows the cycle to terminate and the MCU to enter exception processing for the error condition. Another signal that is used for bus exception control is the halt signal (\overline{HALT}). This signal can be asserted by an external device for debugging purposes to cause single bus cycle operation or (in combination with \overline{BERR}) a retry of a bus cycle in error. To properly control termination of a bus cycle for a retry or a bus error condition, \overline{DSACKx} , \overline{BERR} , and \overline{HALT} can be asserted and negated with the rising edge of the MCU clock. This assures that when two signals are asserted simultaneously, the required setup time and hold time for both of them are met for the same falling edge of the MCU clock. (Refer to **SECTION 8 ELECTRICAL CHARACTERISTICS** for timing requirements.) This or some equivalent precaution should be designed into the external circuitry that provides these signals, or else the internal bus monitor should be used. The acceptable bus cycle terminations for asynchronous cycles are summarized in relation to \overline{DSACKx} assertion as follows (case numbers refer to Table 3-29).

Normal Termination

\overline{DSACKx} is asserted; \overline{BERR} and \overline{HALT} remain negated (case 1).

Halt Termination

\overline{HALT} is asserted at the same time, or before \overline{DSACKx} , and \overline{BERR} remains negated (case 2).

Bus Error Termination

$\overline{\text{BERR}}$ is asserted in lieu of, at the same time, or before $\overline{\text{DSACKx}}$ (case 3), or after $\overline{\text{DSACKx}}$ (case 4), and $\overline{\text{HALT}}$ remains negated; $\overline{\text{BERR}}$ is negated at the same time or after $\overline{\text{DSACKx}}$.

Retry Termination

$\overline{\text{HALT}}$ and $\overline{\text{BERR}}$ are asserted in lieu of, at the same time, or before $\overline{\text{DSACKx}}$ (case 5) or after $\overline{\text{DSACKx}}$ (case 6); $\overline{\text{BERR}}$ is negated at the same time or after $\overline{\text{DSACKx}}$; $\overline{\text{HALT}}$ may be negated at the same time or after $\overline{\text{BERR}}$.

Table 3-29 shows various combinations of control signal sequences and the resulting bus cycle terminations. To ensure predictable operation, $\overline{\text{BERR}}$ and $\overline{\text{HALT}}$ should be negated according to the specifications in **SECTION 8 ELECTRICAL CHARACTERISTICS**. $\overline{\text{DSACKx}}$, $\overline{\text{BERR}}$, and $\overline{\text{HALT}}$ may be negated after $\overline{\text{AS}}$. **WARNING:** If $\overline{\text{DSACKx}}$ or $\overline{\text{BERR}}$ remain asserted into $S2$ of the next bus cycle, that cycle may be terminated prematurely.

EXAMPLE A: A system uses a bus monitor timer to terminate accesses to an unpopulated address space. The timer asserts $\overline{\text{BERR}}$ after time out (case 3).

EXAMPLE B: A system uses error detection and correction on RAM contents. The designer may:

- a. Delay $\overline{\text{DSACKx}}$ until data is verified, and assert $\overline{\text{BERR}}$ and $\overline{\text{HALT}}$ simultaneously to indicate to the MCU to automatically retry the error cycle (case 5), or if data is valid assert $\overline{\text{DSACKx}}$ (case 1).
- b. Delay $\overline{\text{DSACKx}}$ until data is verified and assert $\overline{\text{BERR}}$ with or without $\overline{\text{DSACKx}}$ if data is in error (case 3). This initiates exception processing for software handling of the condition.
- c. Return $\overline{\text{DSACKx}}$ prior to data verification. If data is invalid, $\overline{\text{BERR}}$ is asserted on the next clock cycle (case 4). This initiates exception processing for software handling of the condition.
- d. Return $\overline{\text{DSACKx}}$ prior to data verification; if data is invalid, assert $\overline{\text{BERR}}$ and $\overline{\text{HALT}}$ on the next clock cycle (case 6). The memory controller can then correct the RAM prior to or during the automatic retry.

Table 3-29. DSACK, BERR, and HALT Assertion Results

Case Number	Control Signal	Asserted on Rising Edge of State		Result
		N	N + 2	
1	\overline{DSACKx} \overline{BERR} \overline{HALT}	A NA NA	S NA X	Normal cycle terminate and continue.
2	\overline{DSACKx} \overline{BERR} \overline{HALT}	A NA A/S	S NA S	Normal cycle terminate and halt. Continue when \overline{HALT} is negated.
3	\overline{DSACKx} \overline{BERR} \overline{HALT}	NA/A A NA	X S X	Terminate and take bus error exception, possibly deferred.
4	\overline{DSACKx} \overline{BERR} \overline{HALT}	A A NA	X S NA	Terminate and take bus error exception, possibly deferred.
5	\overline{DSACKx} \overline{BERR} \overline{HALT}	NA/A A A/S	X S S	Terminate and retry when \overline{HALT} is negated.
6	\overline{DSACKx} \overline{BERR} \overline{HALT}	A NA NA	X A A	Terminate and retry when \overline{HALT} is negated.

NOTES:

- N = The number of current even bus state (S2, S4, etc.).
- A = Signal is asserted in this bus state.
- NA = Signal is not asserted in this state.
- X = Don't care.
- S = Signal was asserted in previous state and remains asserted in this state.

3.8.1 Bus Errors

The bus error signal can be used to abort the bus cycle and the instruction being executed. BERR takes precedence over DSACKx, provided it meets the timing constraints described in **SECTION 8 ELECTRICAL CHARACTERISTICS**. **WARNING:** *If BERR does not meet these constraints, it may cause unpredictable operation of the MCU. If BERR remains asserted into the next bus cycle, it may cause incorrect operation of that cycle.* When the bus error signal is issued to terminate a bus cycle, the MCU may enter exception processing immediately following the bus cycle, or it may defer processing the exception. The instruction prefetch mechanism requests instruction words from the bus controller before it is ready to execute them. If a bus error occurs on an instruction fetch, the MCU does not take the exception until it attempts to use that instruction word. Should an intervening instruction cause a branch, or should a task switch occur, the bus

error exception does not occur. The bus error signal is recognized during a bus cycle in any of the following cases:

- \overline{DSACKx} and \overline{HALT} are negated and \overline{BERR} is asserted.
- \overline{HALT} and \overline{BERR} are negated and \overline{DSACKx} is asserted. \overline{BERR} is then asserted within one clock cycle (\overline{HALT} remains negated).
- \overline{BERR} and \overline{HALT} are asserted.

When the MCU recognizes a bus error condition, it terminates the current bus cycle in the normal way. Figure 3-51 shows the timing of a bus error for the case in which \overline{DSACKx} is not asserted. Figure 3-52 shows the timing for a bus error that is asserted after \overline{DSACKx} . Exceptions are taken in both cases. (Refer to bus error exception in the CPU32 reference manual for details of bus error exception processing.)

In the second case where \overline{BERR} is asserted after \overline{DSACKx} is asserted, \overline{BERR} must be asserted within the time specified (refer to **SECTION 8 ELECTRICAL CHARACTERISTICS**) for purely asynchronous operation, or it must be asserted and remain stable during the sample window around the next falling edge of the clock after \overline{DSACKx} is recognized. **WARNING:** *If \overline{BERR} is not stable at this time, the MCU may exhibit erratic behavior.* \overline{BERR} has priority over \overline{DSACKx} . In this case, data may be present on the bus, but may not be valid. This sequence may be used by systems that have memory error detection and correction logic and by external cache memories.

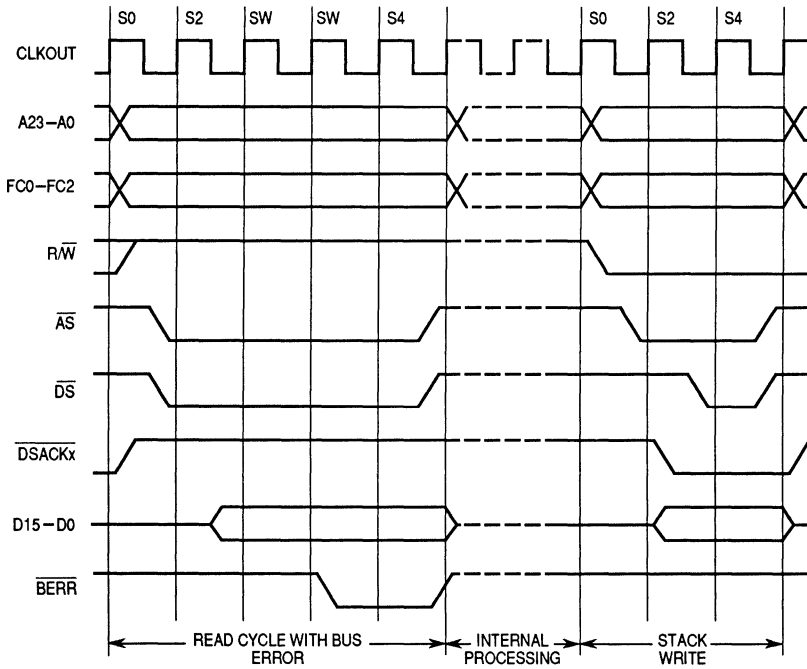


Figure 3-52. Bus Error without DSACKx

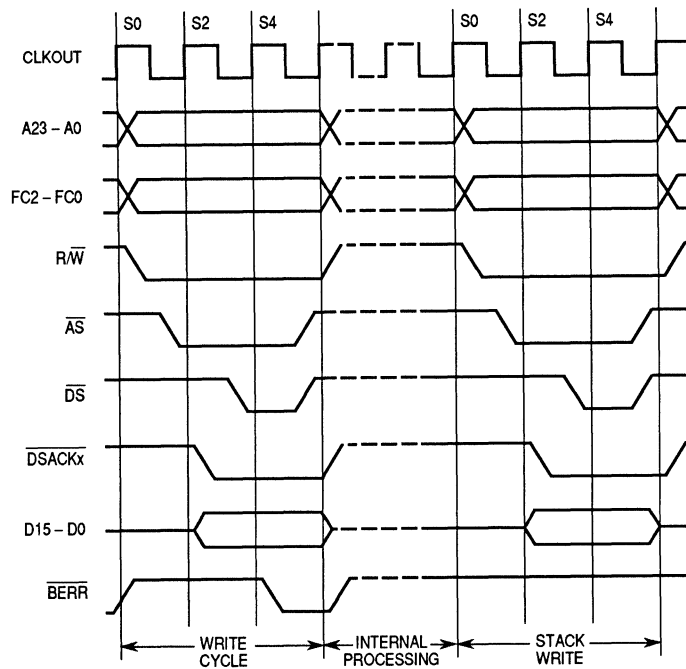


Figure 3-53. Late Bus Error with \overline{DSACKx}

3.8.2 Retry Operation

When the \overline{BERR} and \overline{HALT} signals are both asserted by an external device during a bus cycle, the MCU enters the retry sequence, shown in Figure 3-53. A delayed retry (Figure 3-54), similar to the delayed bus error signal described previously, can also occur. The MCU terminates the bus cycle, places the control signals in their inactive state and does not begin another bus cycle until the \overline{BERR} and \overline{HALT} signals are negated by external logic. After a synchronization delay, the MCU retries the previous cycle using the same access information (address, function code, size, etc.). The \overline{BERR} signal should be negated before S2 of the read cycle to ensure correct operation of the retried cycle.

The MCU retries any read or write cycle of a read-modify-write operation separately; the \overline{RMC} remains asserted during the entire retry sequence. Asserting the \overline{BR} along with \overline{BERR} and \overline{HALT} provides a relinquish and retry operation. The MCU does not relinquish the bus during a read-modify-write operation. Any device that requires the MCU to give up the bus and retry a bus cycle during a read-modify-write cycle must assert \overline{BERR} and \overline{BR} only (\overline{HALT} must not be included). The bus error handler software should examine the read-modify-write

bit in the special status word (refer to special status word in the CPU32 reference manual) and take the appropriate action to resolve this type of fault when it occurs.

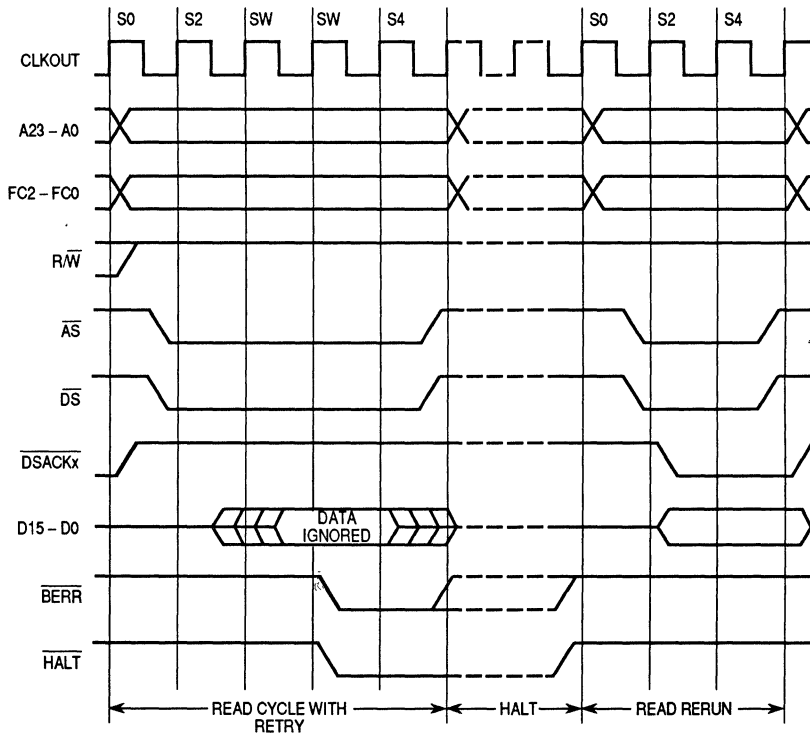


Figure 3-54. Retry Sequence

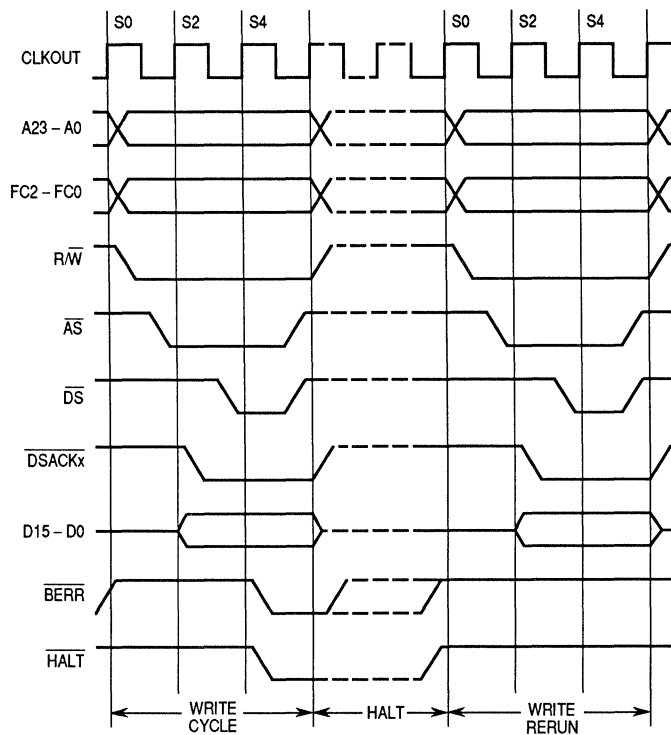


Figure 3-55. Late Retry Sequence

3.8.3 Halt Operation

When halt is asserted and \overline{BERR} is not asserted, the MCU halts external bus activity after negation of \overline{DSACKx} . The MCU may complete the current word transfer in progress. In a long-word to 8-bit transfer, this could be after bus cycle 2 or 4 (refer to Figure 3-8). On a word to 8-bit transfer, the activity would stop after bus cycle 2 (refer to Fig. 3-6). Negating and reasserting \overline{HALT} in accordance with the correct timing requirements provide a single-step (bus cycle to bus cycle) operation. The \overline{HALT} signal affects external bus cycles only, so a program not requiring the use of external bus may continue executing, unaffected by \overline{HALT} signal. Single-cycle mode allows the user to proceed through (and debug) external MCU operations a bus cycle at a time. Because occurrence of a bus error while \overline{HALT} is asserted causes a retry operation, retry cycles must be anticipated while debugging in single-cycle mode. In dynamically sized 8-bit transfers, external bus activity may not stop at the next cycle boundary. The single-step operation and the software trace capability allow the system debugger to trace single bus cycles, single instructions, or changes in program

flow. These MCU capabilities, with a software debugging package, provide debugging flexibility.

When the MCU completes a bus cycle with the $\overline{\text{HALT}}$ signal asserted, [D15:D0] is placed in the high-impedance state, and bus control signals are driven inactive (not high-impedance state); the address, function code, size, and read/write signals remain in the same state. The halt operation has no effect on bus arbitration (refer to **3.9 Bus Arbitration**). When bus arbitration occurs while the MCU is halted, the address and control signals are also placed in the high-impedance state. Once bus mastership is returned to the MCU, if $\overline{\text{HALT}}$ is still asserted, the address, function code, size, and read/write signals are again driven to their previous states. The MCU does not service interrupt requests while it is halted.

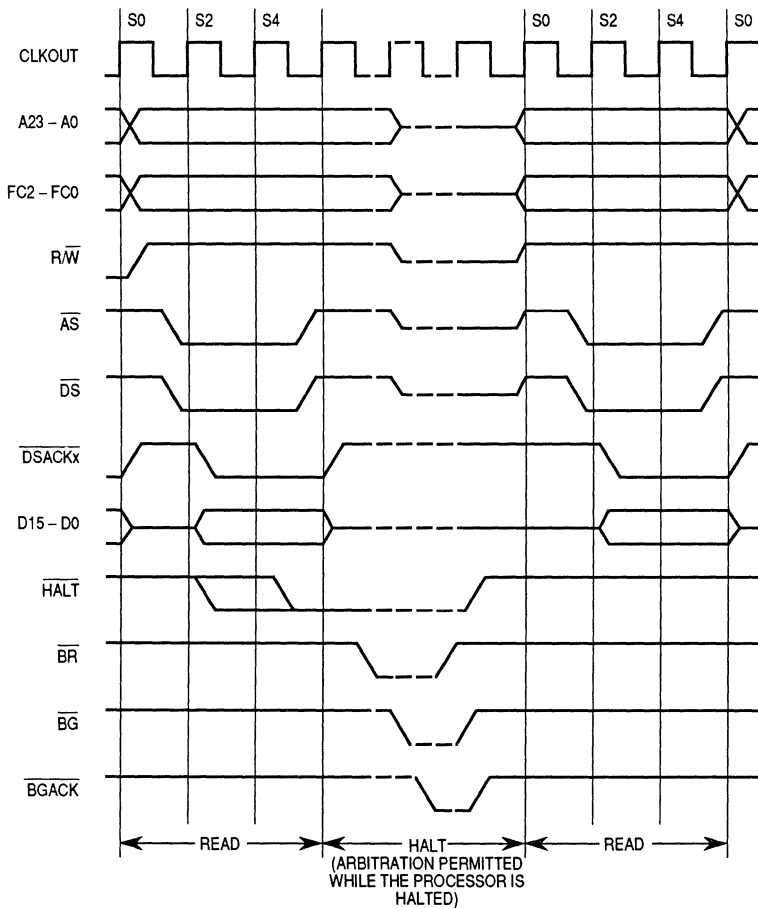


Figure 3-56. $\overline{\text{HALT}}$ Timing

3.8.4 Double Bus Fault

When a bus error or an address error occurs during the exception processing sequence for a previous bus error, a previous address error, a reset, or while the CPU is loading information from a bus error stack frame during a return from exception (RTE) instruction, a double bus fault occurs. For example, the MCU attempts to stack several words containing information about the state of the machine while processing a bus error exception. If a bus error exception occurs during the stacking operation, the second error is considered a double bus fault. When a double bus fault occurs, the MCU halts and drives the $\overline{\text{HALT}}$ line low. Only a reset operation can restart a halted MCU. However, bus arbitration can still occur (refer to **3.9 Bus Arbitration**). A second bus error or address error that occurs after exception processing has completed (during the execution of the exception handler routine, or later) does not cause a double bus fault. A bus cycle that is retried does not constitute a bus error or contribute to a double bus fault either. The MCU continues to retry the same bus cycle as long as the external hardware requests it.

Reset can also be generated internally by the halt monitor, described in **3.1.5.2 Halt Monitor**.

3.9 Bus Arbitration

The bus design of the MCU provides for a single bus master at any one time: either the MCU or an external device. One or more of the external devices on the bus has the capability to become bus master. Bus arbitration is the protocol by which an external device becomes bus master; the bus controller in the MCU manages the bus arbitration signals so that the MCU has the lowest priority. External devices that need to obtain the bus must assert the bus arbitration signals in the sequences described in the following paragraphs. Systems that include several devices that can become bus master require external circuitry to assign priorities to the devices, so that when two or more external devices attempt to become bus master at the same time, the one having the highest priority becomes bus master first. The sequence of the protocol is:

- a. An external device asserts the bus request signal ($\overline{\text{BR}}$);
- b. The MCU asserts the bus grant signal to indicate that the bus is available ($\overline{\text{BG}}$);
- c. The external device asserts the bus grant acknowledge ($\overline{\text{BGACK}}$) signal to indicate that it has assumed bus mastership.

$\overline{\text{BR}}$ may be issued any time during a bus cycle or between cycles. The bus grant ($\overline{\text{BG}}$) is asserted in response to $\overline{\text{BR}}$. *To guarantee operand coherency, $\overline{\text{BG}}$ is only asserted at the end of the operand transfer.* Additionally, $\overline{\text{BG}}$ is not asserted until the end of a read-modify-write operation (when $\overline{\text{RMC}}$ is negated) in response to a $\overline{\text{BR}}$ signal. When the requesting device receives $\overline{\text{BG}}$ and more than one

external device can be bus master, the requesting device should begin whatever arbitration is required. The external device asserts \overline{BGACK} when it assumes bus mastership, and maintains \overline{BGACK} during the entire bus cycle (or cycles) for which it is bus master. The following conditions must be met for an external device to assume mastership of the bus through the normal bus arbitration procedure:

- It must have received \overline{BG} through the arbitration process.
- \overline{BGACK} must be inactive, indicating that no other bus master has claimed ownership of the bus.

This technique allows processing of bus requests during data transfer cycles. Figure 3-56 is a flowchart showing the detail involved in bus arbitration for a single device. A timing diagram for the same operation is shown in SECTION 8 ELECTRICAL CHARACTERISTICS.

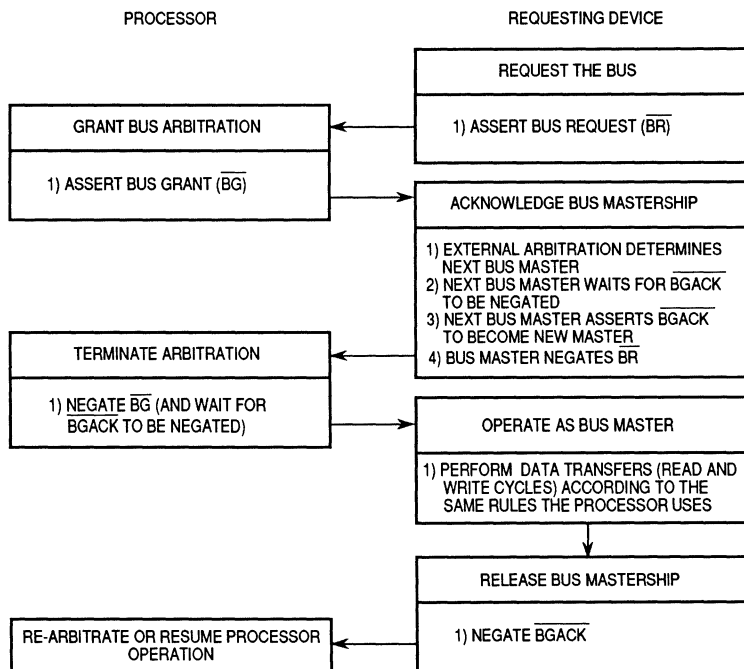


Figure 3-57. Bus Arbitration Flowchart for Single Request

The flowchart shows that \overline{BR} is negated at the time that \overline{BGACK} is asserted. This type of operation applies to a system consisting of the MCU and one device capable of bus mastership. In a system having a number of devices capable of

bus mastership, the bus request line from each device can be wire-ORed to the MCU. In such a system, more than one bus request could be asserted simultaneously. The timing diagram in **SECTION 8 ELECTRICAL CHARACTERISTICS** shows that \overline{BG} is negated a few clock cycles after the transition of the bus grant acknowledge signal. However, if bus requests are still pending after the negation of bus grant, the MCU asserts another bus grant within a few clock cycles after it was negated. This additional assertion of bus grant allows external arbitration circuitry to select the next bus master before the current bus master has finished with the bus. The following paragraphs provide additional information about the three steps in the arbitration process. Bus arbitration requests are recognized during normal processing, \overline{HALT} assertion, and when the CPU has halted due to a double bus fault.

3.9.1 Bus Request

External devices capable of becoming bus masters request the bus by asserting the \overline{BR} signal. This can be a wire-ORed signal that indicates to the MCU that some external device requires control of the bus. The MCU is effectively at a lower bus priority level than the external device and relinquishes the bus after it has completed the current bus cycle (if one has started). If no acknowledge is received while the bus request signal is active, the MCU remains bus master once the bus request is negated. This prevents unnecessary interference with ordinary processing if the arbitration circuitry inadvertently responds to noise or an external device determines that it no longer requires use of the bus before it has been granted mastership.

3.9.2 Bus Grant

This MCU supports operand coherency, so if an operand transfer requires multiple bus cycles, the MCU does not release the bus until the entire transfer is complete. The assertion of bus grant is, therefore, subject to the following constraints:

- The minimum time for \overline{BG} assertion after \overline{BR} is asserted depends on internal synchronization and is specified in **SECTION 8 ELECTRICAL CHARACTERISTICS**.
- During an external operand transfer, the MCU does not assert \overline{BG} until after the last cycle of the transfer (determined by the $SIZx$ and \overline{DSACKx} signals).
- During an external operand transfer, the MCU does not assert \overline{BG} as long as \overline{RMC} is asserted.
- If the show cycle bits are both asserted and the CPU is making internal accesses, the MCU does not assert \overline{BG} until the CPU finishes the internal transfers. Otherwise, the external bus is granted away and the CPU continues to execute internal bus transfers.

Externally, the \overline{BG} signal can be routed through a daisy-chained network or a priority-encoded network. The MCU is not affected by the method of arbitration as long as the protocol is obeyed.

3.9.3 Bus Grant Acknowledge

An external device cannot request and be granted the external bus while another device is the active bus master. A device that asserts \overline{BGACK} remains the bus master until it negates \overline{BGACK} and it should not be negated until all bus cycles required are completed. Bus mastership is terminated at the negation of \overline{BGACK} .

Once an external device receives the bus and \overline{BGACK} is asserted, it should negate \overline{BR} . If \overline{BR} remains asserted after \overline{BGACK} is asserted, the MCU assumes that another device is requesting the bus and prepares to issue another \overline{BG} .

Since external devices have priority over the MCU, the MCU cannot regain control of the external bus until all pending external bus requests have been satisfied.

3.9.4 Bus Arbitration Control

The bus arbitration control unit in the MCU is implemented with a finite-state machine. As discussed previously, all asynchronous inputs to the MCU are internally synchronized in a maximum of two cycles of the clock. As shown in Figure 3-57, input signals labeled R and A are internally synchronized versions of the bus request and bus grant acknowledge signals, respectively. The bus grant output is labeled G and the internal high-impedance control signal is labeled T. If T is true, the address, data, and control buses are placed in the high-impedance state after the next rising edge following the negation of \overline{AS} and the \overline{RMC} signal.

State changes occur on the next rising edge of the clock after the internal signal is valid. The \overline{BG} signal transitions on the falling edge of the clock after a state is reached during which G changes. The bus control signals (controlled by T) are driven by the MCU immediately following a state change, when bus mastership is returned to the MCU. State 0, in which G and T are both negated, is the state of the bus arbiter while the MCU is bus master. Request R and acknowledge A keep the arbiter in state 0 as long as they are both negated.

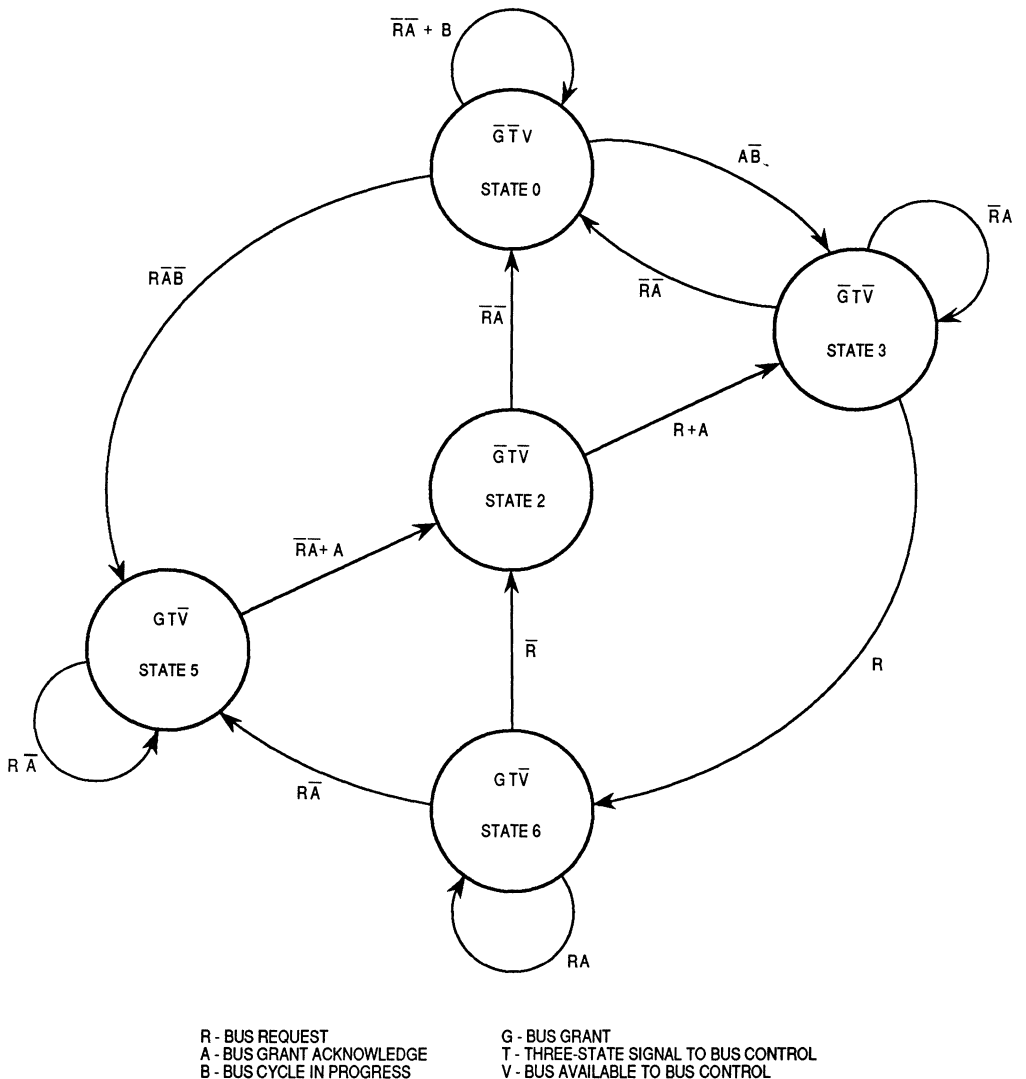


Figure 3-58. Bus Arbitration State Diagram

The MCU does not allow arbitration of the external bus during the \overline{RMC} sequence. For the duration of this sequence the MCU ignores the \overline{BR} input. If mastership of the bus is required during an \overline{RMC} operation, the bus error signal must be used to abort the \overline{RMC} sequence.

3.9.5 Slave Mode Arbitration

*Slave mode is used only for factory production testing of internal modules. It is not supported as a normal operating mode of the MCU. Applications using this MCU should avoid entering slave mode. **This Section is for information only.***

Slave mode is enabled when the SLVEN bit in the module configuration register (MCR) is set to one. This bit can only be set by driving $\overline{DB11}$ to a low state during reset. If SLVEN is set, the external bus interface (EBI) arbitrates for the internal bus whenever external bus arbitration occurs. When \overline{BG} is asserted, the MCU is in slave mode. After an external device gains control of the internal bus, it has full access to all the internal registers, allowing an external master to replace the CPU and functionally test the internal modules.

3.9.6 Show Cycles

The MCU can perform data transfers with its internal modules without using the external bus, but when debugging, it is desirable to have address and data information appear on the external bus. These external bus cycles are called show cycles, and are distinguished by the fact that \overline{AS} is not asserted externally.

After reset, show cycles are disabled and must be enabled by writing to the SHEN bits in the MCR. When show cycles are disabled, the address bus, function codes, size, and read/write signals continue to reflect internal bus activity, but \overline{AS} and \overline{DS} are not asserted externally and the external data bus is in a high-impedance state. When show cycles are enabled, \overline{AS} is not asserted but \overline{DS} is, and internal data is driven on the external data bus. Since internal cycles can continue to run when the external bus has been granted away, the SHEN bits allow the user to halt internal bus activity when the bus is granted away.

The following paragraphs are a state-by-state description of show cycles. Refer to **SECTION 8 ELECTRICAL CHARACTERISTICS** (Figure 8-4 Show Cycles Timing Diagram) for specific timing information.

State 0 — During state 0, the address and function codes become valid, $\overline{R/W}$ is driven to indicate a show read or write cycle, and the size pins indicate the number of bytes to transfer. During a read, the addressed peripheral is driving the data bus, and the user must take care to avoid bus conflicts.

State 41 — One-half clock cycle later, \overline{DS} is asserted to indicate that address information is valid.

State 42 — No action occurs in state 2. The bus controller remains in state 2 until the internal read cycle is complete.

State 43 — \overline{DS} is negated to indicate that show data is valid on the next falling edge of system clock. The external data bus drivers are enabled so that data becomes valid on the external bus as soon as it is available on the internal bus.

State 0 — The address, function codes, $\overline{R/W}$, and size pins change to begin the next cycle. Data from the preceding cycle is valid through state 0.

3.10 Reset Operation

The MCU has reset control logic to determine the cause of reset, synchronize it if necessary, and assert the appropriate reset lines. There are three different lines that the reset control logic can independently drive.

- EXTRST (external reset) drives the external reset pin.
- CLKRST (clock reset) resets the clock module.
- INTRST (internal reset) goes to all other internal circuits.

Table 3-4 summarizes the result of each reset source. Synchronous reset sources are not asserted until the end of the current bus cycle, whether \overline{RMC} is asserted or not. The internal bus monitor is automatically enabled for synchronous resets, and so if the current bus cycle does not terminate normally, the bus monitor terminates it. Only single byte or aligned word writes are guaranteed valid for synchronous resets. External writes are also guaranteed to complete, provided the external configuration logic on the data bus is conditioned by $\overline{R/W}$ as shown in Figure 3-58. Asynchronous reset sources indicate a catastrophic failure, and the reset controller asserts reset to the system immediately.

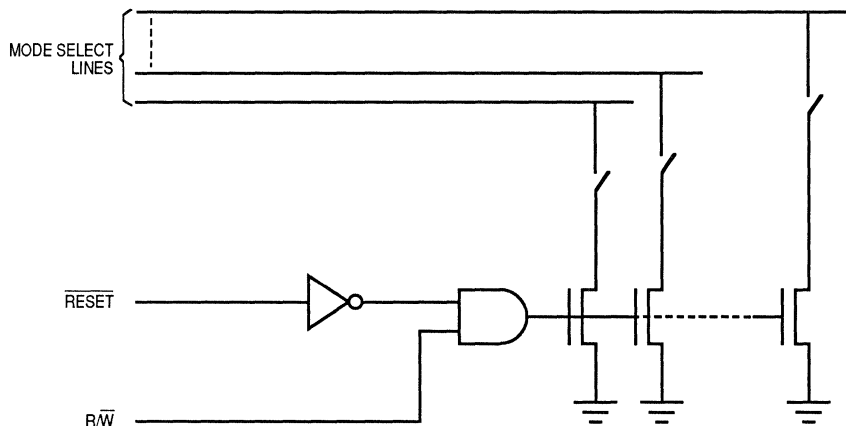


Figure 3-59. Mode Select Conditioning for Reset Operation

If an external device drives the $\overline{\text{RESET}}$ pin low, the reset control logic holds reset asserted internally until the external $\overline{\text{RESET}}$ is released. When the reset control logic detects that the external $\overline{\text{RESET}}$ is no longer being driven, it drives reset low for an additional 512 cycles to guarantee this length of reset to the entire system.

If reset is asserted from any other source, the reset control logic asserts $\overline{\text{RESET}}$ for a minimum of 512 cycles and until the source of reset is negated.

Table 3-30. Reset Source Summary

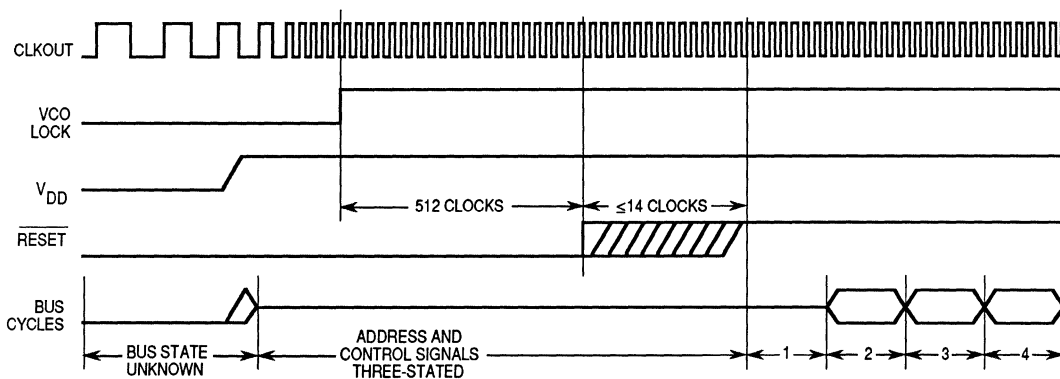
Type	Source	Timing	Reset Lines Asserted by Controller		
EXT (External)	External	Synchronous	INTRST	CLKRST	EXTRST
POW (Power-Up)	EBI	Asynchronous	INTRST	CLKRST	EXTRST
SW (Software Watchdog)	Sys Prot	Asynchronous	INTRST	CLKRST	EXTRST
HLT (Halt)	Sys Prot	Asynchronous	INTRST	CLKRST	EXTRST
LOC (Loss of Clock)	Clock	Synchronous	INTRST	CLKRST	EXTRST
TST (Test)	Test	Synchronous	INTRST		EXTRST
SYS (System)	CPU	Asynchronous			EXTRST

After any internal reset occurs, a 14-cycle rise time is allowed before testing for the presence of an externally asserted reset. If no external reset is detected, the CPU begins its vector fetch.

Figure 3-59 is a timing diagram of the power-up reset operation, showing the relationships between $\overline{\text{RESET}}$, V_{DD} , and bus signals. During the reset period, the entire bus (except for non-three-statable signals, which are driven to their inactive state) three-states. Once $\overline{\text{RESET}}$ negates, all control signals are driven to their inactive state, the data bus is in read mode, and the address bus is driven. After this, the first bus cycle for $\overline{\text{RESET}}$ exception processing begins.

$\overline{\text{RESET}}$ should be asserted for at least 590 clock periods to ensure that the MCU resets. Asserting $\overline{\text{RESET}}$ for 10 clock periods is sufficient for resetting the MCU logic; the additional clock periods prevent a reset instruction from overlapping the external $\overline{\text{RESET}}$ signal. Resetting the MCU causes any bus cycle in progress to terminate as if $\overline{\text{DSACKx}}$ or $\overline{\text{BERR}}$ had been asserted. In addition, the MCU initializes registers appropriately for a reset exception.

When a reset instruction is executed, the MCU drives the $\overline{\text{RESET}}$ signal for 512 clock cycles. In this case, the MCU resets the external devices (if they are configured to respond to $\overline{\text{RESET}}$) of the system, and the internal registers of the MCU are unaffected. The external devices connected to the $\overline{\text{RESET}}$ signal are reset at the completion of the reset instruction.



NOTES:

1. Internal start up time
2. SSP read here
3. PC read here
4. First instruction fetched here

Figure 3-60. Initial Reset Operation Timing

3.11 Test Submodule

*The test submodule is only used for factory production testing of the MCU. It is not intended for general use and is not supported for normal applications. The description of the test submodule contained in this manual is for **informational purposes only** and is not intended to provide operational information. Applications using this MCU should avoid invoking the test features of this submodule.*

3.11.1 Entering Test Mode

Test mode is entered by a combination hardware and software method: a register bit must be set while an external pin is in the correct state. To enter test mode, the following conditions must be met:

- The TSTME pin (test mode enabled — active low) must be pulled low.
- The enter test mode (ETM) bit in the test submodule control register (CREG) must be set. This is a write-once bit, so it must not have been written since reset, and it must be set to one on the first attempt to write it. Writing the bit to zero in initialization software prevents any accidental entry to test mode in normal operation.

The TSTME pin must remain low to stay in test mode. If TSTME goes high while the MCU is in test mode, the MCU is reset, exiting test mode.

The TSTME pin has a second function: when driven to 1.6 times V_{DD} , the MCU places all output driver circuits in a high-impedance state, isolating the MCU from the remainder of the system.

3.11.2 Test Submodule Control Register (CREG)

The test submodule control register (Figure 3-60) configures the test submodule for the test operation desired, provides the bus master with the means for controlling the test sequence, and retains status information on the test submodule.

CREG — Test Submodule Control Register **\$YFFA38**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BUSY	TMARM	COMP	IMBTST	CPUTR	QBIT	MUXEL	—	—	—	—	ACUT	SCONT	SSHOP	SATO	ETM

RESET:

1	<u>TSTME</u>	U	0	0	0	0	0	0	0	0	0	0	0	0	0
---	--------------	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Figure 3-61. Test Submodule Control Register

ETM — Enter Test Mode

- 1 = Enter test mode
- 0 = Stay in normal mode

This bit can be written only once after reset. It can be set only if the TSTME pin is asserted. This bit can be read at any time.

SATO — Start Automatic Test Operation

- 1 = Start an automatic test operation
- 0 = Stay in normal mode

This bit can be read and written at any time.

SSHOP — Start Shifting Operation

- 1 = Start a shifting operation
- 0 = Stay in normal mode

This bit can be read and written at any time.

SCONT — Start Continuous Operation

- 1 = Start continuous operation
- 0 = Stop continuous operation

This bit can be read and written at any time.

ACUT — Activate Circuit Under Test

1 = Assert the ACUTL line

0 = Stay in normal mode

This bit can be written at any time, but always reads zero because it clears in less than a bus cycle.

MUXSEL — Multiplexer Select Bit

1 = Shift in source for master shift register B (MSRB) is the external interrupt pin

0 = Shift in source for MSRB is the internal test line

This bit can be written only in test mode.

QBIT — Quotient Bit

1 = The least significant bit of master shift register B is available at the quotient/freeze (FREEZE/QUOT) pin

0 = The internal freeze status is available at the FREEZE/QUOT pin

This bit can be read and written only in test mode.

CPUTR — CPU Test Register

1 = Scan lines connected to the CPU test register

0 = Scan lines disconnected from the CPU test register

This bit can be written only in test mode, but read at any time.

IMBTST — Intermodule Bus Test

1 = Internal interconnect lines are configured as test lines

0 = Internal interconnect lines have normal function

This bit can be read and written only in test mode.

COMP — Compare Status Bit

1 = Master shift register B contains the correct answer for the user self-test basic test

0 = Master shift register B does not contain the correct answer for the user self-test basic test

This status bit can be read at any time, but cannot be written.

TMARM — Test Mode Armed Status Bit

1 = TSTME pin is asserted; test mode can be entered by setting the ETM control bit

0 = TSTME pin is negated; test mode cannot be entered

This status bit can be read at any time, but cannot be written.

BUSY — Test Submodule Busy Status Bit

1 = Test submodule is busy

0 = Test submodule is not busy

Busy indicates a test function is in progress. This status bit can be read at any time, but cannot be written.

3.11.3 Distributed Register (DREG)

The distributed register configures the master shift registers during factory production tests.

DREG — Distributed Register

\$YFFFA3A

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
—	—	—	—	—	WAIT3	WAIT2	WAIT1	MSRA18	MSRA17	MSRA16	MSRAC	MSRB18	MSRB17	MSRB16	MSRBC
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3-62. Distributed Register

WAIT3–WAIT1 — Wait Counter Preset 3–1

These bits program the delay time between automatic test sequences. These bits can be read or written at any time.

MSRA18–MSRA16 — Master Shift Register A Bits 18–16

These bits are the three most significant bits of master shift register A. These bits can be read or written at any time.

MSRAC — Master Shift Register A Configuration

This bit can be read or written at any time.

MSRB18–MSRB16 — Master Shift Register B Bits 18–16

These bits are the upper three bits of master shift register B. These bits can be read or written at any time.

MSRBC — Master Shift Register B Configuration

This bit can be read or written at any time.

3.11.4 Master Shift Register A (MSRA)

Master shift register A can be read and written by the bus master. Reset does not affect contents of master shift register A.

3.11.5 Shift Count Register A

Shift count register A is an 8-bit shift register that can be read and written by the bus master. After reset, shift count register A is initialized to zero.

3.11.6 Master Shift Register B (MSRB)

Master shift register B can be read and written by the bus master. Reset does not affect the contents of master shift register B.

As a simple shift register, test responses are manually shifted to master shift register B from the module under test. This uncompressed data can then be read 16 bits at a time by the bus master.

3.11.7 Shift Count Register B

Shift count register B is an 8-bit shift register that can be read and written by the bus master. After reset, shift count register B is initialized to zero.

3.11.8 Reps Counter

After reset, the reps counter is set to zero.

SECTION 4 CPU32 OVERVIEW

This section is an overview of the CPU32. Refer to the CPU32 reference manual for a complete description of the capabilities and functions of this module.

The CPU32, the instruction processing module of the M68300 Family, is based on the industry-standard MC68000 core processor with many features of the MC68010 and MC68020 as well as unique features suited for high-performance controller applications. The CPU32 is designed to provide a significant increase in performance over the MC68HC11 CPU to meet the demand for higher performance requirements for the 1990's, while maintaining source code and binary code compatibility with the M68000 Family.

One major goal of the CPU32 is to increase system throughput. This increase could not be achieved by simply increasing the clock/bus frequency or by adding a few new instructions to an existing 8-bit, MC6800-type CPU. A faster, more powerful CPU, capable of processing data sizes up to 32 bits, has been included on the chip as a first step in realizing such a performance increase. As controller applications become more complex and control programs become larger, high-level languages (HLLs) will become the system designer's choice in programming languages. HLLs allow users to develop complex algorithms faster, with few errors, and they provide easier portability. The CPU32 has an instruction set based on the M68000 Family, which can efficiently support HLLs.

Ease of programming is an important consideration in using a microcontroller. An instruction format implementing a register-memory interaction philosophy predominates in the design, and all data resources are available to all operations requiring those resources. All eight multifunction data registers are available as data resources, and all seven general-purpose addressing registers are available for addressing data. Although the program counter (PC) and stack pointers (SP) are special-purpose registers, they are also available for most data addressing activities. The eight general-purpose data registers readily support 8-bit (byte), 16-bit (word), and 32-bit (long-word) operand lengths for all operations. Address manipulation is supported by word and long-word operations. Ease of program checking and diagnosis is further enhanced by trace and trap capabilities at the instruction level.

4.1 Features

Features of the CPU32 are as follows:

- Fully Upward Object Code Compatible with M68000 Family
- Virtual Memory Implementation
- Loop Mode of Instruction Execution
- Fast Multiply, Divide, and Shift Instructions
- Fast Bus Interface with Dynamic Bus Port Sizing
- Improved Exception Handling for Controller Applications
- Enhanced Addressing Modes
 - Scaled Index
 - Address Register Indirect with Base Displacement and Index
 - Expanded PC Relative Modes
 - 32-Bit Branch Displacements
- Instruction Set Enhancements
 - High-Precision Multiply and Divide
 - Trap on Condition Codes
 - Upper and Lower Bounds Checking
 - Enhanced Breakpoint Instruction
- Trace on Change of Flow
- Table Lookup and Interpolate Instruction
- Low Power Stop Instruction
- Hardware Breakpoint Signal, Background Mode
- 16.78-MHz Operating Frequency at -40 to 125°C
- Fully Static Implementation

4

4.2 Architecture Summary

The CPU32 architecture includes several important features that provide both power and versatility to the user. The CPU32 is source and object code compatible with the MC68000 and MC68010. All user-state programs can be executed unchanged. The major CPU32 features are as follows:

- 32-Bit Internal Data Path and Arithmetic Hardware
- 32-Bit Internal Address Bus — 24-Bit External Address Bus on the MC68331
- Rich Instruction Set
- Eight 32-Bit General-Purpose Data Registers
- Seven 32-Bit General-Purpose Address Registers
- Separate User and Supervisor Stack Pointers and Address Spaces
- Separate Program and Data Address Spaces
- Flexible Addressing Modes
- Full Interrupt Processing

4.2.1 Programmer's Model

The programming model of the CPU32 consists of two groups of registers: user model and supervisor model, which correspond to the user and supervisor privilege levels. Executing at the user privilege level, user programs can use only the registers of the user model. Executing at the supervisor level, system software uses the control registers of the supervisor level to perform supervisor functions.

As shown in the programming models (refer to Figures 4-1 and 4-2), the CPU32 has sixteen 32-bit general-purpose registers, a 32-bit program counter, one 32-bit supervisor stack pointer, a 16-bit status register, two alternate function code registers, and a 32-bit vector base register. The user programming model remains unchanged from previous M68000 Family microprocessors. The supervisor programming model, which supplements the user programming model, is used exclusively by the CPU32 system programmers who utilize the supervisor privilege level to implement sensitive operating system functions. The supervisor programming model contains all the controls to access and enable the special features of the CPU32. Application software, written to run at the nonprivileged user level, migrates without modification to the CPU32 from any M68000 platform. The Move From SR instruction, however, is privileged in the CPU32. It is not privileged in the MC68000.

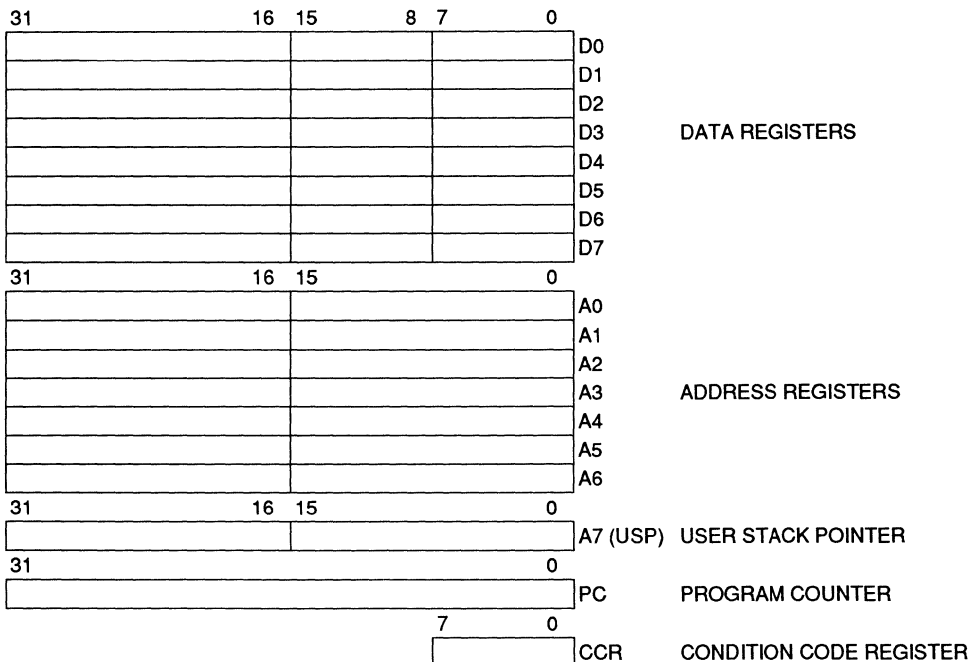


Figure 4-1. User Programming Model

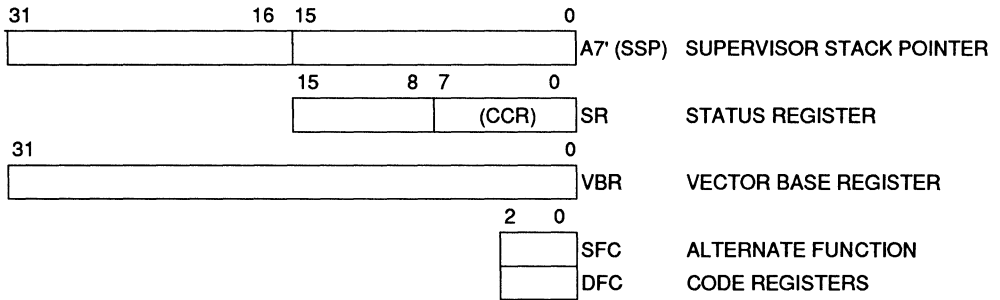


Figure 4-2. Supervisor Programming Model Supplement

4.2.2 Registers

Registers D7–D0 are used as data registers for bit (1–32 bits), byte (8-bit), word (16-bit), long-word (32-bit), and quad-word (64-bit) operations. Registers A6–A0 and the user and supervisor stack pointers are address registers that can be used as software stack pointers or base address registers. Register A7 is a register designation that applies to the user stack pointer in the user privilege level and to the supervisor stack pointer in the supervisor privilege level. In addition, the address registers may be used for word and long-word operations. All of the 16 general-purpose registers (D7–D0, A7–A0) can be used as index registers.

The PC contains the address of the next instruction to be executed by the CPU32. During instruction execution and exception processing, the processor automatically increments the contents of the PC or places a new value in the PC as appropriate.

The status register (SR) (Figure 4-3) stores the processor status. It contains the condition codes that reflect the results of a previous operation and can be used for conditional instruction execution in a program. The condition codes are extend (X), negative (N), zero (Z), overflow (V), and carry (C). The user byte containing the condition codes is the only portion of the SR information available at the user privilege level; it is referenced as the condition code register (CCR) in user programs. At the supervisor privilege level, software can access the full status register, including the interrupt priority mask (three bits), as well as additional control bits. These bits put the processor in one of two trace modes (T1, T0) and in user or supervisor privilege level.

SR — Status Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T1	T0	S	0	0	I2	I1	I0	0	0	0	X	N	Z	V	C
RESET:															
0	0	1	0	0	1	1	1	0	0	0	U	U	U	U	U

Figure 4-3. Status Register

System Byte

T1–T0 — Trace Enable

S — Supervisor/User State

Bits 12–11 — Unimplemented

I2–I0 — Interrupt Priority Mask

User Byte (Condition Code Register)

Bits 7–5 — Unimplemented

X — Extend

N — Negative

Z — Zero

V — Overflow

C — Carry

The vector base register (VBR) contains the base address of the exception vector table in memory. The displacement of an exception vector is added to the value in this register to access the vector table.

Alternate function code registers (SFC and DFC) contain 3-bit function codes. Function codes can be considered extensions of the 24-bit linear address that optionally provide as many as eight 16 Mbyte address spaces. Function codes are automatically generated by the processor to select address spaces for data and programs at the user and supervisor privilege levels and to select a CPU address space used for processor functions (such as breakpoint and interrupt acknowledge cycles). Registers SFC and DFC are used by the MOVES instructions to specify explicitly the function codes of the memory address.

4.2.3 Data Types

Six basic data types are supported:

- Bits
- Packed Binary-Coded Decimal Digits
- Byte Integers (8 bits)
- Word Integers (16 bits)
- Long-Word Integers (32 bits)
- Quad-Word Integers (64 bits)

4.2.3.1 Organization in Registers

The eight data registers can store data operands of 1, 8, 16, 32, and 64 bits and addresses of 16 or 32 bits. The seven address registers and the two stack pointers are used for address operands of 16 or 32 bits. The PC is 32 bits wide.

4.2.3.1.1 Data Registers

Each data register is 32 bits wide. Byte operands occupy the low-order 8 bits; word operands, the low-order 16 bits; and long-word operands, the entire 32 bits. When a data register is used as either a source or destination operand, only the appropriate low-order byte or word (in byte or word operations, respectively) is used or changed; the remaining high-order portion is neither used nor changed. The least significant bit (LSB) of a long-word integer is addressed as bit zero, and the most significant bit (MSB) is addressed as bit 31. Figure 4-4 shows the organization of various types of data in the data registers.

Quad-word data consists of two long words, used only by the product of 32-bit multiply or the dividend of 32-bit divide operations (signed and unsigned). Quad-words may be organized in any two data registers without restrictions on order or pairing. There are no explicit instructions for the management of this data type, although the MOVEM instruction can be used to move a quad-word into or out of the registers.

Binary-coded decimal (BCD) data represents decimal numbers in binary form. Although many BCD codes have been devised, the BCD instructions of the M68000 Family support formats in which the four LSBs consist of a binary number having the numeric value of the corresponding decimal number. In this BCD format, a byte contains two digits; the four LSBs contain the least significant digit, and the four MSBs contain the most significant digit. ABCD, SBCD, and NBCD operate on two BCD digits packed into a single byte.

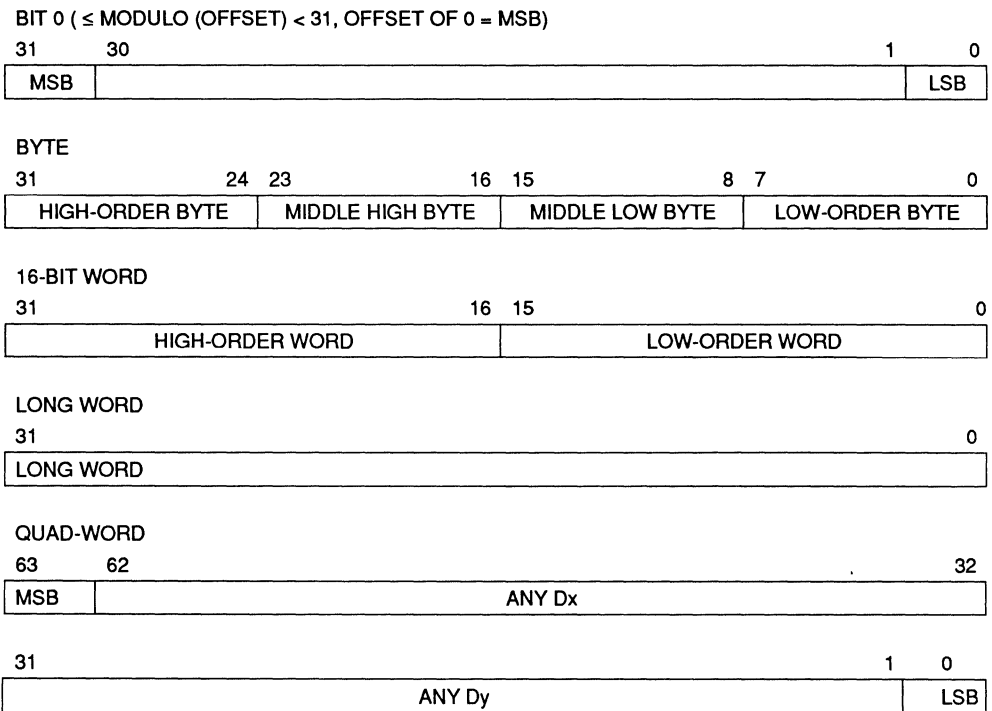


Figure 4-4. Data Organization in Data Registers

4.2.3.1.2 Address Registers

Each address register and stack pointer is 32 bits wide and holds a 32-bit address. Address registers cannot be used for byte-sized operands. Therefore, when an address register is used as a source operand, either the low-order word or the entire long-word operand is used, depending upon the operation size. When an address register is used as the destination operand, the entire register is affected, regardless of the operation size. If the source operand is a word size, it is first sign-extended to 32 bits, and then used in the operation to an address register destination. Address registers are used primarily for addresses and to support address computation. The instruction set includes instructions that add to, subtract from, compare, and move the contents of address registers. Figure 4-5 shows the organization of addresses in address registers.

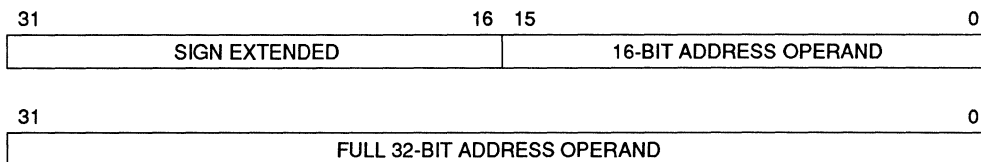


Figure 4-5. Address Organization in Address Registers

4.2.3.1.3 Control Registers

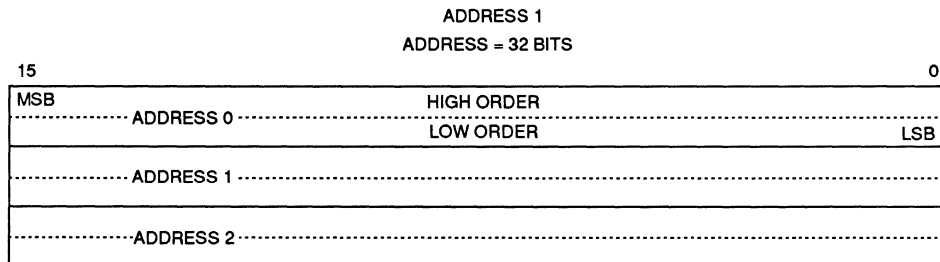
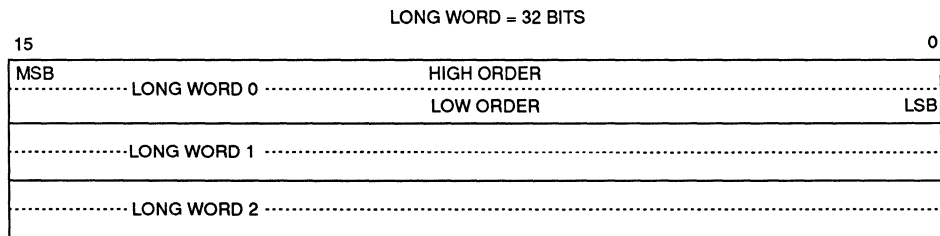
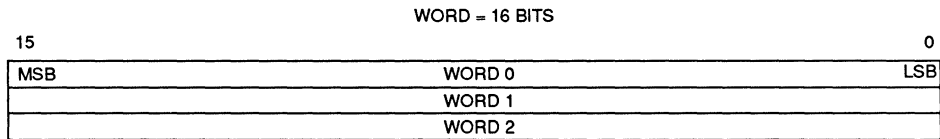
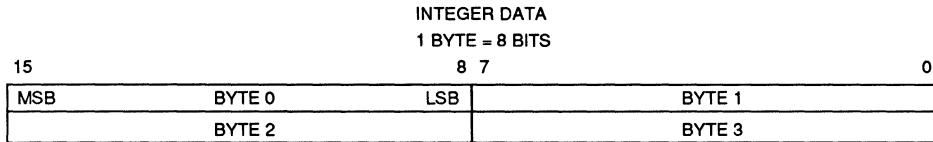
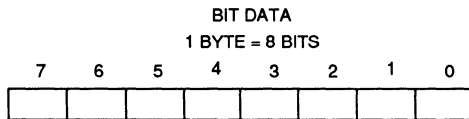
The control registers described in this section contain control information for supervisor functions and vary in size. With the exception of the user portion of the SR (the CCR), they are accessed only by instructions at the supervisor privilege level.

The SR shown in Figure 4-3 is 16 bits wide. Only 11 bits of the SR are defined; all undefined values are reserved by Motorola for future definition. The undefined bits are read as zeros and should be written as zeros for future compatibility. The lower byte of the SR is the CCR. Operations to the CCR can be performed at the supervisor or user privilege level. All operations to the SR and CCR are word-size operations, but for all CCR operations, the upper byte is read as all zeros and is ignored when written, regardless of privilege level.

The SFC and DFC are 32-bit registers with only bits [2:0] implemented which contain the address space values [FC2:FC0] for the read or write operand of the MOVES instruction. The MOVEC instruction is used to transfer values to and from the alternate function code registers. These are long-word transfers; the upper 29 bits are read as zeros and are ignored when written.

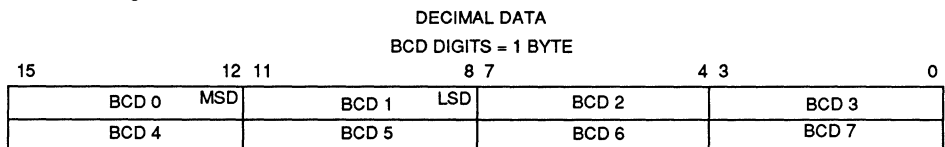
4.2.3.2 Organization in Memory

Memory is organized on a byte-addressable basis in which lower addresses correspond to higher order bytes. The address N of a long-word data item corresponds to the address of the most significant byte of the highest order word. The lower order word is located at address N + 2, leaving the least significant byte at address N + 3. The CPU32 requires long-word and word data as well as instruction words to be aligned on word boundaries (refer to Figure 4-6). Data misalignment is not supported.



MSB = Most Significant Bit

LSB = Least Significant Bit



MSD = Most Significant Digit

LSD = Least Significant Digit

Figure 4-6. Memory Operand Addressing

4.3 System Features

The CPU32 includes a number of features that aid system implementation. These features include a privilege mechanism, separation of address spaces, multilevel priority interrupts, trap instructions, and a trace facility.

The privilege mechanism provides user and supervisor privilege states, privileged instructions, and external distinction of user and supervisor state references. The processor separates references between program and data space. This permits sharing of code segments that access separate data segments.

The CPU32 supports seven priority levels for 199 memory-vectorized interrupts. For each interrupt, the vector location can be provided externally or generated internally. The seventh level provides a nonmaskable interrupt capability.

To simplify system development, instructions are provided to check internal processor conditions and allow software traps. The trace facility allows instruction by instruction tracing of program execution without alteration of the program or special hardware. The following subsections describe the actions of the processor that are outside the normal processing associated with the execution of instructions.

4.3.1 Virtual Memory

The full addressing range of the CPU32 on the MC68331 is 16 Mbyte in each of eight address spaces. Even though most systems implement a smaller physical memory, the system can be made to appear to have a full 16 Mbyte of memory available to each user program by using virtual memory techniques.

A system that supports virtual memory has a limited amount of high-speed physical memory that can be accessed directly by the processor and maintains an image of a much larger virtual memory on a secondary storage device. When the processor attempts to access a location in the virtual memory map that is not resident in physical memory, a page fault occurs. The access to that location is temporarily suspended while the necessary data is fetched from secondary storage and placed in physical memory. The suspended access is then restarted or continued.

The CPU32 uses instruction restart, which requires that only a small portion of the internal machine state be saved. After correcting the fault, the machine state is restored, and the instruction is fetched and started again. This process is completely transparent to the application program.

4.3.2 Loop Mode Instruction Execution

The CPU32 has several features that provide efficient execution of program loops. One of these features is the DBcc looping primitive instruction. To increase the performance of the CPU32, a loop mode has been added to the processor. The loop mode is used by any single word instruction that does not change the program flow. Loop mode is implemented in conjunction with the DBcc instruction. Figure 4-7 shows the required form of an instruction loop for the processor to enter loop mode.

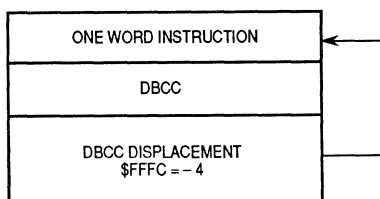


Figure 4-7. Loop Mode Instruction Sequence

The loop mode is entered when the DBcc instruction is executed, and the loop displacement is -4 . Once in loop mode, the processor performs only the data cycles associated with the instruction and suppresses all instruction fetches. The termination condition and count are checked after each execution of the data operations of the looped instruction. The CPU32 automatically exits the loop mode on interrupts or other exceptions. Loopable instructions consist of all single word instructions that do not cause a change of flow.

4.3.3 Vector Base Register (VBR)

The VBR (Figure 4-8) contains the base address of the 1024-byte exception vector table, consisting of 256 exception vectors. Exception vectors contain the memory addresses of routines that begin execution at the completion of exception processing. These routines perform a series of operations appropriate for the corresponding exceptions. Because the exception vectors contain memory addresses, each consists of one long-word, except for the reset vector. The reset vector consists of two long-words: the address used to initialize the supervisor stack pointer, and the address used to initialize the program counter.

The address of an interrupt exception vector is derived from an 8-bit vector number and the VBR. The vector numbers for some exceptions are obtained from an external device; other numbers are supplied automatically by the processor. The processor multiplies the vector number by four to calculate the

vector offset, which is added to the VBR. The sum is the memory address of the vector. All exception vectors are located in supervisor data space, except the reset vector, which is located in supervisor program space. Only the initial reset vector is fixed in the processor's memory map; once initialization is complete, there are no fixed assignments. Since the VBR provides the base address of the vector table, the vector table can be located anywhere in memory; it can even be dynamically relocated for each task that is executed by an operating system. Details of exception processing are provided in the section on exception processing in the CPU manual.

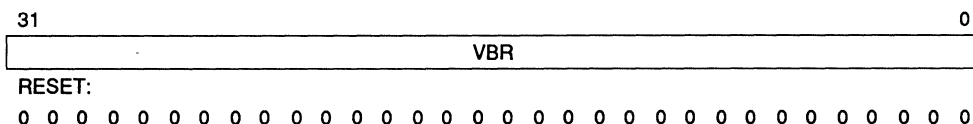


Figure 4-8. Vector Base Register

4.3.4 Exception Processing

The processing of an exception occurs in four steps, with variations for different exception causes. During the first step, a temporary internal copy of the status register is made, and the status register is set for exception processing. During the second step, the exception vector is determined; during the third step, the current processor context is saved. During the fourth step, a new context is obtained, and the processor then proceeds with instruction processing.

Exception processing saves the most volatile portion of the current context by pushing it on the supervisor stack. This context is organized in a format called the exception stack frame. This information always includes the status register and PC content of the processor when the exception occurred. To support generic handlers, the processor places the vector offset in the exception stack frame. The processor also marks the frame with a frame format. The format field allows the return from exception (RTE) instruction to identify what information is on the stack so that it can be properly restored.

4.3.5 Processing States

The processor is always in one of four processing states: normal, exception, halted, or background. The normal processing state is associated with instruction execution; the bus is used to fetch instructions and operands and to store results. The exception processing state is associated with interrupts, trap instructions, tracing, and other exception conditions. The exception may be internally generated explicitly by an instruction or by an unusual condition arising

during the execution of an instruction. Externally, exception processing can be forced by an interrupt, a bus error, or a reset. The halted processing state is an indication of catastrophic hardware failure. For example, if during the exception processing of a bus error another bus error occurs, the processor assumes that the system is unusable and halts. The background processing state is initiated by breakpoints, execution of special instructions, or a double bus fault; it must be enabled by pulling $\overline{\text{BKPT}}$ low during $\overline{\text{RESET}}$. Background processing allows interactive debugging of the system via a simple serial interface.

4.3.6 Privilege States

The processor operates at one of two levels of privilege — user or supervisor. The supervisor level has higher privileges than the user level. Not all instructions are permitted to execute in the lower privileged user level, but all instructions are available at the supervisor level. This scheme allows a separation of supervisor and user levels, so the supervisor can protect system resources from uncontrolled access. The processor uses the privilege level indicated by the S bit in the status register to select either the user or supervisor privilege level and either the USP or an SSP for stack operations.

4.3.7 Block Diagram

A block diagram of the CPU32 is shown in Figure 4-9. The major blocks depicted operate in a highly independent fashion that maximizes concurrency of operation while managing the essential synchronization of instruction execution and bus operation. The bus controller loads instructions from the data bus into the decode unit. The sequencer and control unit provide overall chip control, managing the internal buses, registers, and functions of the execution unit.

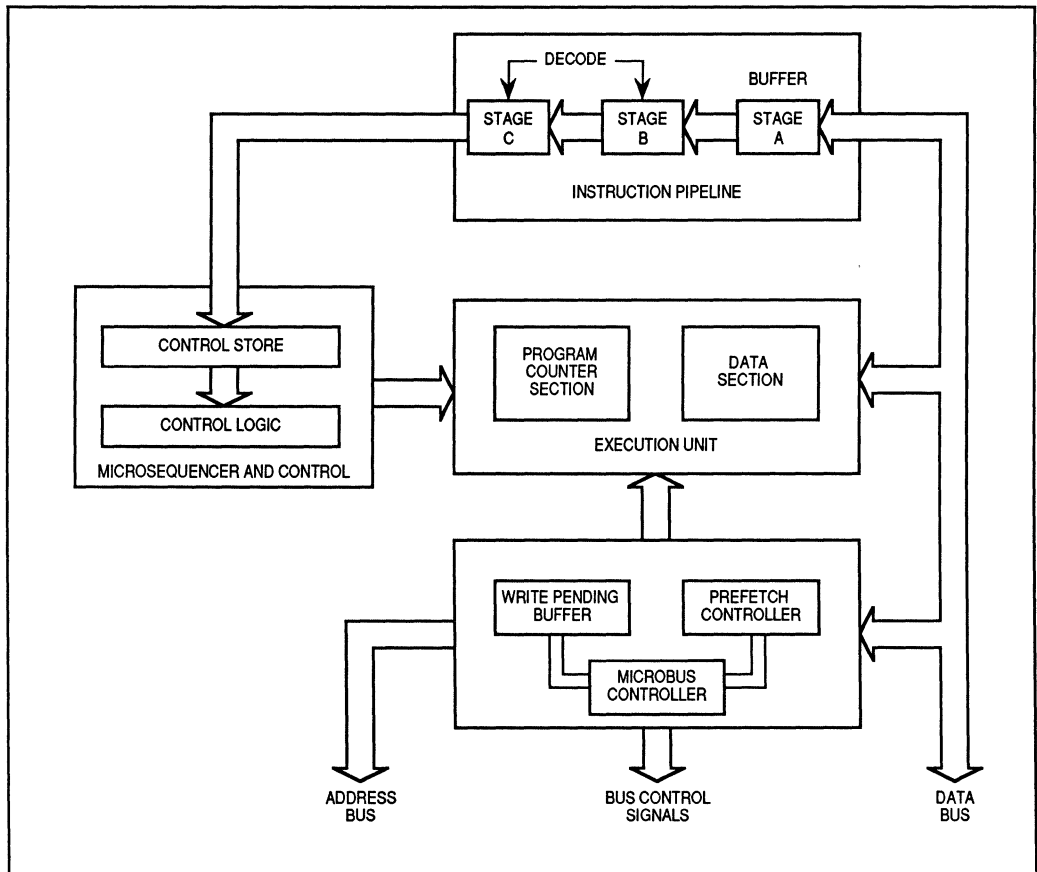


Figure 4-9. CPU32 Block Diagram

4.4 Addressing Modes

Addressing in the CPU32 is register-oriented. Most instructions allow the results of the specified operation to be placed either in a register or directly in memory; this flexibility eliminates the need for extra instructions to store register contents in memory.

The seven basic addressing modes are as follows:

- Register Direct
- Register Indirect
- Register Indirect with Index
- Program Counter Indirect with Displacement
- Program Counter Indirect with Index
- Absolute
- Immediate

Included in the register indirect addressing modes are the capabilities to postincrement, predecrement, and offset. The program counter relative mode also has index and offset capabilities. In addition to these addressing modes, many instructions implicitly specify the use of the status register, stack pointer, and/or program counter.

4.5 Instructions

The instruction set of the CPU32 is very similar to that of the MC68020 (refer to Table 4-1). Two new instructions have been added to facilitate controller applications — low-power stop (LPSTOP) and table lookup and interpolate (TBL5, TBL5N, TBLU, TBLUN). The following MC68020 instructions are not implemented on the CPU32:

BFxxx	— Bit Field Instructions (BFCHG, BFCLR, BFEXTS, BFEXTU, BFFFO, BFINS, BFSET, BFTST)
CALLM, RTM	— Call Module, Return Module
CAS, CAS2	— Compare and Swap (Read-Modify-Write Instructions)
cpxxx	— Coprocessor Instructions (cpBcc, cpDBcc, cpGEN, cpRESTORE, cpSAVE, cpScc, cpTRAPcc)
PACK, UNPK	— Pack, Unpack BCD Instructions
Memory	— Memory Indirect Addressing Modes

The CPU32 traps on unimplemented instructions or illegal effective addressing modes, allowing user-supplied code to emulate unimplemented capabilities or to define special purpose functions. However, Motorola reserves the right to use all currently unimplemented instruction operation codes for future M68000 core enhancements.

4.5.1 M68000 Family Compatibility

It is the philosophy of the M68000 Family that all user-mode programs can execute unchanged on a more advanced processor, and supervisor-mode programs and exception handlers should require only minimal alteration.

The CPU32 can be thought of as an intermediate member of the M68000 Family. Object code from an MC68000 or MC68010 may be executed on the CPU32, and many of the instruction and addressing mode extensions of the MC68020 are also supported. Refer to the CPU32 reference manual for a detailed comparison of the CPU32 and MC68020 instruction set.

Table 4-1. Instruction Set Summary

Mnemonic	Description
ABCD ADD ADDA ADDI ADDQ ADDX AND ANDI ASL, ASR	Add Decimal with Extend Add Add Address Add Immediate Add Quick Add with Extend Logical AND Logical AND Immediate Arithmetic Shift Left and Right
Bcc BCHG BCLR BGND BKPT BRA BSET BSR BTST	Branch Conditionally Test Bit and Change Test Bit and Clear Background Breakpoint Branch Test Bit and Set Branch to Subroutine Test Bit
CHK, CHK2 CLR CMP CMPA CMPI CMPM CMP2	Check Register Against Upper and Lower Bounds Clear Compare Compare Address Compare Immediate Compare Memory to Memory Compare Register Against Upper and Lower Bounds
DBcc DIVS, DIVSL DIVU, DIVUL	Test Condition, Decrement and Branch Signed Divide Unsigned Divide
EOR EORI EXG EXT, EXTB	Logical Exclusive OR Logical Exclusive OR Immediate Exchange Registers Sign Extend
LEA LINK LPSTOP LSL, LSR	Load Effective Address Link and Allocate Low Power Stop Logical Shift Left and Right
ILLEGAL	Take Illegal Instruction Trap
JMP JSR	Jump Jump to Subroutine

Mnemonic	Description
MOVE MOVE CCR MOVE SR MOVE USP MOVEA MOVEC MOVEM MOVEP MOVEQ MOVES	Move Move Condition Code Register Move Status Register Move User Stack Pointer Move Address Move Control Register Move Multiple Registers Move Peripheral Move Quick Move Alternate Address Space
MULS, MULS.L MULU, MULU.L	Signed Multiply Unsigned Multiply
NBCD NEG NEGX NOP	Negate Decimal with Extend Negate Negate with Extend No Operation
OR ORI	Logical Inclusive OR Logical Inclusive OR Immediate
PEA	Push Effective Address
RESET ROL, ROR ROXL, ROXR	Reset External Devices Rotate Left and Right Rotate with Extend Left and Right
RTD RTE RTR RTS	Return and Deallocate Return from Exception Return and Restore Codes Return from Subroutine
SBCD Scc STOP SUB SUBA SUBI SUBQ SUBX SWAP	Subtract Decimal with Extend Set Conditionally Stop Subtract Subtract Address Subtract Immediate Subtract Quick Subtract with Extend Swap Register Words
TBLS, TBLSN	Table Lookup and Interpolate (Signed)
TBLU, TBLUN	Table Lookup and Interpolate (Unsigned)
TAS TRAP TRAPcc TRAPV TST	Test Operand and Set Trap Trap Conditionally Trap on Overflow Test Operand
UNLK	Unlink

4.5.2 New Instructions

Two new instructions have been added to the MC68000 instruction set for use in controller applications. They are low power stop (LPSTOP) and table lookup and interpolate (TBL).

4.5.2.1 Low Power Stop (LPSTOP)

In applications where power consumption is a consideration, the CPU32 forces the device into a low power standby mode when immediate processing is not required. The low power stop mode is entered by executing the LPSTOP instruction. The processor remains in this mode until a user-specified (or higher) interrupt level or reset occurs.

4.5.2.2 Table Lookup and Interpolate (TBL)

To maximize throughput for real-time applications, reference data is often precalculated and stored in memory for quick access. The storage of each data point could require an inordinate amount of memory. The table instruction requires only a sample of data points stored in the array, reducing memory requirements. Intermediate values are recovered with this instruction via linear interpolation. The results are optionally rounded with the round-to-nearest algorithm.

4.6 Development Support

The following features have been implemented on the CPU32 to enhance the instrumentation and development environment:

- M68000 Family Development Support
- Background Debug Mode
- Deterministic Opcode Tracking
- Hardware Breakpoints

4.6.1 M68000 Family Development Support

All M68000 Family members include features to facilitate applications development. These features include the following:

Trace on Instruction Execution — M68000 Family processors include an instruction by instruction tracing facility as an aid to program development. The MC68020, MC68030, MC68040, and CPU32 also allow tracing only of those instructions causing a change in program flow. In the trace mode, a trace exception is generated after an instruction is executed, allowing a debugger program to monitor the execution of a program under test.

Breakpoint Instruction — An emulator may insert software breakpoints into the target code to indicate when a breakpoint has occurred. On the MC68010, MC68020, MC68030, and CPU32, this function is provided via illegal instructions, \$4848–\$484F, to serve as breakpoint instructions.

Unimplemented Instruction Emulation — During instruction execution, when an attempt is made to execute an illegal instruction, an illegal instruction exception occurs. Unimplemented instructions (F-line, A-line, . . .) utilize separate exception vectors to permit efficient emulation of unimplemented instructions in software.

4.6.2 Background Debug Mode

Microcomputer systems generally provide a debugger, implemented in software, for system analysis at the lowest level. The background debug mode on the CPU32 is unique in that the debugger has been implemented in CPU microcode. Registers can be viewed and/or altered, memory can be read or written to, and test features can be invoked. Incorporating these capabilities on-chip simplifies the environment in which the in-circuit emulator operates. With an integrated debugger, the traditional emulator configuration, as shown in Figure 4-10, may be replaced by a bus state analyzer (BSA), shown in Figure 4-11. The BSA simply monitors the traffic on the internal bus, whereas the in-circuit emulator replaces the processor in the target system with hardware in the emulator, and all external bus traffic must traverse the cable between the emulator and the target system.

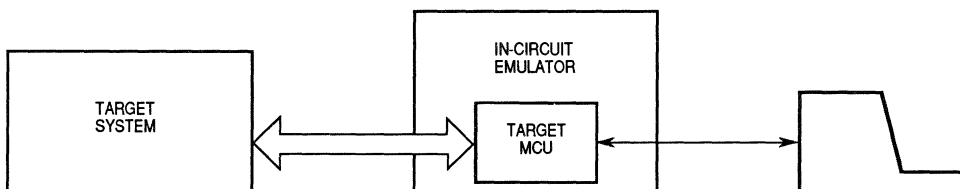


Figure 4-10. Traditional In-Circuit Emulator Diagram

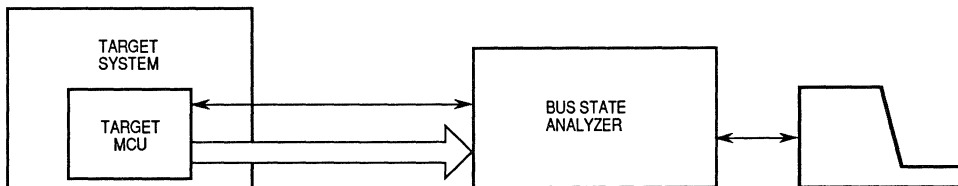


Figure 4-11. Bus State Analyzer Configuration

As each command is accumulated in the serial shifter, a microaddress is generated which points to the microcode routine corresponding to that command. If the command can complete without additional serial traffic, it does; however, if addresses or operands are required, the microcode waits as each word is assembled. Result operands are loaded into the output shift register to be shifted out as the next command is read. Table 4-2 summarizes the command set available in the background debug mode.

Table 4-2. Background Mode Command Summary

Command	Mnemonic	Description
Read D/A Register	RDREG/RAREG	Read the selected address or data register and return the results via the serial interface.
Write D/A Register	WDREG/WAREG	The data operand is written to the specified address or data register.
Read System Register	RSREG	The specified system control register is read. All registers that can be read in supervisor mode can be read in background mode.
Write System Register	WSREG	The operand data is written into the specified system control register.
Read Memory Location	READ	Read the sized data at the memory location specified by the long-word address. The source function code register (SFC) determines the address space accessed.
Write Memory Location	WRITE	Write the operand data to the memory location specified by the long-word address. The destination function code (DFC) register determines the address space accessed.
Dump Memory Block	DUMP	Used in conjunction with the READ command to dump large blocks of memory. An initial READ is executed to set up the starting address of the block and retrieve the first result. Subsequent operands are retrieved with the DUMP command.
Fill Memory Block	FILL	Used in conjunction with the WRITE command to fill large blocks of memory. An initial WRITE is executed to set up the starting address of the block and supply the first operand. Subsequent operands are written with the FILL command.
Resume Execution	GO	The pipe is flushed and re-filled before resuming instruction execution at the current PC.
Patch User Code	CALL	Current program counter is stacked at the location of the current stack pointer. Instruction execution begins at user patch code.
Reset Peripherals	RST	Asserts RESET for 512 clock cycles. The CPU is not reset by this command. Synonymous with the CPU RESET instruction.
No Operation	NOP	NOP performs no operation and may be used as a null command.

4.6.3 Deterministic Opcode Tracking

CPU32 function code outputs are augmented by two supplementary signals to monitor the instruction pipeline. The instruction pipe (IPIPE) output indicates the start of each new instruction and each midinstruction pipeline advance. The instruction fetch (IFETCH) output identifies the bus cycles in which the operand is loaded into the instruction pipeline. Pipeline flushes are also signalled with IFETCH. Monitoring these two signals allows a bus analyzer to synchronize itself to the instruction stream and monitor its activity.

4.6.4 On-Chip Breakpoint Hardware

An external breakpoint input and on-chip breakpoint hardware allow a breakpoint trap on any memory access. Off-chip address comparators preclude breakpoints unless show cycles are enabled. Breakpoints on instruction prefetches that are ultimately flushed from the instruction pipeline are not acknowledged; operand breakpoints are always acknowledged. Acknowledged breakpoints initiate exception processing at the address in exception vector number 12, or alternately enter background mode.

SECTION 5 QUEUED SERIAL MODULE (QSM)

The queued serial module (QSM) provides the microcontroller unit (MCU) with two serial communication interfaces divided into two submodules: the queued serial peripheral interface (QSPI) and the serial communications interface (SCI).

The QSPI is a full-duplex, synchronous serial interface for communicating with peripherals and other MCUs. It is enhanced by the addition of a queue for receive and transmit data.

The SCI is a full-duplex universal asynchronous receiver transmitter (UART) serial interface. These submodules operate independently.

This section provides a block diagram, memory map, pin description, and register descriptions of the QSM, with a breakdown of both the QSPI and SCI submodules. Operation of the QSPI submodule includes master mode and slave mode. For a detailed description refer to **5.5.5.1 Master Mode** and **5.5.5.2 Slave Mode**.

In addition, operation of the SCI submodule is divided into transmit and receive. A description of these operations is given in **5.6.4 Transmitter Operation** and **5.6.5 Receiver Operation**. To aid in grasping an understanding of the numerous bits and fields of the registers that appear throughout the text, a quick reference guide identifies all bit/field acronyms. (Refer to Table 5-3.)

5.1 Block Diagram

Figure 5-1 depicts the major components of the QSM, which consist of the global registers, logic control, and the QSPI and SCI submodules. Refer to **5.5 QSPI Submodule** and **5.6 SCI Submodule** for further definition of these components.

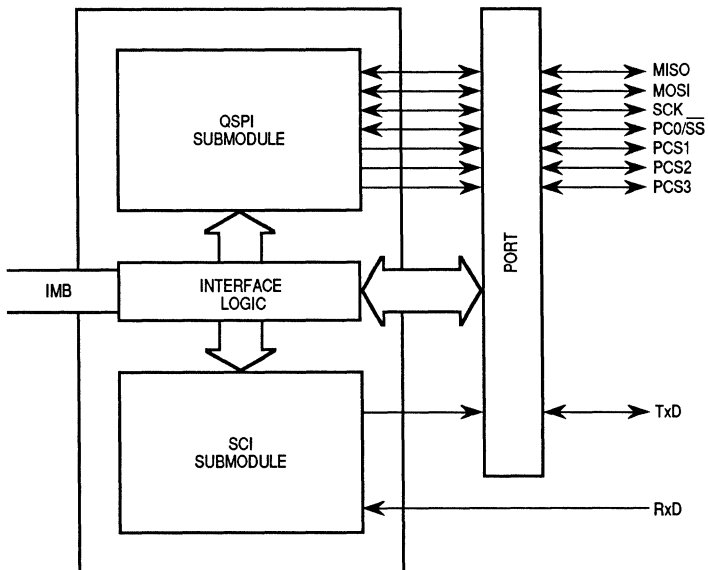


Figure 5-1. QSM Block Diagram

5.2 Memory Map

The QSM memory map is comprised of the global registers, the QSPI and SCI control and status registers, and the QSPI RAM as shown in Figure 5-2. For an accurate location of the QSM memory in the MCU memory map, refer to **1.3 Module Memory Map**. The QSM memory map may be divided into two segments: supervisor-only data space and assignable data space.

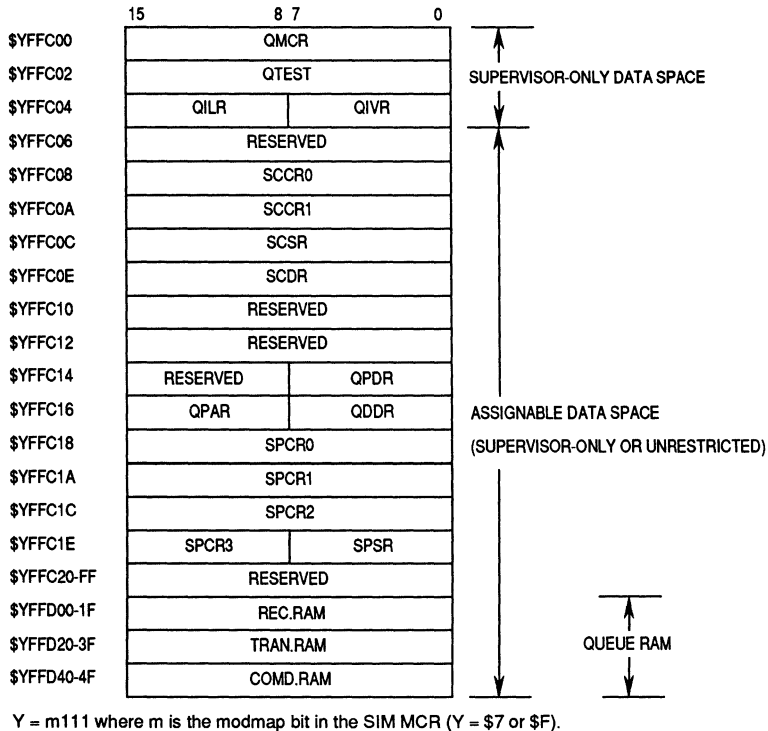


Figure 5-2. QSM Memory Map

The supervisor-only data space segment contains the QSM global registers. These registers define parameters needed by the QSM to integrate with the MCU. Access to these registers is permitted only when the CPU is operating in supervisor mode (CPU status register, S bit = 1).

Assignable data space can be either restricted to supervisor-only access or unrestricted to both supervisor and user accesses. The supervisor (SUPV) bit in the QSM module configuration register (QMCR) designates the assignable data space as either supervisor or unrestricted. If SUPV is set, then the space is

designated as supervisor-only space. Access is then permitted only when the CPU is operating in supervisor mode. All attempts to read supervisor data spaces when not in supervisor mode (CPU status register, S-bit = 0) return a value of zero, and all attempts to write have no effect. If SUPV is clear, both user and supervisor accesses are permitted. To clear SUPV in the QMCR, the CPU must be in supervisor mode (CPU status register, S-bit = 1). Refer to Processing States in the CPU32 manual for more information on supervisor mode.

The QSM assignable data space segment contains the submodules QSPI and SCI, control/status registers, and the QSPI RAM. All registers and RAM may be accessed on byte, word, and long-word boundaries. The 80 bytes of static RAM are distinct from the QSM register set. All bytes not used by the QSPI may be used as general-purpose RAM. When operating, the QSPI submodule uses three noncontiguous blocks of the 80-byte RAM for receive, transmit, and control data. More information on the QSPI RAM can be found in **5.5.4.6 QSPI Ram**.

The contents of most locations in the memory map may be rewritten with the identical value to that location, with one exception. (Refer to **5.5.4.3 QSPI Control Register 2 (SPCR2)**.) Writing a different value to certain control registers when a submodule using that register is enabled can cause unpredictable results. If register bits are to be changed, the CPU should disable the submodule in an orderly fashion before altering the registers to maintain predictable operation.

5.3 QSM Pins

The QSM has nine external pins as shown in Figure 5-1. Eight of the pins, if not in use for their submodule function, can be used as general-purpose I/O port pins. The ninth pin, RXD, is an input-only pin used exclusively by the SCI submodule.

Table 5-1 summarizes the QSM pin functions, which are determined by the QSPI mode of operation (master or slave), SCI operation, the pin assignment register (QPAR), and by the appropriate QSM data direction register (QDDR) bit.

Table 5-1. QSM Pin Summary

	Pin	Mode	QDDR Bit	Pin Function
QSPI Pins	MISO	Master	0	Serial Data Input to QSPI
			1	Output Value from QPDR
		Slave	0	Input Value to QPDR
			1	Serial Data Output from QSPI
	MOSI	Master	0	Input Value to QPDR
			1	Serial Data Output from QSPI
		Slave	0	Serial Data Input to QSPI
			1	Output Value from QPDR
	SCK	Master	0	Input Value to QPDR
			1	Clock Output from QSPI
		Slave	0	Clock Input to QSPI
			1	Output Value from QPDR
PCS0/SS	Master	0	Input (May Cause Mode Fault)	
		1	Output Selects Peripheral(s)	
	Slave	0	Input Selects the QSPI	
		1	Output Value from QPDR	
PCS3-PCS1	Master	0	Input Value to QPDR	
		1	Output Selects Peripherals	
	Slave	0	Input Value to QPDR	
		1	Output Value from QPDR	
SCI Pins	TXD	Transmit	X	Serial Data Output from SCI (TE = 1)
	RXD	Receive	NA	Serial Data Input to SCI

X = QDDR bit ignored

The QSM pin control registers — QDDR, QSM pin assignment register (QPAR), and QSM port data register (QPDR) — affect pins being used as general-purpose I/O pins. The QSPI control register 0 (SPCR0) has one bit that affects seven pins employed as general-purpose output pins. Within this register the wired-OR mode (WOMQ) control bit determines whether MISO, MOSI, SCK, and PCS3–PCS0 function as open-drain output pins or as normal output pins, regardless of their use as general-purpose I/O pins or as QSPI output pins. Likewise, the SCI control register 1 (SCCR1) has one bit that affects the TXD pin when it is employed as a general-purpose output. In this register the wired-OR mode (WOMS) control bit determines whether TXD functions as an open-drain output pin or a normal output pin, regardless of this pin's use as a general-purpose output pin or as an SCI output pin.

5.4 Registers

Registers of the QSM are divided into four categories: QSM global registers, QSM pin control registers, QSPI submodule registers, and SCI submodule registers. The QSPI and SCI registers are defined in **5.5 QSPI Submodule** and **5.6 SCI Submodule**, respectively. Writes to unimplemented bits have no meaning or effect, and reads from unimplemented bits always return a logic zero value.

The modmap bit of the system integration module (SIM) module configuration register (MCR) defines the most significant bit (A23) of the address, shown in each register figure as Y (Y = \$7 or \$F). This bit, concatenated with the rest of the address given, forms the absolute address of each register.

Table 5-2 is a summary of the registers, bits, and reset states for the full QSM module.

As previously mentioned, Table 5-3 is a quick reference guide to all the bits/fields of the QSM module. Along with the function, the register and register location of each bit/field are identified.

Table 5-2. QSM Register Summary

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
QMCRR \$YFFC00	STOP	FRZ1	FRZ0	0	0	0	0	0	SUPV	0	0	0	IARB				
RESET:	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
QTEST \$YFFC02	0	0	0	0	0	0	0	0	0	0	0	0	TSBD	SYNC	TQSM	TMM	
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QILR-QIVR \$YFFC04	0	0	ILQSPI			ILSCI			INTV								
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
\$YFFC06	Reserved																
SCCR0 \$YFFC08	0	0	0	SCBR													
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCCR1 \$YFFC0A	0	LOOPS	WOMS	ILT	PT	PE	M	WAKE	TIE	TCIE	RIE	ILIE	TE	RE	RWU	SBK	
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
SCSR \$YFFC0C	0	0	0	0	0	0	0	TDRE	TC	RDRF	RAF	IDLE	OR	NF	FE	PF	
RESET:	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	
SCDR \$YFFC0E	0	0	0	0	0	0	0	R8/T8	R7/T7	R6/T6	R5/T5	R4/T4	R3/T3	R2/T2	R1/T1	R0/T0	
RESET:	0	0	0	0	0	0	0	U	U	U	U	U	U	U	U	U	
\$YFFC10	Reserved																
\$YFFC12	Reserved																
QPDR \$YFFC14	0	0	0	0	0	0	0	0	D7 (TXD)	D6 (PCS3)	D5 (PCS2)	D4 (PCS1)	D3 (PCS0*)	D2 (SCK)	D1 (MOSI)	D0 (MISO)	
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
QPAR-QDDR \$YFFC16	0	PCS3	PCS2	PCS1	PCS0*	0	MOSI	MISO	TXD	PCS3	PCS2	PCS1	PCS0*	SCK	MOSI	MISO	
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
SPCRO \$YFFC18	MSTR	WOMQ	BITS				CPOL	CPHA	SPBR								
RESET:	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
SPCR1 \$YFFC1A	SPE	DSCKL						DTL									
RESET:	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
SPCR2 \$YFFC1C	SPIFIE	WREN	WRTO	0	ENDQP				0	0	0	0	NEWQP				
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
SPCR3-SPSR \$YFFC1E	0	0	0	0	0	LOOPQ	HMIE	HALT	SPIF	MODF	HALTA	0	CPTQP				
RESET:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
\$YFFC20- \$YFFCFF	Reserved																
REC.RAM \$YFFD00- \$YFFD1F	QSPI Receive Data (16 Words)																
TRAN.RAM \$YFFD20- \$YFFD3F	QSPI Transmit Data (16 Words)																
COMD.RAM \$YFFD40- \$YFFD4F	CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*	CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*	

Y = m111, where m is the modmap bit in the module configuration register for the SIM (Y = \$7 or \$F).

* The PCS0 bit listed above represents the dual-function PCS0/SS.

U = Unaffected by reset.

Reserved locations read as zeros, writes have no meaning or effect.

Table 5-3. Bit/Field Quick Reference Guide (Sheet 1 of 2)

Bit/Field Mnemonic	Function	Register	Register Location
SPBR	Serial Clock Baud Rate	SPCR0	QSPI
BITS	Bits Per Transfer	SPCR0	QSPI
BITSE	Bits Per Transfer Enable	QSPI RAM	QSPI
SCBR	Baud Rate	SCCR0	SCI
CONT	Continue	QSPI RAM	QSPI
CPHA	Clock Phase	SPCR0	QSPI
CPOL	Clock Polarity	SPCR0	QSPI
CPTQP	Completed Queue Pointer	SPSR	QSPI
DSCK	Peripheral Select Chip (PSC) to Serial Clock (SCK) Delay	QSPI RAM	QSPI
DSCKL	Delay before Serial Clock (SCK)	SPCR1	QSPI
DT	Delay after Transfer	QSPI RAM	QSPI
DTL	Length of Delay after Transfer	SPCR1	QSPI
ENDQP	Ending Queue Pointer	SPCR2	QSPI
FE	Framing Error Flag	SCSR	SCI
FRZ1-0	Freeze1-0	QMCR	QSM
HALT	Halt	SPCR3	QSPI
HALTA	Halt Acknowledge Flag	SPSR	QSPI
HMIE	Halt Acknowledge Flag (HALTA) and Mode Fault Flag (MODF) Interrupt Enable	SPCR3	QSPI
IARB	Interrupt Arbitration Identification Number	QMCR	QSM
IDLE	Idle Line Detected Flag	SCSR	SCI
ILIE	Idle Line Interrupt Enable	SCCR1	SCI
ILQSPI	Interrupt Level for QSPI	QILR	QSM
ILSCI	Interrupt Level of SCI	QILR	QSM
ILT	Idle Line Detect Type	SCCR1	SCI
INTV	Interrupt Vector	QIVR	QSM
LOOPS	SCI Loop Mode	SCCR1	SCI
LOOPQ	QSPI Loop Mode	SPCR3	QSPI
M	Mode Select (8/9 Bit)	SCCR1	SCI
MISO	Master In Slave Out	QPAR/QDDR/QPDR	QSM
MODF	Mode Fault Flag	SPSR	QSPI
MOSI	Master Out Slave In	QPAR/QDDR/QPDR	QSM
MSTR	Master/Slave Mode Select	SPCR0	QSPI
NEWQP	New Queue Pointer Value	SPCR2	QSPI

Table 5-3. Bit/Field Quick Reference Guide (Sheet 2 of 2)

Bit/Field Mnemonic	Function	Register	Register Location
NF	Noise Error Flag	SCSR	SCI
OR	Overrun Error Flag	SCSR	SCI
PCS0/SS	Peripheral Chip-Select/Slave Select	QPAR/QDDR/QPDR	QSM
PCS3-PCS1	Peripheral Chip-Selects	QPAR/QDDR/QPDR	QSM
PE	Parity Enable	SCCR1	SCI
PF	Parity Error Flag	SCSR	SCI
PT	Parity Type	SCCR1	SCI
R8-R0	Receive 8-0	SCDR	SCI
RAF	Receiver Active Flag	SCSR	SCI
RDRF	Receive Data Register Full Flag	SCSR	SCI
RE	Receiver Enable	SCCR1	SCI
RIE	Receiver Interrupt Enable	SCCR1	SCI
RWU	Receiver Wakeup	SCCR1	SCI
SBK	Send Break	SCCR1	SCI
SCK	Serial Clock	QDDR/QPDR	QSM
SPE	QSPI Enable	SPCR1	QSPI
SPIF	QSPI Finished Flag	SPSR	QSPI
SPIFIE	SPI Finished Interrupt Enable	SPCR2	QSPI
STOP	Stop	QMCR	QSM
SUPV	Supervisor/Unrestricted	QMCR	QSM
SYNC	SCI Baud Clock Sync Signal	QTEST	QSM
T8-T0	Transmit 8-0	SCDR	SCI
TC	Transmit Complete Flag	SCSR	SCI
TCIE	Transmit Complete Interrupt Enable	SCCR1	SCI
TDRE	Transmit Data Register Empty Flag	SCSR	SCI
TE	Transmit Enable	SCCR1	SCI
TIE	Transmit Interrupt Enable	SCCR1	SCI
TMM	Test Memory Map	QTEST	QSM
TQSM	Test QSM Enable	QTEST	QSM
TSBD	SPI Test Scan Path Select	QTEST	QSM
TXD	Transmit Data	QDDR/QPDR	QSM
WAKE	Wakeup Type	SCCR1	SCI
WOMQ	Wired-OR Mode for QSPI Pins	SPCR0	QSPI
WOMS	Wired-OR Mode for SCI Pins	SCCR1	SCI
WREN	Wrap Enable	SPCR2	QSPI
WRTO	Wrap To Select	SPCR2	QSPI

5.4.1 Overall QSM Configuration Summary

After reset, the QSM remains in an idle state, requiring initialization of several registers before any serial operations may begin execution. The following registers, fields, and bits are fully described later in this section. A general sequence guide for initialization follows:

- QMCR (refer to **5.4.2.1 QSM Configuration Register (QMCR)**)

This register must be initialized to properly configure:

- Interrupt arbitration identification number used by the entire QSM module
- Supervisor/unrestricted bit (SUPV)
- FREEZE and/or STOP configuration should remain cleared to zero for normal operation.

- QIVR and QILR (refer to **5.4.2.3 QSM Interrupt Level Register (QILR)** and **5.4.2.4 QSM Interrupt Vector Register (QIVR)**)

These registers are written to choose the base vector number for the entire QSM module and individual interrupt levels for the QSPI and SCI submodules.

- QPDR and QDDR (refer to **5.4.3.1 QSM Port Data Register (QPDR)** and **5.4.3.3 QSM Data Direction Register (QDDR)**)

The pin control registers should be initialized in the order QPDR and then QDDR, thus establishing the default state and direction of the QSM pins.

For configuration of the QSPI submodule, initialize as follows:

- RAM (refer to **5.5.4.6 QSPI Ram**)
- QPAR (refer to **5.4.3.2 QSM Pin Assignment Register (QPAR)**)

Assignment of appropriate pins to the QSPI must be made with this register.

- SPCR0 (refer to **5.5.4.1 QSPI Control Register 0 (SPCR0)**)

The system designer must choose a transfer rate (baud) for operation in master mode, an appropriate clock phase, clock polarity, and the number of bits to be transferred in a serial operation. Master/slave mode select (MSTR) must be set to configure the QSPI for master mode or cleared to configure operation in slave mode. WOMQ should be set to enable or cleared to disable wired-OR mode operation.

- **SPCR1 (refer to 5.5.4.2 QSPI Control Register 1 (SPCR1))**
 - SPE must be set to enable the QSPI; this register should be written last.
 - DTL allows the user to program a delay after any serial transfer, which is invoked by the DT bit for any serial transfer.
 - DSCKL allows the user to set a delay before SCK (after PCS valid), which is invoked by the DSCK bit for any transfer.
- **SPCR2 (refer to 5.5.4.3 QSPI Control Register 2 (SPCR2))**
 - NEWQP and ENDQP, respectively, determine the beginning of a queue and the number of serial transfers (up to 16) to be considered a complete queue.
 - WREN is set to enable queue wraparound, and WRTO determines the address used in wraparound mode.
 - SPIFIE is set to enable interrupts when SPIF is asserted.
- **SPCR3 (refer to 5.5.4.4 QSPI Control Register 3 (SPCR3))**
 - HALT may be used for program debug, and HMIE is set to enable CPU interrupts when HALTA or MODF is asserted.
 - LOOPQ is set only to enable a feedback loop that can be used for self-test mode.

For configuration of the SCI submodule, initialize as follows:

- **SCCR0 (refer to 5.6.3.1 SCI Control Register 0 (SCCR0))**

The system designer must choose a transfer rate (baud) for serial transfer operation.

- **SCCR1 (refer to 5.6.3.2 SCI Control Register 1 (SCCR1))**
 - The type of serial frame (8- or 9-bit) and the use of parity must be determined by M, PE, and PT.
 - For receive operation, the system designer must consider use and type of wakeup (WAKE, RWU, ILT, ILIE). The receiver must be enabled (RE) and, usually, RIE should be set.
 - For transmit operation, the transmitter must be enabled (TE) and, usually, TIE should be set. The use of wired-OR mode (WOMS) must also be decided. Once the transmitter is configured, data is not sent until TDRE and TC are cleared. To clear TDRE and TC, the SCSR read must be followed by a write to SCDR (either the lower byte or the entire word).

5.4.2 QSM Global Registers

The QSM global registers contain system parameters used by both the QSPI and the SCI submodules. These registers define parameters used by the QSM to interface with the CPU and other system modules. The four global registers are listed in Table 5-4.

Table 5-4. QSM Global Registers

Address	Name	Usage
\$YFFC00	QMCR	QSM Configuration Register
\$YFFC02	QTEST	QSM Test Register
\$YFFC04	QILR	QSM Interrupt Level Register
\$YFFC05	QIVR	QSM Interrupt Vector Register

5.4.2.1 QSM Configuration Register (QMCR)

QMCR (Figure 5-3) contains parameters for interfacing to the CPU and the intermodule bus (IMB). This register can be modified only when the CPU is in supervisor mode.

QMCR — QSM Configuration Register

\$YFFC00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STOP	FRZ1	FRZ0	0	0	0	0	0	SUPV	0	0	0	IARB			

RESET:

0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0

Figure 5-3. QSM Configuration Register

STOP — Stop Enable

1 = QSM clock operation stopped

0 = Normal QSM clock operation

STOP places the QSM into a low power state by disabling the system clock in most parts of the module. QMCR is the only register guaranteed to be readable while STOP is asserted. The QSPI RAM is not readable; however, writes to RAM or any register are guaranteed valid while STOP is asserted. STOP may be negated by the CPU and by reset.

The system software must stop each submodule before asserting STOP to avoid complications at restart and to avoid data corruption. The SCI submodule receiver and transmitter should be disabled, and the operation should be verified for completion before asserting STOP. The QSPI submodule should be stopped by asserting the HALT bit in SPCR3 and by asserting STOP after the HALTA flag is set.

FRZ1 — Freeze1

1 = Halt the QSM (on a transfer boundary)

0 = Ignore the FREEZE signal on the IMB

FRZ1 determines what action is taken by the QSM when the FREEZE signal of the IMB is asserted. FREEZE is asserted whenever the CPU enters the background mode.

WARNING

Ignoring the FREEZE signal can cause unpredictable results in the background mode operation of the QSM, because the CPU is unable to service interrupt requests in this mode. If FRZ1 is equal to one when the FREEZE line is asserted, the QSM comes to an orderly halt on a transfer boundary as if HALT had been asserted. The output pins continue to drive their last state. Once the FREEZE signal is negated, the QSM module restarts automatically.

FRZ0 — Freeze0

Reserved for future enhancement.

Bits 12–8 — Not Implemented

SUPV — Supervisor/Unrestricted

1 = Supervisor access

All registers in the QSM are placed in supervisor-only space. For any access from within user mode, address acknowledge (AACK) is not returned and the bus cycle is transferred externally.

0 = User access

Because the QSM contains a mix of supervisor and user registers, AACK returns for accesses with either supervisor or user mode, and the bus cycle remains internal. If a supervisor-only register is accessed in user mode, the module responds as if an access had been made to an unimplemented register location.

SUPV defines the assignable QSM registers as either supervisor-only data space or unrestricted data space.

Bits 6–4 — Not Implemented

IARB — Interrupt Arbitration Identification Number

Each module that generates interrupts, including the QSM, must have an IARB field. The value in this field is used to arbitrate for the IMB when two or more modules generate simultaneous interrupts of the same priority level. No two modules can share the same IARB value. The reset value of the IARB field is \$0, which prevents the QSM from arbitrating during an interrupt acknowledge cycle (IACK). The IARB field should be initialized by system software to a value between \$F (highest priority) and \$1 (lowest priority). Otherwise, any interrupts generated are identified by the CPU as spurious.

5.4.2.2 QSM Test Register (QTEST)

QTEST (Figure 5-4) is used in testing the QSM. Accesses to QTEST must be made while the MCU is in test mode. Refer to **3.11 Test Submodule** for information on test mode.

QTEST — QSM Test Register

\$YFFC02

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	TSBD	SYNC	TQSM	TMM

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Figure 5-4. QSM Test Register

TSBD — SPI Test Scan Path Select

- 1 = Enable delay to SCK scan path
- 0 = Enable SPI baud clock scan path

SYNC — SCI Baud Clock Synchronization Signal

- 1 = Inhibit SCI source signal (QCSCI1)
- 0 = Activate SCI source signal

TQSM — QSM Test Enable

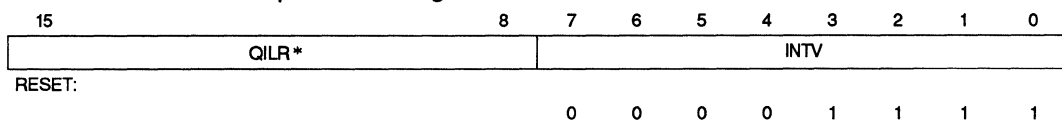
- 1 = Enable QSM to send test scan paths
- 0 = Disable scan path

TMM — Test Memory Map

- 1 = QSM responds to test memory addresses
- 0 = QSM responds to QSM memory addresses

zero for an SCI interrupt and with a one for a QSPI interrupt. Writes to INTV0 have no meaning or effect. Reads of INTV0 return a value of one.

QIVR — QSM Interrupt Vector Register **\$YFFC05**



*QILR — QSM Interrupt Level Register

Figure 5-6. QSM Interrupt Vector Register

5.4.3 QSM Pin Control Registers

Table 5-5 identifies the three pin control registers of the QSM. The QSM determines the use of nine pins, eight of which form a parallel port on the MCU. Although these pins are used by the serial subsystems, any pin may alternately be assigned as general-purpose I/O on a pin-by-pin basis. For use of these pins as general-purpose I/O, they must not be assigned to the QSPI submodule in register QPAR. To avoid briefly driving incorrect data, the first byte to be output should be written before register QDDR is configured for any output pins. QDDR should then be written to determine the direction of data flow on the pins and to output the value contained in register QPDR for all pins defined as outputs. Subsequent data for output is then written to QPDR.

Table 5-5. QSM Pin Control Registers

Address	Name	Usage
\$YFFC15	QPDR	QSM Port Data Register
\$YFFC16	QPAR	QSM Pin Assignment Register
\$YFFC17	QDDR	QSM Data Direction Register

5.4.3.1 QSM Port Data Register (QPDR)

QPDR (Figure 5-7) determines the actual input or output value of a QSM port pin, if the pin is defined in QPAR as general-purpose I/O. All QSM port pins may be used as general-purpose I/O. Writes to this register affect the pins defined as outputs; reads of this register return the actual value of the pins.

QPDR — QSM Port Data Register**\$YFFC15**

15	8	7	6	5	4	3	2	1	0	
RESERVED			D7 (TXD)	D6 (PCS3)	D5 (PCS2)	D4 (PCS1)	D3 (PCS0/SS)	D2 (SCK)	D1 (MOSI)	D0 (MISO)

RESET:

0 0 0 0 0 0 0 0 0

Figure 5-7. QSM Port Data Register**5.4.3.2 QSM Pin Assignment Register (QPAR)**

QPAR (Figure 5-8) determines which of the QSPI pins, with the exception of the SCK pin, are actually used by the QSPI submodule, and which pins are available for general-purpose I/O. Pins may be assigned to the QSPI or to function as general-purpose I/O on a pin-by-pin basis. QSPI pins designated by QPAR as general-purpose I/O are controlled only by QDDR and QPDR. The QSPI has no effect on these pins. QPAR does not affect the operation of the SCI submodule.

5**QPAR — QSM Pin Assignment Register****\$YFFC16**

15	14	13	12	11	10	9	8	7	0
0	PCS3	PCS2	PCS1	PCS0/SS	0	MOSI	MISO	QDDR*	

RESET:

0 0 0 0 0 0 0 0 0

0 = General-purpose I/O

1 = QSPI module

*QDDR — QSM Data Direction Register

Figure 5-8. QSM Pin Assignment Register**Bit 15 — Not Implemented**

TE in register SCCR1 determines whether the TXD pin is controlled by the SCI or functions as a general-purpose I/O pin.

PCS3–PCS1 — Peripheral Chip-Selects 3–1**PCS0/SS — Peripheral Chip-Select 0/Slave Select**

These bits determine whether the associated QSM port pins function as general-purpose I/O pins or are assigned to the QSPI submodule.

Bit 10 — Not Implemented

When the QSPI is enabled, the SCK pin is required.

MOSI — Master Out Slave In

MISO — Master In Slave Out

These bits determine whether the associated QSM port pin functions as a general-purpose I/O pin or is assigned to the QSPI submodule.

5.4.3.3 QSM Data Direction Register (QDDR)

QDDR (Figure 5-9) determines each I/O pin, except for TXD, as an input or an output regardless of whether the QSPI submodule is enabled or disabled. All QSM pins are configured during reset as general-purpose inputs. (The QSPI and SCI are disabled.) The RXD pin remains an input pin dedicated to the SCI submodule and does not function as a general-purpose I/O pin.

QDDR — QSM Data Direction Register

\$YFFC17

15	8	7	6	5	4	3	2	1	0
QPAR*		TXD	PCS3	PCS2	PCS1	PCS0/SS	SCK	MOSI	MISO

RESET.

0 0 0 0 0 0 0 0 0 0

0 = Input

1 = Output

*QPAR — QSM Pin Assignment Register

Figure 5-9. QSM Data Direction Register

TXD — Transmit Data

This bit determines the direction of the TXD pin (input or output), only if the SCI transmitter is disabled. If the SCI transmitter is enabled, the TXD bit is ignored, and the TXD pin is forced to function as an output.

PCS3–PCS1 — Peripheral Chip-Selects 3–1

PCS0/SS — Peripheral Chip-Select 0/Slave Select

SCK — Serial Clock

MOSI — Master Out Slave In

MISO — Master In Slave Out

All of these bits determine the QSPI port pin operation to be input or output.

5.5 QSPI Submodule

The QSPI submodule communicates with external peripherals and other MCUs via synchronous serial bus. The QSPI is fully compatible with the serial peripheral interface (SPI) systems found on other Motorola devices such as the M68HC11 and M68HC05 Families. It has all of the capabilities of the SPI system as well as several new features. The following paragraphs describe the

features, block diagram, pin descriptions, programmer's model (memory map) inclusive of registers, and the master and slave operation of the QSPI.

5.5.1 Features

Standard SPI features are listed below, followed by a list of the additional features offered on the QSPI:

- Full Duplex, Three-Wire Synchronous Transfers
- Half Duplex, Two-Wire Synchronous Transfers
- Master or Slave Operation
- Programmable Master Bit Rates
- Programmable Clock Polarity and Phase
- End-of-Transmission Interrupt Flag
- Master-Master Mode Fault Flag
- Easily Interfaces to Simple Expansion Parts (A/D Converters, EEPROMS, Display Drivers, etc.)

QSPI-enhanced features are as follows:

- Programmable Queue — up to 16 preprogrammed transfers
- Programmable Peripheral Chip-Selects — four pins select up to 16 SPI chips
- Wraparound Transfer Mode — for autoscanning of serial A/D (or other) peripherals, with no CPU overhead
- Programmable Transfer Length — from 8–16 bits inclusive
- Programmable Transfer Delay — from 1 μ s to 0.5 ms (at 16.78 MHz)
- Programmable Queue Pointer
- Continuous Transfer Mode — up to 256 bits

5.5.1.1 Programmable Queue

A programmable queue allows the QSPI to perform up to 16 serial transfers without CPU intervention. Each transfer corresponds to a queue entry containing all the information needed by the QSPI to independently complete one serial transfer. This unique feature greatly reduces CPU/QSPI interaction, resulting in increased CPU and system throughput.

5.5.1.2 Programmable Peripheral Chip-Selects

Four peripheral chip-select pins allow the QSPI to access up to 16 independent peripherals by decoding the four peripheral chip-select signals. Up to four independent peripherals can be selected by direct connection to a chip-select pin. The peripheral chip-selects simplify interfacing to two or more serial peripherals by providing dedicated peripheral chip-select signals, alleviating the need for CPU intervention.

5.5.1.3 Wraparound Transfer Mode

Wraparound transfer mode allows automatic, continuous re-execution of the preprogrammed queue entries. Newly transferred data replaces previously transferred data. Wraparound simplifies interfacing with A/D converters by automatically providing the CPU with the latest A/D conversions in the QSPI RAM. Consequently, serial peripherals appear as memory-mapped parallel devices to the CPU.

5.5.1.4 Programmable Transfer Length

The number of bits in a serial transfer is programmable from 8 to 16 bits, inclusive. For example, 10 bits could be used for communicating with an external 10-bit A/D converter. Likewise, a vacuum fluorescent display driver might require a 12-bit serial transfer. The programmable length simplifies interfacing to serial peripherals that require different data lengths.

5.5.1.5 Programmable Transfer Delay

An inter-transfer delay may be programmed from approximately 1 to 500 μs (using a 16.78-MHz system clock). For example, an A/D converter may require time between transfers to complete a new conversion. The default delay is 1 μs . The programmable length of delay simplifies interfacing to serial peripherals that require delay time between data transfers.

5.5.1.6 Programmable Queue Pointer

The QSPI has a pointer that identifies the queue location containing the data for the next serial transfer. The CPU can switch from one task to another in the QSPI by writing to the queue pointer, changing the location in the queue that is to be transferred next. Otherwise, the pointer increments after each serial transfer. By segmenting the queue, multiple-task support can be provided by the QSPI.

5.5.1.7 Continuous Transfer Mode

The continuous transfer mode allows the user to send and receive an uninterrupted bit stream with a peripheral. A minimum of 8 bits and a maximum of 256 bits may be transferred in a single burst without CPU intervention. Longer transfers are possible; however, minimal CPU intervention is required to prevent loss of data. A 1 μs pause (using a 16.78-MHz system clock) is inserted between each queue entry transfer.

5.5.2 Block Diagram

Figure 5-10 provides a block diagram of the QSPI submodule components.

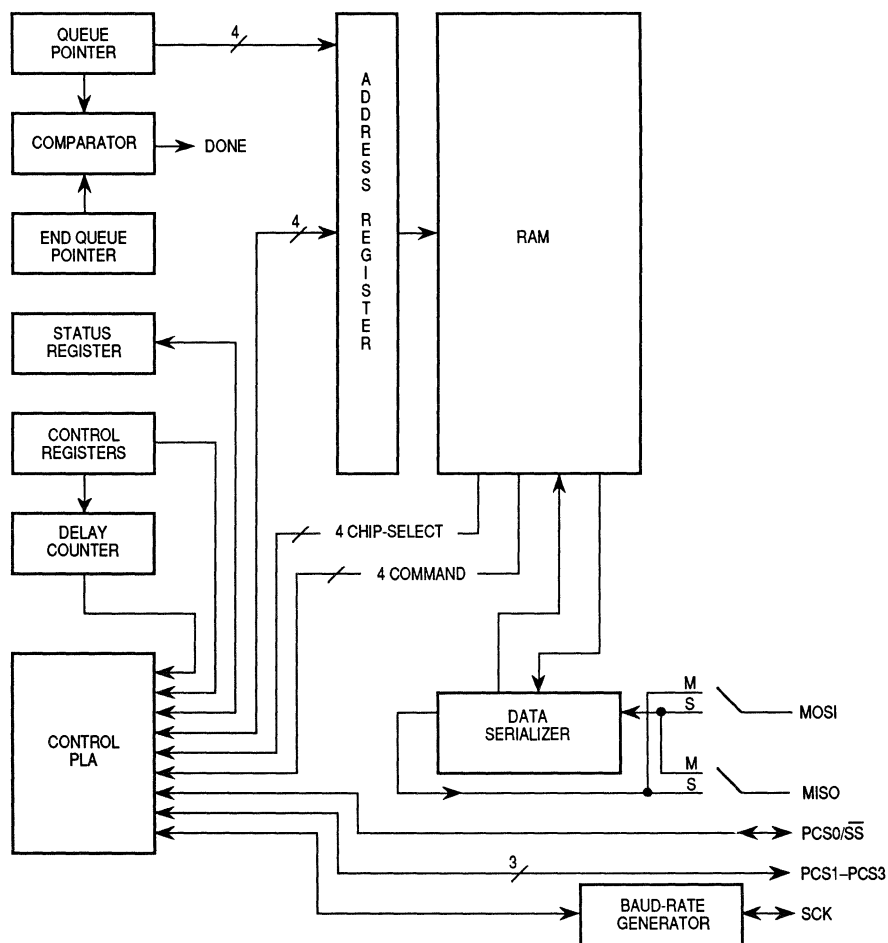


Figure 5-10. QSPI Submodule Diagram

5.5.3 QSPI Pins

Seven pins are associated with the QSPI; however, when not needed for a QSPI application, they may be configured as general-purpose I/O pins. Figure 5-10 identifies the QSPI pins.

Table 5-6 lists the QSPI external input and output pins and their functions. QSM register QDDR determines whether the pins are designated as input or output. The user must initialize QDDR for the QSPI to function correctly.

Table 5-6. External Pin Inputs/Outputs to the QSPI

Pin Names	Mnemonics	Mode	Function
Master In Slave Out	MISO	Master Slave	Serial Data Input to QSPI Serial Data Output from QSPI
Master Out Slave In	MOSI	Master Slave	Serial Data Output from QSPI Serial Data Input to QSPI
Serial Clock	SCK ¹	Master Slave	Clock Output from QSPI Clock Input to QSPI
Peripheral Chip-Selects	PCS3–PCS1	Master	Outputs Select Peripheral(s)
Peripheral Chip-Select ² Slave Select ³	PCS0/ SS	Master Slave	Output Selects Peripheral(s) Input Selects the QSPI
Slave Select ⁴	$\overline{\text{SS}}$	Master	May Cause Mode Fault

NOTES:

1. All QSPI pins (except SCK) can be used as general-purpose I/O if they are not used by the QSPI while the QSPI is operating.
2. An output (PCS0) when the QSPI is in master mode.
3. An input ($\overline{\text{SS}}$) when the QSPI is in slave mode.
4. An input (SS) when the QSPI is in master mode; useful in multimaster systems.

5.5.4 Programmer's Model and Registers

The programmer's model (memory map) for the QSPI submodule consists of the QSM global and pin control registers (refer to **5.4.2 QSM Global Registers** and **5.4.3 QSM Pin Control Registers**), four QSPI control registers, one status register, and the 80-byte QSPI RAM. Table 5-7 lists the registers and the QSPI RAM of the programmer's model. All of the registers and RAM can be read and written by the CPU. The four control registers must be initialized in proper order before the QSPI is enabled to ensure defined operation. Only the control registers must adhere to the order of sequence prescribed in **5.4.1 Overall QSM Configuration Summary**. Write register SPCR1 last when setting up the QSPI, as this register contains the QSPI enable bit (SPE). Asserting this bit starts the QSPI. QSPI control registers are reset to a defined state and may then be changed by the CPU. Reset values are shown below each register.

Table 5-7. QSPI Registers

Address	Name	Usage
\$YFFC18-9	SPCR0	QSPI Control Register 0
\$YFFC1A-B	SPCR1	QSPI Control Register 1
\$YFFC1C-D	SPCR2	QSPI Control Register 2
\$YFFC1E	SPCR3	QSPI Control Register 3
\$YFFC1F	SPSR	QSPI Status Register
\$YFFD00-1F	RAM	QSPI Receive Data (16 Words)
\$YFFD20-3F	RAM	QSPI Transmit Data (16 Words)
\$YFFD40-4F	RAM	QSPI Command Control (8 Words)

In general, rewriting the same value into a control register does not affect the QSPI operation with the exception of NEWQP (bits 3-0) in SPCR2. Rewriting the same value to these bits causes the RAM queue pointer to restart execution at the designated location.

If control bits are to be changed, the CPU should halt the QSPI first. With the exception of SPCR2, writing a different value into a control register while the QSPI is enabled may disrupt operation. SPCR2 is buffered, preventing any disruption of the current serial transfer. After completion of the current serial transfer, the new SPCR2 values become effective.

5.5.4.1 QSPI Control Register 0 (SPCR0)

SPCR0 (Figure 5-11) contains parameters for configuring the QSPI before it is enabled. Although the CPU can read and write this register, the QSM has read-only access.

SPCR0 — QSPI Control Register 0 \$YFFC18

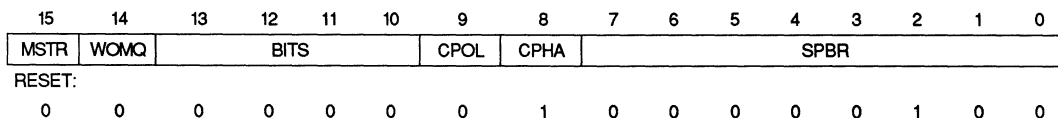


Figure 5-11. QSPI Control Register 0

MSTR — Master/Slave Mode Select

- 1 = QSPI is system master and can initiate transmission to external SPI devices.
- 0 = QSPI is a slave device, and only responds to externally generated serial transfers.

MSTR configures the QSPI for either master or slave mode operation. This bit is cleared on reset and may only be written by the CPU, not the QSM.

WOMQ — Wired-OR Mode for QSPI Pins

1 = All QSPI port pins designated as output by QDDR function as open-drain outputs and can be wire-ORed to other external lines.

0 = Output pins have normal outputs instead of open-drain outputs.

WOMQ allows the QSPI pins to be wire-ORed, regardless of whether they are used as general-purpose outputs or as QSPI outputs. WOMQ affects the QSPI pins whether the QSPI is enabled or disabled. This bit does not affect the SCI submodule transmit (TXD) pin, which has its own WOMS bit in an SCI control register.

BITS — Bits Per Transfer

In master mode, BITS determines the number of data bits transferred for each serial transfer in the queue that has the command control bit (BITSE of the QSPI RAM) equal to one. If BITSE equals zero for a command, 8 bits are transferred for that command regardless of the value in BITS. Data transfers from 8 to 16 bits are supported. Illegal (reserved) values all default to 8 bits. BITSE is not used in slave mode. All transfers are of the length specified by BITS. Table 5-8 shows the number of bits per transfer.

**Table 5-8. Bits per Transfer if
Command Control Bit BITSE = 1**

Bit 13	Bit 12	Bit 11	Bit 10	Bits per Transfer
0	0	0	0	16
0	0	0	1	Reserved
0	0	1	0	Reserved
0	0	1	1	Reserved
0	1	0	0	Reserved
0	1	0	1	Reserved
0	1	1	0	Reserved
0	1	1	1	Reserved
1	0	0	0	8
1	0	0	1	9
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

CPOL — Clock Polarity

- 1 = The inactive state value of SCK is high.
- 0 = The inactive state value of SCK is low.

CPOL is used to determine the inactive state value of the serial clock (SCK). CPOL is used in conjunction with CPHA to produce the desired clock-data relationship between master and slave device(s). For an understanding of the QSPI clock/data timing relationship, refer to the timing diagrams in Figures 5-24–5-27.

CPHA — Clock Phase

- 1 = Data is changed on the leading edge of SCK and captured on the following edge of SCK.
- 0 = Data is captured on the leading edge of SCK and changed on the following edge of SCK.

CPHA determines which edge of SCK causes data to change and which edge of SCK causes data to be captured. CPHA is used in conjunction with CPOL to produce the desired clock-data relationship between master and slave device(s). Note that CPHA is set at reset.

SPBR — Serial Clock Baud Rate

The QSPI internally generates the baud rate for SCK, the frequency of which is programmable by the user. The clock signal is derived from the MCU system clock using a modulus counter. At reset, BAUD is initialized to a 2.1-MHz SCK frequency.

The user programs a baud rate for SCK by writing a baud value from 2 to 255. The following equation determines the SCK baud rate:

$$\text{SCK Baud Rate} = \text{System Clock} / (2 * \text{SPBR}) \tag{5-1}$$

or

$$\text{SPBR} = \text{System Clock} / (2 * \text{SCK Baud Rate Desired}) \tag{5-2}$$

where SPBR equals 2, 3, 4, . . . , 255.

Programming SPBR with the values zero or one disables the QSPI baud rate generator. SCK is disabled and assumes an inactive state value. No serial transfers occur. SPBR has 254 active values. Table 5-9 lists several possible baud values and the corresponding SCK frequency based on a 16.78-MHz system clock.

Table 5-9. Examples of SCK Frequencies

System Clock Frequency	Required Division Ratio	Value of SPBR	Actual SCK Frequency
16.78 MHz	4	2	4.19 MHz
	8	4	2.10 MHz
	16	8	1.05 MHz
	34	17	493 kHz
	168	84	100 kHz
	510	255	33 kHz

5.5.4.2 QSPI Control Register 1 (SPCR1)

SPCR1 (Figure 5-12) contains parameters for configuring the QSPI before it is enabled. Although the CPU can read and write this register, the QSM has read access only, except for SPE. This bit is automatically cleared by the QSPI after completing all serial transfers or when a mode fault occurs.

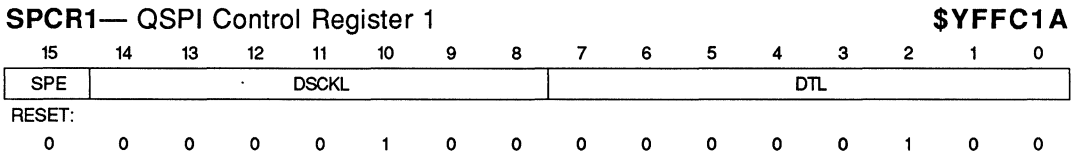


Figure 5-12. QSPI Control Register 1

SPE — QSPI Enable

1 = The QSPI is enabled and the pins allocated by QSM register QPAR are controlled by the QSPI.

0 = The QSPI is disabled, and the seven QSPI pins can be used as general-purpose I/O pins, regardless of the values in QPAR.

This bit enables or disables the QSPI Submodule. Setting SPE causes the QSPI to begin operation. If the QSPI is a master, setting SPE causes the QSPI to begin initiating serial transfers. If the QSPI is a slave, the QSPI begins monitoring the PCS0/SS pin to respond to the external initiation of a serial transfer.

When the QSPI is disabled, the CPU may use the QSPI RAM. When the QSPI is enabled, both the QSPI and the CPU have access to the QSPI RAM. The CPU has both read and write access capability to all 80 bytes of the QSPI RAM. The QSPI can read only the transmit data segment and the command control segment, and can write only the receive data segment of the QSPI RAM.

By clearing SPE, the QSPI turns itself off automatically when it is finished. An error condition called mode fault (MODF) also clears SPE. This error occurs

when PCS0/SS is configured for input, the QSPI is a system master (MSTR = 1), and PCS0/SS is driven low externally.

To stop the QSPI, assert HALT, then wait until HALTA is set. SPE may then be safely cleared to zero, providing an orderly method of quickly shutting down the QSPI after the current serial transfer is completed. The CPU can immediately disable the QSPI by just clearing SPE; however, loss of data from a current serial transfer may result and confuse an external SPI device.

DSCCKL — Delay before SCK

This bit determines the length of time the QSPI delays from peripheral chip-select (PCS) valid to SCK transition for serial transfers in which the command control bit, DSCCK of the QSPI RAM, equals one. PCS may be any of the four peripheral chip-select pins. The following equation determines the actual delay before SCK:

$$\text{PCS to SCK Delay} = [\text{DSCCKL}/\text{System Clock Frequency}] \quad (5-3)$$

where DSCCKL equals {1,2,3, . . . 127}.

5

NOTE

A zero value for DSCCKL causes a delay of 128/system clocks, which equals 7.6 μs for a 16.78-MHz system clock. Because of design limits, a DSCCKL value of one defaults to the same timing as a value of two.

If a queue entry's DSCCK equals zero, then DSCCKL is not used. Instead, the PCS valid-to-SCK transition is one-half SCK period.

DTL — Length of Delay after Transfer

These bits determine the length of time that the QSPI delays after each serial transfer in which the command control bit, DT of the QSPI RAM, equals one. The following equation is used to calculate the delay:

$$\text{Delay after transfer} = [(32 * \text{DTL})/\text{system clock frequency}] \quad (5-4)$$

where DTL equals {1, 2, 3, . . . 255}.

NOTE

A zero value for DTL causes a delay-after-transfer value of ((32 * 256) /system clock), which equals 488.5 μs with a 16.78-MHz system clock.

If DT equals zero, a standard delay is inserted.

$$\begin{aligned} \text{Standard Delay-after-Transfer} &= \lceil 17/\text{System Clock} \rceil & (5-5) \\ &= 1 \mu\text{s with a 16.78-MHz System Clock} \end{aligned}$$

Delay after transfer can be used to ensure that the deselect time requirement (for peripherals having such a requirement) is met. Some peripherals must be deselected for a minimum period of time between consecutive serial transfers. A delay after transfer can be inserted between consecutive transfers to a given peripheral to ensure that its minimum deselect time requirement is met or to allow serial A/D converters to complete conversion before the next transfer is made.

5.5.4.3 QSPI Control Register 2 (SPCR2)

SPCR2 (Figure 5-13) contains parameters for configuring the QSPI. Although the CPU can read and write this register, the QSM has read access only. Writes to this register are buffered. A write to SPCR2 that changes any of the bit values (while the QSPI is operating) is ineffective on the current serial transfer, but becomes effective on the next serial transfer. Reads of SPCR2 return the actual current value of the register, not the buffer. Refer to **5.5.5 Operating Modes and Flowcharts** for a detailed description of this register.

SPCR2 — QSPI Control Register 2														\$YFFC1C	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPIFIE	WREN	WRTO	0	ENDQP				0	0	0	0	NEWQP			
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5-13. QSPI Control Register 2

SPIFIE — SPI Finished Interrupt Enable

1 = QSPI interrupts enabled

0 = QSPI interrupts disabled

SPIFIE enables the QSPI to generate a CPU interrupt upon assertion of the status flag SPIF. Because of its special buffering, the value written to SPIFIE applies only upon completion of the queue (the transfer of the entry indicated by ENDQP). Thus, if a single sequence of queue entries is to be transferred (i.e., no WRAP), then SPIFIE should be set to the desired state before the first transfer.

If a subqueue (see bit NEWQP) is to be used, the same CPU write that causes a branch to the subqueue may enable or disable the SPIF interrupt for the subqueue. The primary queue retains its own selected interrupt mode, either enabled or disabled.

The SPIF interrupt must be cleared by clearing SPIF. Later interrupts may then be prevented by clearing SPIFIE to zero.

The QSPI has three possible interrupt sources, but only one interrupt vector. These sources are SPIF, MODF, and HALTA. When the CPU responds to a QSPI interrupt, the user must ascertain the exact interrupt cause by reading register SPSR. Any interrupt that was set may then be cleared by writing to SPSR with a zero in the bit position corresponding to the exact interrupt source. Clearing SPIFIE does not immediately clear an interrupt already caused by SPIF.

WREN — Wrap Enable

1 = Wraparound mode enabled

0 = Wraparound mode disabled

WREN enables or disables wraparound mode. If enabled, the QSPI executes commands in the queue through the command contained in ENDQP. Execution continues at either address \$0 or at the address found in NEWQP, depending on the state of WRTO. The QSPI continues looping until either WREN is negated, HALT is asserted, or SPE is negated. Once WREN is negated, the QSPI finishes executing commands through the command at the address contained in ENDQP, sets the SPIF flag, and stops. When WREN is set, SPIF is set each time the QSPI transfers the entry indicated by ENDQP.

WRTO — Wrap To

When wraparound mode is enabled and after the end of queue has been reached, WRTO determines which address the QSPI executes next. End of queue is determined by an address match with ENDQP. Execution wraps to address \$0 if WRTO is not set, or to the address found in NEWQP if WRTO is set.

Bit 12 — Not Implemented

ENDQP — Ending Queue Pointer

This field determines the last absolute address in the queue to be completed by the QSPI. After completing each command, the QSPI compares the queue pointer value of the just-completed command with the value of ENDQP. If the two values match, the QSPI assumes it has reached the end of the programmed queue and sets the SPIF flag to so indicate.

The QSPI RAM queue has 16 entries: \$0–\$F. The user may program the NEWQP to start executing commands beginning at any of the 16 addresses. Similarly, the user may program the ENDQP to stop execution of commands at any of the 16 addresses.

The queue is a circular data structure. If ENDQP is set to a lower address than NEWQP, the QSPI executes commands through address \$F, and then continues execution at address \$0 and so on until it stops after executing the command at address ENDQP. A maximum of 16 commands are executed before stopping, unless wraparound mode is enabled or unless the user modifies NEWQP and/or ENDQP.

The user may write a NEWQP value at any time, changing the flow of execution. ENDQP may also be written at any time, changing the length of the queue. Wraparound mode may also be enabled, causing continuous execution until the mode is disabled or the QSPI is halted.

Bits 7–4 — Not Implemented

NEWQP — New Queue Pointer Value

NEWQP determines which queue entry the QSPI transfers first. NEWQP should be initialized before the QSPI is enabled with SPE. NEWQP may also be written while the QSPI is operating. When this happens, the QSPI completes transfer of the queue entry in progress and then immediately begins transferring queue entries starting with the entry indicated by the NEWQP.

In this way, NEWQP provides additional functionality to the QSPI by providing a mechanism for supporting multiple queues or subqueues within the QSPI RAM. By changing the value in NEWQP, the user can cause the QSPI to execute a sequence of QSPI commands beginning at any location in the queue. Therefore, the user is able to set up in advance separate subqueues for different tasks within the QSPI RAM. By writing to NEWQP, selection between the different subqueues within the QSPI RAM is accomplished.

If wraparound mode is enabled by setting WREN and WRTO in SPCR2, NEWQP assumes an additional function. When the end of the queue is reached, as determined by ENDQP, the address contained in NEWQP is used by the QSPI to wrap around to the first queue entry. The QSPI then re-executes the queued commands repeatedly until halted.

5.5.4.4 QSPI Control Register 3 (SPCR3)

SPCR3 (Figure 5-14) contains parameters for configuring the QSPI. The CPU can read and write this register; the QSM has read-only access.

15	14	13	12	11	10	9	8	0
0	0	0	0	0	LOOPQ	HMIE	HALT	SPSR*

RESET:

0 0 0 0 0 0 0 0 0

*SPSR — QSPI Status Register

Figure 5-14. QSPI Control Register 3

Bits 15–11 — Not Implemented

LOOPQ — QSPI Loop Mode

1 = Feedback path enabled

0 = Feedback path disabled

LOOPQ enables or disables the feedback path on the data serializer for testing. If enabled, LOOPQ routes serial output data back into the data serializer, instead of received data. If disabled, LOOPQ allows regular received data into the data serializer. LOOPQ does not affect the QSPI output pins.

HMIE — HALTA and MODF Interrupt Enable

1 = HALTA and MODF interrupts enabled

0 = HALTA and MODF interrupts disabled

HMIE enables or disables QSPI interrupts to the CPU caused when either the HALTA status flag or the MODF status flag in SPSR is asserted. When HMIE is set, the assertion of either flag causes the QSPI to send a hardware interrupt to the CPU. When HMIE is clear, the asserted flag does not cause an interrupt.

HALT — Halt

1 = Halt enabled

0 = Halt not enabled

This bit is used by the CPU to stop the QSPI on a queue boundary. The QSPI halts in a known state from which it can later be restarted. When HALT is asserted by the CPU, the QSPI finishes executing the current serial transfer (up to 16 bits) and then halts. While halted, if the command control bit (CONT of the QSPI RAM) for the last command was asserted, the QSPI continues driving the peripheral chip-select pins with the value designated by the last command before the halt. If CONT was clear, the QSPI drives the peripheral chip-select pins to the value in QSM register QPDR.

If HALT is asserted during the last command in the queue, the QSPI completes the last command, asserts both HALTA and SPIF, and clears SPE. If the last queue command has not been executed, asserting HALT does not set SPIF nor clear SPE. QSPI execution continues when the CPU clears HALT.

5.5.4.5 QSPI Status Register (SPSR)

SPSR (Figure 5-15) contains QSPI status information. Only the QSPI can assert the bits in this register. The CPU reads this register to obtain status information and writes this register to clear status flags. CPU writes to CPTQP have no effect.

SPSR — QSPI Status Register

\$YFFC1F

15	7	6	5	4	3	2	1	0
SPCR3*				SPIF	MODF	HALTA	0	CPTQP
RESET:								
				0	0	0	0	0

*SPCR3 — QSPI Control Register 3

Figure 5-15. QSPI Status Register

5

SPIF — QSPI Finished Flag

1 = QSPI finished

0 = QSPI not finished

SPIF is set when the QSPI finishes executing the last command determined by the address contained in ENDQP in SPCR2. When the address of the command being executed matches the ENDQP, the SPIF flag is set after finishing the serial transfer.

If wraparound mode is enabled (WREN = 1), the SPIF is set, after completion of the command defined by ENDQP, each time the QSPI cycles through the queue. If SPIFIE in SPCR2 is set, an interrupt is generated when SPIF is asserted. Once SPIF is set, the CPU may clear it by reading SPSR followed by writing SPSR with a zero in SPIF.

MODF — Mode Fault Flag

1 = Another SPI node requested to become the network SPI master while the QSPI was enabled in master mode (MSTR = 1), or the PCS0/SS pin was incorrectly pulled low by external hardware.

0 = Normal operation

MODF is asserted by the QSPI when the QSPI is the serial master (MSTR = 1) and the slave select (PCS0/SS) input pin is pulled low by an external driver. This is possible only if the PCS0/SS pin is configured as input by QDDR. This low input to SS is not a normal operating condition. It indicates that a multimaster system conflict may exist, that another MCU is requesting to become the SPI network master, or simply that the hardware is incorrectly affecting PCS0/SS. SPE in SPCR1 is cleared, disabling the QSPI. The QSPI pins revert to control by QPDR. If MODF is set and HMIE in SPCR3 is asserted, the QSPI generates an interrupt to the CPU.

The CPU may clear MODF by reading SPSR with MODF asserted, followed by writing SPSR with a zero in MODF. After correcting the mode fault problem, the QSPI can be re-enabled by asserting SPE.

The PCS0/SS pin may be configured as a general-purpose output instead of input to the QSPI. This inhibits the mode fault checking function. In this case, MODF is not used by the QSPI.

HALTA — Halt Acknowledge Flag

1 = QSPI halted

0 = QSPI not halted

HALTA is asserted by the QSPI when it has come to an orderly halt at the request of the CPU, via the assertion of HALT. To prevent undefined operation, the user should not modify any QSPI control registers or RAM while the QSPI is halted.

If HMIE in SPCR3 is set, the QSPI sends interrupt requests to the CPU when HALTA is asserted. The CPU can only clear HALTA by reading SPSR with HALTA set and then writing SPSR with a zero in HALTA.

Bit 4 — Not Implemented

CPTQP — Completed Queue Pointer

CPTQP contains the queue pointer value of the last command in the queue that was completed. The value of CPTQP is not updated until the command has been completed entirely. While the first command in a queue is executing, CPTQP contains either the reset value (\$0) or the pointer to the last command completed in the previous queue.

If the QSPI is halted, CPTQP may be used to determine which commands have not been executed. The CPTQP may also be used to determine which locations in the receive data segment of the QSPI RAM contain valid received data.

5.5.4.6 QSPI Ram

The QSPI uses an 80-byte block of dual-access static RAM, which can be accessed by both the QSPI and the CPU. Because of sharing, the length of time taken by the CPU to access the QSPI RAM, when the QSPI is enabled, may be longer than when the QSPI is disabled. From one to four CPU wait states may be inserted by the QSPI in the process of reading or writing.

The size and type of access of the QSPI RAM by the CPU affects the QSPI access time. The QSPI is byte, word, and long-word addressable. Only word accesses of the RAM by the CPU are coherent accesses because these accesses are an indivisible operation. If the CPU makes a coherent access of the QSPI RAM, the QSPI cannot access the QSPI RAM until the CPU is finished. However, a long-word or misaligned word access is not coherent because the

CPU must break its access of the QSPI RAM into two parts, which allows the QSPI to access the QSPI RAM between the two accesses by the CPU.

The RAM is divided into three segments: receive data (REC.RAM), transmit data (TRAN.RAM), and command control (COMD.RAM). Receive data is information received from a serial device external to the MCU. Transmit data is information stored by the CPU for transmission to an external peripheral chip. Command control contains all the information needed by the QSPI to perform the transfer. Figure 5-16 illustrates the organization of the RAM.

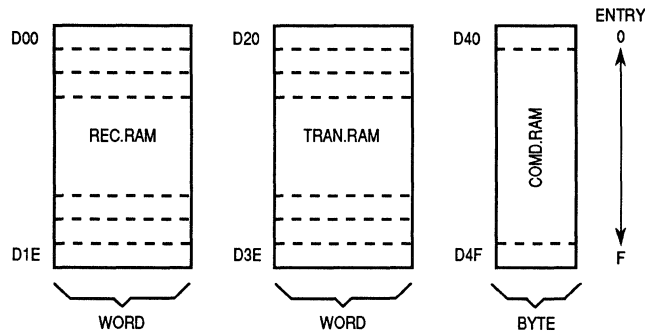


Figure 5-16. Organization of the QSPI RAM

Once the CPU has set up the queue of QSPI commands and enabled the QSPI, the QSPI operates independently of the CPU. The QSPI executes all of the commands in its queue, sets a flag indicating that it is finished, and then either interrupts the CPU or waits for CPU intervention.

5.5.4.6.1 Receive Data Ram (REC.RAM)

This segment of the RAM stores the data that is received by the QSPI from peripherals, SPI bus masters, or other MCUs. The CPU reads this segment of RAM to retrieve the data from the QSPI. Data stored in receive RAM is right-justified, i.e., the least significant bit is always in the right-most bit position within the word (bit 0) regardless of the serial transfer length. Unused bits in a receive queue entry are set to zero by the QSPI upon completion of the individual queue entry. The CPU can access the data using byte, word, or long-word addressing.

The CPTQP value in SPSR shows which queue entries have been executed. The CPU uses this information to determine which locations in receive RAM contain valid data before reading them.

5.5.4.6.2 Transmit Data Ram (TRAN.RAM)

This segment of the RAM stores the data that is to be transmitted by the QSPI to peripherals. The CPU normally writes one word of data into this segment for each queue command to be executed. If the corresponding peripheral, such as a serial input port, is used solely to input data, then this segment does not need to be initialized.

Information to be transmitted by the QSPI should be written by the CPU to the transmit data segment in a right-justified manner. The information in the transmit data segment of the RAM cannot be modified by the QSPI. The QSPI merely copies the information to its data serializer for transmission to a peripheral. Information in transmit RAM remains there until it is re-written by the CPU.

5.5.4.6.3 Command Ram (CMD.RAM)

The command segment of the QSPI RAM is used only by the QSPI when it is in master mode. The CPU writes one byte of control information to this segment for each QSPI command to be executed. The information in the command RAM cannot be modified by the QSPI. It merely uses the information to perform the serial transfer.

COMD.RAM consists of 16 bytes. Each byte is divided into two fields. The first, the peripheral chip-select field, activates the correct serial peripheral during the transfer. The second, the command control field, provides transfer options specifically for that command/serial transfer. This feature gives the user more control over each transfer, providing the flexibility to interface to external SPI chips with different requirements (refer to Figure 5-17).

A maximum of 16 commands can be in the queue command control bytes. These bytes are assigned an address from \$0-\$F. Queue execution by the QSPI proceeds from the address contained in NEWQP through the address contained in ENDQP. Both of these fields are contained in SPCR2.

COMD.RAM — Command Ram**\$YFFD40**

7	6	5	4	3	2	1	0
CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*
—	—	—	—	—	—	—	—
CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*

\$YFFD4F

COMMAND CONTROL

PERIPHERAL CHIP-SELECT

*The PCS0 bit represents the dual-function PCS0/ \overline{SS} .**Figure 5-17. Command Ram****PCS3–PCS0/ \overline{SS} — Peripheral Chip-Select**

The four peripheral chip-select bits can be used directly to select one of four external chips for the serial transfer, or decoded by external hardware to select one of 16 chip-select patterns for the serial transfer. More than one peripheral chip-select may be activated at a time, which is useful for broadcast messages in a multinode SPI system. More than one peripheral chip may be connected to each PCS pin. Care must be taken by the system designer not to exceed the maximum drive capability of the pins as defined in **SECTION 8 ELECTRICAL CHARACTERISTICS** for QSM pins.

QSM register QPDR determines the state of the PCS pins when the QSPI is disabled, and also determines the state of PCS pins that are not assigned to the QSPI when the QSPI is enabled. QPDR determines the state of pins assigned to the QSPI between transfers as well.

To use a peripheral chip-select pin, the CPU assigns the pin to the QSPI in QPAR by writing a one to the appropriate bit. The default value of the PCS pin should be written to QPDR. Next, the pin must be defined as an output in QDDR by setting the appropriate bit, which causes the pin to start driving the default value.

The QSPI RAM may then be initialized for a serial transmission, with the peripheral chip-select bits of the command control byte appropriately configured to activate the desired PCS pin(s) during the serial transfer. When the command is executed, the PCS pin(s) are driven to the values contained in the appropriate control byte. After completing the serial transfer, the QSPI returns control of the peripheral chip-select signal(s) (if CONT = 0 in the command control byte) to register QPDR.

CONT — Continue

1 = Keep peripheral chip-selects asserted after transfer is complete

0 = Return control of peripheral chip-selects to QPDR after transfer is complete

Some peripheral chips must be deselected between every QSPI transfer. Other chips must remain selected between several sequential serial transfers. CONT is designed to provide the flexibility needed to handle both cases.

If CONT = 1 and the peripheral chip-select pattern for the next command is the same as that of the present command, the QSPI drives the PCS pins to the same value continuously during the two serial transfers. An unlimited number of serial transfers may be sent to the same peripheral(s) without deselecting it (them) by setting CONT = 1.

If CONT = 1 and the peripheral chip-select pattern for the next command is different from that of the present command, the QSPI drives the PCS pins to the new value for the second serial transfer. Although this case is similar to CONT = 0, a difference remains. When CONT = 1, the QSPI continues to drive the PCS pins using the pattern from the first transfer until it switches to using the pattern for the second transfer.

When CONT = 0, the QSPI drives the PCS pins to the values found in register QPDR between serial transfers.

BITSE — Bits Per Transfer Enable

1 = Number of bits set in BITS field of SPCR0

0 = 8 bits

DT — Delay After Transfer

A/D converters require a known amount of time to perform a conversion. The conversion time for serial CMOS A/D converters may range from 1 – 100 μ s.

To facilitate interfacing to peripherals with a latency requirement, the QSPI provides a programmable delay at the end of the serial transfer, with the DT field. The user may avoid using this delay option by executing transfers with other peripheral devices between transfers with the peripheral that requires a delay. This interleaved operation improves the effective serial transfer rate.

The amount of the delay between transfers is programmable by the user via the DTL field in SPCR1. The range may be set from 1 to 489 μ s at 16.78 MHz.

DSCK — PCS to SCK Delay

1 = DSKL field in SPCR1 specifies value of delay from PCS valid to SCK

0 = PCS valid to SCK transition is 1/2 SCK

5.5.5 Operating Modes and Flowcharts

The QSPI utilizes an 80-byte block of dual-access static RAM accessible by both the QSPI and the CPU. The RAM is divided into three segments: 16 command control bytes, 16 transmit data words of information to be transmitted, and 16 receive data words for data to be received. Once the CPU has a) set up a queue of QSPI commands, b) written the transmit data segment with information to be sent, and c) enabled the QSPI, the QSPI operates independently of the CPU. The QSPI executes all of the commands in its queue, sets a flag indicating completion, and then either interrupts the CPU or waits for CPU intervention.

The QSPI operates on a queue data structure contained in the QSPI RAM. Control of the queue is handled by three pointers: the new queue pointer (NEWQP), the completed queue pointer (CPTQP), and the end queue pointer (ENDQP). NEWQP, contained in SPCR2, points to the first command in the queue to be executed by the QSPI. CPTQP, contained in SPSR, points to the command last executed by the QSPI. ENDQP, also contained in SPCR2, points to the last command in the queue to be executed by the QSPI, unless wraparound mode is enabled (WREN = 1).

At reset, NEWQP is initialized to \$0, causing QSPI execution to begin at queue address \$0 when the QSPI is enabled (SPE = 1). CPTQP is set by the QSPI to the queue address (\$0-\$F) last executed, but is initialized to \$0 at reset. ENDQP is also initialized to \$0 at reset, but should be changed by the user to reflect the last queue entry to be transferred before enabling the QSPI. Leaving NEWQP and ENDQP set to \$0 causes a single transfer to occur when the QSPI is enabled.

The organization of the QSPI RAM requires that one byte of command control data, one word of transmit data, and one word of receive data all correspond to one queue entry, \$0-\$F.

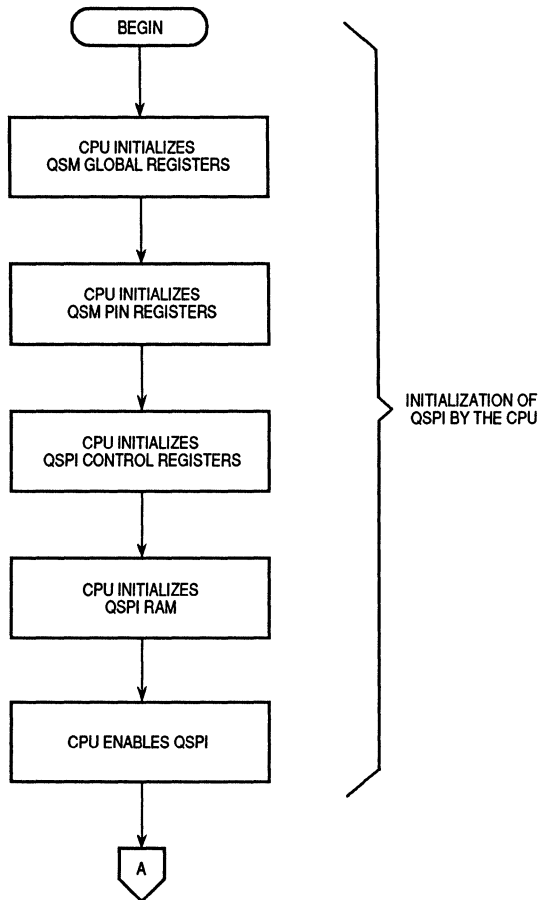
After executing the current command, ENDQP is checked against CPTQP for an end-of-queue condition. If a match occurs, the SPIF flag is set and the QSPI stops unless wraparound mode is enabled.

The QSPI operates in one of two modes: master or slave. Master mode is used when the MCU originates all data transfers. Slave mode is used when another MCU or a peripheral to the MCU initiates all serial transfers to the MCU via the QSPI. Switching between the two operating modes is achieved under software control by writing to the master (MSTR) bit in SPCR0.

In master mode, the QSPI executes the queue of commands as defined by the control bits in each entry. Chip-select pins are activated; data is transmitted, received, and placed in the QSPI RAM.

In slave mode, a similar operation occurs in response to the slave select (\overline{SS}) pin activated by an external SPI bus master. The primary differences are a) no peripheral chip-selects are generated, and b) the number of bits transferred is controlled in a different manner. When the QSPI is selected, it executes the next queue transfer to correctly exchange data with the external device.

The following flowcharts, Figures 5-18 – 5-23, outline the operation of the QSPI for both master and slave modes. Note that the CPU must initialize the QSM global and pin registers and the QSPI control registers before enabling the QSPI for either master or slave operation. If using master mode, the necessary command control RAM should also be written before enabling the QSPI. Any data to be transmitted should also be written before the QSPI is enabled. When wrap mode is used, data for subsequent transmissions may be written at any time.



(PROCEED TO FIGURE 5-19 FOR MASTER MODE
OR TO FIGURE 5-22 FOR SLAVE MODE)

Figure 5-18. Flowchart of QSPI Initialization Operation

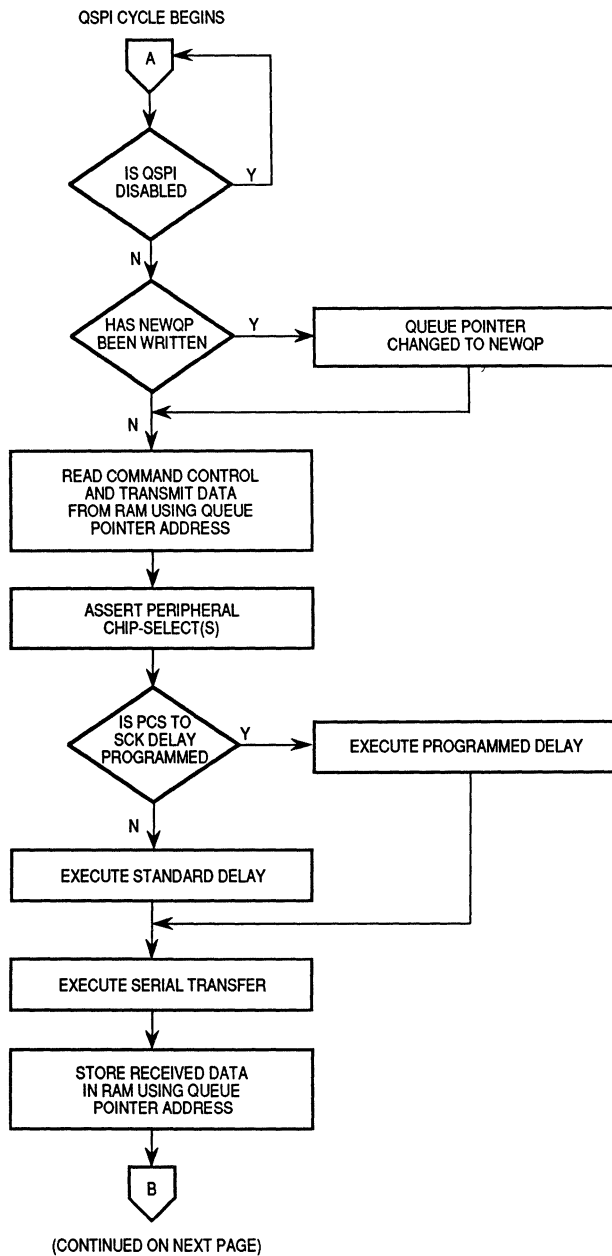
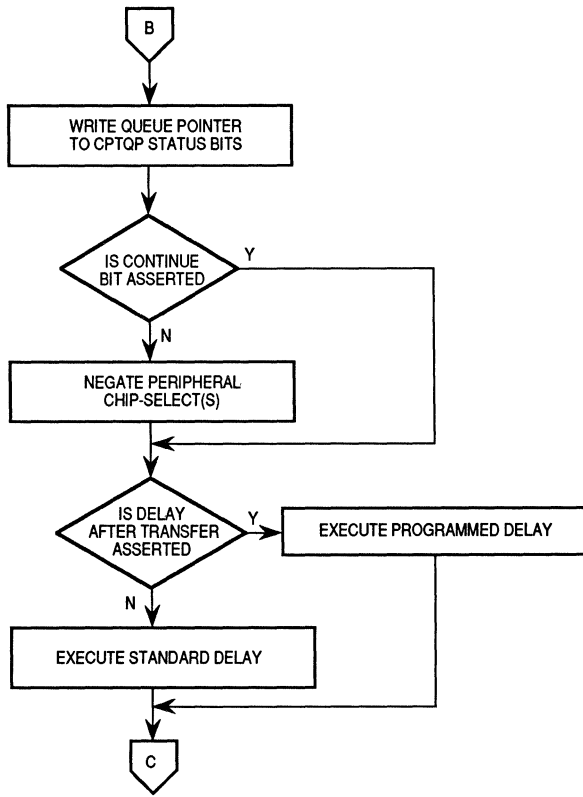


Figure 5-19. Flowchart of QSPI Master Operation (Part 1)



(CONTINUED ON NEXT PAGE)

Figure 5-20. Flowchart of QSPI Master Operation (Part 2)

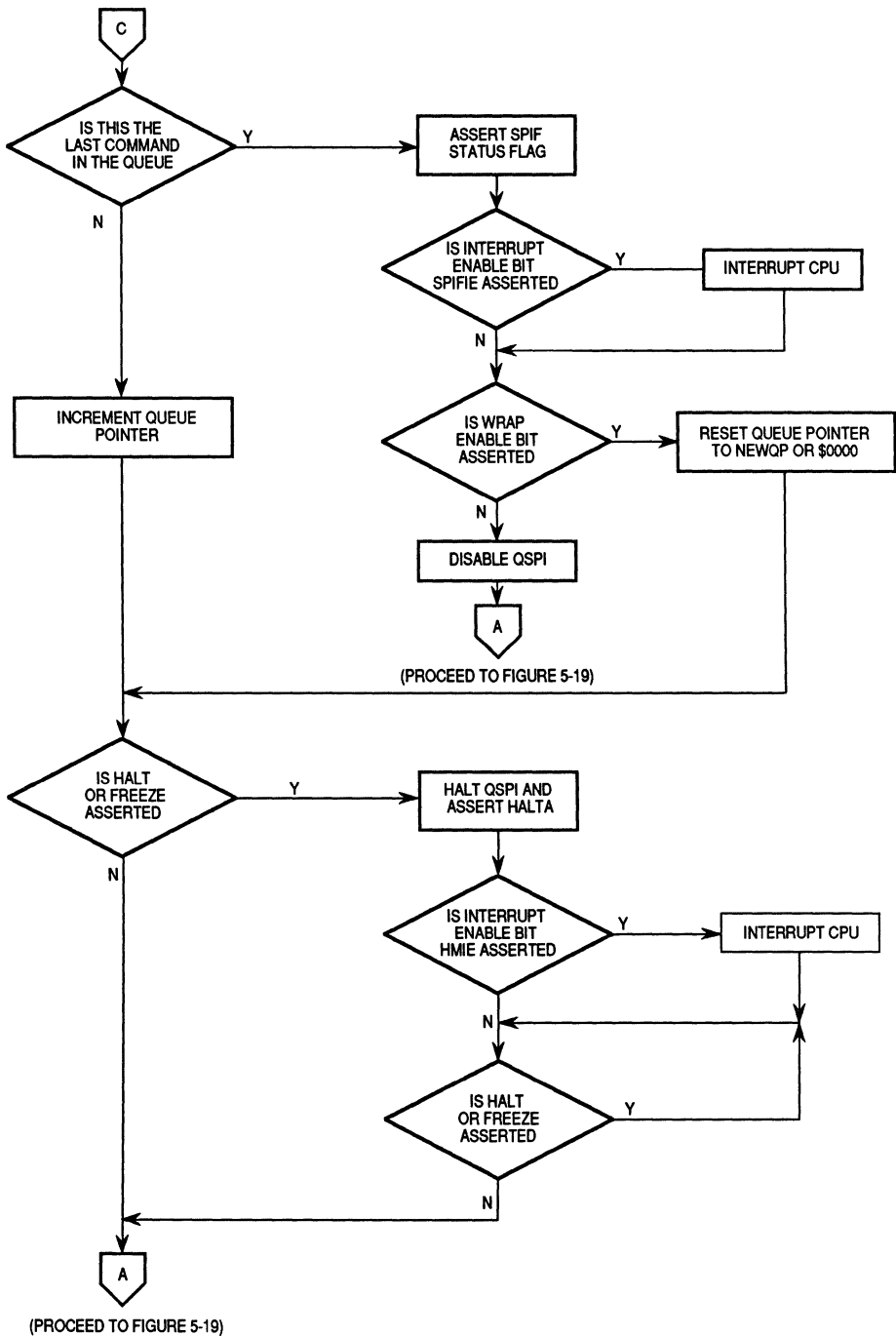


Figure 5-21. Flowchart of QSPI Master Operation (Part 3)

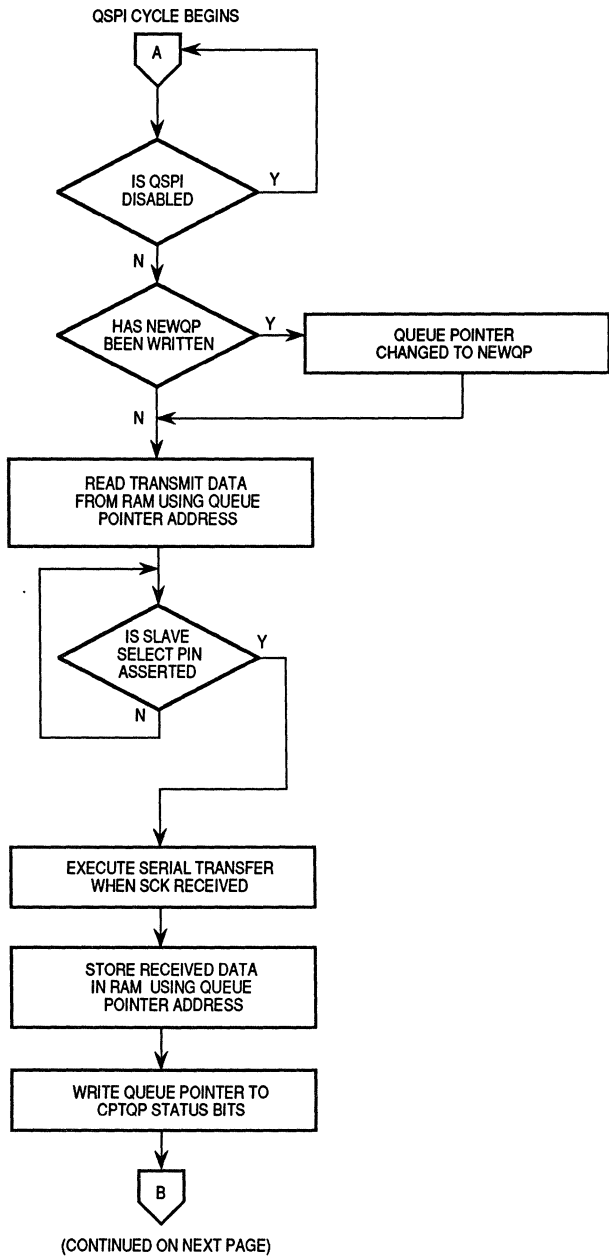


Figure 5-22. Flowchart of QSPI Slave Operation (Part 1)

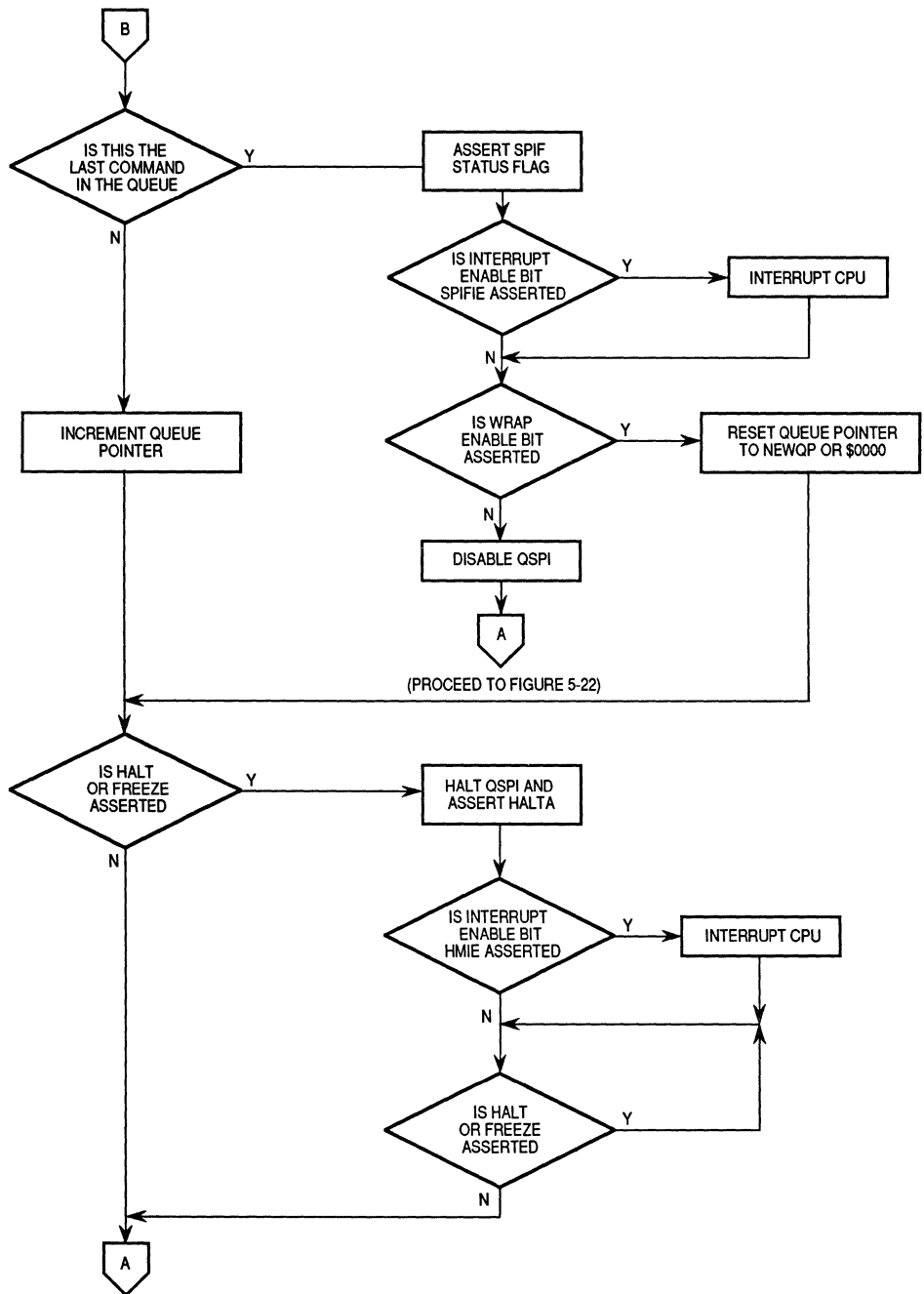


Figure 5-23. Flowchart of QSPI Slave Operation (Part 2)

Although the QSPI inherently supports multimaster operation, no special arbitration mechanism is provided. The user is given a mode fault flag (MODF) to indicate a request for SPI master arbitration; however, the system software must implement the arbitration. Note that unlike previous SPI systems, e.g., on the M68HC11 Family, MSTR is not cleared by a mode fault being set nor are the QSPI pin output drivers disabled; however, the QSPI is disabled when software clears SPE in QSPI register SPCR1.

Normally, the SPI bus performs simultaneous bidirectional synchronous transfers. The serial clock on the SPI bus master supplies the clock signal (SCK) to time the transfer of the bits. Four possible combinations of clock phase and polarity may be employed.

Data is transferred with the most significant bit first. The number of bits transferred per command defaults to eight, but may be programmed to a value from 8–16 bits, using the BITSE field.

Typically, outputs used for the SPI bus are not open-drain unless multiple SPI masters are in the system. If needed, WOMQ in SPCR0 may be set to provide open-drain outputs. An external pullup resistor should be used on each output bus line. WOMQ affects all QSPI pins regardless of whether they are assigned to the QSPI or used as general-purpose I/O.

5.5.5.1 Master Mode

When operated in master mode, the QSPI may initiate serial transfers. The QSPI is unable to respond to any externally initiated serial transfers. QSM register QDDR should be written to direct the data flow on the QSPI pins used. The SCK pin should be configured as an output. Pins MOSI and PCS3–PCS0/SS should be configured as outputs as necessary. MISO should be configured as an input if necessary.

QSM register QPAR should be written to assign the necessary bits to the QSPI. The pins necessary for master mode operation are MISO and/or MOSI, SCK, and one or more of the PCS pins, depending on the number of external peripheral chips to be selected. MISO is used as the data input pin in master mode, and MOSI is used as the data output pin in master mode. Either or both may be necessary, depending on the particular application. SCK is the serial clock output in master mode.

PCS3 – PCS0/SS are the select pins used to select external SPI peripheral chips for a serial transfer initiated by the QSPI. These pins operate as either active-high or active-low chip-selects. Other considerations for initialization are prescribed in **5.4.1 Overall QSM Configuration Summary**.

5.5.5.1.1 Master Mode Operation

After reset, the QSM registers and the QSPI control registers must be initialized as described above. In addition to the command control segment, the transmit data segment may, depending upon the application, need to be initialized. If meaningful data is to be sent out from the QSPI, the user should write the data to the transmit data segment before enabling the QSPI.

Shortly after SPE is set, the QSPI commences operation at the address indicated by NEWQP. The QSPI transmits the data found in the transmit data segment at the address indicated by NEWQP, and the QSPI stores received data in the receive data segment at the address indicated by NEWQP. Data is transferred synchronously with the internally generated SCK.

Transmit data is loaded into the data serializer (refer to Figure 5-10). The QSPI employs control bits, CPHA and CPOL, to determine which SCK edge the MISO pin uses to latch incoming data and which edge the MOSI pin uses to start driving the outgoing data. SPBR of SPCR0 determines the baud rate of SCK. DSCK and DSCKL determine any peripheral chip-selects valid to SCK start delay.

The number of bits transferred is determined by BITSE and BITS fields. Two options are available: the user may use the default value of 8 bits, or the user may program the length from 8 – 16 bits, inclusive.

Once the proper number of bits are transferred, the QSPI stores the received data in the receive data segment, stores the internal working queue pointer value in CPTQP, increments the internal working queue pointer, and loads the next data required for transfer from the queue. The internal working queue pointer address is the next command executed unless the CPU writes a new value first.

If CONT is set and the peripheral chip-select pattern does not change between the current and the pending transfer, the PCS pins are continuously driven in their designated state during and between both serial transfers. If the peripheral chip-select pattern changes, then the first pattern is driven out during execution of the first transfer, followed by the QSPI switching to the next pattern of the second transfer when execution of the second transfer begins. If CONT is clear, the deselected peripheral chip-select values (found in register QPDR) are driven out between transfers.

DT causes a delay to occur after the specified serial transfer is completed. The length of the delay is determined by DTL. When DT is clear, the standard delay (1 μ s at a 16.78-MHz system clock) occurs after the specified serial transfer is completed.

5.5.5.1.2 Master Wraparound Mode

When the QSPI reaches the end of the queue, it always sets the SPIF flag whether wraparound mode is enabled or disabled. An optional interrupt to the CPU is generated when SPIF is asserted. At this point, the QSPI clears SPE and stops unless wraparound mode is enabled. A description of SPIFIE may be found in **5.5.4.3 QSPI Control Register 2 (SPCR2)**.

In wraparound mode, the QSPI cycles through the queue continuously. Each time the end of the queue is reached, the SPIF flag is set. If the CPU fails to clear SPIF it remains set, and the QSPI continues to send interrupt requests to the CPU (assuming SPIFIE is set). The user may avoid causing CPU interrupts by clearing SPIFIE. As SPIFIE is buffered, clearing it after the SPIF flag is asserted does not immediately stop the CPU interrupts, but only prevents future interrupts from this source. To clear the current interrupt, the CPU must read QSPI register SPSR with SPIF asserted, followed by a write to SPSR with a zero in SPIF (clear SPIF).

Execution continues in wraparound mode, even while the QSPI is requesting interrupt service from the CPU. The internal working queue pointer increments to the next address, and the commands are executed again. SPE is not cleared by the QSPI. New receive data overwrites previously received data in the receive data segment.

Wraparound mode is properly exited in two ways: a) The CPU may disable wraparound mode by clearing WREN. The next time the end of the queue is reached, the QSPI sets SPIF, clears SPE, and stops; or, b) The CPU sets HALT. This second method halts the QSPI after the current transfer is completed, allowing the CPU to negate SPE. The CPU can immediately stop the QSPI by clearing SPE; however, this method is not recommended as it causes the QSPI to abort a serial transfer in process.

5.5.5.2 Slave Mode

When operating in slave mode, the QSPI may respond to externally initiated serial transfers. The QSPI is unable to initiate any serial transfers. Slave mode is typically used when multiple MCUs are in an SPI bus network, because only one device can be the SPI master (in master mode) at any given time.

QSM register QDDR should be written to direct data flow on the QSPI pins used. The MISO and MOSI pins, if needed, should be configured as output and input, respectively. Pins SCK and PCS0/SS should be configured as inputs.

QSM register QPAR should be written to assign the necessary bits to the QSPI. The pins necessary for slave mode operation are MISO and/or MOSI, SCK, and PCS0/SS. MISO is the data output pin in slave mode, and MOSI is the data

input pin in slave mode. Either or both may be necessary depending on the particular application. The serial clock (SCK) is the slave clock input in slave mode. $\overline{\text{PCS0/SS}}$ is the slave select pin used to select the QSPI for a serial transfer by the external SPI bus master when the QSPI is in slave mode. The external bus master selects the QSPI by driving $\overline{\text{PCS0/SS}}$ low. The command control segment is not implemented in slave mode; therefore, the CPU does not need to initialize it. This segment of the QSPI RAM and any other unused segments may be employed by the CPU as general-purpose RAM. Other considerations for initialization are prescribed in **5.4.1 Overall QSM Configuration Summary**.

5.5.5.2.1 Description of Slave Operation

After reset, the QSM registers and the QSPI control registers must be initialized as described above. Although the command control segment is not used, the transmit and receive data segments may, depending upon the application, need to be initialized. If meaningful data is to be sent out from the QSPI, the user should write the data to the transmit data segment before enabling the QSPI.

If SPE is set and MSTR is not set, a low state on the slave select ($\overline{\text{PCS0/SS}}$) pin commences slave mode operation at the address indicated by NEWQP. The QSPI transmits the data found in the transmit data segment at the address indicated by NEWQP, and the QSPI stores received data in the receive data segment at the address indicated by NEWQP. Data is transferred in response to an external slave clock input at the SCK pin.

Because the command control segment is not used, the command control bits and peripheral chip-select codes have no effect in slave mode operation. The QSPI does not drive any of the four peripheral chip-selects as outputs. $\overline{\text{PCS0/SS}}$ is used as an input.

Although CONT cannot be used in slave mode, a provision is made to enable receipt of more than 16 data bits. While keeping the QSPI selected ($\overline{\text{PCS0/SS}}$ is held low), the QSPI stores the number of bits, designated by BITS, in the current receive data segment address, increments NEWQP, and continues storing the remaining bits (up to the BITS value) in the next receive data segment address.

As long as $\overline{\text{PCS0/SS}}$ remains low, the QSPI continues to store the incoming bit stream in sequential receive data segment addresses, until either the value in BITS is reached or the end-of-queue address is used with wraparound mode disabled. When the end of the queue is reached, the SPIF flag is asserted, optionally causing an interrupt. If wraparound mode is disabled, any additional incoming bits are ignored. If wraparound mode is enabled, storing continues at either address \$0 or the address of NEWQP, depending on the WRTO value.

When using this capability to receive a long incoming data stream, the proper delay between transfers must be used. The QSPI requires time, approximately 1 μ s at 16.78-MHz system clock, to prefetch the next transmit RAM entry for the next transfer. Therefore, the user may select a baud rate that provides at least a 1 μ s delay between successive transfers to ensure no loss of incoming data. If the system clock is operating at a slower rate, the delay between transfers must be increased proportionately.

Because the BITSE option in the command control segment is no longer available, BITS sets the number of bits to be transferred for all transfers in the queue until the CPU changes the BITS value. As mentioned above, until PCS0/ \overline{SS} is negated (brought high), the QSPI continues to shift one bit for each pulse of SCK. If PCS0/ \overline{SS} is negated before the proper number of bits (according to BITS) is received, the QSPI, the next time it is selected, resumes storing bits in the same receive data segment address where it left off. If more than 16 bits are transferred before negating the PCS0/ \overline{SS} , the QSPI stores the number of bits indicated by BITS in the current receive data segment address, then increments the address and continues storing as described above. Note that PCS0/ \overline{SS} does not necessarily have to be negated between transfers.

Once the proper number of bits (designated by BITS) are transferred, the QSPI stores the received data in the receive data segment, stores the internal working queue pointer value in CPTQP, increments the internal working queue pointer, and loads the new transmit data from the transmit data segment into the data serializer. The internal working queue pointer address is used the next time PCS0/ \overline{SS} is asserted, unless the CPU writes to the NEWQP first.

The DT and DSCK command control bits are not used in slave mode. As a slave, the QSPI does not drive the clock line nor the chip-select lines and, therefore, does not generate a delay.

In slave mode, the QSPI shifts out the data in the transmit data segment. The transmit data is loaded into the data serializer (refer to Figure 5-9) for transmission. This serializer shifts the 16 bits of data out in sequence, most significant bit first, as clocked by the incoming SCK signal. The QSPI uses CPHA and CPOL to determine which incoming SCK edge the MOSI pin uses to latch incoming data, and which edge the MISO pin uses to drive the data out.

The QSPI transmits and receives data until reaching the end of the queue (defined as a match with the address in ENDQP), regardless of whether PCS0/ \overline{SS} remains selected or is toggled between serial transfers. Receiving the proper number of bits causes the received data to be stored. The QSPI always transmits as many bits as it receives at each queue address, until the BITS value is reached or PCS0/ \overline{SS} is negated.

5.5.5.2.2 Slave Wraparound Mode

When the QSPI reaches the end of the queue, it always sets the SPIF flag, whether wraparound mode is enabled or disabled. An optional interrupt to the CPU is generated when SPIF is asserted. At this point, the QSPI clears SPE and stops unless wraparound mode is enabled. A description of SPIFIE bit can be found in **5.5.4.3 QSPI Control Register 2 (SPCR2)**.

In wraparound mode, the QSPI cycles through the queue continuously. Each time the end of the queue is reached, the SPIF flag is set. If the CPU fails to clear SPIF, it remains set, and the QSPI continues to send interrupt requests to the CPU (assuming SPIFIE is set). The user may avoid causing CPU interrupts by clearing SPIFIE. As SPIFIE is buffered, clearing it after the SPIF flag is asserted does not immediately stop the CPU interrupts, but only prevents future interrupts from this source. To clear the current interrupt, the CPU must read QSPI register SPSR with SPIF asserted, followed by a write to SPSR with zero in SPIF (clear SPIF).

Execution continues in wraparound mode even while the QSPI is requesting interrupt service from the CPU. The internal working queue pointer is incremented to the next address and the commands are executed again. SPE is not cleared by the QSPI. New receive data overwrites previously received data located in the receive data segment.

Wraparound mode is properly exited in two ways: a) The CPU may disable wraparound mode by clearing WREN. The next time end of the queue is reached, the QSPI sets SPIF, clears SPE, and stops; or, b) The CPU sets HALT. This second method halts the QSPI after the current transfer is completed, allowing the CPU to negate SPE. The CPU can immediately stop the QSPI by clearing SPE; however, this method is not recommended, as it causes the QSPI to abort a serial transfer in process.

5.5.5.3 QSPI Pin Timing

Table 5-10 and Figures 5-24–5-27 show the timing relationships for the QSPI pins. The figures are separated for master and slave mode timings. Both of these mode timings depend on the clock phase (CPHA) bit used. Although the clock polarity (CPOL) bit has no effect on the timing values, it does determine the inactive state of the serial clock.

Table 5-10. QSPI Pin Timing

Num	Function	Min	Max	Unit
	Operating Frequency Master Slave	DC DC	1/4 1/4	System Clock Frequency System Clock Frequency
1	Cycle Time Master Slave	4 TBD	— —	System Clocks System Clocks
2	Enable Lead Time Master Slave	2 240	128 —	System Clocks ns
3	Enable Lag Time Master Slave	1/2 —	1/2 180	SCK ns
4	Clock (SCK) High or Low Time Master Slave	2 2	255 —	System Clocks System Clocks
5	Sequential Transfer Delay Master Slave (Does Not Require Deselect)	17 13	8192 —	System Clocks System Clocks
6	Data Setup Time (Inputs) Master Slave	Nominal 50 Nominal 50	30 20	ns ns
7	Data Hold Time (Inputs) Master Slave	Nominal 50 Nominal 50	0 20	ns ns
8	Access Time Slave	—	1/4	SCK
9	MISO Disable Time Slave	—	1/2	SCK
10	Data Valid (after SCK Edge)* Master Slave	Nominal 50 — —	50 50	ns ns
11	Data Hold Time (Outputs) Master Slave	0 0	TBD TBD	ns ns
12	Rise Time* Outputs (SCK, MOSI, MISO, PCS3–PCS0) Inputs (SCK, MOSI, MISO, SS)	— —	30 TBD	ns μs
13	Fall Time* Outputs (SCK, MOSI, PCS3–PCS0, MISO) Inputs (SCK, MOSI, MISO, SS)	— —	30 TBD	ns μs

*Assumes 200 pF load on all QSPI pins

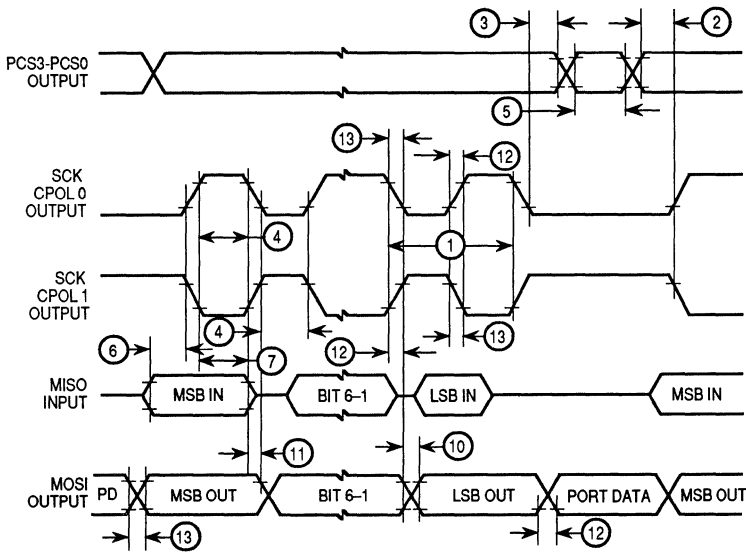


Figure 5-24. QSPI Timing Master, CPHA 0

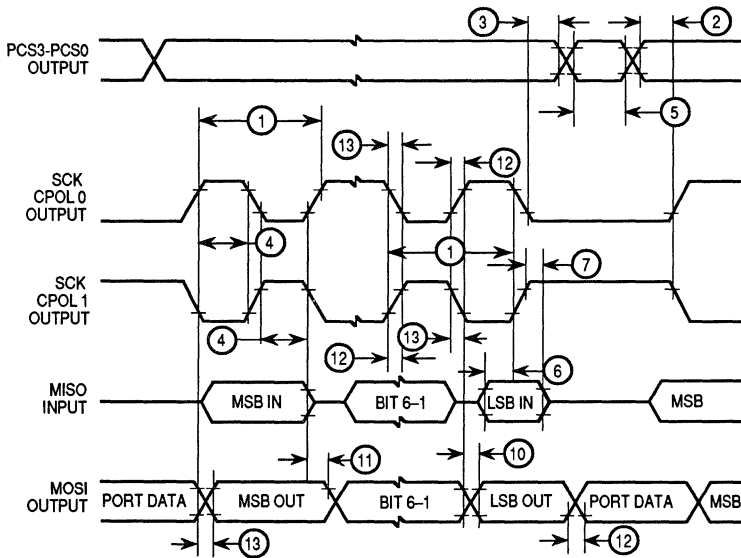


Figure 5-25. QSPI Timing Master, CPHA 1

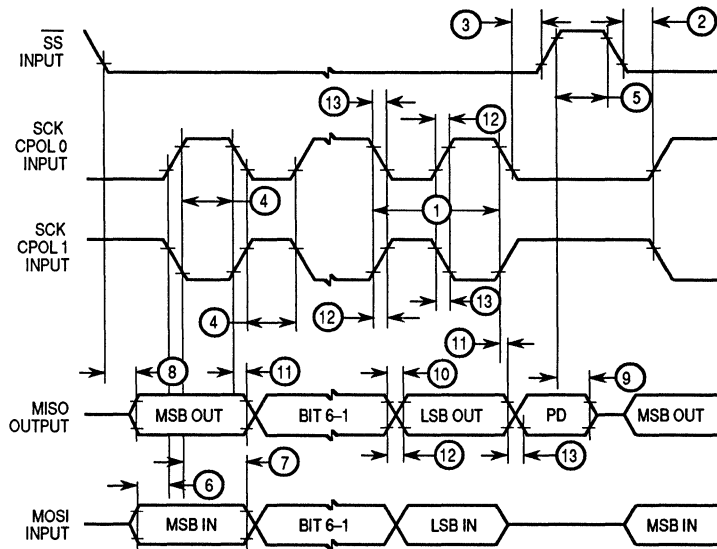


Figure 5-26. QSPI Timing Slave, CPHA 0

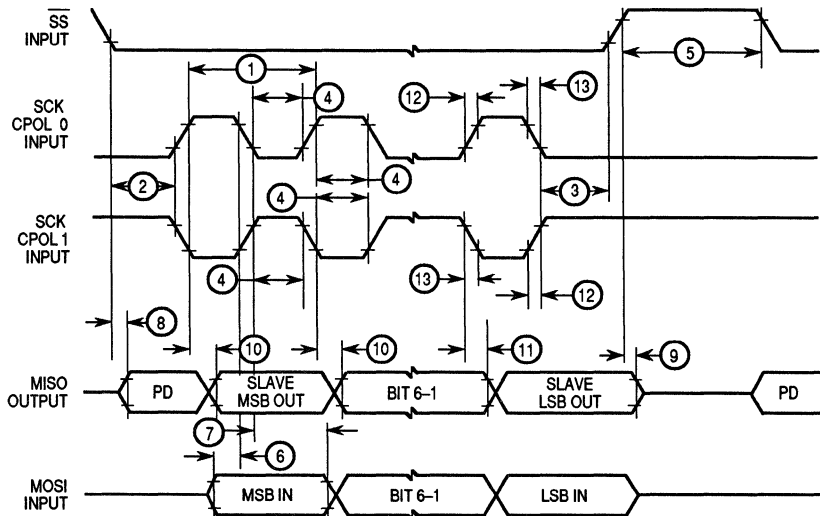


Figure 5-27. QSPI Timing Slave, CPHA 1

5.6 SCI Submodule

The SCI submodule is used to communicate with external devices and other MCUs via an asynchronous serial bus. The SCI is fully compatible with the SCI systems found on other Motorola MCUs such as the M68HC11 and M68HC05 Families. It has all of the capabilities of previous SCI systems as well as several significant new features. The following paragraphs describe the features, pins, programmer's model (memory map), registers, and the transmit and receive operations of the SCI.

5.6.1 Features

Standard SCI features are listed below, followed by a list of additional features offered.

Standard SCI Two-Wire System Features:

- Standard Nonreturn-to-Zero (NRZ) Mark/Space Format
- Advanced Error Detection Mechanism (detects noise duration up to 1/16 of a bit-time)
- Full-Duplex Operation
- Software Selectable Word Length (8- or 9-bit words)
- Separate Transmitter and Receiver Enable Bits
- May be Interrupt Driven
- Four Separate Interrupt Enable Bits

Standard SCI Receiver Features:

- Receiver Wakeup Function (idle or address mark bit)
- Idle-Line Detect
- Framing Error Detect
- Noise Detect
- Overrun Detect
- Receive Data Register Full Flag

Standard SCI Transmitter Features:

- Transmit Data Register Empty Flag
- Transmit Complete Flag
- Send Break

QSM-Enhanced SCI Two-Wire System Features:

- 13-Bit Programmable Baud-Rate Modulus Counter
- Even/Odd Parity Generation and Detection

QSM-Enhanced SCI Receiver Features:

- Two Idle-Line Detect Modes
- Receiver Active Flag

13-Bit Programmable Baud-Rate Modulus Counter

A baud rate modulus counter has been added to provide the user with more flexibility in choosing the crystal frequency for the system clock. The modulus counter allows the SCI baud rate generator to produce standard transmission frequencies for a wide range of system clocks. The user is no longer constrained to select crystal frequencies based on the desired serial baud rate. This counter provides baud rates from 64 baud to 524 kbaud with a 16.78-MHz system clock.

Even/Odd Parity Generation and Detection

The user now has the choice either of seven or eight data bits plus one parity bit, or of eight or nine data bits with no parity bit. Even or odd parity is available. The transmitter automatically generates the parity bit for a transmitted byte. The receiver detects when a parity error has occurred on a received byte and sets a parity error flag.

Two Idle-Line Detect Modes

Standard Motorola SCI systems detect an idle line when 10 or 11 consecutive bit-times are all ones. Used with the receiver wakeup mode, the receiver can be awakened prematurely if the message preceding the start of the idle line contained ones in advance of its stop bit. The new (second) idle-line detect mode starts counting idle time only after a valid stop bit is received, which ensures correct idle-line detection.

Receiver Active Flag (RAF)

RAF indicates the status of the receiver. It is set when a possible start bit is detected and is cleared when an idle line is detected. RAF is also cleared if the start bit is determined to be line noise. This flag can be used to prevent collisions in systems with multiple masters.

5.6.2 SCI Pins

There are two unidirectional pins associated with the SCI. The SCI controls the transmit data (TXD) pin when enabled, while the receive data (RXD) pin remains a dedicated input pin to the SCI. TXD is available as a general-purpose I/O pin when the SCI transmitter is disabled; however, when used as a general-purpose I/O, TXD may be configured either as input or output as determined by QSM register QDDR. Figure 5-1 illustrates these two pins. The SCI pins and their functions are listed in Table 5-11.

Table 5-11. External Pin Inputs/Outputs to the SCI

Pin Names	Mnemonics	Mode	Function
Receive Data	RXD	Receiver Disabled Receiver Enabled	Not Used Serial Data Input to SCI
Transmit Data	TXD	Transmitter Disabled Transmitter Enabled	General-Purpose I/O Serial Data Output from SCI

5.6.3 Programmer's Model and Registers

The programmer's model (memory map) for the SCI submodule consists of the QSM global and pin control registers (refer to **5.4.2 QSM Global Registers** and **5.4.3 QSM Pin Control Registers**) and the four SCI registers. The SCI registers are listed in Table 5-12 and consist of two control registers, one status register, and one data register. All registers may be read or written at any time by the CPU. Rewriting the same value to any SCI register does not disrupt operation; however, writing a different value into an SCI register when the SCI is running may disrupt operation. To change register values, the receiver and transmitter should be disabled with the transmitter allowed to finish first. The status flags in register SCSR may be cleared at any time.

Table 5-12. SCI Registers

Address	Name	Usage
\$YFFC08	SCCR0	SCI Control Register 0
\$YFFC0A	SCCR1	SCI Control Register 1
\$YFFC0C	SCSR	SCI Status Register
\$YFFC0E	SCDR	SCI Data Register Transmit Data Register (TDR)* Receive Data Register (RDR)*

*Reads access the RDR; writes access the TDR.

When initializing the SCI, the SCCR1 has two bits that should be written last, the transmitter enable (TE) and receiver enable (RE) bits, which enable the SCI. Registers SCCR0 and SCCR1 should both be initialized at the same time or before TE and RE are asserted. A single word write to SCCR1 can be used to initialize the SCI and enable the transmitter and receiver.

5.6.3.1 SCI Control Register 0 (SCCR0)

SCCR0 (Figure 5-28) contains the parameter for configuring the SCI baud rate. The baud rate should be set before the SCI is enabled. The CPU can read and write this register at any time.

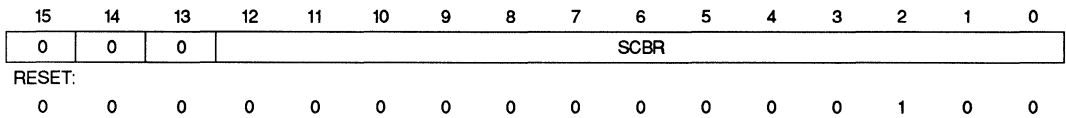


Figure 5-28. SCI Control Register 0

Bits 15-13 — Not Implemented

SCBR — Baud Rate

The SCI baud rate is programmed by writing a 13-bit value to SCBR and is derived from the MCU system clock using a modulus counter.

The SCI receiver operates asynchronously. Therefore, the SCI requires an internal clock to synchronize itself to the incoming data stream. The SCI baud-rate generator produces a receiver sampling clock with a frequency 16 times that of the expected baud rate of the incoming data. From transitions within the received waveform, the SCI determines the most likely position of the bit boundaries and adjusts sampling points to the proper positions within the bit period. The receiver sampling rate is always 16 times the frequency of the SCI baud rate, which is calculated using the following equation:

$$\text{SCI Baud} = \text{System Clock} / (32 * \text{SCBR}) \tag{5-6}$$

where SCBR equals {1, 2, 3, . . . 8191}. Note that zero is a disallowed value for SCBR.

Writing a value of zero to SCBR disables the baud rate generator. There are 8191 different bauds available. The baud value depends on the value for SCBR and the system clock, as used in the above equation. Table 5-13 shows possible baud rates for a 16.78-MHz system clock. The maximum baud rate with this system clock speed is 524 kbaud.

Table 5-13. Examples of SCI Baud Rates

Nominal Baud Rate	Actual Baud Rate	Percent Error	Value of SCBR
500,000.00	524,288.00	4.86	1
38,400.00	37,449.14	-2.48	14
32,768.00	32,768.00	0.00	16
19,200.00	19,418.07	1.14	27
9,600.00	9,532.51	-0.70	55
4,800.00	4,809.98	0.21	109
2,400.00	2,404.99	0.21	218
1,200.00	1,199.74	-0.02	437
600.00	599.87	-0.02	874
300.00	299.94	-0.02	1,748
110.00	110.01	0.01	4,766
64.00	64.00	0.01	8,191

NOTE: These rates are based on a 16.78-MHz system clock.

More accurate baud rates can be obtained by varying the system clock frequency with the VCO synthesizer. Each VCO speed increment adjusts the baud rate up or down by 1/64 or 1.56%.

5.6.3.2 SCI Control Register 1 (SCCR1)

SCCR1 (Figure 5-29) contains parameters for configuration of the SCI. The CPU can read and write this register at any time. The SCI may modify the RWU bit in some circumstances. In general, the interrupts enabled by these control bits are cleared by reading the status register SCSR, followed by reading (for receiver status bits) or by writing (for transmitter status bits) the data register SCDR. For further detail refer to **5.6.4 Transmitter Operation** and **5.6.5 Receiver Operation**, respectively.

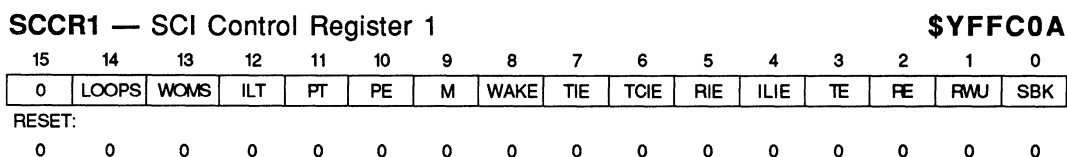


Figure 5-29. SCI Control Register 1

LOOPS — LOOP Mode

1 = Test SCI operation, looping, feedback path enabled

0 = Normal SCI operation, no looping, feedback path disabled

LOOPS controls a feedback path on the data serial shifter. If enabled, the output of the SCI transmitter is fed back into the receive serial shifter as receiver input, and no data is driven out of the TXD pin nor is data received from the RXD pin. The TXD pin is driven high (idle line). Both the transmitter and receiver must be enabled for loop mode to function.

WOMS — Wired-OR Mode for SCI Pins

1 = If configured as an output, TXD is an open-drain output

0 = If configured as an output, TXD is a normal CMOS output

WOMS determines whether the TXD pin is an open-drain output or a normal CMOS output. This bit is used only when TXD is an output. If the TXD pin is being used as a general-purpose input pin, WOMS has no effect.

ILT — Idle-Line Detect Type

1 = Long idle-line detect (starts counting when the first one is received after a stop bit(s))

0 = Short idle-line detect (starts counting when the first one is received)

ILT determines which one of two types of idle-line detection is to be used by the SCI receiver. The short idle-line detection circuitry causes the SCI receiver to start counting ones at any point (even during the frame), which means that the stop bit and any contiguous one data bits at the end of the last byte are counted toward the 10 or 11 ones in an idle frame. Hence, the data content of the last byte transmitted may affect the timing of idle-line detection.

The long idle-line detection circuitry causes the SCI receiver to start counting ones right after a stop bit, which means that the stop bit and any contiguous one data bits in a previous data byte are not counted toward the 10 or 11 ones in an idle line. Hence, the data content of the last byte transmitted does not affect the timing of idle-line detection.

PT — Parity Type

1 = Odd parity

If the data contains an even number of ones, then the parity bit equals one.

If the data contains an odd number of ones, then the parity bit equals zero.

0 = Even parity

If the data contains an even number of ones, then the parity bit equals zero.

If the data contains an odd number of ones, then the parity bit equals one.

When parity is enabled, PT determines whether parity is even or odd for both the receiver and the transmitter.

PE — Parity Enable

1 = SCI parity enabled; the transmitter generates the parity bit and the receiver checks incoming parity.

0 = SCI parity disabled

PE determines whether parity is enabled or disabled for both the receiver and the transmitter. If PE is set, the transmitter internally generates the parity bit and appends it to the data bits during transmission. The receiver checks the last bit before a stop bit to determine if the correct parity was received. If the received parity bit is not correct, the SCI sets the PF error flag in SCSR.

When PE is set, the most significant bit (MSB) of the data field is used for the parity function, which results in either seven or eight bits of user data, depending on the condition of M bit. Table 5-14 lists the available choices.

Table 5-14. M and PE Bit Fields

M	PE	Result
0	0	8 Data Bits
0	1	7 Data Bits, 1 Parity Bit
1	0	9 Data Bits
1	1	8 Data Bits, 1 Parity Bit

M — Mode Select

1 = SCI frame: 1 start bit, 9 data bits, 1 stop bit (11 bits total)

0 = SCI frame: 1 start bit, 8 data bits, 1 stop bit (10 bits total)

The M bit determines the SCI frame format. If M is clear (its reset value), the frame format is one start bit, eight data bits, one stop bit. If M is set, the frame format is one start bit, nine data bits, one stop bit.

The ninth data bit can be controlled by software to perform a function such as address mark. Frames with the ninth data bit set could be identified as an address mark. All receivers in a network could be placed in wakeup mode until an address mark is detected, at which time all receivers would wake up and read the address. All receivers being addressed could continue to receive the following message, while all receivers not being addressed could be put back into wakeup mode.

The ninth data bit could also serve as a second stop bit. By setting this bit permanently to one, communication with other SCIs requiring two stop bits could be accommodated.

Note that only 10 or 11 bits in a frame are allowed. If parity is to be enabled, the last data bit must be used for this purpose. The parity bit may be odd, even, mark, or space. Parity and address (control) bits are mutually exclusive. A choice must be made between one or the other, or neither. Every frame must have one start bit

and at least one stop bit. The possible combinations are given in the bit description of PE.

WAKE — Wakeup by Address Mark

1 = SCI receiver awakened by address mark (eighth or ninth (last) bit set)

0 = SCI receiver awakened by idle-line detection

WAKE determines which one of two conditions wakes up the SCI receiver when it is in wakeup mode. If WAKE is clear (its reset value), the detection of an idle line (10 or 11 contiguous ones) which clears RWU causes the SCI receiver to wake up. If WAKE is set, the detection of an address mark (the last data bit of a frame is set) which clears RWU causes the SCI receiver to wake up.

TIE — Transmit Interrupt Enable

1 = SCI TDRE interrupts enabled

0 = SCI TDRE interrupts inhibited

When set, TIE enables an SCI interrupt whenever the TDRE flag in SCSR is set. The interrupt is blocked by negating TIE.

TCIE — Transmit Complete Interrupt Enable

1 = SCI TC interrupts enabled

0 = SCI TC interrupts inhibited

When set, TCIE enables an SCI interrupt whenever the TC flag in SCSR is set. The interrupt may be cleared by reading SCSR when TC is set and then by writing the transmit data register (TDR) of SCDR. The interrupt is blocked by negating TCIE.

RIE — Receiver Interrupt Enable

1 = SCI RDRF interrupts enabled

0 = SCI RDRF interrupts inhibited

When set, RIE enables an SCI interrupt whenever the RDRF flag in SCSR is set. The interrupt is blocked by negating RIE.

ILIE — Idle-Line Interrupt Enable

1 = SCI IDLE interrupts enabled

0 = SCI IDLE interrupts inhibited

When set, ILIE enables an SCI interrupt whenever the IDLE flag in SCSR is set. The interrupt is blocked by negating ILIE.

TE — Transmitter Enable

1 = SCI transmitter enabled, TXD pin dedicated to the SCI transmitter

0 = SCI transmitter disabled, TXD pin may be used as general-purpose I/O

When set, TE enables the SCI transmitter and assigns to it the TXD pin. When TE is clear, the TXD pin may be used for general-purpose I/O. An idle frame, called a preamble, consisting of 10 (or 11) contiguous ones, is automatically transmitted

whenever TE is changed from zero to one. Refer to **5.6.4 Transmitter Operation** for a detailed description of TE and the SCI transmit operation.

RE — Receiver Enable

- 1 = SCI receiver enabled
- 0 = SCI receiver disabled

RE enables the SCI receiver when set. When disabled, the receiver status bits RDRF, IDLE, OR, NF, FE, and PF are inhibited and are not asserted by the SCI. Refer to **5.6.5 Receiver Operation** for a complete description of RE and the SCI receiver operation.

RWU — Receiver Wakeup

- 1 = Wakeup mode enabled, all received data ignored until awakened
- 0 = Normal receiver operation, all received data recognized

Setting RWU enables the wakeup function, which allows the SCI to ignore received data until awakened by either an idle line or address mark (as determined by WAKE). When in wakeup mode, the receiver status flags are not set, and interrupts are inhibited. This bit is cleared automatically (returned to normal mode) when the receiver is awakened.

SBK — Send Break

- 1 = Break frame(s) transmitted after completion of the current frame
- 0 = Normal operation

SBK provides the ability to transmit a break code (10 or 11 contiguous zeros) from the SCI. When SBK is set, the SCI completes the current frame transmission (if it is transmitting) and then begins transmitting continuous frames of 10 (or 11) zeros until SBK is cleared. If SBK is toggled by writing it first to a one and then immediately to a zero (in less than one serial frame interval), the transmitter sends only one or two break frames before reverting to mark (idle line) or before commencing to send data. SBK is normally used to broadcast the termination of a transmission.

5.6.3.3 SCI Status Register (SCSR)

SCSR (Figure 5-30) contains flags that the SCI sets to inform the user of various operational conditions. These flags are automatically cleared either by hardware or by a special acknowledgement sequence consisting of an SCSR read (either the upper byte, the lower byte, or the entire word) with a flag bit set, followed by a read (or write in the case of flags TDRE and TC) of data register SCDR (either the lower byte, or the entire word). An upper byte access of SCDR is only meaningful for reads. Note that a long-word read can consecutively access both registers SCSR and SCDR. This action clears the receive status flag bits that were set at the time of the read, but does not clear the TDRE or TC flags. To clear TDRE or TC, the SCSR read must be followed by a write to register SCDR (either the lower byte or the entire word).

If an internal SCI signal for setting a status bit comes after the CPU has read the asserted status bits but before the CPU has written or read register SCDR, the newly set status bit is not inadvertently cleared. Instead, register SCSR must be read again with the status bit set, and register SCDR must be written or read before the status bit is cleared.

NOTE

None of the status bits are cleared by reading a status bit while it is asserted and then by writing zero to that same bit. The procedure outlined above must be followed. Emphasis is also given to note that reading either byte of register SCSR causes all 16 bits to be accessed, and any status bits already set in either byte are armed to clear on a subsequent read or write of register SCDR.

5

As mentioned, register SCSR co-functions with register SCDR. SCDR is a combination of two data registers: the TDR and the RDR. Each of these data registers has a serial shifter.

SCSR — SCI Status Register **\$YFFC0C**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	TDRE	TC	RDRF	RAF	IDLE	OR	NF	FE	PF
RESET:															
0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

Figure 5-30. SCI Status Register

Bits 15–9 — Not Implemented

TDRE — Transmit Data Register Empty Flag

1 = A new character may now be written to register TDR

0 = Register TDR still contains data to be sent to the transmit serial shifter

TDRE is set when the byte in register TDR is transferred to the transmit serial shifter. If this bit is zero, the transfer is yet to occur and a write to TDR will overwrite the previous value. New data is not transmitted if TDR is written without first clearing TDRE, which is accomplished by reading register SCSR with TDRE set, followed by a write to TDR. Reset sets this bit.

TC — Transmit Complete Flag

- 1 = SCI transmitter is idle
- 0 = SCI transmitter is busy

TC is set when the transmitter finishes shifting out all data, queued preambles (mark/idle line), or queued breaks (logic zero). TC is cleared when SCSR is read with TC set, followed by a write to register TDR.

RDRF — Receive Data Register Full Flag

- 1 = Register RDR contains new data
- 0 = Register RDR is empty or contains previously read data

RDRF is set when the content of the receive serial shifter is transferred to register RDR. If one or more errors are detected in the received word, the appropriate receive-related flag(s) NF, FE, and/or PF are set within the same clock cycle. RDRF is cleared when register SCSR is read with RDRF set, followed by a read of register RDR.

RAF — Receiver Active Flag

- 1 = SCI receiver is busy
- 0 = SCI receiver is idle

RAF indicates whether the SCI receiver is busy. This flag is set when the SCI receiver detects a possible start bit and is cleared when the chosen type of idle line is detected. RAF can be used to reduce collisions in systems with multiple masters.

The SCI receiver samples each start bit 16 times (at a rate of 16 times the baud rate). The 16 sample times are called RT1–RT16. RAF is set initially at RT1. The SCI receiver samples RT3, RT5, and RT7. If the receiver line is high during two or three of the three receive time (RT) samples, the start bit is considered invalid, and RAF is subsequently cleared. A more detailed description is found in **5.6.5.1 Receiver Bit Processor**.

IDLE — Idle-Line Detected Flag

- 1 = SCI receiver detected an idle-line condition
- 0 = SCI receiver did not detect an idle-line condition

IDLE is set when the SCI receiver detects an idle-line condition (reception of a minimum of 10 or 11 consecutive ones as specified by ILT in SCCR1). This bit is not set by the idle-line condition when RWU in SCCR1 is set. Once cleared, IDLE is not set again until after RDRF is set (after the line is active and becomes idle again). If a break is received, RDRF is set, allowing a subsequent idle line to be detected again. IDLE is cleared when SCSR is read with IDLE set, followed by a read of register RDR.

OR — Overrun Error Flag

1 = RDRF is not cleared before new data arrives

0 = RDRF is cleared before new data arrives

OR is set when a new byte is ready to be transferred from the receive serial shifter to register RDR, and RDR is already full (RDRF is still set). Data transfer is inhibited until OR is cleared. Previous data in RDR remains valid, but additional data received during an overrun condition (including the byte that set OR) is lost.

A difference exists between OR and the other receiver status flags. NF, FE, and PF all reflect the status of data already transferred to register RDR. OR reflects an operational condition that resulted in a loss of data to RDR. OR is cleared when SCSR is read with OR set, followed by a read of register RDR.

NF — Noise Error Flag

1 = Noise occurred on the received data

0 = No noise detected on the received data

NF is set when the SCI receiver detects noise on a valid start bit, on any of the data bits, or on the stop bit(s). It is not set by noise on the idle line or on invalid start bits. Each bit is sampled three times for noise. If the three samples are not at the same logic level, the majority value is used for the received data value, and NF is set. NF is not set until the entire frame is received and RDRF is set. Although an interrupt is not explicitly associated with NF, an interrupt may be generated with RDRF and NF checked in this manner. NF is cleared when SCSR is read with NF set, followed by a read of register RDR.

FE — Framing Error Flag

1 = Framing error or break occurred on the received data

0 = No framing error on the received data

FE is set when the SCI receiver detects a zero where a stop bit (one) was to occur. A framing error results when the frame boundaries in the received bit stream are not synchronized with the receiver bit counter. FE is not set until the entire frame is received and RDRF is set. Although an interrupt is not explicitly associated with FE, an interrupt may be generated with RDRF and FE checked in this manner. A break can also cause FE to be set. FE is cleared when SCSR is read with FE set, followed by a read of register RDR.

PF — Parity Error Flag

1 = Parity error occurred on the received data

0 = No parity error occurred on the received data

PF is set when the SCI receiver detects a parity error. PF is not set until the entire frame is received and RDRF is set. Although an interrupt is not explicitly associated with PF, an interrupt may be generated with RDRF and PF checked in this manner. PF is cleared when SCSR is read with PF set, followed by a read of the register RDR.

5.6.3.4 SCI Data Register (SCDR)

SCDR (Figure 5-31) contains two data registers, both at the same address. The first register is the RDR, which is a read-only register. It contains data received over the SCI serial interface. Initially, data is received into the receive serial shifter and is transferred by the receiver into RDR. The second register is the SCI TDR, which is a write-only register. Data to be transmitted over the SCI serial interface is written to TDR. The transmitter transfers this data to the transmit serial shifter, adding on additional format bits before the data is sent out on the SCI serial interface.

SCDR — SCI Data Register **\$YFFC0E**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	R8/T8	R7/T7	R6/T6	R5/T5	R4/T4	R3/T3	R2/T2	R1/T1	R0/T0
RESET:															
0	0	0	0	0	0	0	U	U	U	U	U	U	U	U	U

Figure 5-31. SCI Data Register

R8/T8 — Receive 8/Transmit 8

This bit is the ninth serial data bit received (R8) when the SCI system is configured for a 9-bit data operation ($M = 1$). When the SCI system is configured for an 8-bit data operation ($M = 0$), this bit has no meaning or effect.

This bit is the ninth serial data bit transmitted (T8) when the SCI system is configured for 9-bit data operation ($M = 1$). When the SCI system is configured for an 8-bit data operation ($M = 0$), this bit has no meaning or effect.

Accesses to the lower byte of SCDR triggers the mechanism for clearing the status bits or for initiating transmissions whether byte, word, or long-word accesses are used.

R0–R7/T0–T7 — Receive 0–7/Transmit 0–7

The first eight bits (7-0) contain the first eight data bits to be received (R0–R7) when SCDR is read, and also contain the first eight data bits to be transmitted (T0–T7) when SCDR is written.

5.6.4 Transmitter Operation

The transmitter consists of a transmit serial shifter and a parallel transmit data register (TDR) located in SCDR (refer to **5.6.3.4 SCI Data Register (SCDR)**). A character may be loaded into the TDR while another character is being shifted out, a capability called double buffering. The transmit serial shifter cannot be directly accessed by the CPU. The output of the transmit serial shifter is connected to the TXD pin whenever the transmitter is operating (TE = 1, or TE = 0 and transmitter operation not yet complete).

The following definitions apply to the transmitter and receiver operation:

Bit-Time — The time required to serially transmit or receive one bit of data, which is equal to one cycle of the baud frequency.

Start Bit — One bit-time of logic zero that indicates the beginning of a data frame. A start bit must begin with a one-to-zero transition and be preceded by at least three receive time (RT) samples of logic one.

Stop Bit — One bit-time of logic one that indicates the end of a data frame.

Frame — A start bit, followed by a specified number of data or information bits, terminated by a stop bit. The number of data or information bits must agree between the transmitting and receiving devices. The most common frame format is one start bit followed by eight data bits (LSB first) terminated by one stop bit, for a total of 10 bit-times in the frame. The SCI optionally provides a 9-bit data format that results in an 11 bit-time frame.

The M bit in SCCR1 specifies the number of bit-times in the frame (10 or 11). The most common format for nonreturn-to-zero (NRZ) serial interface is one start bit (logic zero or space), followed by eight data bits (terminated LSB first), by one stop bit (logic one or mark). In addition to this standard format, the SCI provides hardware support for a 9-bit data format. This format is one start bit, eight data bits (LSB first), a parity or address (control) bit, and one stop bit. Following are all the possible formats:

- Start bit, seven data bits, two stop bits
- Start bit, seven data bits, address bit, one stop bit
- Start bit, seven data bits, address bit, two stop bits
- Start bit, seven data bits, parity bit, one stop bit
- Start bit, eight data bits, one stop bit
- Start bit, eight data bits, two stop bits
- Start bit, eight data bits, parity bit, one stop bit
- Start bit, eight data bits, address bit, one stop bit

When the transmitter is enabled by writing a one to TE in SCCR1, a check is made to determine if the transmit serial shifter is empty. If empty (TC = 1), a preamble consisting of all ones (no start bits) is transmitted. If the transmit serial shifter is not empty (TC = 0), then normal shifting continues until the word in progress with stop bit(s) is sent. The preamble (an all ones frame) is then transmitted.

When TE is cleared, the transmitter is disabled only after all pending information is transmitted, including any data in the transmit serial shifter (inclusive of the stop bit), any queued preamble (idle frame), or any queued break (logic zero frame). The TC flag is set, and the TXD pin reverts to control by QPDR and QDDR. This function allows the user to terminate a transmission sequence in the following manner. After loading the last byte into register TDR and receiving the interrupt from TDRE in SCSR, (indicating that the data has transferred into the transmit serial shifter), the user clears TE. The last frame is transmitted normally, and the TXD pin reverts to control by QPDR and QDDR.

To insert a delimiter between two messages and place the nonlistening receivers in wakeup mode or to signal a retransmission (by forcing an idle line), TE is set to zero and then to one before the word in the transmit serial shifter has completed transmission. The transmitter waits until that word is transmitted and then starts transmission of a preamble (10 or 11 contiguous ones). After the preamble is transmitted, and if TDRE is set (no new data to transmit), the line continues to mark (remain high). Otherwise, normal transmission of the next word begins.

Two SCI messages may be separated with minimum idle time by using a preamble of 10 bit-times (11 if a 9-bit data format is specified) of marks (logic ones). The entire process can occur using the following procedure:

- a. Write the last byte of the first message to the TDR.
- b. Wait for TDRE to go high, indicating that the last byte is transferred to the transmit serial shifter.
- c. Clear TE and then set TE back to one. This queues the preamble to follow the stop bit of the current transmission immediately.
- d. Write the first byte of the second message to register TDR.

In this sequence, if the first byte of the second message is not transferred to register TDR prior to the finish of the preamble transmission, then the transmit data line (TXD pin) simply marks idle (logic one) until TDR is finally written. Also, if the last byte of the first message finishes shifting out (including the stop bit) and TE is clear, TC will go high and transmission will be considered complete. The TXD pin reverts to being a general-purpose I/O line.

The CPU writes data to be transmitted to register TDR, which automatically loads the data into the transmit serial shifter. Before writing to TDR, the user should check TDRE in SCSR. If TDRE = 0, then data is still waiting to be sent to the transmit serial shifter. Writing to TDR with TDRE clear overwrites previous data to be transferred. If TDRE = 1, then register TDR is empty, and new data may be written to TDR clearing TDRE.

As soon as the data in the transmit serial shifter has shifted out and if a new byte of data is in TDR (TDRE = 0), then the new data is transferred from register TDR to the transmit serial shifter, and TDRE is automatically set. An interrupt may optionally be generated at this point.

The data in the transmit serial shifter is prefixed by a start bit (logic zero) and suffixed by the ninth data bit, if M = 1, and by one stop bit. The ninth data bit can be used as normal data or as an extra stop bit. A parity bit is substituted if PE = 1. This data stream is shifted out over the TXD pin. When the data is completely shifted out and no preamble or send break is requested, then TC is set to one and the TXD pin remains high (logic one or mark).

Parity generation is enabled by setting PE in SCCR1 to a one. The last data bit, bit eight (or bit nine of the data if M = 1), is used as the parity bit, which is inserted between the normal data bits and the stop bit(s).

When TE is cleared, the transmitter yields control of the TXD pin in the following manner: If no information is being shifted out (i.e., if the transmitter is in an idle state, TC = 1), then the TXD pin reverts to being a general-purpose I/O pin. If a transmission is still in progress (TC = 0), the characters in the transmit serial shifter continue to be shifted out normally, followed by any queued break. When finished, TXD reverts to being a general-purpose I/O pin. To avoid terminating the transmitter before all data is transferred, the software should always wait for TDRE to be set before clearing TE.

Transmissions may be purposely aborted by the send break function. By writing SBK in SCCR1 to a one, a nonzero integer multiple of 10 bit-times (11 if 9-bit data format is specified) of space (logic zero) is transmitted. If SBK is set while a transmission is in progress, the character in the transmit serial shifter finishes normally (including the stop bit) before the break function begins. Break frames are sent until either SBK or TE is cleared. To guarantee the minimum break time, SBK should be quickly toggled to one and then back to zero. After the break time, at least one bit-time of mark idle (logic one) is transmitted to ensure that a subsequent start bit can be recognized.

The TXD pin has several control options to provide flexible operation. WOMS in SCCR1 can select either open-drain output (for wired-OR operation) or normal

CMOS output. WOMS controls the function of the TXD pin whether the pin is being used for SCI transmissions (TE = 1) or as a general-purpose I/O pin.

In an SCI system with multiple transmitters, the wired-OR mode should be selected for the TXD pin of all transmitters, allowing multiple output pins to be coupled together. In the wired-OR mode, an external pullup resistor on the TXD pin is necessary.

In some systems, a mark (logic one) signal is desired on the TXD pin, even when the transmitter is disabled. This is accomplished by writing a one to QPDR in the appropriate position and configuring the TXD pin as an output in QDDR. When the transmitter releases control of the TXD pin, it reverts to driving a logic one output, which is the same as mark or idle.

5.6.5 Receiver Operation

The receiver can be divided into two segments. The first is the receiver bit processor logic that synchronizes to the asynchronous receive data and evaluates the logic sense of each bit in the serial stream. The second receiver segment controls the functional operation and the interface to the CPU including the conversion of the serial data stream to parallel access by the CPU.

5.6.5.1 Receiver Bit Processor

The receiver bit processor contains logic to synchronize the bit-time of the incoming data and to evaluate the logic sense of each bit. To accomplish this an RT clock, which is 16 times the baud rate, is used to sample each bit. Each bit-time can thus be divided into 16 time periods called RT1–RT16. The receiver looks for a possible start bit by watching for a high-to-low transition on the RXD pin and by assigning the RT time labels appropriately.

When the receiver is enabled by writing RE in SCCR1 to one, the receiver bit processor logic begins an asynchronous search for a start bit. The goal of this search is to gain synchronization with a frame. The bit-time synchronization is done at the beginning of each frame so that small differences in the baud rate of the receiver and transmitter are not cumulative. The SCI also synchronizes on all one-to-zero transitions in the serial data stream, which makes the SCI tolerant to small frequency variations in the received data stream.

The sequence of events used by the receiver to find a start bit is listed below.

- a. Sample RXD input during each RT period and maintain these samples in a serial pipeline that is three RT periods deep.
- b. If RXD is low during this RT period, go to step a.
- c. If RXD is high during this RT period, store this sample and proceed to step d.
- d. If RXD is low during this RT period, but not high for the previous three RT periods (which is noise only), set an internal working noise flag and go to step a, since this transition was not a valid start bit transition.
- e. If RXD is low during this RT period and has been high for the previous three RT periods, call this period RT1, set RAF, and proceed to step f.
- f. Skip RT2 but place RT3 in the pipeline and proceed to step g.
- g. Skip RT4 and sample RT5. If both RT3 and RT5 are high (RT1 was noise only), set an internal working noise flag. Go to step c and clear RAF. Otherwise, place RT5 in the pipeline and proceed to step h.
- h. Skip RT6 and sample RT7. If any two of RT3, RT5, or RT7 is high (RT1 was noise only), set an internal working noise flag. Go to step c and clear RAF. Otherwise, place RT7 in the pipeline and proceed to step i.
- i. A valid start bit is found and synchronization is achieved. From this point on until the end of the frame, the RT clock will increment starting over again with RT1 on each one-to-zero transition or each RT16. The beginning of a bit-time is thus defined as RT1 and the end of a bit-time as RT16.

Upon detection of a valid start bit, synchronization is established and is maintained through the reception of the last stop bit, after which the procedure starts all over again to search for a new valid start bit. During a frame's reception, the SCI resynchronizes the RT clock on any one-to-zero transitions.

Additional logic in the receiver bit processor determines the logic level of the received bit and implements an advanced noise-detection function. During each bit-time of a frame (including the start and stop bits), three logic-sense samples are taken at RT8, RT9, and RT10. The logic sense of the bit-time is decided by a majority vote of these three samples. This logic level is shifted into register RDR for every bit except the start and stop bits.

If RT8, RT9, and RT10 do not all agree, an internal working noise flag is set. Additionally for the start bit, if RT3, RT5, and RT7 do not all agree, the internal working noise flag is set. If this flag is set for any of the bit-times in a frame, the NF flag in SCSR is set concurrently with the RDRF flag in SCSR when the data is transferred to register RDR. The user must determine if the data received with NF set is valid. Noise on the RXD pin does not necessarily corrupt all data.

Figure 5-38 explores the case where the majority vote of RT8, RT9, and RT10 returns a logic-high level. However, the start bit is a special case that overrules the majority voting scheme. In review, at least three of the samples taken at RT1, RT3, RT5, and RT7 must be low. The start bit is detected and the RT clock is synchronized; because RT8–RT10 were not unanimous, the NF flag is set.

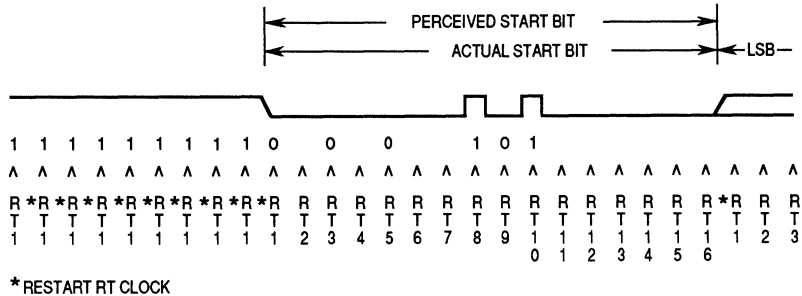


Figure 5-38. Start Search Example 7

5.6.5.2 Receiver Functional Operation

The receiver contains a receive serial shifter and a parallel RDR. While one character is in the process of being shifted in, another character may be held in RDR. This capability is called double buffering. The receive serial shifter cannot be accessed directly by the CPU. The input of the receive serial shifter is connected to the majority sampling logic of the receive bit processor.

The receiver is enabled when RE in SCCR1 is set to one. When RE is zero, the receiver is initialized and most of the receiver bit processor logic is disabled. The receiver bit processor logic drives a state machine (run by the RT clock) that determines the logic level for each bit-time. This state machine controls when the bit processor logic is to sample the RXD pin and also controls when data is to be passed to the receive serial shifter. Data is shifted into the receive serial shifter according to the most recent synchronization of the RT clock with the incoming data stream. From this point on, the data is moved synchronously with the MCU system clock.

The first bit shifted in is the start bit, which is always a logic zero. The next eight bits shifted in are the basic data byte (LSB first). The next bit shifted in depends on the mode selected by M in SCCR1. If M = 1, then the bit is the ninth data bit and is placed in R8 of SCDR, concurrent with the transfer of data from the receive serial shifter to register RDR.

The last bit shifted in for each frame is the stop bit, which is always a logic one. If a logic zero is sensed during this bit-time, the FE error flag in SCSR is set. A framing error is usually caused by mismatched baud rates between the receiver and transmitter or by a significant burst of noise. Note that a framing error is not always caught; the data in the expected stop bit-time may be a logic one regardless.

When the stop bit is received, the frame is considered to be complete, and the received character in the receive serial shifter is transferred in parallel to RDR. If $M = 1$, the ninth bit is transferred at the same time; however, if the RDRF flag in SCSR is set, transfers are inhibited. Instead, the OR error flag is set, indicating to the user that the CPU needs to service register RDR faster. The data in RDR is preserved, but the data in the receive serial shifter is lost.

All status flags associated with a serially received frame are set simultaneously and at a time that does not interfere with CPU access to the affected registers. When a completed frame is received, either the RDRF or the OR flag is always set. If RIE in SCCR1 is set, an interrupt results whenever RDRF is set. The receiver status flags NF, FE, and PF are set simultaneously with RDRF, as appropriate. These receiver flags are never set with OR because the flags only apply to the data in the receive serial shifter. The receiver status flags do not have separate interrupt enables, since they are set simultaneously with RDRF and must be read by the user at the same time as RDRF.

All receiver status flags are cleared by the following sequence. Register SCSR is read first, followed by a read of register SCDR. Reading SCSR not only informs the CPU of the status of the received data, but also arms the clearing mechanism. Reading SCDR supplies the received data to the CPU and clears all of the status flags: RDRF, IDLE, OR, NF, FE, and PF.

5.6.5.2.1 Idle-Line Detect

The receiver hardware includes the ability to detect an idle line. This function can be used to indicate when a group of serial transmissions is finished. An idle line is defined as a minimum of 10 bit-times (or 11 if a 9-bit data format is selected) of contiguous ones on the RXD pin. During a typical serial transmission, frames are transmitted isochronously, that is, no idle time occurs between frames. Even if all data bits in a frame are logic ones, the start bit ensures that at least one logic zero bit-time occurs for each frame.

Motorola MCUs from the M68HC11 and M68HC05 Families have SCIs with only one type of idle-line detect circuitry. On these MCUs, the receiver bit processor starts counting logic one bit-times at any point (even within a frame). This method allows the earliest recognition of an idle line because the stop bit and any contiguous ones preceding the stop bit are counted with the logic ones

in the idle line following the stop bit. In some applications, the CPU overhead prevents the servicing of interrupts as soon as possible to ensure that no bit-time of an idle line occurs between frames. Although this idle line causes no deterioration of the message content, if one bit-time should occur after a data byte of all ones, the combination is seen as an idle line and causes sleeping SCIs to wake up.

The SCI on the QSM module contains this same idle-line detect logic, called short idle-line detect, as well as long idle-line detect. In long idle-line detect mode, the SCI begins counting logic ones after the stop bit is received. The data content of a byte, therefore, does not affect how quickly the idle line is detected. When RXD goes idle for the minimum required time, the IDLE flag in SCSR is set. ILT in SCCR1 is used to choose between short and long idle-line detection.

If ILIE in SCCR1 is set, a hardware interrupt request is generated when the IDLE flag is set. This flag is cleared by reading SCSR with IDLE set, followed by reading register RDR. The IDLE flag is not set again until after at least one frame has been received (RDRF = 1), which prevents an extended idle interval from causing more than one interrupt.

5.6.5.2.2 Receiver Wakeup

The SCI receiver hardware provides a receiver wakeup function to support multinode networks containing more than one receiver. This function allows the transmitting device to direct a message to an individual receiver or group of receivers by sending an address frame at the start of a message. All receivers not addressed for the current message invoke the receiver wakeup function, which effectively allows them to sleep through the rest of the message. Therefore, the CPU is alleviated from servicing register RDR, resulting in increased system performance.

The SCI receiver is placed in wakeup mode by writing a one to RWU in SCCR1. While RWU is set, all receiver status flag bits are inhibited from being set. Note that the IDLE flag cannot be used when RWU is set. Although the CPU can clear RWU by writing a zero to SCCR1, it is normally left alone by software and is cleared automatically by hardware in one of two methods: idle-line wakeup or address-mark wakeup.

WAKE in SCCR1 determines which method of wakeup is to be employed. If WAKE = 0, idle-line wakeup is selected. This method is compatible with the method originally used on the MC6801. If WAKE = 1, address-mark wakeup is selected, which uses a one in the MSB of data to denote an address frame and uses a zero to denote a normal data frame. Each method has its particular advantages and disadvantages.

Both wakeup methods require a software device addressing and recognition scheme and, therefore, can conform to all transmitters and receivers. The addressing information is usually the first frame(s) of the message. Receivers for which the message is not intended may set RWU and go back to sleep for the remainder of the message.

Idle-line wakeup allows a receiver to sleep until an idle line is detected, causing RWU to be cleared by the receiver and causing the receiver to wake up. The receiver waits through the idle times for the first frame of the next message. If the receiver is not the intended addressee, RWU may be set to put the receiver back to sleep. This method of receiver wakeup requires that a minimum of one frame of idle line be imposed between messages. As previously stated, no idle time is allowed between frames within a message.

Address-mark wakeup uses a special frame format to wake up the receiver. All frames consist of seven (or eight) data bits plus an MSB that indicates an address frame when set to a one. The first frame of each message should be an address frame. All receivers in the system must use a software scheme to determine which messages address them. If the message is not intended for a particular receiver, the CPU sets RWU so that the receiver goes back to sleep, thereby eliminating additional CPU overhead for servicing the rest of the message.

When the first frame of a new message is received with the MSB set, denoting an address frame, RWU is cleared. The byte is received normally, transferred to register RDR, and the RDRF flag is set. Address-mark wakeup allows messages to include idle times between frames and eliminates idle time between messages; however, an efficiency loss results from the extra bit-time (address bit) that is required on all frames.

SECTION 6 GENERAL-PURPOSE TIMER (GPT) OVERVIEW

The general-purpose timer (GPT), a module in Motorola's family of modular microcontrollers, is a simple yet flexible 11-channel timer for use in systems where a moderate level of CPU control is required. The GPT can be broken into several nearly independent submodules: the capture/compare unit, the pulse accumulator, and the pulse-width modulation unit.

The compare/capture unit features three input capture channels, four output compare channels, and one channel that can be selected as an input capture or output compare channel. These channels share a 16-bit free-running counter (TCNT) which derives its clock from a nine-stage prescaler or from the external clock input pin, PCLK.

The pulse accumulator channel logic includes its own 8-bit counter and can operate in either event counting mode or gated time accumulation mode.

The pulse-width modulation submodule has two outputs that are periodic waveforms whose duty cycles may be independently selected and modified by user software. The PWM unit has its own 16-bit free-running counter which is clocked by an output of the nine-stage prescaler (the same prescaler used by the compare/capture unit) or by the clock input pin, PCLK.

If not needed for timing functions, any of the GPT pins can be used for general-purpose input/output. The input capture and output compare pins are bidirectional and may be used to form an 8-bit parallel port. The PWM pins are outputs only. The PAI and PCLK pins are inputs only.

The GPT bus interface provides the connection to the intermodule bus (IMB). This bus provides a standard interface between different modules and the CPU.

Table 6-1 shows the registers in the GPT. The addresses shown are on word boundaries, however, all registers can be accessed using byte or word operations. The TCNT, TICx, TOCx, TI4O5, and PWMCNT registers must be accessed by word operations to ensure coherency.

Coherency is the reading or writing of data identical in age. Using byte accesses when reading a register such as the TCNT, there is a possibility that data in the

byte not being accessed will change while the other byte is read. To make sure this does not happen both bytes must be accessed at the same time.

Two control registers, the module configuration register (MCR) and the interrupt control register (ICR) can only be accessed while the processor is in supervisor mode.

For a complete functional description of the GPT refer to the GPT Reference Manual. For a description of individual bits refer to **Appendix E**.

Table 6-1. GPT Register Map

	ADDRESS	WORD		
		15	8 7	0
S	\$YFF900	MCR		
S	\$YFF902	RESERVED		
S	\$YFF904	ICR		
U	\$YFF906	PDDR	PDR	
U	\$YFF908	OC1M	OC1D	
U	\$YFF90A	TCNT		
U	\$YFF90C	PACTL	PACNT	
U	\$YFF90E	TIC1		
U	\$YFF910	TIC2		
U	\$YFF912	TIC3		
U	\$YFF914	TOC1		
U	\$YFF916	TOC2		
U	\$YFF918	TOC3		
U	\$YFF91A	TOC4		
U	\$YFF91C	TI4O5		
U	\$YFF91E	TCTL1	TCTL2	
U	\$YFF920	TMSK1	TMSK2	
U	\$YFF922	TFLG1	TFLG2	
U	\$YFF924	CFORC	PWMC	
U	\$YFF926	PWMA	PWMB	
U	\$YFF928	PWMCNT		
U	\$YFF92A	PWMABUF	PWMBBUF	
U	\$YFF92C	PRESCL (Lower 9 bits)		
	\$YFF92E	RESERVED		
	\$YFF93F			

S = Supervisor accessible only

U = User or Supervisor depending on state of SUPV in the MCR

Y = m111, where m is the state of the modmap bit in the module configuration register of the system integration module (Y = \$7 or \$F).

6.1 Features

- Modular Architecture
- Input Capture/Output Compare Unit
 - Three Input Capture Pins
 - Four Output Compare Pins
 - One Input Capture/Output Compare Pin
- One Pulse Accumulator/Event Counter Pin
- Two Channel PWM Unit
 - Programmable Clock Logic
 - 8-Bit Resolution
 - Independent Clock Source
- Dedicated Clock Input Pin
- Nine Stage Prescaler
 - Independent Prescaler Taps for the Capture/Compare Unit and the PWM Unit

6.2 Signal Descriptions

The GPT has twelve signal pins that provide connections to the internal functions of the module. This section contains brief descriptions of the GPT input and output signals in their functional groups.

The block diagram in Figure 6-1 shows the primary and alternate functions of the signal pins. When the pins are not needed for their primary function they can be used for general-purpose input or output. The block diagram also shows which pins are bidirectional and which are either input or output only.

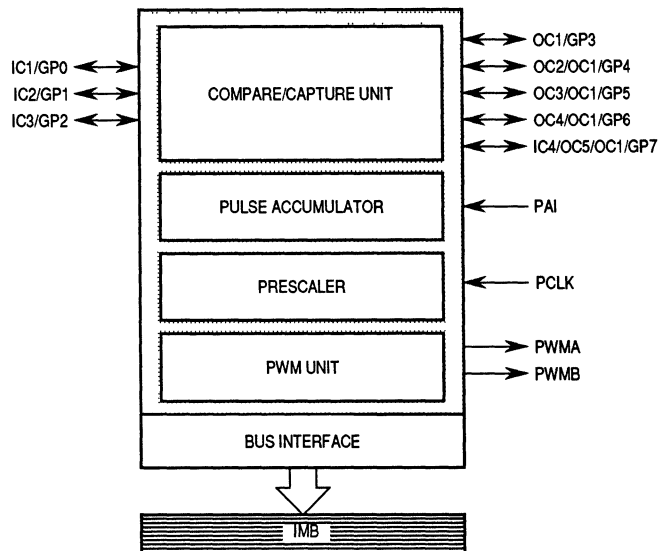


Figure 6-1. GPT Block Diagram

6.2.1 Input Capture Pins (IC1–IC3)

These pins are used by the input capture functions of the GPT. Each pin is associated with a single input capture function. The pin inputs are designed in such a way that any pulse longer than two system clocks is guaranteed to pass and any pulse shorter than one system clock is ignored. Each pin has a dedicated 16-bit capture register to hold the captured counter value. When any of the pins are not needed for the input capture function they can be used for general-purpose I/O. Refer to **6.3.2 Input Capture Functions** for additional details of the input capture function.

6.2.2 Input Capture/Output Compare Pin (IC4/OC5)

This pin can be configured to be used by an input capture or an output compare function. It has one 16-bit register which is used for holding either the input capture value or the output match value. When used as an input the signal is conditioned in such a way that any pulse longer than two system clocks is guaranteed to pass and any pulse shorter than one system clock is ignored. If this pin is not needed for either the input capture or output compare function it can be used for general-purpose I/O. Refer to **6.3.2 Input Capture Functions** and **6.4 Output Compare Functions** for additional details on the operation of these functions.

6.2.3 Output Compare Pins (OC1–OC4)

These pins are used for the output compare functions of the GPT and operate independently of each other. There is a dedicated 16-bit compare register and 16-bit comparator for each pin. Pins OC2, OC3, and OC4 are associated with a specific output compare function while the OC1 function can affect the output of any combination of output compare pins. Automatic preprogrammed pin actions will occur on a successful match. The programmable pin actions differ between OC2-OC5 and OC1. If the OC1 pin is not needed for the output compare function it can be used to output the clock selected for the timer counter register (TCNT). Any of the pins can be used for general-purpose I/O if not needed for the output compare function. For additional details on the operation of the output compare function refer to **6.4 Output Compare Functions**.

6.2.4 Pulse Accumulator Input Pin (PAI)

The PAI pin is the signal input to the pulse accumulator. If not needed for this function it can be used as a general-purpose input pin. The signal is conditioned in such a way that any pulse longer than two system clocks is guaranteed to pass and any pulse shorter than one system clock is ignored. For more details on the pulse accumulator function refer to **6.6 Pulse Accumulator**.

6.2.5 Pulse Width Modulation (PWMA, PWMB)

The PWMA and PWMB pins are used as outputs for the PWM functions. These outputs can be programmed to generate a periodic waveform with a variable frequency and duty cycle. The pins can be used for general-purpose output if not needed for the PWM function. PWMA can also be used to output the clock selected as the input to the PWM counter (PWMCNT). For more details on the PWM functions refer to **6.8 Pulse Width Modulation (PWM) Unit**.

6.2.6 Auxiliary Timer Clock Input (PCLK)

PCLK is an external clock input which is dedicated to the GPT. The signal is conditioned in such a way that any pulse longer than two system clocks is guaranteed to pass and any pulse shorter than one system clock is ignored. PCLK can be used as the clock source for the capture/compare unit or the PWM unit in place of one of the prescaler outputs. If this pin is not used as a clock input it can be used as a general-purpose input pin. Refer to **6.7 Prescaler** and **6.10 General-Purpose I/O** for additional information on PCLK.

6.3 Compare/Capture Unit

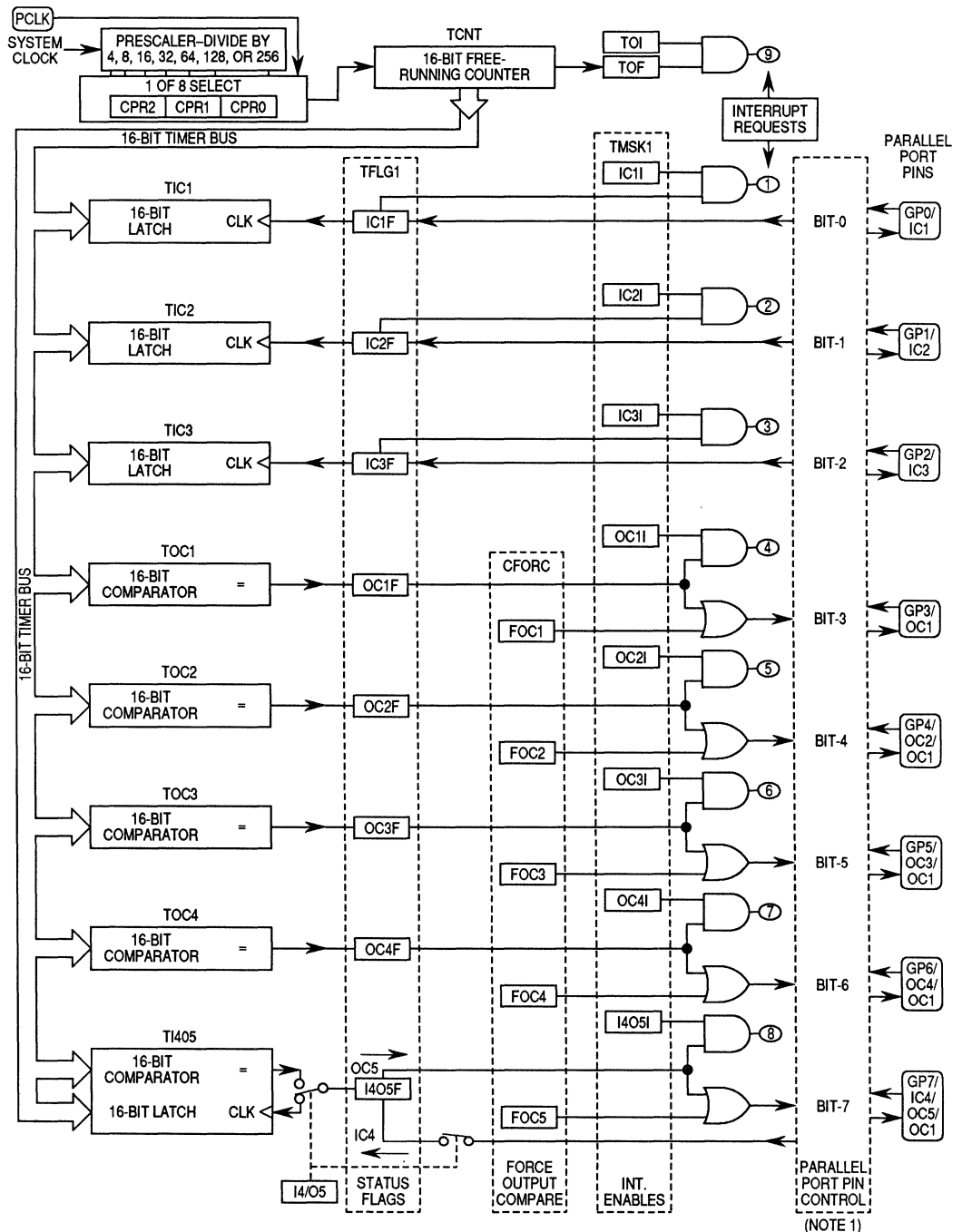
The compare/capture unit is one of the major submodules of the GPT. It contains the timer counter (TCNT), the input capture (IC) functions and the output compare (OC) functions.

6.3.1 Timer Counter

The timer counter (TCNT) is the key timing component in the compare/capture unit. The timer counter is a 16-bit free-running counter that starts counting after the processor comes out of reset. The counter cannot be stopped during normal operation. Refer to **6.11 Special Modes** on how to stop the counter. After reset, the GPT is configured to use the system clock divided by four as the input to the counter. The prescaler divides the system clock and provides selectable input frequencies. User software can configure the system to use one of seven outputs from the Prescaler or an external clock through the PCLK input pin. Refer to **6.7 Prescaler** for more detail on prescaler operation.

The counter appears as a register in the GPT and can be read any time with user software without affecting its value. Because the GPT is interfaced to the IMB and the IMB supports a 16-bit bus, a word read gives a coherent value. If coherency is not needed byte accesses can be made. The counter is set to \$0000 on reset and is a read-only register. There are two exceptions, test mode and freeze mode. Any value can be written to the timer counter while in these modes. Refer to **6.11.1 Test Mode** and **6.11.3 Freeze Mode** for information on test and freeze mode operation.

When the counter rolls over from \$FFFF to \$0000 the timer overflow bit is set in timer interrupt flag register 2 (TFLG2). An interrupt can be enabled by setting the corresponding interrupt enable bit (TOI) in the timer interrupt mask register 2 (TMSK2). Refer to **6.9 Interrupts** for information on interrupt operation.



NOTE 1. Parallel port pin actions controlled by DDR, OC1M, OC1D, and TCTL1 registers

Figure 6-2. Compare/Capture Block Unit Diagram

6.3.2 Input Capture Functions

Each GPT input capture pin (IC1, IC2, IC3, and also IC4/OC5 when used as an input capture function), has a dedicated 16-bit latch, input edge-detection/selection logic and interrupt generation logic. All of the input capture functions use the same 16-bit timer counter (TCNT). The latch captures the contents of TCNT when the selected event occurs at the corresponding input capture pin. The edge detection logic contains control bits which allow user software to select the edge polarity that will be recognized. These are the EDGExA and EDGExB bits in timer control register 2 (TCTL2). Each of the input capture functions can be independently configured to detect rising edges only, falling edges only, any edge (rising or falling) or disable the input capture function. The input capture functions operate independently of each other and can capture the same TCNT value if the input edges are all detected within the same timer count cycle.

The interrupt generation logic includes a status flag, which indicates that an edge has been detected, and a local interrupt enable bit, which determines if the corresponding input capture function will generate a hardware interrupt request. The input capture sets the ICxF bit in the timer interrupt flag register 1 (TFLG1) and can cause an interrupt if the corresponding ICxI bit is set in the timer interrupt mask register 1 (TMSK1). If the interrupt request is inhibited, (the ICxI bit cleared) the input capture is operating in polled mode where software must read the status flag to recognize that an edge was detected. Refer to **6.9 Interrupts** for additional details on interrupt operation.

Input capture events are generally asynchronous to the timer counter. Because of this, they are conditioned by a synchronizer and digital filter. This synchronizes the input events to the system clock so that actual latching of the TCNT contents will occur on the opposite half-cycle of the system clock from when the counter is being incremented. The input is conditioned in such a way that any event longer than two system clocks is guaranteed to be captured and any signal shorter than one system clock will be filtered out and have no effect. Notice the relationship of the system clock to the output of the synchronizer as shown in Figure 6-3. The value latched into the capture register by an input capture corresponds to the value of the counter several system clock cycles after the input transition which triggered the edge detection logic. There can be up to one clock cycle of uncertainty in latching of the input transition. The maximum time is determined by the system clock frequency.

Since the input capture register is a 16-bit register, a word access is required to ensure coherency. If this is not required, each byte can be accessed independently using byte accesses. The input capture registers can be read at any time without affecting their values.

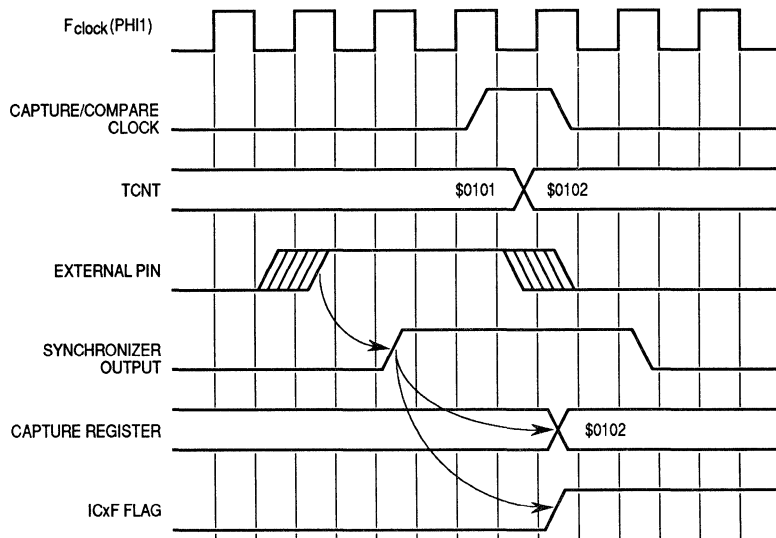


Figure 6-3. Input Capture Timing Example

An input capture occurs every time a selected edge is detected even if the input capture flag is already set. This means the value read from the input capture register corresponds to the most recent edge at the pin, which may not be the edge that caused the input capture flag to be set.

If any of the pins IC1–IC3 are not needed for an input capture function, they can be used as general-purpose input/output. The data direction of the pin is determined by the state of bits in the parallel data direction register (PDDR). For more information on general-purpose I/O refer to **6.10 General-Purpose I/O**.

6.3.2.1 Input Capture Registers (TIC1–3)

The input capture registers are 16-bit read-only registers which are used to latch the value of TCNT when a specified transition is detected on the corresponding input capture pin. Reads of these registers should be word accesses to ensure coherency. They are reset to \$FFFF.

When not used for the input capture functions these registers can be used as data storage locations.

6.3.2.2 Input Capture 4/Output Compare 5 Register (TI4O5)

Input capture 4/output compare 5 (TI4O5) serves either as an input capture register or as an output compare register depending on the function chosen for

the I4/O5 pin. To make this pin serve as an input capture pin, the I4/O5 bit in the pulse accumulator control register (PACTL) must be set to a logic level one. Set the bit to a logic level zero for the pin to be used as output compare. Refer to **6.6.1 Pulse Accumulator Register/Pulse Accumulator Counter (PACTL/PACNT)**. TI4O5 is reset to \$FFFF.

6.3.2.3 Timer Control Register 2 (TCTL2)

TCTL2 is used to select the edge to which the input capture logic will respond. The input capture logic can be disabled, an input capture can occur on a rising edge, a falling edge, or any edge.

6.4 Output Compare Functions

Each of the GPT output compare pins (OC1, OC2, OC3, OC4, and IC4/OC5, when used by an output compare function, has associated with it a dedicated 16-bit compare register, a 16-bit comparator, and interrupt generation logic. When the programmed contents of an output compare register matches TCNT, an output compare status flag (OCxF) bit in TFLG1 is set. Certain automatic actions are initiated for that output compare function. These automatic actions can be a hardware interrupt request and state changes at the related timer output pin.

An interrupt will be generated on a successful output match, if the interrupt enable bit (OCxI) for this output compare function is set in TMSK1. Please refer to **6.9 Interrupts** for details on interrupt operation.

The output compare logic is designed to prevent false compares during data transition times.

Control bits in the CFORC register allow for early forced compares. Refer to **6.4.4 Timer Compare Force Register (CFORC)**.

The operation of OC1 is slightly different from that of the other output compare functions. Refer to **6.4.3 Output Compare 1 (OC1)** for a description of this output function and its operation.

6.4.1 Timer Control Register 1 (TCTL1)

The automatic actions for OC2–OC4 and IC4/OC5, if it is configured as an output compare function, are controlled by pairs of bits (OMx and OLx) in timer control register 1 (TCTL1). The automatic pin actions for each output compare are independently selectable.

6.4.2 Output Compare Registers (TOC1–4) (TI4O5)

All output compare registers are 16-bit read/write registers which are initialized to \$FFFF by reset. If an output compare register is not used for an output compare function it may be used as a storage location. A read or write must be a 16-bit operation to ensure coherency. If coherency is not needed byte accesses can be used.

For output compare functions, 16-bit read/write output compare registers TOC1-4 and TI4O5 are written to a desired match value and compared against TCNT to control specified pin actions.

6.4.3 Output Compare 1 (OC1)

Output compare 1 is unique because it can automatically affect any or all of the five output compare pins (OC1–OC5) as a result of a successful output match. The two registers that control this capability are the OC1 action mask register (OC1M) and the OC1 action data register (OC1D).

Register OC1M specifies the output pins that are affected as a result of a successful OC1 compare, and register OC1D is used to specify the data to be transferred to the affected pins. If an OC1 match and another output match occur at the same time and both attempt to alter the same pin, the OC1 function controls the state of the pin.

This function allows control of multiple I/O pins automatically with a single output match. It also allows more than one output compare function to control the state of a single I/O pin. This allows pulses as short as one timer count to be generated.

6.4.4 Timer Compare Force Register (CFORC)

The CFORC register allows forced early compares. The action taken as a result of a forced compare is the same as if there was a match between the OCx register and the free-running counter, except that the corresponding interrupt status flag bits are not set. The forced channels will trigger their programmed pin actions to occur immediately after the write to CFORC.

The CFORC register is implemented as the upper byte of a 16-bit register which also contains the PWM control register (PWMC). It can be accessed as 8 bits or a word access can be used. Reads of the force compare bits (FOCx) have no meaning and always return zeros. These bits are self-negating.

6.5 Input Capture 4/Output Compare 5 (IC4/OC5)

The input capture 4/output compare 5 pin has multiple functions. As discussed in the previous sections this pin can be used as an input capture pin, an output

compare pin or as a general-purpose I/O pin. These features are controlled by the DDRI4O5 bit in the parallel data direction register (PDDR) and a function enable bit (I4O5) in the pulse accumulator control register (PACTL). The function enable bit configures the pin for the input capture (IC4) or output compare function (OC5). After reset, both bits are cleared to zero configuring the pin as an input, but also enabling the OC5 function.

The 16-bit register used with the IC4/OC5 function acts as either the input capture register or as the output compare register depending on which function is selected. When used as the input capture 4 register, it cannot be written to except in test or freeze mode. Refer to **6.11 Special Modes** for information on freeze and test mode.

6.6 Pulse Accumulator

The pulse accumulator counter (PACNT) is an 8-bit read/write up counter which can operate in an external event counting or gated time accumulation mode. Figure 6-4 shows a block diagram of the pulse accumulator.

In the event counting mode, the counter increments each time a selected edge on the pulse accumulator input (PAI) pin is detected. The maximum clocking rate is the system clock divided by four.

In the gated time accumulation mode the selected clock increments PACNT when the PAI pin is in the active state. There are four clock sources available, as shown in Figure 6-4.

The bits in the pulse accumulator control register (PACTL) control the operation of PACNT. Bits PACLK[1:0] select the clock sources used in gated time accumulation mode. The PAMOD bit selects event counting or gated mode operation. The PEDGE control bit determines which edge is detected in event counting mode or the active state in gated time accumulation mode.

The PACTL and PACNT registers are implemented as one 16-bit register, but may be accessed with byte or word access cycles. Both registers are cleared at reset, but the PAIS and PCLKS bits will show the state of the PAI and PCLK pins respectively.

Two maskable interrupts are available from the pulse accumulator. The pulse accumulator overflow flag indicates that the pulse accumulator count has rolled over from \$FF to \$00. This can be used to extend the range of the counter beyond 8 bits. The pulse accumulator flag indicates that a selected edge has been detected at the PAI pin. In the event counting mode, this second interrupt is generated when the edge being counted is detected. In gated time accumulation mode, it is generated at the end of the timing period, i.e., when the PAI input changes from the active to the inactive state. Hardware interrupt

requests for these two conditions are enabled by the PAOVI and PAII bits in the TMSK2 register. The status bits PAOVF and PAIF bits are located in the TFLG2 register. These two bits indicate that the above events have occurred. For more information on interrupt operation refer to **6.9 Interrupts**.

If not needed for the pulse accumulator function, the PAI pin may be used for general-purpose input. The state of the PAI pin is reflected by the state of the PAIS bit in the PACTL register.

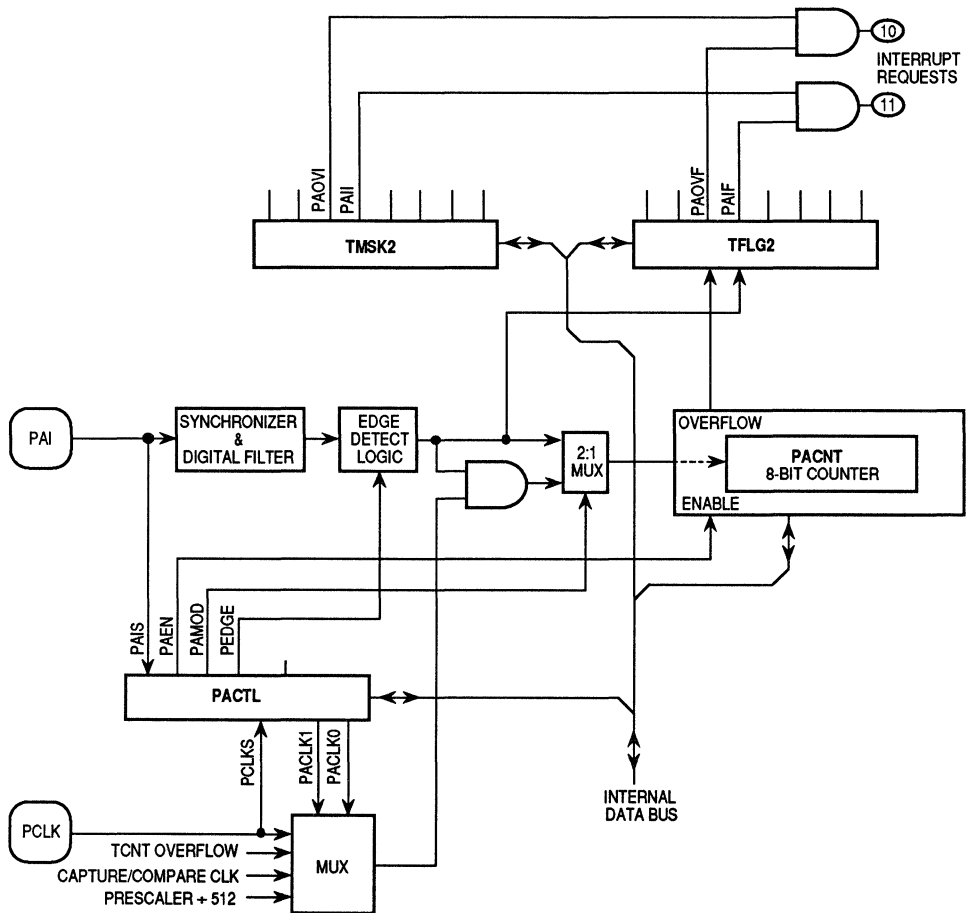


Figure 6-4. Pulse Accumulator Block Diagram

6.6.1 Pulse Accumulator Register/Pulse Accumulator Counter (PACTL/PACNT)

The PACTL register is used to select the operational mode of the pulse accumulator. PACNT is the pulse accumulator 8-bit read/write up counter. Another control bit, I4/O5, configures the input capture 4/output compare 5 pin as an input capture or output compare. Refer to **6.3.2.2 Input Capture 4/Output Compare 5 Register (TI4O5)** for more information on this bit.

6.7 Prescaler

Both the capture/compare and the PWM units have their own independent 16-bit free-running counters as the main timing component. These counters derive their clocks from the prescaler or the external input pin PCLK. Figure 6-5 shows the block diagram of the prescaler.

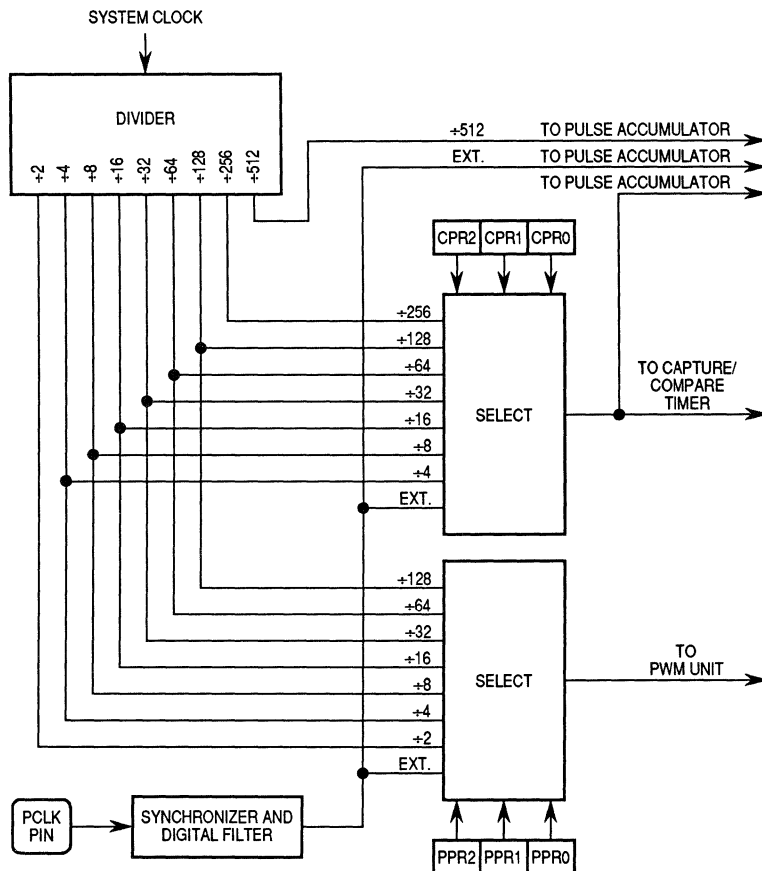


Figure 6-5. Prescaler Block Diagram

The system clock is divided by a nine-stage divider chain which provides outputs of the system clock divided by 2, 4, 8, 16, 32, 64, 128, 256 and 512. Connected to the outputs of the divider are 2 multiplexers, one for the compare/capture unit, the other for the PWM unit. These provide one of seven taps, plus an external input from the PCLK pin to the PWM and compare/capture units. The outputs of the multiplexers are controlled by bits CPR[2:0] in the timer interrupt mask register 2 (TMSK2) for TCNT and bits PPR[2:0] in the PWM control register (PWMC) for the PWM counter (PWMCNT).

After reset, these bits are cleared and the GPT is configured to use the system clock divided by 4 for TCNT and the system clock divided by 2 for PWMCNT. Initialization software may change the division factor by writing to these bits. The bits for the PWM unit may be written at any time but the ones for the compare/capture unit can only be written once except when the GPT is in test mode or freeze mode.

The nine-bit prescaler may be read at any time. In test or freeze mode the prescaler may be written. Word accesses must be used to ensure coherency. If coherency is not needed byte accesses may be used. The value of the prescaler will be in bits 8:0 while bits 15:9 are unimplemented and will be read as zeros.

Another feature of the GPT is the capability to output the selected prescaler outputs (including the PCLK pin) from the two multiplexers to external pins. The CPROUT bit in the TMSK2 register configures the OC1 pin to output the TCNT clock from the timer mux and the PPROUT bit in the PWMC register configures the PWMA pin to output the PWM clock from the PWM mux. These two bits may be written at anytime. The clock signals on OC1 and PWMA do not have a 50% duty cycle. They have the period of the selected clock but are high for only one system clock time.

The prescaler also supplies three clock signals to the pulse accumulator clock select mux. These are the system clock divided by 512, the external clock signal from the PCLK pin and the compare/capture clock signal.

6.8 Pulse Width Modulation (PWM) Unit

The pulse width modulation unit has two PWM outputs, PWMA and PWMB, which are controlled by same clock output of the prescaler mux. This clock is the input to a 16-bit counter which is used by both of the PWM channels. The output of the counter is multiplexed to provide two operational modes, fast mode or slow mode. This gives a clocking rate 1/256 (fast mode) or 1/32768 (slow mode) of the output of the prescaler mux. The duty cycle ratios of the two PWM channels are individually controlled by software. The PWM pins may be used as output pins if not used for PWM functions. The PWMA pin may also be used to output

the clock used to drive the PWM counter. Figure 6-6 is a block diagram of the pulse width modulation unit.

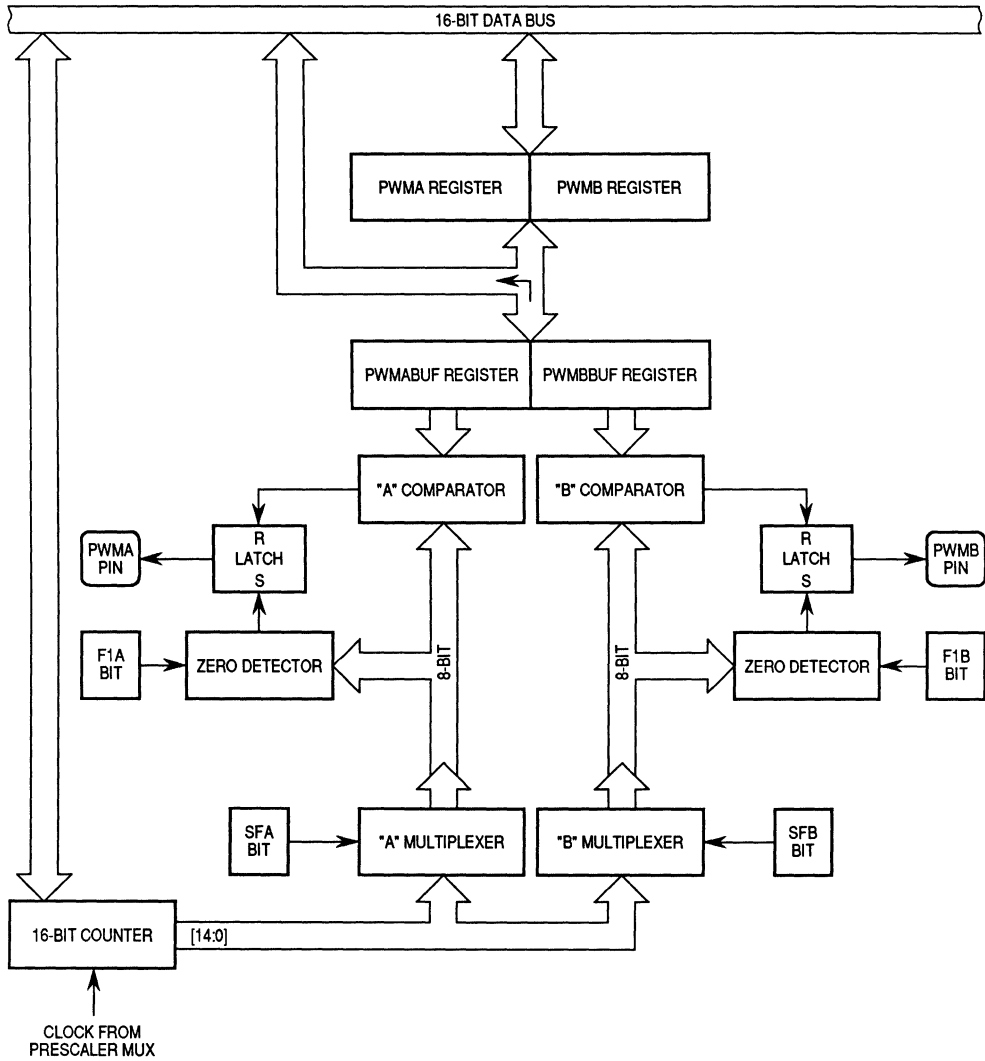


Figure 6-6. PWM Block Diagram

6.8.1 Counter

The 16-bit counter in the PWM unit is similar to the timer counter in the compare/capture unit. After reset, the GPT is configured to use the system clock divided by two as the input to the free-running counter. Initialization software may reconfigure the counter to use one of seven prescaler outputs or an external clock from the PLCK input pin.

Software can read the counter at any time without affecting its value. A read of the PWM count register (PWMCNT) must be a word access to ensure coherency but byte accesses can be made if coherency is not needed. The counter is cleared to \$0000 during reset and is a read-only register except in freeze or test mode.

Fifteen of the sixteen bits of the counter are output to multiplexers A and B which independently provide the fast and slow modes of the PWM unit. The fast/slow mode is selected by the SFA bit for PWMA and the SFB bit for PWMB in the PWM control register (PWMC). These two bits and the PPR[2:0] bits in the PWMC register control the output frequency of the PWM unit. In the fast mode, bits [7:0] of PWMCNT clock the PWM logic, while in slow mode, bits [14:7] are used to clock the PWM logic. This makes the period of a PWM channel in slow mode 128 times longer than when in fast mode. Figure 6-7 shows fast and slow modes of one of the channels. Table 6-2 shows a range of PWM output frequencies using a 16.78 MHz system clock.

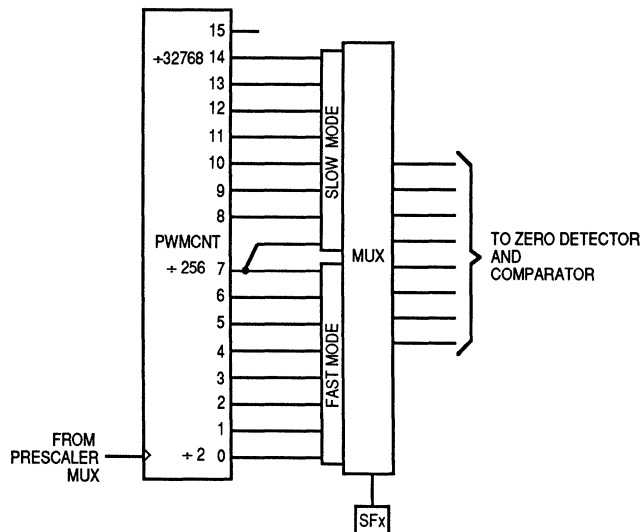


Figure 6-7. Fast/Slow Mode

Table 6-2. PWM Frequency Range Using 16.78 MHz System Clock

PPR[2:0]	Prescaler Tap	Fast Mode	Slow Mode
000	Div 2 = 8.39 MHz	32.8 kHz	256 Hz
001	Div 4 = 4.19 MHz	16.4 kHz	128 Hz
010	Div 8 = 2.10 MHz	8.19 kHz	64.0 Hz
011	Div 16 = 1.05 MHz	4.09 kHz	32.0 Hz
100	Div 32 = 524 kHz	2.05 kHz	16.0 Hz
101	Div 64 = 262 kHz	1.02 kHz	8.0 Hz
110	Div 128 = 131 kHz	512 Hz	4.0 Hz
111	PCLK	PCLK/256	PCLK/32768

6.8.2 PWM Function

The pulse width values of the PWM outputs are associated with registers PWMA and PWMB. Each of these registers is 8 bits in length. They are implemented as two bytes of a 16-bit register and may be accessed as separate bytes or as one 16-bit register. A value of \$00 loaded into either of these registers results in a continuously low output on the corresponding output pin. A value of \$80 results in a 50% duty cycle output, and so on, to the maximum value, \$FF, which corresponds to an output which is at "1" for 255/256 of the cycle. A 100% duty cycle is available by using the F1A (for PWMA) and F1B (for PWMB) bits in the PWMC register. These are the lower two bits of the CFORC register but can be accessed at the same word address as PWMC. Setting these bits to ones forces a continuously high output on the corresponding output pins after the end of the current cycle.

When the MCU writes to register PWMA or PWMB, the new value will only be picked up at the end of a complete cycle. This prevents the PWM from generating glitches (erroneous data) when being updated. The current duty cycle value is in the PWMx buffer register (PWMxBUF). The new value is transferred from the PWMx register to PWMxBUF at the end of the current cycle.

The data and control registers, PWMA, PWMB, and PWMC, are reset to \$00 during reset. These registers may be written or read at any time. PWMC is implemented as the lower byte of a 16-bit register. The upper byte is the CFORC register. The buffer registers, PWMABUF and PWMBBUF, are read-only at all times and may be accessed as separate bytes or as one 16-bit register.

6.8.3 PWM Registers A/B (PWMA/PWMB)

PWMA/PWMB — PWM Registers A/B

\$YFF926, \$YFF927

These read/write registers contain the pulse-width value of the next PWM output waveform on the corresponding PWM pin.

6.8.4 PWM Buffer Registers A/B (PWMABUF/PWMBBUF)

PWMABUF/PWMBBUF — PWM Buffer Registers A/B

\$YFF92A, \$YFF92B

These read-only registers contain the values associated with the duty cycles of the corresponding PWMs in progress. They are updated from PWMA/B at the end of each PWM cycle.

6.8.5 PWM Pins

If not needed for PWM outputs, pins PWMA and PWMB may be used for general-purpose output. Two bits in the CFORC register control whether the pins are used for PWMs or for discrete output. If used for discrete output, the values of the F1A and F1B bits in the PWM control register (PWMC) will be driven out on these pins. This feature is separately selected for the two PWM pins. When read, the F1A and F1B bits reflect the states of the PWMA and PWMB pins, respectively. Refer to **6.10 General-Purpose I/O** for additional information.

6.9 Interrupts

The GPT is capable of generating one of seven interrupt priority levels on the intermodule bus (IMB). The GPT contains control registers which set the interrupt priority level and the arbitration priority of the module, enable the interrupts of the eleven interrupt sources and adjust their priority internally.

The interrupt priority level of the GPT can be one of eight levels, 7–0. This level is selected by the interrupt request level (IRL) bits in the interrupt configuration register (ICR). A level seven is the highest priority and a level zero disables interrupts.

When an interrupt is requested, and is at a higher level than the current interrupt level set by the interrupt mask in the CPU status register, the CPU will initiate an interrupt acknowledge cycle (IACK). The module will decode the IACK cycle and compare the CPU recognized level to the level that the module is currently requesting. Refer to the appropriate CPU Manual for more information on the interrupt mask. If a match occurs, then arbitration with other modules begins.

Interrupting modules present their arbitration ID on the IMB and the module with the highest ID wins. If the GPT wins the arbitration, it will then generate a uniquely encoded interrupt vector that indicates which timer channel is requesting service.

The arbitration ID for the GPT module is selected by the IARB bits in the GPT module configuration register (MCR). The IMB is designed to arbitrate between a maximum of sixteen modules, so the IARB field of the MCR can have a value from zero through fifteen. A module with an IARB of 15 always wins the

arbitration when two or more modules with the same interrupt level contend for the interrupt request.

To deal with simultaneous interrupts, a hard-wired priority scheme is implemented. This scheme assures that the vector returned to the CPU will point to the interrupt with the highest priority. The priority arrangement, along with the associated vector address for each channel, is shown in Table 6-3. The vector is prevented by hardware from changing due to a new interrupt while it is being driven out on the IMB.

The priority adjust bits (PAB) in the interrupt configuration register (ICR) can change the priority of one of the channels. The user can place any single interrupt source at the highest priority level by changing the PAB value. Other than this one exception, all other priority relationships remain the same. Table 6-3 shows the priority relationships of the timer channels.

Table 6-3. Timer Interrupt Priorities and Vector Addresses

Interrupt Source		Priority Level	Vector Address
Name	Function		
—	Adjusted Channel	0 (Highest)	\$X0
IC1	Input Capture 1	1	\$X1
IC2	Input Capture 2	2	\$X2
IC3	Input Capture 3	3	\$X3
OC1	Output Compare 1	4	\$X4
OC2	Output Compare 2	5	\$X5
OC3	Output Compare 3	6	\$X6
OC4	Output Compare 4	7	\$X7
IC4/OC5	Input Capture 4/Output Compare 5	8	\$X8
TOF	Timer Overflow Flag	9	\$X9
PAOVF	Pulse Accumulator Overflow Flag	10	\$XA
PAIF	Pulse Accumulator Input Flag	11 (Lowest)	\$XB

X = Four-bit Vector Base Address (VBA)

6.9.1 Interrupt Status Flags

When an event occurs in the GPT, such as a timer overflow, an input capture, or any event that could generate an interrupt, that event sets a status flag in the timer interrupt flag registers (TFLG1/TFLG2). User software can read the status registers to see if an event has occurred. If an event has occurred, then the polling routine can transfer control to a software routine that services that event.

If interrupts have been enabled for that event, the CPU will enter an interrupt service routine. Using interrupts does not require continuously polling the status flags to see if an event has taken place.

6.9.2 Timer Interrupt Flag Registers 1–2 (TFLG1/TFLG2)

The timer interrupt flag register indicates when an event has occurred in the GPT and is divided into two 8-bit registers: TFLG1 and TFLG2. The registers can be addressed as one 16-bit register or as individual 8-bit registers. The registers are initialized to zero at reset.

This register along with the timer interrupt mask registers (TMSK1/TMSK2) allow the GPT to operate in a polled or interrupt driven system. For each bit in TFLGx there is a corresponding bit in the TMSKx register in the same bit position. If the mask bit is set and an associated event occurs, a hardware interrupt request is generated.

6.9.3 Timer Interrupt Mask Registers 1–2 (TMSK1/TMSK2)

The timer interrupt mask register enables specific interrupts in the GPT and is divided into two 8-bit registers: TMSK1 and TMSK2. The registers can be addressed as one 16-bit register or as individual 8-bit registers. The registers are initialized to zero at reset.

This register along with the timer interrupt flag registers 1–2 (TFLG1/TFLG2) allow the GPT to operate in a polled or interrupt driven system. For each bit in TMSKx there is a corresponding bit in the TFLCx register in the same bit position. If the mask bit is set and an associated event occurs, a hardware interrupt request is generated.

This register also controls the operation of the timer prescaler. Refer to **6.7 Prescaler** for additional details on prescaler operation and control.

6.10 General-Purpose I/O

Any pin on the GPT can be used as general-purpose I/O when not being used for a GPT function. Some pins are bidirectional, others are output only or input only. The pins that are bidirectional are associated with the compare/capture functions. The direction of each pin is controlled by the corresponding data direction bit in the parallel data direction register (PDDR).

Parallel data is read from and written to the parallel data register (PDR). Pin data may be read from the PDR even when the pins are configured for an alternate timer function. Data read from the parallel data register always reflects the state of the external pin, while data written to the parallel data register may not always affect the external pin.

Data written to the PDR does not directly affect pins used by the output compare functions, but the data is latched so that if the output compare function is later disabled, the last data written to the PDR will be driven out on the associated output pin (if the pin is configured as an output pin). Data written to the PDR can cause input captures if the corresponding pin is configured as an input capture function.

The pulse accumulator input (PAI) and the external clock input (PCLK) pins provide general-purpose input. The state of these pins can be read by accessing the PAIS and PCLKS bits in the pulse accumulator control register (PACTL).

The pulse-width modulation A and B (PWMA/PWMB) output pins can serve as general-purpose output pins. The force PWM value (FPWMx) and the force logic one (F1x) bits in the compare force (CFORC) and PWM control (PWMC) registers, respectively, control their operation.

6.11 Special Modes

The GPT can enter a number of special modes besides its normal operational mode. These are test mode (selected by a bit in SIM CREG), stop mode, freeze mode and single-step mode. These different modes are selected by certain bits in the module configuration register (MCR). There is also one other mode, which is supervisor mode. This mode allows system software to limit access to certain bits in the GPT.

6.11.1 Test Mode

The test mode is intended for factory production testing of the GPT and other modules within the specific MCU on which the GPT is incorporated. This description of the test mode is for informational purposes only and is not intended to provide operational information. Applications should avoid using test mode.

Test mode is entered by a combination hardware and software method. A register bit (the ETM bit of the CREG register in the SIM) must be set while an external pin (TSTME) is asserted.

The only way test mode is used on the GPT is to allow write access to registers and bits that otherwise are read-only. Because the timing functions are simple, no other special test logic is included in this module. However, the test register location is reserved by Motorola for future use. All of the registers, the prescaler, counters, and control registers may be read and written by diagnostic software. Also, the outputs of the prescaler muxes may be driven out on external pins. With these simple features, the GPT can be easily tested. For more information on test mode refer to the test submodule section in the appropriate MCU manual.

6.11.2 Stop Mode

In STOP mode the system clock is stopped in most of the module and will remain stopped until the STOP bit is negated by the CPU or by a reset. All counters and prescalers within the timer will stop counting while the STOP bit is asserted. Only the module configuration register (MCR) and the interrupt configuration register (ICR) should be accessed while in the stop mode. Accesses to other GPT registers may result in unpredictable behavior. While in stop mode GPT power consumption is reduced. This may be useful in low power applications. During debugging of an application it can be useful to disable module operation.

6.11.3 Freeze Mode

MCUs in Motorola's family of modular microcontrollers have an alternate operating mode besides their normal mode. This mode is the background debug mode (BDM). In BDM all normal processing is suspended and the user has the ability to view the contents of registers and memory locations and to do certain other operations. Refer to the appropriate CPU manual to see what operations are available. BDM must be enabled at reset before it can be entered.

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Several sources within the MCU cause the CPU to go into background debug mode. These sources can be an external break-point, the BGND instruction and a double bus fault. Refer to the appropriate CPU manual for details. When the CPU enters background debug mode the FREEZE signal on the IMB and the FREEZE pin will be asserted. Assertion of FREEZE is the first indication the CPU has gone into BDM. While in BDM, each module in the MCU can independently enter freeze mode by asserting the FRZ bit(s) for the module (FRZ0 for the GPT).

While in freeze mode a snap-shot of most of the internal registers is available and certain write operations can be done which are not normally allowed. Freeze mode freezes the current state of the timer. The prescaler and the pulse accumulator do not increment and changes to the pins while in freeze mode are ignored. (The input synchronizers for the input pins are not clocked.) All of the other timer functions that are controlled by the CPU will operate normally, for example, registers can be written to change pin directions, force output compares, and read or write I/O pins.

The prescaler and the pulse accumulator will remain stopped and the input pins will be ignored until the FREEZE signal is negated (the CPU is no longer in BDM), the FRZ0 bit is negated, or the MCU is reset. All activities that were started just prior to freeze mode being entered will be completed. For example, if an input edge on an input capture pin was detected just as the FREEZE signal was asserted, the capture will occur and the corresponding interrupt flag will be set. This will happen even if it takes a few clocks after the beginning of freeze mode.

While the FREEZE signal is asserted, the CPU has write access to registers and bits that are normally read-only, or write-once. The write-once bits can be written to as often as needed.

6.11.4 Single-Step Mode (STOPP and INCP)

Two bits in the module configuration register (MCR) allow debugging of the GPT without the MCU entering BDM. As in freeze mode, the prescaler and the pulse accumulator stop counting and changes at input pins are ignored when the STOPP bit is asserted. Reads of the GPT pins will return the state of the pin when the STOPP bit was set. After the STOPP bit has been set the INCP bit can be used to increment the prescaler and clock the input synchronizers once. The INCP bit is self-negating after the prescaler is incremented. The INCP bit can be repeatedly set and will increment the prescaler and input synchronizers each time. The INCP bit has no effect when the STOPP bit is not set.

6.11.5 Supervisor Mode

Certain registers in the GPT are always in supervisor data space and the other registers are programmable to be in supervisor or unrestricted data space. The supervisor (SUPV) bit in the MCR selects the location where these programmable registers reside.

If the SUPV bit is set, the space is designated as supervisor only. Access is then permitted only when the CPU is operating in supervisor mode. Attempts to access the registers with user software (user data space) will cause the bus cycle to be transferred externally. Results can then be unpredictable depending on the hardware environment. If SUPV is clear, then both user and supervisor accesses are permitted. Attempting to access a supervisor-only register (i.e., those denoted with an "S") from user software will cause the GPT to respond as if an unimplemented register was accessed. Writes have no effect and reads return zeros. Refer to the GPT register map (Table 6-1) to determine which registers are supervisor only or assignable to either data space.

SECTION 7 EMULATION OVERVIEW

Motorola provides both low-cost and high-performance development tools to support the MC68331. The M68331EVS evaluation system provides low-cost emulation for the MC68331. The CDS32 workstation provides a cost-effective high-performance emulation environment. A free assembler (part number M68HXBASM2) and a C compiler (part number M68NXBCC300) on the MCU Bulletin Board (512-891-FREE) are available for product evaluation. Powerful, integrated software tools for MS-DOS computers are provided to support high-level-language development and debugging. Many development support tools from major third-party vendors are also available.

The background debug mode (BDM) feature on the MC68331 MCU significantly reduces the external logic necessary to provide emulation. Additionally, the use of the M68000 Family architecture for the CPU and external bus (based on the MC68020) permits the use of many existing or slightly modified existing development tools. Motorola and third-party development support companies take advantage of these features to provide new emulation and debugging options. These new features can be used at minimum system cost when provided with an interface connector on their target system to enable BDM communication.

7.1 M68331EVK

The M68331EVK low-cost development solution provides a cost-effective solution for initial MCU evaluation. The common evaluation module (EVM) monitor/debugger functions, such as memory and register modification and display, single-stepping and tracing, and operand fetch breakpoints are supported. A one-line assembler/disassembler provides a quick code modification capability. Additionally, breakpoints on the access of any address are provided. The M68331EVK consists of an M68331BCC and an M68300PFB.

7.2 M68331EVS

The M68331EVS provides additional capability by incorporating the M68300DI development interface.

The M68331EVS consists of the M68331EVK and the M68300DI. These boards all plug together to form a total system, but can be separated for different modes of use. The M68331BCC and M68300DI may be placed directly in the user's target application. Different configurations are possible, as shown in Figure 7-1.

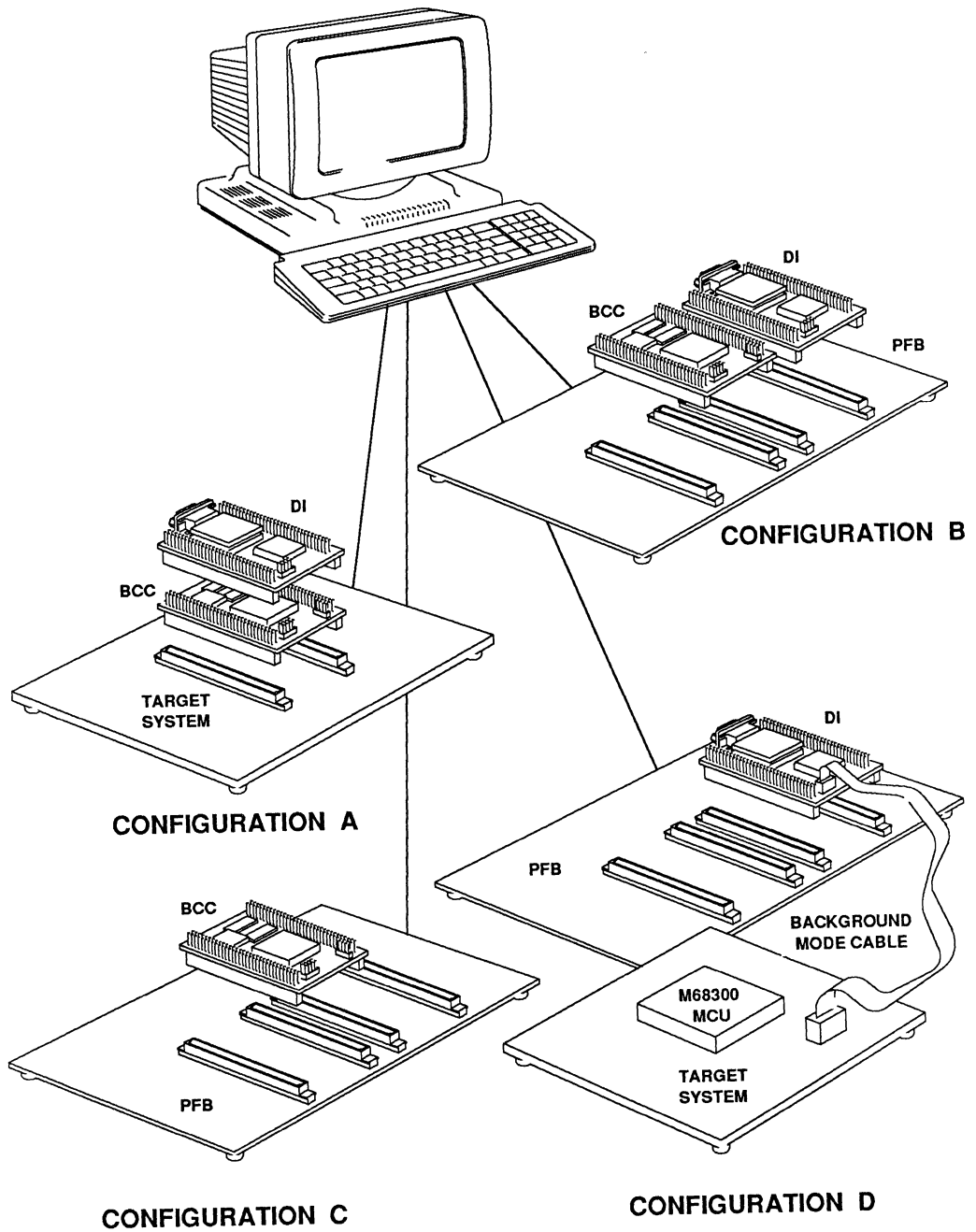


Figure 7-1. Configuration Overview

7.2.1 M68331BCC

The M68331BCC is the heart of the emulation system. It contains the MC68331 MCU, 128 Kbytes of erasable programmable read-only memory (EPROM), 64 Kbytes of static RAM, an RS-232C level converter chip, and a 32.768 kHz crystal, all on a printed circuit board approximately the size of a standard business card. The business card computer (BCC) is sold separately. All signals from the MCU are provided by two 64-pin double-row headers that plug directly into any standard high-density breadboard.

The BCC's EPROM is a 64K × 16 array. It contains a powerful monitor/debugger for standalone operation, called CPU32Bug. The RAM is accessed as 32K × 16, and is used for variable storage by CPU32Bug as well as user emulation memory. This board runs independently of the other boards when provided with a 5-V supply and a terminal for the monitor interface. User programs can be downloaded into RAM and executed under monitor control.

7.2.2 M68300DI

The M68331DI provides a development interface for the BCC. On board is an M68HC11 MCU that interfaces with the BCC via background mode. Serial communication via RS-232C to a host computer (IBM-PC or clone) provides the user with EVSbug, an enhanced monitor/debugger based on the CDS32 emulator human interface, that runs under MS-DOS. A hardware breakpoint chip provides hardware breakpoints on any address access, including addresses internal to the MCU.

The DI provides additional features. It executes code running on the host computer to control the BCC (hardware debug configuration), or any MC68331, via an 8-pin connector for the background mode configuration. The DI is capable of programming the EPROM on the BCC with code downloaded from the host computer when operating in the software debug mode.

7.2.3 M68300PFB

The M68331PFB provides a platform board for the EVS. The BCC and/or the DI can plug directly onto the platform board (PFB). Four sockets allow the addition of 32K × 8 static RAMs, 32K × 8 EPROMS, or 64K × 8 EPROMS to provide additional emulation memory for user code. Jumper options allow the MC68331 to boot from EPROMS on the PFB. The EVS is powered by a 5-V (±10%) supply via a convenient connector. Two DB9 connectors provide RS-232C interfaces to a host computer for EVS control. One DB9 connector interfaces the BCC to a terminal for CPU32Bug. The other DB9 interfaces the DI to an MS-DOS computer for EVSbug operation. Other connectors on the PFB bring out the MCU's pins for connection of a logic analyzer. The PFB and the BCC can be used together to perform software benchmarking and verification.

7.3 CDS32 High-Performance Emulation Solution

Based on the MC68331 MCU, this hardware development tool provides an environment that can operate with any MS-DOS host computer via RS-232C. CDS32 support of the MC68331 consists of emulation and bus-state analysis. The emulator provides full-featured, real-time emulation capability for the MC68331. Object code, created on a personal computer, can be downloaded to the CDS32 for execution. Over 1 Mbyte of emulation memory is provided, alleviating the need for target memory during prototyping. An 8K × 160-bit analyzer buffer with four trigger event terms provides adequate capability to trace real-time events. Flexible breakpoint operation simplifies the process of hardware debug. A one-line assembler/disassembler allows quick changes to be made to the user's code. Emulation speeds up to 33 MHz are supported.

The CDS32 is integrated with the user's target system via a smart probe. This probe consists of a small PC board that contains an MC68331 and some buffer logic for bus analysis support on the CDS32. By inserting the probe into a socket on the target system in place of an MC68331, all MCU functions, clocking, and emulation memory can be provided by the CDS32. An adapter to connect an MC68331 soldered onto the user's target application board is in development. Control signals and data are sent by the probe to the CDS32 station via a flat ribbon cable. This interface to the CDS32 is shown in Figure 7-2.

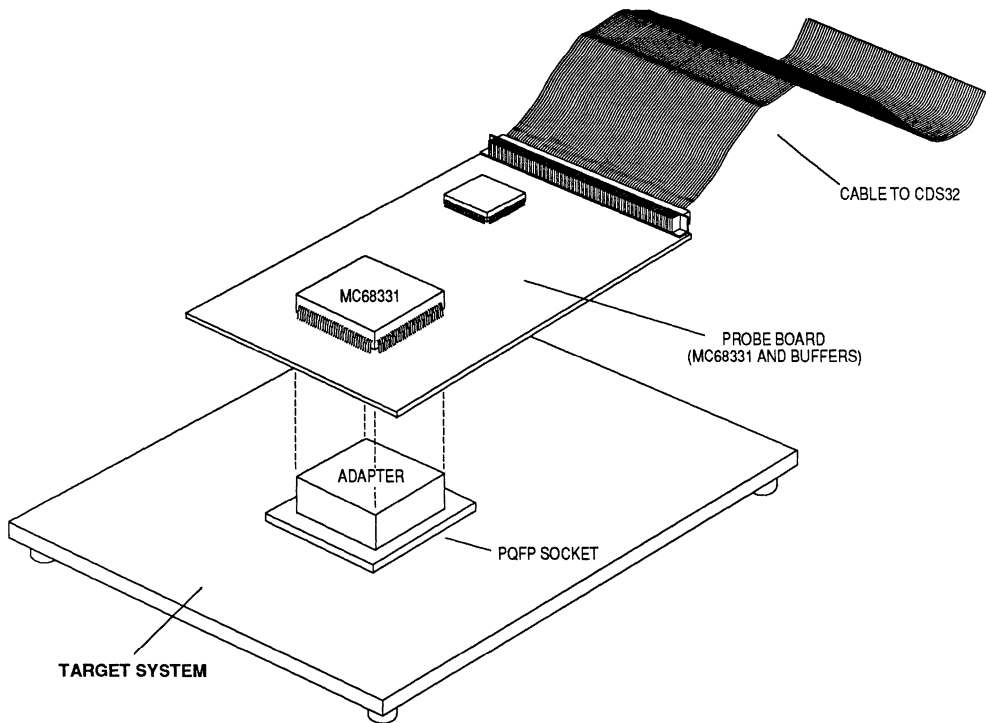


Figure 7-2. CDS32 Interface

7.4 Freeware

An MS-DOS-based assembler and C compiler are available free from Motorola for initial product evaluation and development. The assembler does not contain many of the advanced features found in commercial assemblers and is an unsupported product. The C compiler supports a subset of the Kernighan and Ritchie C compiler implementation and supports only the 68000 instruction set. The free software is available through the Motorola MCU Bulletin Board at (512) 891-FREE.

7.5 MS-DOS Software

Motorola software tools for the MC68331 provide a user-friendly development environment for creating and debugging code. The tools include a cross C compiler, macro-assembler/linker, and source level debugger (SLD) for MS-DOS computers. The C compiler allows code to be written in either C or assembly language. Optimized for execution speed, the C compiler supports modular programming features and promotes software maintainability. The SLD shrinks

prototyping time by providing debug capabilities at the C language level. The SLD is part of the CDS32 emulator package and is not sold separately. The software tools operate on the IBM PC/XT, PC/AT, PS/2, and compatibles.

Third-party hardware and software development tools already exist. Assemblers and compilers are available on a wide range of computer hosts. Emulator and logic analyzer support for the MC68331 is available from a variety of third-party vendors as well. Contact Motorola for additional information.

7.6 User Requirements

The Motorola and third-party development tools provide development support for the user, even when the MCU is positioned in the final system. This can be accomplished if the target system provides a small 2×4 "Berg" (or double-row header) connector (male preferred) for a connection to the development hardware. This connector should be provided by every user who wishes to test or debug application boards in final configuration. Refer to Figure 7-3 for the connector pinout.

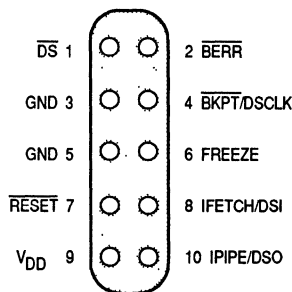


Figure 7-3. Berg Connector Pinout

The user of the MC68331 is strongly urged by Motorola to provide these signals from the MCU to the connector as outlined above. This connector may be placed anywhere on the user's target board, as shown in Figure 7-2. Both the M68331EVS and the CDS32 emulator support this interface, providing the user with both an extremely powerful debugging tool at a minimum system cost, and a means of testing the user's boards after the MCU has been soldered in place.

SECTION 8 ELECTRICAL CHARACTERISTICS

This section contains electrical characteristics and associated timing information for the MC68331.

8.1 Maximum Ratings

The following ratings define the conditions under which the device operates without damage. Sections of the device may not operate normally while being exposed to the electrical extremes and contains circuitry to protect against damage from high static voltages or electrical fields. It is advised, however, that normal precautions be taken to avoid application of any voltages higher than maximum-rated voltages to this high-impedance circuit. Reliability of operation is enhanced if unused inputs are tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}).

Rating	Symbol	Value	Unit
Supply Voltage	V_{DD}	-0.3 to +6.5	V
Input Voltage	V_{in}	-0.3 to +6.5	V
Operating Temperature Range MC68331C MC68331V MC68331M	T_A	TL to TH -40 to 85 -40 to 105 -40 to 125	°C
Storage Temperature Range	T_{stg}	-55 to 150	°C

8.2 Thermal Characteristics

Characteristic	Symbol	Value	Unit
Thermal Resistance Plastic 132-Pin Surface Mount	θ_{JA}	44	°C/W

8.3 Power Considerations

The average chip-junction temperature (T_J) in C can be obtained from:

$$T_J = T_A + (P_D \theta_{JA}) \quad (10-1)$$

where

- T_A = Ambient Temperature, °C
- θ_{JA} = Package Thermal Resistance, Junction-to-Ambient, °C/W
- P_D = $P_{INT} + P_{I/O}$
- P_{INT} = $I_{DD} \times V_{DD}$, Watts — Chip Internal Power
- $P_{I/O}$ = Power Dissipation on Input and Output Pins — User Determined

For most applications $P_{I/O} < P_{INT}$ and can be neglected. An approximate relationship between P_D and T_J (if $P_{I/O}$ is neglected) is:

$$P_D = K + (T_J + 273^\circ\text{C}) \quad (10-2)$$

Solving equations 1 and 2 for K gives:

$$K = P_D + (T_A + 273^\circ\text{C}) + \theta_{JA} \times P_D^2 \quad (10-3)$$

where K is a constant pertaining to the particular part. K can be determined from equation (3) by measuring P_D (at equilibrium) for a known T_A . Using this value of K, the values of P_D and T_J can be obtained by solving equations (1) and (2) iteratively for any value of T_A .

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8.4 Control Timing ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H)

Characteristic	Symbol	Min	Max	Unit
System Frequency (See Note)	f_{sys}	dc	16.78	MHz
Crystal Frequency	f_{XTAL}	25	50	kHz
On-Chip VCO System Frequency	f_{sys}	0.131*	16.78	MHz
On-Chip VCO Frequency Range	f_{VCO}	0.1	35	MHz
External Clock Operation	f_{sys}	dc	16.78	MHz
PLL Startup Time ($C = 0.1 \mu\text{F}$, Stable V_{DD} and Crystal)	t_{rc}	—	10	ms

NOTE: All internal registers retain data at 0 Hz.

* VCO minimum frequency is four times the crystal frequency. The frequency shown is for a 32.768 kHz crystal.

8.5 DC Characteristics ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L \text{ to } T_H$)

Characteristic	Symbol	Min	Max	Unit
Input High Voltage	V_{IH}	$0.7 \times V_{DD}$	$V_{DD} + 0.3$	V
Input Low Voltage	V_{IL}	$V_{SS} - 0.3$	$0.2 \times V_{DD}$	V
Input Leakage Current $V_{in} = V_{DD}$ or V_{SS} $\overline{TSTME/TSC}$, \overline{BKPT} , $T2CLK$, RXD	I_{in}	-2.5	2.5	μA
Hi-Z (Off-State) Leakage Current (See Note 1) $V_{in} = V_{DD}$ or V_{SS} $V_{in} = V_{DD}$ or V_{SS} Group 1 and Group 2 I/O Pins Group 3 I/O Pins \overline{HALT} , \overline{RESET}	I_{OZ}	-2.5 -20	2.5 20	μA
Output High Voltage (See Notes 1 and 2) $I_{OH} = -0.8 \text{ mA}$, $V_{DD} = 4.5 \text{ V}$ All Outputs except \overline{HALT} , \overline{RESET}	V_{OH}	$V_{DD} - 0.8$	—	V
Output Low Voltage (see Note 1) $I_{OL} = 1.6 \text{ mA}$ \overline{CLKOUT} , $\overline{FREEZE/QUOT}$, \overline{IPIPE} , Group 1 I/O Pins $I_{OL} = 5.3 \text{ mA}$ \overline{CSBOOT} , $\overline{BG/CS}$ and Group 2 I/O Pins $I_{OL} = 15.3 \text{ mA}$ \overline{HALT} , \overline{RESET}	V_{OL}	— — —	0.4 0.4 0.4	V
RAM Standby Voltage	V_{SB}	3.0	V_{DD}	V
RAM Standby Current	I_{SB}	—	50	μA
Total Supply Current RUN (See Note 3) STOP (VCO Off)	I_{DD} S_{IDD}	— —	125 500	mA μA
Power Dissipation	P_D	—	690	mW
Input Capacitance (See Notes 1 and 4) All Input-Only Pins All I/O Pins	C_{in}	— —	10 20	pF
Load Capacitance (See Note 1) \overline{CLKOUT} , $\overline{FREEZE/QUOT}$, \overline{IPIPE} and Group 1 I/O Pins \overline{CSBOOT} , $\overline{BG/CS}$ and Group 2 I/O Pins \overline{HALT} , \overline{RESET}	C_L	— — —	90 100 130	pF

NOTES:

- Input-Only Pins: $\overline{TSTME/TSC}$, \overline{BKPT} , $T2CLK$, RXD
Output-Only Pins: \overline{CSBOOT} , $\overline{BG/CS}$, \overline{CLKOUT} , $\overline{FREEZE/QUOT}$, \overline{IPIPE}
Input/Output Pins:
Group 1: $D15-D0$, \overline{IFETCH} , Port A (TP15-TP8), Port B (TP7-TP0)
Group 2: Port C ($A23-A19/CS$, $FC2-FC0/\overline{CS}$), Port D (\overline{MISO} , $\overline{MOSI/SDA}$, \overline{SCK} , $\overline{PCS0/SS}$, $\overline{PCS3-PCS1/TXD}$), Port E ($\overline{DSACK0}$, $\overline{DSACK1}$, \overline{AVEC} , \overline{RMC} , \overline{DS} , \overline{AS} , $\overline{SIZ0}$, $\overline{SIZ1}$), Port F (\overline{MODCK} , $\overline{IRQ7-IRQ1}$), $A18-A0$, $\overline{R/W}$, \overline{BERR} , $\overline{BR/CS}$, $\overline{BGACK/CS}$
Group 3: \overline{HALT} , \overline{RESET}
- V_{OH} specification for \overline{HALT} and \overline{RESET} is not applicable because they are open-drain pins. V_{OH} specification is not applicable to Port D (\overline{MISO} , $\overline{MOSI/SDA}$, \overline{SCK} , $\overline{PCS0/SS}$, $\overline{PCS3-PCS1}$, \overline{TXD}) in wire-OR mode.
- Supply current measured with system clock frequency of 16.78 MHz.
- Input capacitance is periodically sampled rather than 100% tested.

8.6 AC Timing Specifications ($V_{DD} = 5.0 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H , see Note 1)

Num	Characteristic	Symbol	Min	Max	Unit
F ₁ ¹¹	Frequency of Operation (32.768 kHz crystal)	f	0.13	16.78	MHz
1	Clock Period	t _{cyc}	59.6	—	ns
1A	E Clock Period	t _{Ecyc}	476	—	ns
2, 3	Clock Pulse Width	t _{cw}	28	—	ns
2A, 3A	E Clock Pulse Width	t _{ECW}	236	—	ns
4, 5	Clock Rise and Fall Time	t _{crf}	—	5	ns
4A, 5A	Rise and Fall Time — All Outputs except CLKOUT	t _{rf}	—	8	ns
6	Clock High to Address, FC, SIZE, $\overline{\text{RMC}}$ Valid	t _{CHAV}	0	30	ns
7	Clock High to Address, Data, FC, SIZE, $\overline{\text{RMC}}$ High-Impedance	t _{CHAZx}	0	60	ns
8	Clock High to Address, FC, SIZE, $\overline{\text{RMC}}$ Invalid	t _{CHAZn}	0	—	ns
9	Clock Low to $\overline{\text{AS}}$, $\overline{\text{DS}}$, $\overline{\text{CS}}$, $\overline{\text{IFETCH}}$ Asserted	t _{CLSA}	3	30	ns
9A ²	$\overline{\text{AS}}$ to $\overline{\text{DS}}$ or $\overline{\text{CS}}$ Asserted (Read)	t _{STSA}	-15	15	ns
11	Address, FC, SIZE, $\overline{\text{RMC}}$ Valid to $\overline{\text{AS}}$, $\overline{\text{CS}}$ (and $\overline{\text{DS}}$ Read) Asserted	t _{AVSA}	15	—	ns
12	Clock Low to $\overline{\text{AS}}$, $\overline{\text{DS}}$, $\overline{\text{CS}}$, $\overline{\text{IFETCH}}$ Negated	t _{CLSN}	3	30	ns
13	$\overline{\text{AS}}$, $\overline{\text{DS}}$, $\overline{\text{CS}}$ Negated to Address, FC, SIZE Invalid (Address Hold)	t _{SNAI}	15	—	ns
14	$\overline{\text{AS}}$, $\overline{\text{CS}}$ (and $\overline{\text{DS}}$ Read) Width Asserted	t _{SWA}	100	—	ns
14A	$\overline{\text{DS}}$, $\overline{\text{CS}}$ Width Asserted Write	t _{SWAW}	45	—	ns
14B	$\overline{\text{AS}}$, $\overline{\text{CS}}$ (and $\overline{\text{DS}}$ Read) Width Asserted (Synchronous Cycle)	t _{SWDW}	40	—	ns
15 ³	$\overline{\text{AS}}$, $\overline{\text{DS}}$, $\overline{\text{CS}}$ Width Negated	t _{SN}	40	—	ns
16	Clock High to $\overline{\text{AS}}$, $\overline{\text{DS}}$, R/W High-Impedance	t _{CHSZ}	—	60	ns
17	$\overline{\text{AS}}$, $\overline{\text{DS}}$, $\overline{\text{CS}}$ Negated to R/W High	t _{SNRN}	15	—	ns
18	Clock High to R/W High	t _{CHRH}	0	30	ns
20	Clock High to R/W Low	t _{CHRL}	0	30	ns
21	R/W High to $\overline{\text{AS}}$ Asserted	t _{RAAA}	15	—	ns
22	R/W Low to $\overline{\text{DS}}$ Asserted (Write)	t _{RASA}	70	—	ns
23	Clock High to Data Out Valid	t _{CHDO}	—	30	ns
24	Data Out Valid to Negating Edge of $\overline{\text{AS}}$ (Synchronous Write)	t _{DVASN}	15	—	ns
25	$\overline{\text{DS}}$, $\overline{\text{CS}}$ Negated to Data Out Invalid (Data Out Hold)	t _{SNDOI}	15	—	ns
26	Data Out Valid to $\overline{\text{DS}}$ Asserted (Write)	t _{DVSA}	15	—	ns
27 ⁹	Data In Valid to Clock Low (Data Setup)	t _{DICL}	5	—	ns
27A	Late $\overline{\text{BERR}}$, $\overline{\text{HALT}}$, $\overline{\text{BKPT}}$ Asserted to Clock Low (Setup Time)	t _{BELCL}	20	—	ns
28	$\overline{\text{AS}}$, $\overline{\text{DS}}$ Negated to $\overline{\text{DSACKx}}$, $\overline{\text{BERR}}$, $\overline{\text{HALT}}$, $\overline{\text{AVEC}}$ Negated	t _{SNDN}	0	80	ns
29 ⁴	$\overline{\text{DS}}$ Negated to Data In Invalid (Data In Hold)	t _{SNDI}	0	—	ns
29A ⁴	$\overline{\text{DS}}$ Negated to Data In High-Impedance	t _{SHDI}	—	60	ns
30 ⁴	CLKOUT Low to Data In Invalid (Synchronous Hold)	t _{CLDI}	15	—	ns
30A ⁴	CLKOUT Low to Data In High-Impedance	t _{CLDH}	—	90	ns

8.6 AC Timing Specifications (continued)

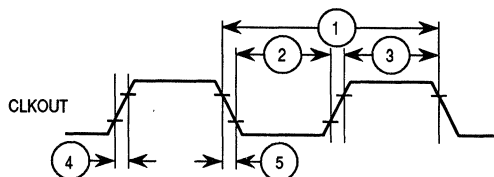
Num	Characteristic	Symbol	Min	Max	Unit
31 ⁵	DSACKx Asserted to Data In Valid	t _{DADI}	—	50	ns
32	HALT and RESET Input Transition Time	t _{HRRf}	—	200	ns
33	Clock Low to BG Asserted	t _{CLBA}	—	30	ns
34	Clock Low to BG Negated	t _{CLBN}	—	30	ns
35 ⁶	BR Asserted to BG Asserted (RMC Not Asserted)	t _{BRAGA}	1	—	Clks
37	BGACK Asserted to BG Negated	t _{GAGN}	1	2	Clks
39	BG Width Negated	t _{GH}	2	—	Clks
39A	BG Width Asserted	t _{GA}	1	—	Clks
46	R/W Width Asserted (Write or Read)	t _{RWA}	150	—	ns
46A	R/W Width Asserted (Synchronous Write or Read)	t _{RWAS}	90	—	ns
47A ⁹	Asynchronous Input Setup Time BR, BG, DSACKx, BERR, AVEC, HALT	t _{AIST}	5	—	ns
47B	Asynchronous Input Hold Time	t _{AIHT}	15	—	ns
48 ⁷	DSACKx Asserted to BERR, HALT Asserted	t _{DABA}	—	30	ns
53	Data Out Hold from Clock High	t _{DOCH}	0	—	ns
54	Clock High to Data Out High-Impedance	t _{CHDH}	—	28	ns
55	R/W Asserted to Data Bus Impedance Change	t _{RADC}	40	—	ns
56	RESET Pulse Width (Reset Instruction)	t _{HRPW}	512	—	Clks
57	BERR Negated to HALT Negated (Rerun)	t _{BNHN}	0	—	ns
70	Clock Low to Data Bus Driven (Show)	t _{SCLDD}	0	30	ns
71	Data Setup Time to Clock Low (Show)	t _{SCLDS}	15	—	ns
72	Data Hold from Clock Low (Show)	t _{SCLDH}	10	—	ns
80	Address, R/W Valid to E Rise	t _{EAV}	75	—	ns
81	Address, R/W Hold Time	t _{EAH}	30	—	ns
82 ⁸	Address Access Time	t _{EACCA}	289	—	ns
83 ⁸	MPU Access Time	t _{EACCE}	206	—	ns
84	Read Data Setup Time	t _{EDSR}	30	—	ns
85	Read Data Hold Time	t _{EDHR}	5	—	ns
85A	E Low to Data In High-Impedance	t _{ELDI}	—	60	ns
86	E Fall to Write Data Driven	t _{EFWDD}	0	60	ns
87	Write Data Delay Time	t _{EDDW}	—	0	ns
88	Write Data Hold Time	t _{EDHW}	30	—	ns
89	Address, R/W Valid to AS, CS Fall	t _{EASL}	15	—	ns
90	Delay Time, AS to E Rise	t _{EASED}	150	—	ns
91	Delay Time, E Low to AS Negated	t _{ELASN}	0	—	ns
91A	Delay Time, E Low to CS Negated	t _{ELCSN}	20	—	ns
92	Pulse Width AS Negated (E Cycle)	t _{EPWASH}	30	—	ns
S1	Slave Mode AS, DS Valid to Clock High	t _{SASCH}	10	—	ns

8.6 AC Timing Specifications (concluded)

Num	Characteristic	Symbol	Min	Max	Unit
S2	Slave Mode Address, $\overline{R/\overline{W}}$, FC, SIZ Valid to Clock Low	t_{SAVCL}	15	—	ns
S3	Slave Mode Address, $\overline{R/\overline{W}}$, FC, SIZ Hold Time from Clock Low	t_{SAHCL}	15	—	ns
S4	Slave Mode Clock High to \overline{DSACK} Asserted	t_{SDSKA}	—	30	ns
S5	Slave Mode \overline{DSACK} Hold Time from Clock Low	t_{SDSCKH}	0	30	ns
S6	Slave Mode Clock Low to Read Data Valid	t_{SCLDV}	—	30	ns
S7	Slave Mode Read Data Hold Time from Clock Low	t_{SSRDH}	0	30	ns
S8	Slave Mode Write Data Input Setup Time to Clock Low	t_{SDSCL}	20	—	ns
S9	Slave Mode Write Data Hold Time from Clock Low	t_{SDHCL}	20	—	ns
S10	Slave Mode \overline{DSACK} Asserted to \overline{AS} , \overline{DS} Negated	t_{SDLAH}	0	—	ns

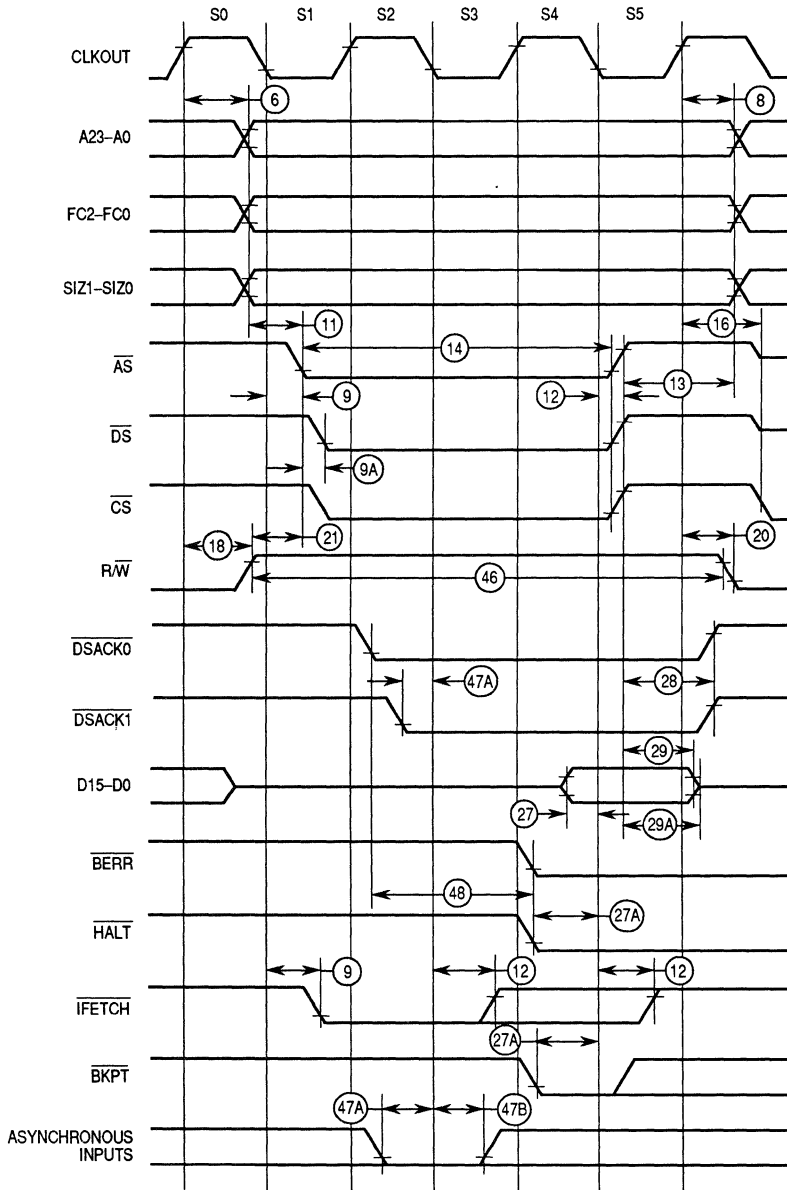
NOTES:

- All AC timing is shown with respect to 20% V_{DD} and 70% V_{DD} levels unless otherwise noted.
- This number can be reduced to 5 ns if strobes have equal loads.
- If multiple chip-selects are used, the \overline{CS} width negated (#15) applies to the time from the negation of a heavily loaded chip-select to the assertion of a lightly loaded chip-select. The \overline{CS} width negated specification between multiple chip-selects does not apply to chip-selects being used for synchronous E cycles.
- These hold times are specified with respect to \overline{DS} on asynchronous reads and with respect to CLKOUT on synchronous reads. The user is free to use either hold time.
- If the asynchronous setup time (#47A) requirements are satisfied, the \overline{DSACKx} low to data setup time (#31) and \overline{DSACKx} low to \overline{BERR} low setup time (#48) can be ignored. The data must only satisfy the data-in to clock low setup time (#27) for the following clock cycle; \overline{BERR} must satisfy only the late \overline{BERR} low to clock low setup time (#27A) for the following clock cycle.
- To ensure coherency during every operand transfer, \overline{BG} will not be asserted in response to \overline{BR} until after all cycles of the current operand transfer are complete and \overline{RMC} is negated.
- In the absence of \overline{DSACKx} , \overline{BERR} is an asynchronous input using the asynchronous setup time (#47A).
- Synchronous E cycle address access time = $t_{EAV} + t_{rt} + t_{ECW} - t_{EDSR} = 289$ ns (16.78 MHz clock). Synchronous E Cycle MPU access time = $t_{ECW} - t_{EDSR} = 206$ ns (16.78 MHz clock).
- Initial masks of MC68331 devices require increased input setup times. Motorola will be testing the input data setup time (t_{D1CL}) and the asynchronous input setup time (t_{A1ST}) at 15 ns maximum until circuit improvements are completed. The interim data setup time value will decrease each access time defined in Note 10 by 10 ns.
- Address access time = $2t_{cyc} + t_{CW} - t_{CHAV} - t_{D1CL} = 112.2$ ns (16.78 MHz clock).
Chip-Select access time = $2t_{cyc} - t_{CLSA} - t_{D1CL} = 84.2$ ns (16.78 MHz clock).
Synchronous Address Access Time = $t_{cyc} + t_{CW} - t_{CHAV} - t_{D1CL} = 52.6$ ns (16.78 MHz clock).
Synchronous Chip-Select Access Time = $t_{cyc} - t_{CLSA} - t_{D1CL} = 24.6$ ns (16.78 MHz clock).
- As shown in 8.4 the crystal frequency can be between 25–50 kHz, and the minimum frequency is four times the crystal frequency. The maximum frequency is still as noted.



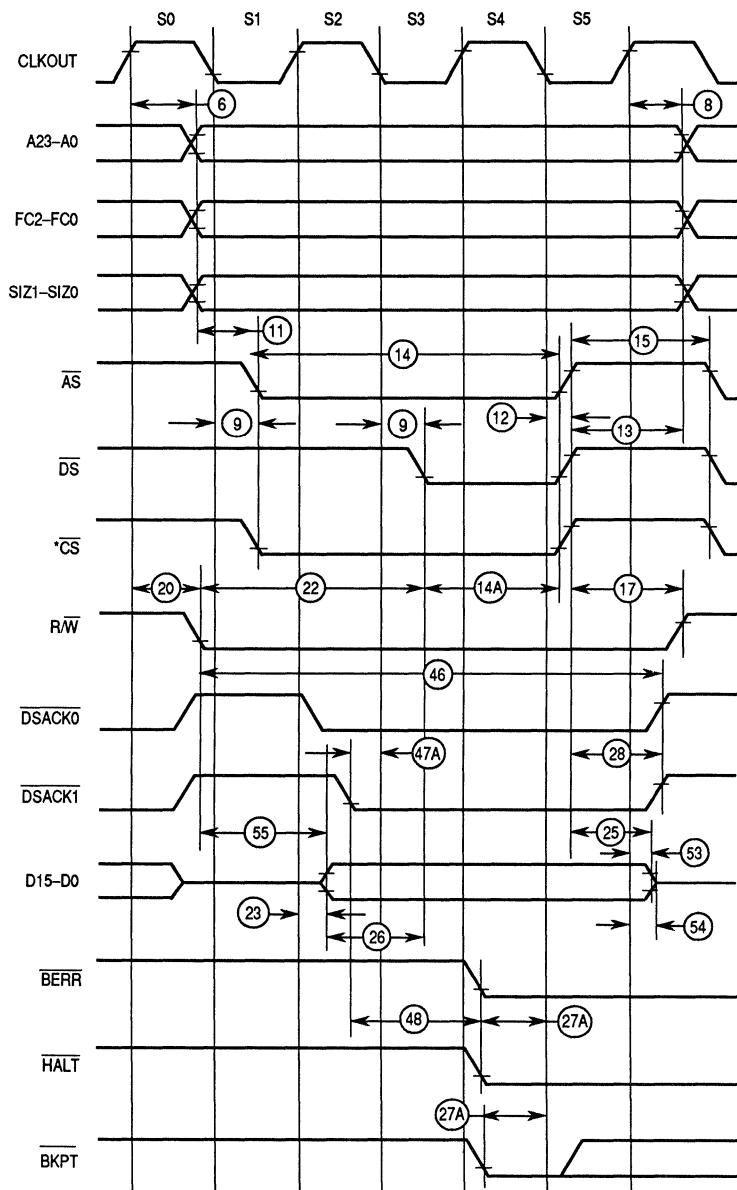
NOTE: All timing shown with respect to 20% and 70% V_{DD}

Figure 8-1. Clock Output Timing



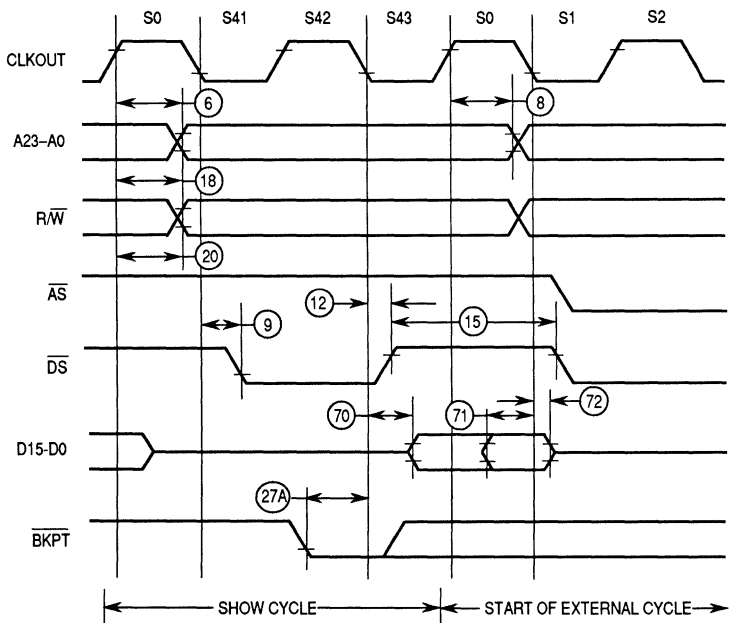
NOTE: All timing is shown with respect to 20% and 70% V_{DD}

Figure 8-2. Read Cycle Timing Diagram



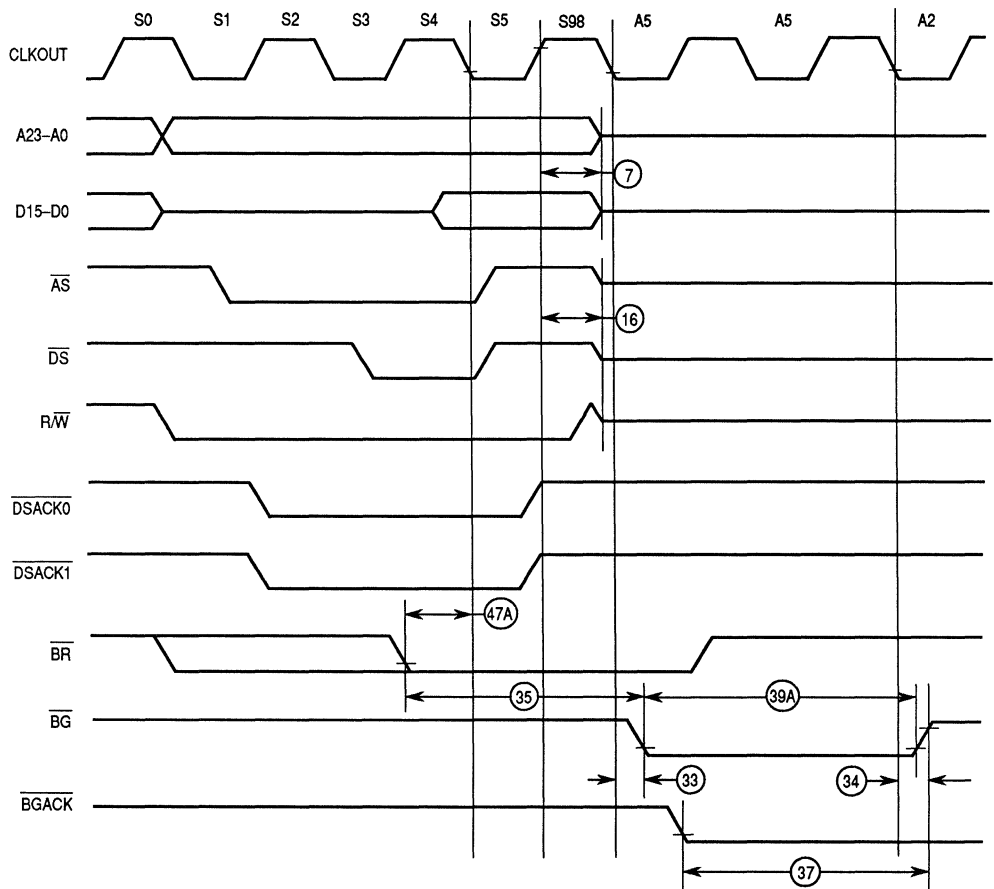
NOTE: All timing with respect to 20% and 70% V_{DD}
 *Timing dependent on programmed options (i.e., timed with respect to \overline{DS} or \overline{AS} assertion)

Figure 8-3. Write Cycle Timing Diagram



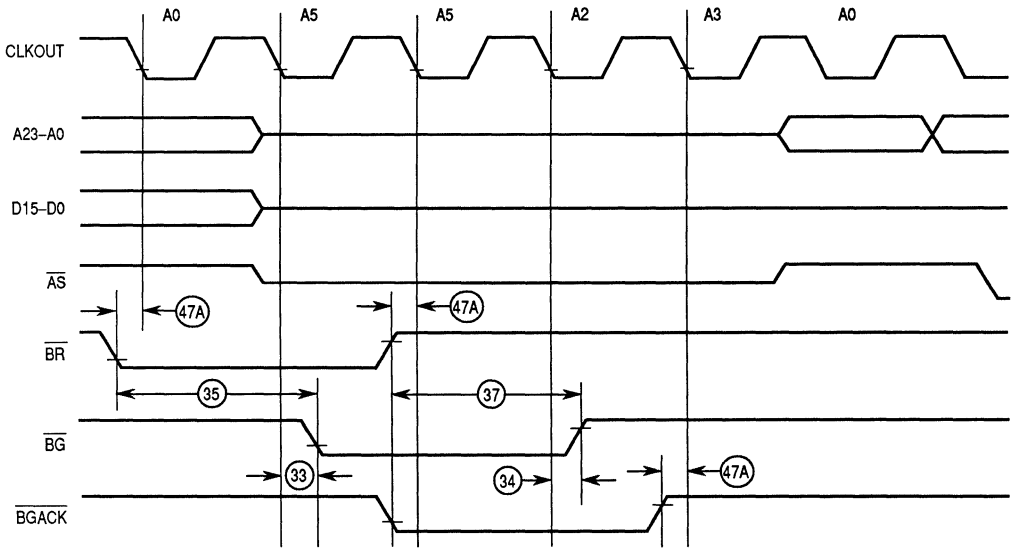
NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-4. Show Cycle Timing Diagram



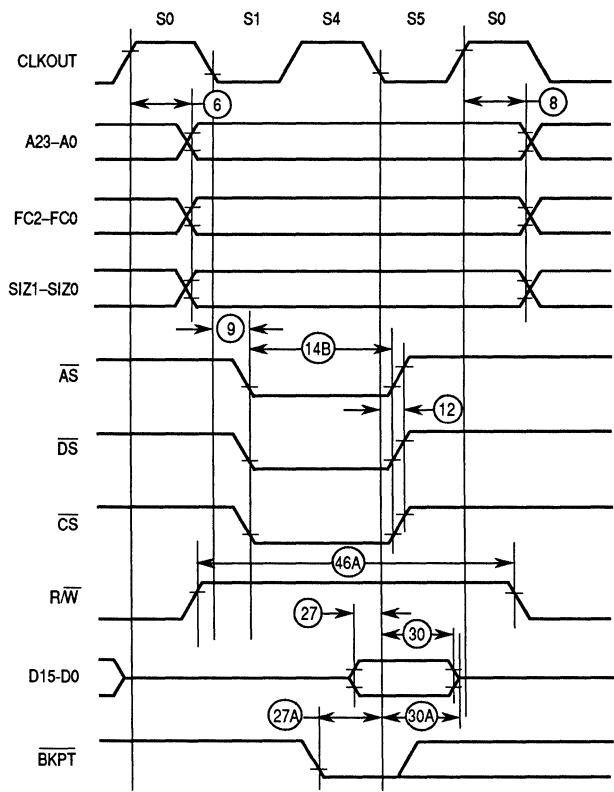
NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-5. Bus Arbitration Timing Diagram — Active Bus Case



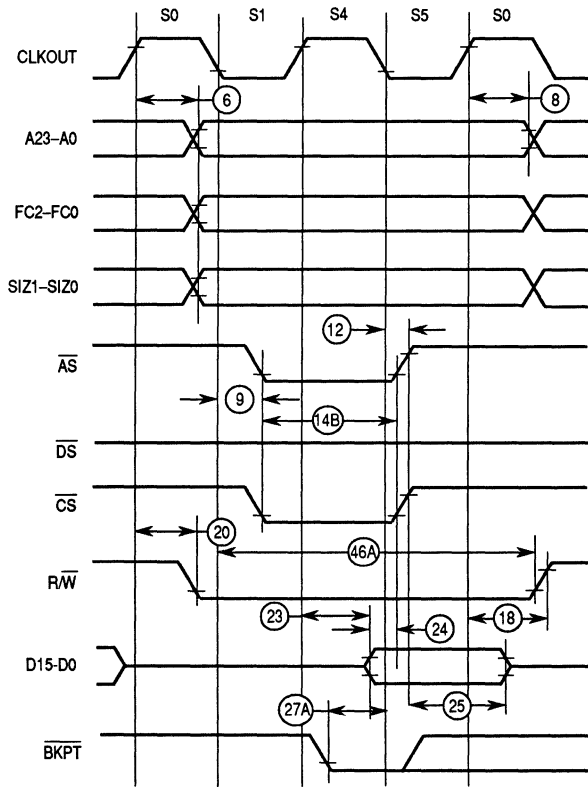
NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-6. Bus Arbitration Timing Diagram — Idle Bus Case



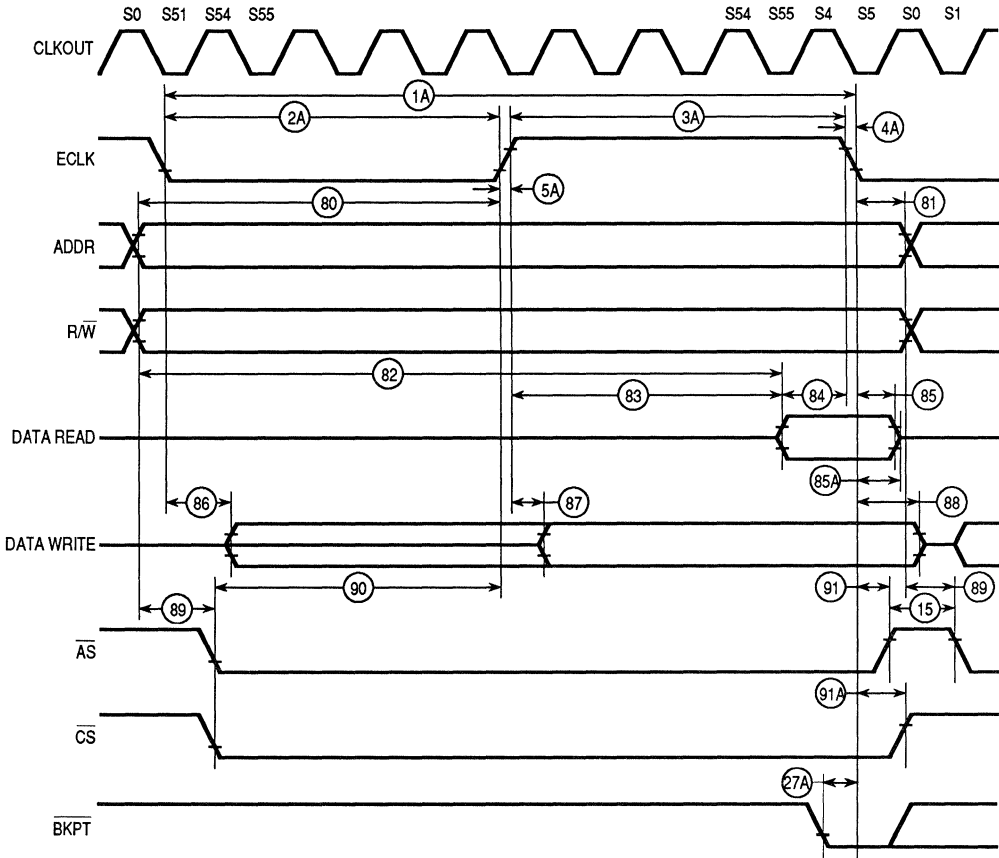
NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-7. Synchronous Read Cycle Timing Diagram



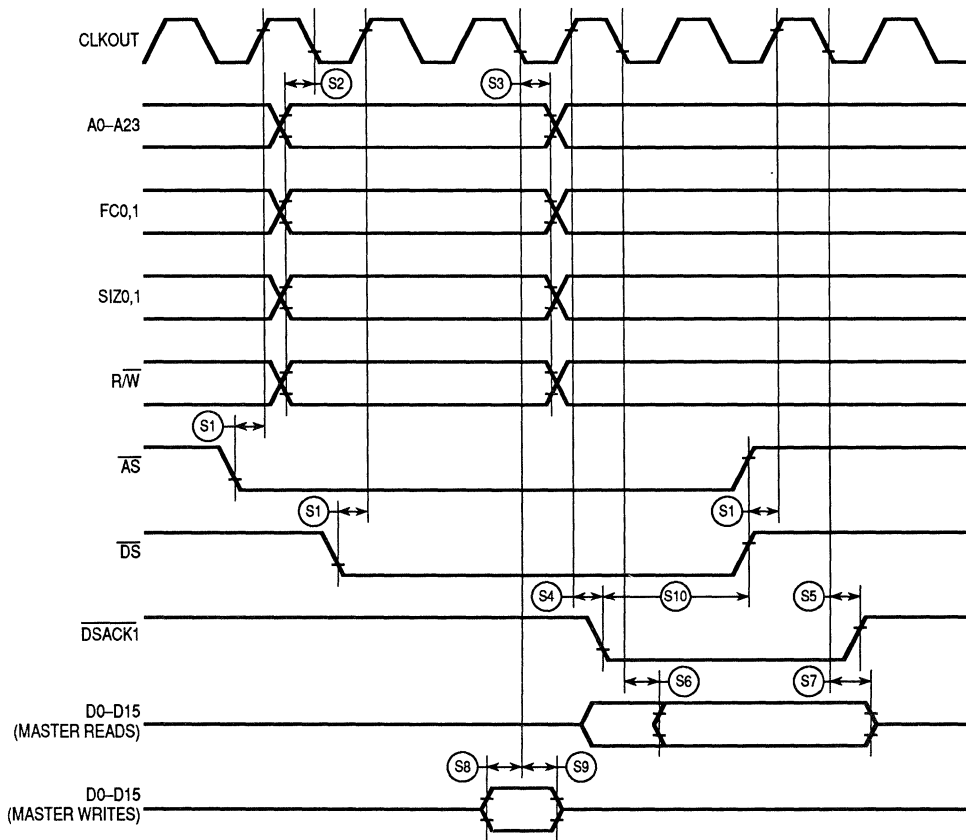
NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-8. Synchronous Write Cycle Timing Diagram



NOTE: All timing is shown with respect to 20% and 70% V_{DD} .

Figure 8-9. Synchronous E Cycle Timing Diagram



NOTE: All timing with respect to 20% and 70% V_{DD}

Figure 8-10. Slave Mode Read and Write Timing Diagram

SECTION 9 ORDERING INFORMATION and MECHANICAL DATA

This section contains detailed information to be used as a guide when ordering.

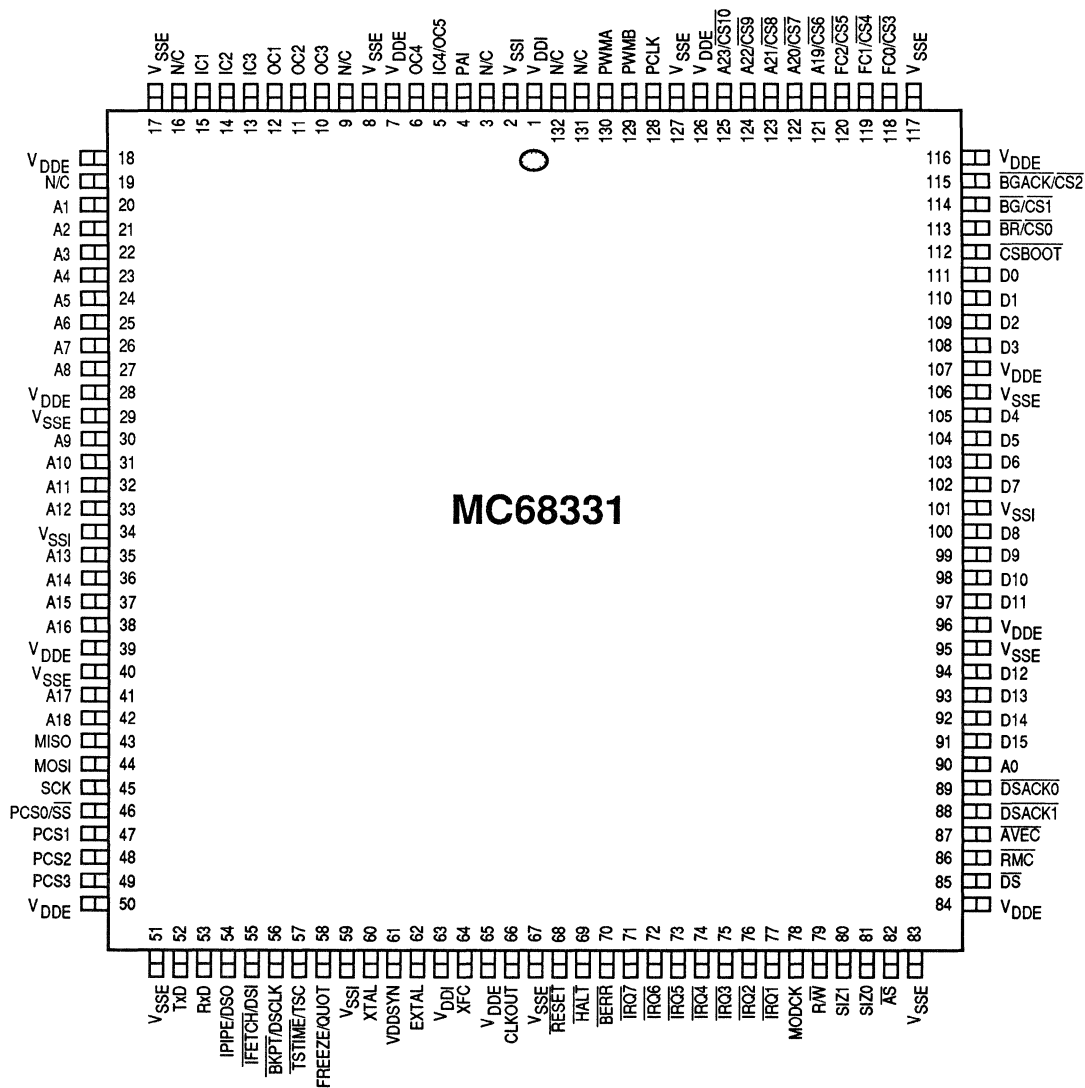
The XC68331FE is a conditionally qualified part and is currently available. The MC68331FC is the fully qualified part and should be available in the first quarter of 1992. The FD suffix part is designed for automatic assembly systems. Please check with your local Motorola representative or distributor for current availability of these parts.

9.1 Standard MC68331 Ordering Information

Package Type	Frequency (MHz)	Temperature	Order Number
Ceramic Surface Mount FE Suffix	16.78	-40°C to +85°C	XC68331FE (now) MC68331FE (1Q92) SPAKXC68331FE* SPAKMC68331FE* (1Q92)
		-40°C to +105°C	MC68331VFE (1Q92)
		-40°C to +125°C	MC68331MFE (1Q92)
Plastic Surface Mount FC Suffix	16.78	-40°C to +85°C	XC68331FC (3Q91) MC68331FC (1Q92) SPAKXC68331FC* (3Q91) SPAKMC68331FC* (1Q92)
		-40°C to +105°C	MC68331VFC (1Q92)
		-40°C to +125°C	MC68331MFC (1Q92)
Molded Carrier Ring FD Suffix	16.78	-40°C to +85°C	XC68331FD (3Q91)
		-40°C to +105°C	MC68331VFD (1Q92)
		-40°C to +125°C	MC68331MFD (1Q92)

*These are sample packs which must be ordered in multiples of two parts and are shipped in special cases.

9.2 FC, FD and FE Suffix — Pin Assignment

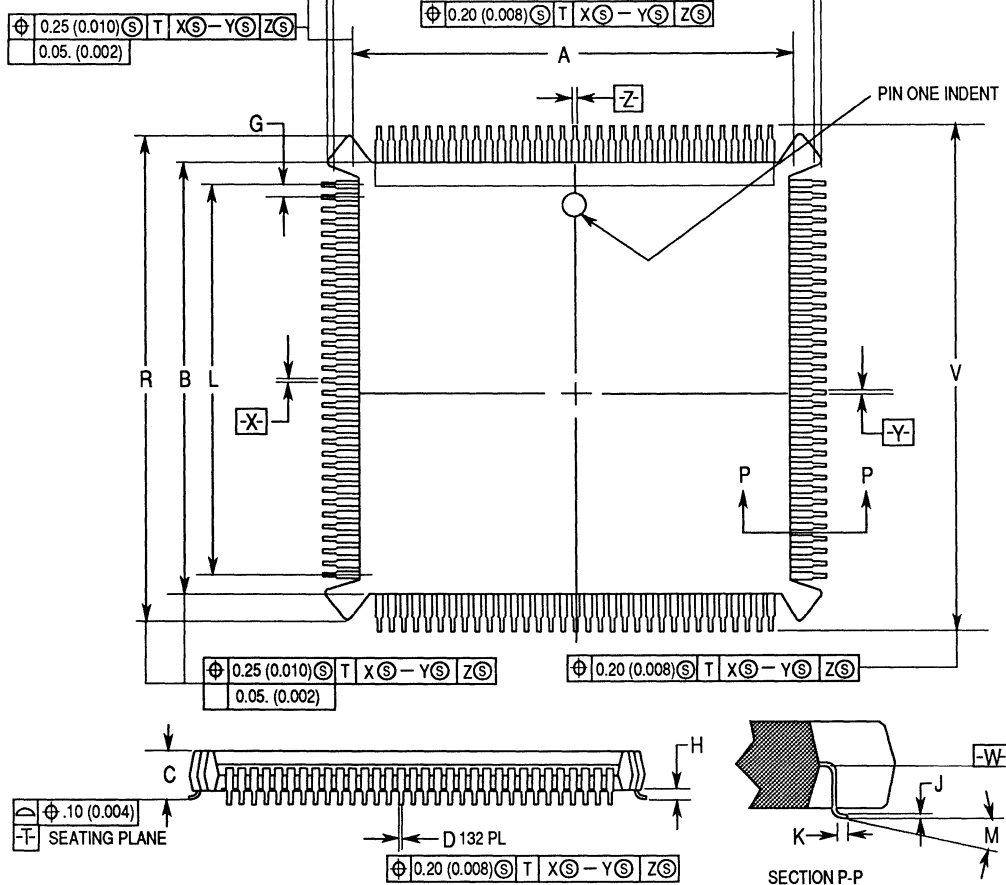


9.3 FC Suffix — Package Dimensions

FC SUFFIX

PLASTIC SURFACE MOUNT

CASE 831A-01



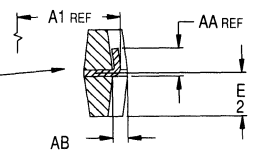
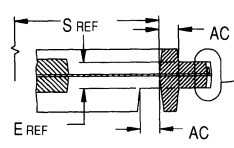
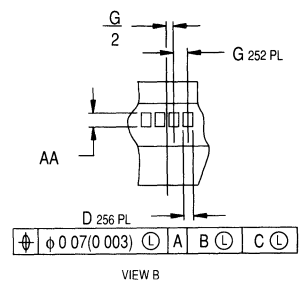
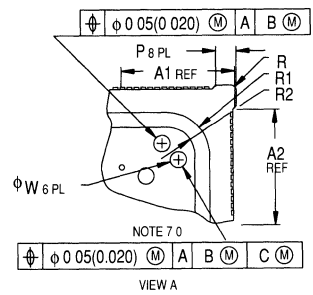
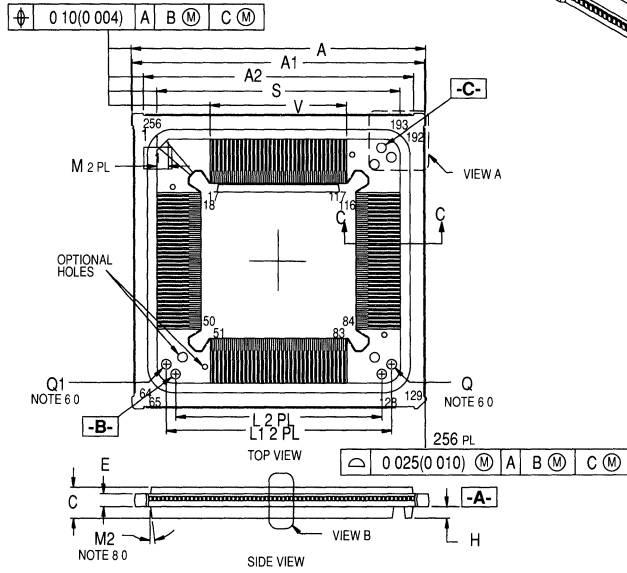
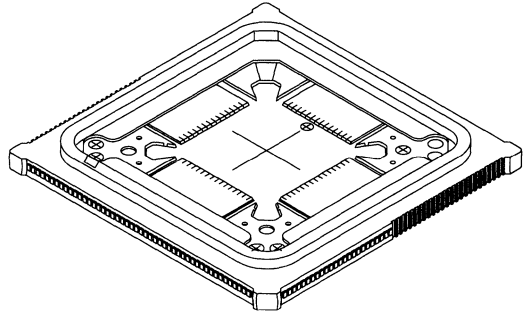
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	24.06	24.20	0.947	0.953
B	24.06	24.20	0.947	0.953
C	4.07	4.57	0.160	0.180
D	0.21	0.30	0.008	0.012
G	0.64 BSC		0.025 BSC	
H	0.51	1.01	0.020	0.040
J	0.16	0.20	0.006	0.008
K	0.51	0.76	0.020	0.030
M	0°	8°	0°	8°
N	27.88	28.01	1.097	1.103
R	27.88	28.01	1.097	1.103
S	27.31	27.55	1.075	1.085
V	27.31	27.55	1.075	1.085

NOTES:

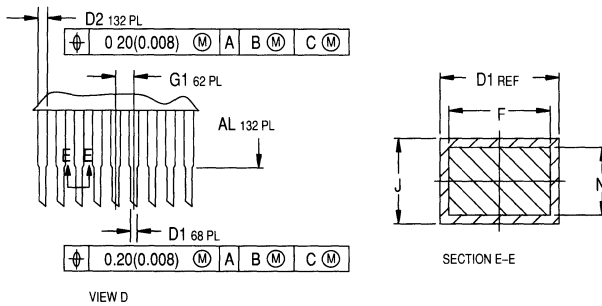
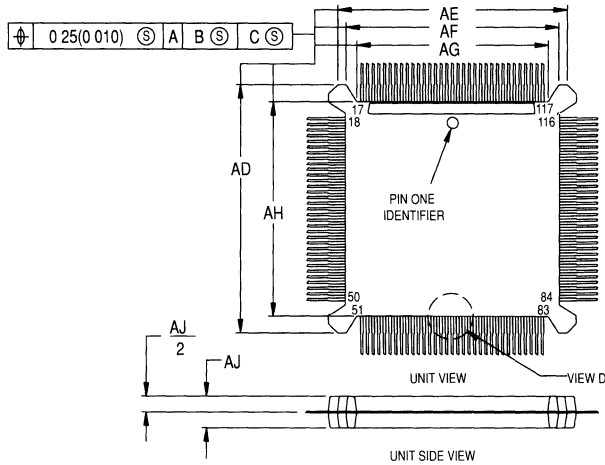
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCHES
3. DIM A, B, N, AND R DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE MOLD PROTRUSION FOR DIMENSIONS A AND B IS 0.25 (0.010), FOR DIMENSIONS N AND R IS 0.18 (0.007).
4. DATUM PLANE -W- IS LOCATED AT THE UNDERSIDE OF LEADS WHERE LEADS EXIT PACKAGE BODY.
5. DATUMS X-Y AND Z TO BE DETERMINED WHERE CENTER LEADS EXIT PACKAGE BODY AT DATUM -W-.
6. DIM S AND V TO BE DETERMINED AT SEATING PLANE, DATUM -T-.
7. DIM A, B, N AND R TO BE DETERMINED AT DATUM PLANE -W-.

9.4 FD Suffix — Package Dimensions

FD SUFFIX
MOLDED CARRIER RING
CASE 878-01



9



SECTION C-C

NOTES

- 1 ALL DIMENSIONS AND TOLERANCES CONFORM TO ANSI Y14 5M-1982
- 2 CONTROLLING DIMENSION MILLIMETER
- 3 A, AD, AE, AF AND AH DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION ALLOWABLE MOLD PROTRUSION IS 0.20(0.008) PER SIDE FOR AE DIMENSION IS 0.18(0.007)
- 4 A, S1 AND AH DIMENSIONS INCLUDE MOLD MISMATCH, AND ARE MEASURED AT THE PARTING LINE
- 5 UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE SYMMETRICAL ABOUT CENTERLINES
- 6 B AND C DATUM HOLES ARE TO BE USED FOR TRIM, FORM AND EXCISE OF THE MOLDED PACKAGE ONLY HOLES Q1 AND Q2 ARE TO BE USED FOR ELECTRICAL TESTING ONLY
- 7 NON-DATUM HOLES ONLY
- 8 APPLIES TO RING AND PACKAGE FEATURES

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	45.87	46.13	1.806	1.816
A1	45.70 BSC 1.799 BSC			
A2	41.37	41.63	1.629	1.639
C	4.70	4.90	0.185	0.193
D	0.40	0.50	0.016	0.020
D1	0.21	0.30	0.008	0.012
D2	0.31	0.40	0.012	0.016
E	1.90	2.10	0.075	0.083
F	0.19	0.27	0.007	0.011
G	0.65 BSC 0.026 BSC			
G1	0.635 BSC		0.025 BSC	
H	1.70	1.90	0.067	0.075
J	0.16	0.20	0.006	0.008
L	32.20 BSC		1.268 BSC	
L1	35.20 BSC		1.386 BSC	
M	1.30	2.30	0.051	0.091
M2	6°	8°	6°	8°
N	0.145	0.16	0.0057	0.0063
P	1.77	2.03	0.070	0.080

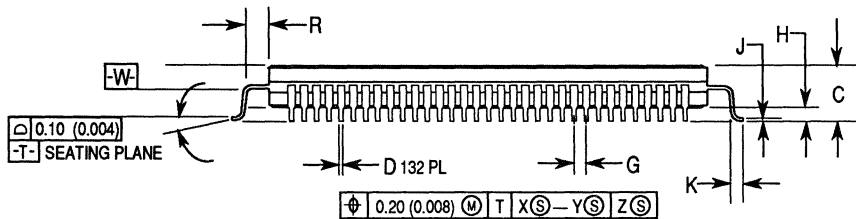
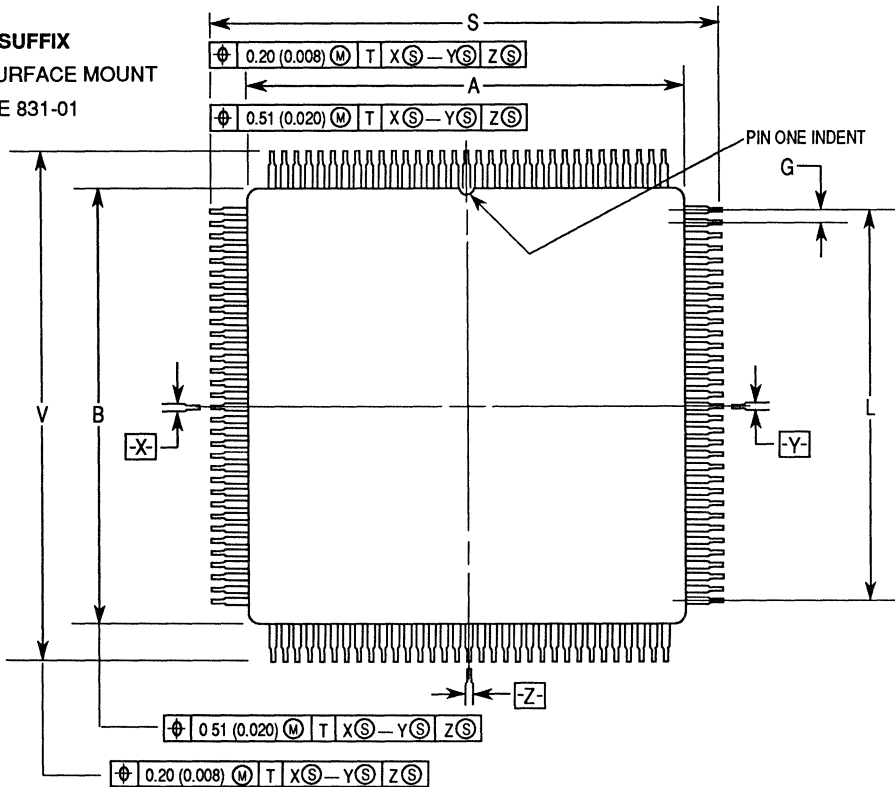
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
R	0.40	0.60	0.016	0.024
R1	3.50	4.50	0.138	0.177
R2	2.00	3.00	0.079	0.118
S	37.87	38.13	1.491	1.501
W	21.21	21.31	0.835	0.839
W	1.45	1.55	0.057	0.061
AA	0.45	0.85	0.018	0.033
AB	0.30	0.60	0.012	0.024
AC	1.37	1.63	0.054	0.064
AD	27.88	28.01	1.098	1.103
AE	25.79	25.93	1.015	1.021
AF	23.91	24.05	0.941	0.947
AG	21.52		0.847	0.853
AH	24.06	24.20	0.947	0.953
AJ	3.46	3.66	0.136	0.144
AL	14.00	14.10	0.551	0.555

ISSUE 0

DATE 01/07/91

9.5 FE Suffix — Package Dimensions

FE SUFFIX
CERAMIC SURFACE MOUNT
CASE 831-01



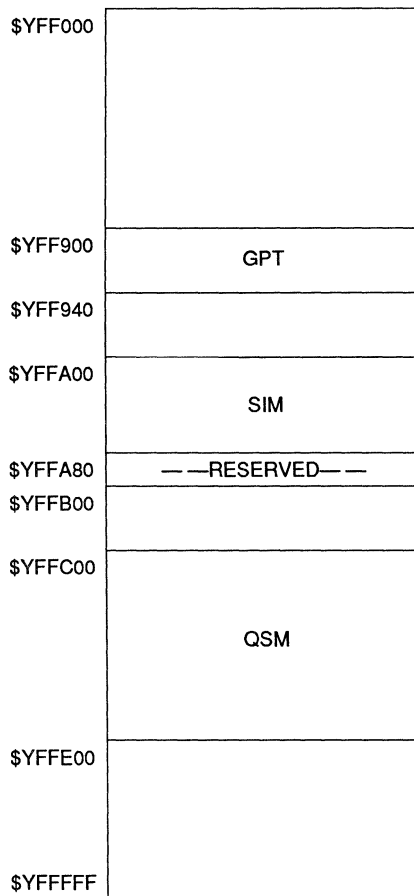
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	21.85	22.86	0.860	0.900
B	21.85	22.86	0.860	0.900
C	3.94	4.31	0.155	0.170
D	0.204	0.292	0.0080	0.0115
G	0.64 BSC		0.025 BSC	
H	0.64	0.88	0.025	0.035
J	0.13	0.20	0.005	0.008
K	0.51	0.76	0.020	0.030
L	20.32 REF		0.800 REF	
M	0°	8°	0°	8°
R	0.64	—	0.025	—
S	27.31	27.55	1.075	1.085
V	27.31	27.55	1.075	1.085

NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH
3. DIM A AND B DEFINE MAXIMUM CERAMIC BODY DIMENSIONS INCLUDING GLASS PROTRUSION AND MISMATCH OF CERAMIC BODY TOP AND BOTTOM.
4. DATUM PLANE -W- IS LOCATED AT THE UNDERSIDE OF LEADS WHERE LEADS EXIT PACKAGE BODY.
5. DATUMS X-Y AND Z TO BE DETERMINED WHERE CENTER LEADS EXIT PACKAGE BODY AT DATUM -W-.
6. DIM S AND V TO BE DETERMINED AT SEATING PLANE, DATUM -T-.
7. DIM A AND B TO BE DETERMINED AT DATUM PLANE -W-.

APPENDIX A MC68331 MEMORY MAP

A.1 MC68331 Module Memory Map



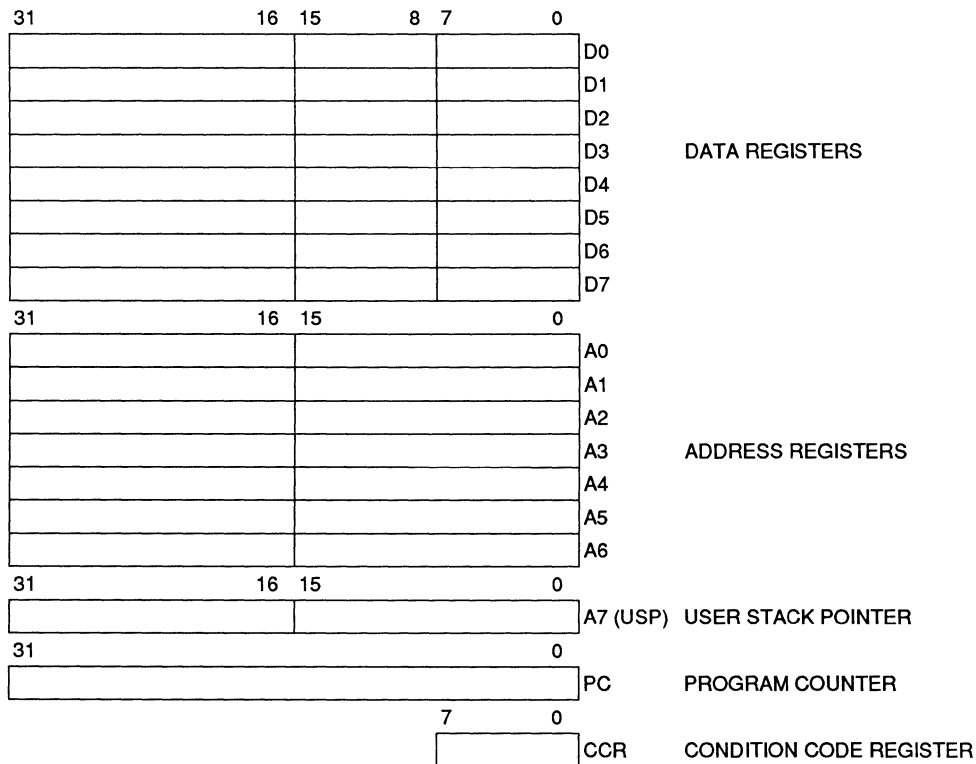
A

Module	Size (Bytes)	Address Bus Decoding						Base Address
		A23	—	—	—	—	A0	
GPT	64	M111	1111	1111	1001	00XX	XXXX	\$YFF900
SIM	128	M111	1111	1111	1010	0XXX	XXXX	\$YFFA00
QSM	512	M111	1111	1111	110X	XXXX	XXXX	\$YFFC00

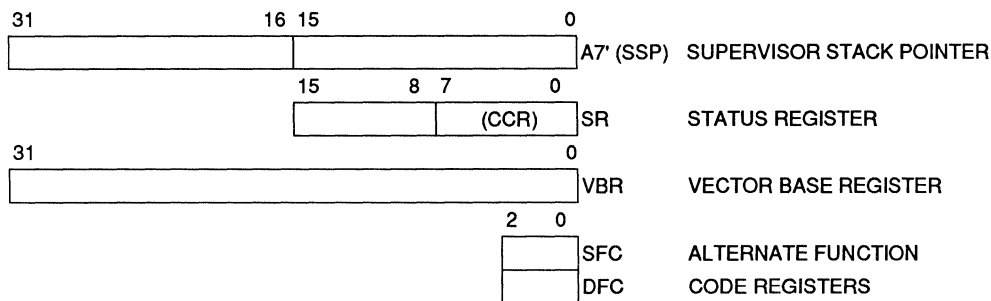
A

APPENDIX B PROGRAMMING MODEL and INSTRUCTION SUMMARY

B.1 User Programming Model



B.2 Supervisor Programming Model Supplement



B.3 Status Register

SR — Status Register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T1	T0	S	0	0	I2	I1	I0	0	0	0	X	N	Z	V	C

RESET:

0 0 1 0 0 1 1 1 0 0 0 U U U U U

System Byte

T1–T0 — Trace Enable

S — Supervisor/User State

Bits 12–11 — Unimplemented

I2–I0 — Interrupt Priority Mask

User Byte (Condition Code Register)

Bits 7–5 — Unimplemented

X — Extend

N — Negative

Z — Zero

V — Overflow

C — Carry

B

B.4 Instruction Set Summary

Mnemonic	Description
ABCD ADD ADDA ADDI ADDQ ADDX AND ANDI ASL, ASR	Add Decimal with Extend Add Add Address Add Immediate Add Quick Add with Extend Logical AND Logical AND Immediate Arithmetic Shift Left and Right
Bcc BCHG BCLR BGND BKPT BRA BSET BSR BTST	Branch Conditionally Test Bit and Change Test Bit and Clear Background Breakpoint Branch Test Bit and Set Branch to Subroutine Test Bit
CHK, CHK2 CLR CMP CMPA CMPI CMPM CMP2	Check Register Against Upper and Lower Bounds Clear Compare Compare Address Compare Immediate Compare Memory to Memory Compare Register Against Upper and Lower Bounds
DBcc DIVS, DIVSL DIVU, DIVUL	Test Condition, Decrement and Branch Signed Divide Unsigned Divide
EOR EORI EXG EXT, EXTB	Logical Exclusive OR Logical Exclusive OR Immediate Exchange Registers Sign Extend
LEA LINK LPSTOP LSL, LSR	Load Effective Address Link and Allocate Low Power Stop Logical Shift Left and Right
ILLEGAL	Take Illegal Instruction Trap
JMP JSR	Jump Jump to Subroutine

Mnemonic	Description
MOVE MOVE CCR MOVE SR MOVE USP MOVEA MOVEC MOVEM MOVEP MOVEQ MOVES	Move Move Condition Code Register Move Status Register Move User Stack Pointer Move Address Move Control Register Move Multiple Registers Move Peripheral Move Quick Move Alternate Address Space
MULS, MULS:L MULU, MULU:L	Signed Multiply Unsigned Multiply
NBCD NEG NEGX NOP	Negate Decimal with Extend Negate Negate with Extend No Operation
OR ORI	Logical Inclusive OR Logical Inclusive OR Immediate
PEA	Push Effective Address
RESET ROL, ROR ROXL, ROXR	Reset External Devices Rotate Left and Right Rotate with Extend Left and Right
RTD RTE RTR RTS	Return and Deallocate Return from Exception Return and Restore Codes Return from Subroutine
SBCD Scc STOP SUB SUBA SUBI SUBQ SUBX SWAP	Subtract Decimal with Extend Set Conditionally Stop Subtract Subtract Address Subtract Immediate Subtract Quick Subtract with Extend Swap Register Words
TBLS, TBLSN TBLU, TBLUN	Table Lookup and Interpolate (Signed) Table Lookup and Interpolate (Unsigned)
TAS TRAP TRAPcc TRAPV TST	Test Operand and Set Trap Trap Conditionally Trap on Overflow Test Operand
UNLK	Unlink

B.5 Background Mode Command Summary

Command	Mnemonic	Description
Read D/A Register	RDREG/RAREG	Read the selected address or data register and return the results via the serial interface.
Write D/A Register	WDREG/WAREG	The data operand is written to the specified address or data register.
Read System Register	RSREG	The specified system control register is read. All registers that can be read in supervisor mode can be read in background mode.
Write System Register	WSREG	The operand data is written into the specified system control register.
Read Memory Location	READ	Read the sized data at the memory location specified by the long-word address. The source function code register (SFC) determines the address space accessed.
Write Memory Location	WRITE	Write the operand data to the memory location specified by the long-word address. The destination function code (DFC) register determines the address space accessed.
Dump Memory Block	DUMP	Used in conjunction with the READ command to dump large blocks of memory. An initial READ is executed to set up the starting address of the block and retrieve the first result. Subsequent operands are retrieved with the DUMP command.
Fill Memory Block	FILL	Used in conjunction with the WRITE command to fill large blocks of memory. An initial WRITE is executed to set up the starting address of the block and supply the first operand. Subsequent operands are written with the FILL command.
Resume Execution	GO	The pipe is flushed and re-filled before resuming instruction execution at the current PC.
Patch User Code	CALL	Current program counter is stacked at the location of the current stack pointer. Instruction execution begins at user patch code.
Reset Peripherals	RST	Asserts RESET for 512 clock cycles. The CPU is not reset by this command. Synonymous with the CPU RESET instruction.
No Operation	NOP	NOP performs no operation and may be used as a null command.

B

APPENDIX C SYSTEM INTEGRATION MODULE (SIM) MEMORY MAP and REGISTERS

C.1 SIM Register Map

SIM Register Map (Sheet 1 of 2)

FC	ADDRESS	15	8	7	0	
101	YFFA00	MODULE CONFIGURATION (MCR)				
101	YFFA02	MODULE TEST (SIMTR)				TEST
101	YFFA04	CLOCK SYNTHESIZER CONTROL (SYNCR)				CLOCK
101	YFFA06	UNUSED	RESET STATUS REGISTER (RSR)			
101	YFFA08	MODULE TEST E (SIMTRE)				EBI
101	YFFA0A	UNUSED	UNUSED			
101	YFFA0C	UNUSED	UNUSED			
101	YFFA0E	UNUSED	UNUSED			
X01	YFFA10	UNUSED	PORTE DATA (PORTE)			EBI
X01	YFFA12	UNUSED	PORTE DATA (PORTE)			
X01	YFFA14	UNUSED	PORTE DATA DIRECTION (DDRE)			
101	YFFA16	UNUSED	PORTE PIN ASSIGNMENT (PEPAR)			
X01	YFFA18	UNUSED	PORTF DATA (PORTF)			EBI
X01	YFFA1A	UNUSED	PORTF DATA (PORTF)			EBI
X01	YFFA1C	UNUSED	PORTF DATA DIRECTION (DDRF)			
101	YFFA1E	UNUSED	PORTF PIN ASSIGNMENT (PFPAR)			EBI
101	YFFA20	UNUSED	SYSTEM PROTECTION CONTROL (SYPCR)			SYS-PROTECT
101	YFFA22	PERIODIC INTERRUPT CONTROL (PICR)				MOD CONF
101	YFFA24	PERIODIC INTERRUPT TIMING (PITR)				MOD CONF
101	YFFA26	UNUSED	SOFTWARE SERVICE (SWSR)			SYS-PROTECT
101	YFFA28	UNUSED	UNUSED			
101	YFFA30	TEST MODULE MASTER SHIFT A (TSTMSRA)				TEST
101	YFFA32	TEST MODULE MASTER SHIFT B (TSTMSRB)				
101	YFFA34	TEST MODULE SHIFT COUNT.A.(TSTSCA)	TEST MODULE SHIFT COUNT.B.(TSTSCB)			
101	YFFA36	TEST MODULE REPETITION COUNTER (TSTRC)				
101	YFFA38	TEST MODULE CONTROL (CREG)				
X01	YFFA3A	TEST MODULE DISTRIBUTED REGISTER (DREG)				TEST
	YFFA3C	UNUSED	UNUSED			
	YFFA3E	UNUSED	UNUSED			
X01	YFFA40	UNUSED	PORT C DATA (CSPDR)			CHIP-SELECT
X01	YFFA42	UNUSED	UNUSED			
101	YFFA44	CHIP-SELECT PIN ASSIGNMENT (CSPARO)				



SIM Register Map (Sheet 2 of 2)

FC	ADDRESS	15	8	7	0	
101	YFFA46	CHIP-SELECT PIN ASSIGNMENT (CSPAR1)				
101	YFFA48	CHIP-SELECT BASE BOOT (CSBARBT)				
101	YFFA4A	CHIP-SELECT OPTION BOOT (CSORBT)				
101	YFFA4C	CHIP-SELECT BASE 0 (CSBAR0)				
101	YFFA4E	CHIP-SELECT OPTION 0 (CSOR0)				
101	YFFA50	CHIP-SELECT BASE 1 (CSBAR1)				
101	YFFA52	CHIP-SELECT OPTION 1 (CSOR1)				
101	YFFA54	CHIP-SELECT BASE 2 (CSBAR2)				
101	YFFA56	CHIP-SELECT OPTION 2 (CSOR2)				
101	YFFA58	CHIP-SELECT BASE 3 (CSBAR3)				
101	YFFA5A	CHIP-SELECT OPTION 3 (CSOR3)				
101	YFFA5C	CHIP-SELECT BASE 4 (CSBAR4)				
101	YFFA5E	CHIP-SELECT OPTION 4 (CSOR4)				
101	YFFA60	CHIP-SELECT BASE 5 (CSBAR5)				
101	YFFA62	CHIP-SELECT OPTION 5 (CSOR5)				
101	YFFA64	CHIP-SELECT BASE 6 (CSBAR6)				
101	YFFA66	CHIP-SELECT OPTION 6 (CSOR6)				
101	YFFA68	CHIP-SELECT BASE 7 (CSBAR7)				
101	YFFA6A	CHIP-SELECT OPTION 7 (CSOR7)				
101	YFFA6C	CHIP-SELECT BASE 8 (CSBAR8)				
101	YFFA6E	CHIP-SELECT OPTION 8 (CSOR8)				
101	YFFA70	CHIP-SELECT BASE 9 (CSBAR9)				
101	YFFA72	CHIP-SELECT OPTION 9 (CSOR9)				
101	YFFA74	CHIP-SELECT BASE 10 (CSBAR10)				
101	YFFA76	CHIP-SELECT OPTION 10 (CSOR10)				CHIP-SELECT
	YFFA78	UNUSED	UNUSED	UNUSED	UNUSED	
	YFFA7A	UNUSED	UNUSED	UNUSED	UNUSED	
	YFFA7C	UNUSED	UNUSED	UNUSED	UNUSED	
	YFFA7E	UNUSED	UNUSED	UNUSED	UNUSED	

X = Depends on state of SUPV bit in SIM MCR

Y = m111, where m is the modmap bit in the SIM MCR (Y = \$7or \$F)

C

C.2 SIM Registers

MCR — Module Control Register

\$YFFA00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXOFF	FRZSW	FRZBM	0	SLVEN	0	SHEN1	SHEN0	SUPV	MM	0	0	IARB3	IARB2	IARB1	IARB0

RESET:

0 1 1 0 DB11 0 0 0 1 1 0 0 1 1 1 1

EXOFF — External Clock Off

1 = The CLKOUT pin is placed in a high-impedance state.

0 = The CLKOUT pin is driven from an internal clock source.

FRZSW — Freeze Software Enable

1 = When FREEZE is asserted, the software watchdog and periodic interrupt timer counters are disabled, preventing interrupts from occurring when software is debugged.

0 = When FREEZE is asserted, the software watchdog and periodic interrupt timer counters continue to run.

FRZBM — Freeze Bus Monitor Enable

1 = When FREEZE is asserted, the bus monitor is disabled.

0 = When FREEZE is asserted, the bus monitor continues to operate as programmed.

SLVEN — Slave Mode Enabled

1 = Any external master winning control of the external bus also gains direct access to the internal peripherals.

0 = The internal peripherals are not available to an external master. This bit is a read-only status bit that reflects the state of DB11 during reset.

SHEN1–0 — Show Cycle Enable

These two control bits determine what the EBI does with the external bus during internal transfer operations.

SHEN1	SHEN0	Action
0	0	Show cycles disabled, external arbitration enabled.
0	1	Show cycles enabled, external arbitration disabled.
1	0	Show cycles enabled, external arbitration enabled.
1	1	Show cycles enabled, external arbitration enabled; internal activity is halted by a bus grant.

C

SUPV — Supervisor/Unrestricted Data Space

1 = Registers with access controlled by the SUPV bit are restricted to supervisor access only when FC2 = 1

0 = Registers with access controlled by the SUPV bit are unrestricted (FC2 is a don't care)

MM — Module Mapping

1 = Internal modules are addressed from \$FFF000–\$FFFFFF, which is in the absolute short addressing range

0 = Internal modules are addressed from \$7FF000–\$7FFFFFF

IARB3–IARB0 — Interrupt Arbitration Bits

The system software must initialize the IARB field to a value from \$F (highest priority) to \$1 (lowest priority).

SIMTR — System Integration Module Test Register

\$YYFA02

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MASK						0	0	SOSEL1	SOSEL0	SHIRQ1	SHIRQ0	FBIT1	FBIT0	BWC1	BWC0

RESET:

* * * * * 0 0 1 1 0 0 0 0 0 0

*At Reset this is the Mask number.

MASK — Revision Number for this Part

SOSEL1–SOSEL0 — Scan-Out Select

SHIRQ1–SHIRQ0 — Show Interrupt Request

FBIT1–FBIT0 — Force Bits

BWC1–BWC0 — Bandwidth Control Bits

SYNCR — Clock Synthesizer Control Register

\$YYFA04

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
W	X	Y5	Y4	Y3	Y2	Y1	Y0	EDIV	0	0	SLIMP	SLOCK	RSTEN	STSIM	STEXT

RESET:

0 0 1 1 1 1 1 1 0 0 0 U U 0 0 0

U = Unaffected by reset

$$FSYSTEM = FCRYSTAL [4(Y + 1)2^{2W + X}]$$

W — Frequency Control Bit

X — Frequency Control Bit

Y5–Y0 — Frequency Control Bits



EDIV — E-Clock Divide Rate

- 1 = E-clock = system clock divided by 16
- 0 = E-clock = system clock divided by 8

SLIMP — Limp Mode

- 1 = A loss of crystal reference has been detected and the VCO is running at approximately half of maximum speed
- 0 = External crystal frequency is VCO reference

SLOCK — Synthesizer Lock

- 1 = VCO has locked on to the desired frequency (or system clock is driven externally)
- 0 = VCO is enabled, but has not yet locked

RSTEN — Reset Enable

- 1 = Loss of crystal causes a system reset
- 0 = Loss of crystal causes the VCO to operate at a nominal speed without external reference (limp mode), and the MCU continues to operate at that speed

STSIM — Stop Mode System Integration Clock

- 1 = When the LPSTOP instruction is executed, the SIM clock is driven from the VCO
- 0 = When the LPSTOP instruction is executed, the SIM clock is driven from the crystal oscillator and the VCO is turned off to conserve power

STEXT — Stop Mode External Clock

- 1 = When the LPSTOP instruction is executed, the external clock pin (CLKOUT) is driven from the SIM clock, as determined by the STSIM bit
- 0 = When the LPSTOP instruction is executed, the external clock is held low to conserve power

Some System Frequencies from 32.768-kHz Reference

Y	W = 0 X = 0	W = 0 X = 1	W = 1 X = 0	W = 1 X = 1
0 = 000000	131	262	524	1049
1 = 000001	262	524	1049	2097
2 = 000010	393	786	1573	3146
3 = 000011	524	1049	2097	4194
4 = 000100	655	1311	2621	5243
5 = 000101	786	1573	3146	6291
6 = 000110	918	1835	3670	7340
7 = 000111	1049	2097	4194	8389
8 = 001000	1180	2359	4719	9437
9 = 001001	1311	2621	5243	10486
10 = 001010	1442	2884	5767	11534
11 = 001011	1573	3146	6291	12583
12 = 001100	1704	3408	6816	13631
13 = 001101	1835	3670	7340	14680
14 = 001110	1966	3932	7864	15729
15 = 001111	2097	4194	8389	16777
16 = 010000	2228	4456	8913	

RSR — Reset Status Register

\$YFFA07

7	6	5	4	3	2	1	0
EXT	POW	SW	HLT	0	LOC	SYS	TST

EXT — External Reset

1 = The last reset was caused by an external signal.

POW — Power-Up Reset

1 = The last reset was caused by the power-up reset circuit.

SW — Software Watchdog Reset

1 = The last reset was caused by the software watchdog circuit.

HLT — Halt Monitor Reset

1 = The last reset was caused by the system protection submodule halt monitor.

LOC — Loss of Clock Reset

1 = The last reset was caused by a loss of frequency reference to the clock submodule.

SYS — System Reset

1 = The last reset was caused by the CPU executing a reset instruction.

TST — Test Submodule Reset

1 = The last reset was caused by the test submodule.

SIMTRE — System Integration Module Test Register (E-Clock)

YFFA08

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

RESET:

This write-only register is reserved for factory testing. A write to this register in test mode forces the E-clock phase to synchronize with the system clock.

PORTE — Port E Data Register

\$YFFA11,YFFA13

7	6	5	4	3	2	1	0
PE7	PE6	PE5	PE4	PE3	PE2	PE1	PE0

RESET:

U U U U U U U

PE7-0 — Port E Data

DDRE — Port E Data Direction Register

\$YFFA15

7	6	5	4	3	2	1	0
DDE7	DDE6	DDE5	DDE4	DDE3	DDE2	DDE1	DDE0

RESET:

0 0 0 0 0 0 0 0

DDE7-0 — Data Direction E (Input/Output)

1 = Output

0 = Input

PEPAR — Port E Pin Assignment Register

\$YFFA17

7	6	5	4	3	2	1	0
(PEPA7) SIZ1	(PEPA6) SIZ0	(PEPA5) AS	(PEPA4) DS	(PEPA3) RMC	(PEPA2) AVEC	(PEPA1) DSACK1	(PEPA0) DSACK0

RESET:

DB8 DB8 DB8 DB8 DB8 DB8 DB8 DB8

PEPA7-0 — Port E Pin Assignment (I/O Function)

SIZ1-DSACK0 — Control Bus Function

A one on DB8 at reset sets the pins to the bus control function; otherwise, they are general-purpose I/O.



PORTF — Port F Data Register**\$YFFA19,YFFA1B**

7	6	5	4	3	2	1	0
PF7	PF6	PF5	PF4	PF3	PF2	PF1	PF0

RESET:

U U U U U U U U

PF7–0 — Port F Data

DDRF — Port F Data Direction Register**\$YFFA1D**

7	6	5	4	3	2	1	0
DDF7	DDF6	DDF5	DDF4	DDF3	DDF2	DDF1	DDF0

RESET:

0 0 0 0 0 0 0 0

DDF7–0 — Data Direction F (Input/Output)

1 = Output

0 = Input

PFPAR — Port F Pin Assignment Register**\$YFFA1F**

7	6	5	4	3	2	1	0
(PFFA7) IRQ7	(PFFA6) IRQ6	(PFFA5) IRQ5	(PFFA4) IRQ4	(PFFA3) IRQ3	(PFFA2) IRQ2	(PFFA1) IRQ1	(PFFA0) MODCK

RESET:

DB9 DB9 DB9 DB9 DB9 DB9 DB9 DB9

PFFA7–0 — Port E Pin Assignment (I/O Function)

IRQ7–1 — Control Bus Function

MODCK — Clock Mode Select

A one on DB9 at reset sets the pins to the bus control function; otherwise, they are general-purpose I/O.

C**SYPCCR — System Protection Control Register****\$YFFA21**

7	6	5	4	3	2	1	0
SWE	SWP	SWT1	SWT0	HME	BME	BMT1	BMT0

RESET:

1 MODCK 0 0 0 0 0 0

SWE — Software Watchdog Enable

1 = Software watchdog enabled

0 = Software watchdog disabled

SWP — Software Watchdog Prescale

1 = Software watchdog clock prescaled by 512

0 = Software watchdog clock not prescaled

At reset SWP takes on the inverted value of the MODCK pin.

SWT1–SWT0 — Software Watchdog Timing

These bits control the divide ratio used to establish the timeout period for the software watchdog timer. The calculation for the software timeout period is given in the following equation.

$$\text{Timeout Period} = 1 / (\text{EXTAL Frequency} / \text{Divide Count})$$

or

$$\text{Timeout Period} = \text{Divide Count} / \text{EXTAL Frequency}$$

Software Timeout Periods for Watchdog Timeout

Bits 6-4	Software Timeout Period	32.768-kHz Crystal Period	16.718-MHz External Clock Period
000	$2^9 / \text{EXTAL Input Frequency}$	15.6 Milliseconds	30.6 Microseconds
001	$2^{11} / \text{EXTAL Input Frequency}$	62.5 Milliseconds	122.5 Microseconds
010	$2^{13} / \text{EXTAL Input Frequency}$	250 Milliseconds	490 Microseconds
011	$2^{15} / \text{EXTAL Input Frequency}$	1 Second	1.96 Microseconds
100	$2^{18} / \text{EXTAL Input Frequency}$	8 Seconds	15.6 Milliseconds
101	$2^{20} / \text{EXTAL Input Frequency}$	32 Seconds	62.7 Milliseconds
110	$2^{22} / \text{EXTAL Input Frequency}$	128 Seconds	250 Milliseconds
111	$2^{24} / \text{EXTAL Input Frequency}$	512 Seconds	1 Second

HME — Halt Monitor Enable

1 = Enable halt monitor function

0 = Disable halt monitor function

BME — Bus Monitor External Enable

1 = Enable bus monitor function for an internal to external bus cycle

0 = Disable bus monitor function for an internal to external bus cycle

BMT — Bus Monitor Timing

Bits 1–0	Bus Monitor Timeout Period
00	64 System Clocks (CLK)
01	32 System Clocks (CLK)
10	16 System Clocks (CLK)
11	8 System Clocks (CLK)

PICR — Periodic Interrupt Control Register**\$YFFA22**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	PIRQL2	PIRQL1	PIRQL0	PIV7	PIV6	PIV5	PIV4	PIV3	PIV2	PIV1	PIV0

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1

PIRQL2–0 — Periodic Interrupt Request Level

Bits 10–8	Interrupt Request Level
000	Periodic Interrupt Disabled
001	Interrupt Request Level 1
010	Interrupt Request Level 2
011	Interrupt Request Level 3
100	Interrupt Request Level 4
101	Interrupt Request Level 5
110	Interrupt Request Level 6
111	Interrupt Request Level 7

PIV7–PIV0 — Periodic Interrupt Vector

These bits contain the value of the vector generated during an IACK cycle in response to an interrupt from the periodic timer.

PITR — Periodic Interrupt Timing Register**\$YFFA24**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	PTP	PITR7	PITR6	PITR5	PITR4	PITR3	PITR2	PITR1	PITR0

RESET:

0 0 0 0 0 0 0 0 $\overline{\text{MODCK}}$ 0 0 0 0 0 0 0 0

PTP — Periodic Timer Prescaler

1 = Periodic timer clock prescaled by a value of 512

0 = Periodic timer clock not prescaled

MODCK	PTP
0	1
1	0

PITR7–PITR0 — PITM Field (Periodic Interrupt Timing Modulus)

The periodic interrupt timing register (PITR) contains the count value for the periodic timer. A zero value turns off the periodic timer.

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The period of the periodic timer can be calculated using the following equation:

$$\text{PIT Period} = \text{PITM}/(\text{EXTAL}/\text{Prescaler})/4$$

where

- PIT Period = Periodic Interrupt Timer Period
- PITM = Periodic Interrupt Timer Register Modulus (PITR7–PITR0)
- EXTAL = Crystal Frequency
- Prescaler = 512 or 1 depending on the state of the PTP bit in the PITR

SWSR — Software Service Register

\$YFFA27

7	6	5	4	3	2	1	0
SWSR7	SWSR6	SWSR5	SWSR4	SWSR3	SWSR2	SWSR1	SWSR0

RESET:

0 0 0 0 0 0 0

The software watchdog service sequence consists of the following two steps:

1. Write \$55 to the software service register (SWSR)
2. Write \$AA to the SWSR

Both writes must occur in the order shown before the watchdog timeout, but any number of instructions can be executed between the two writes.

TSTMSRA — Master Shift Register A

\$YFFA30

Master shift register A contains the stimulus to be transferred from the test submodule to the module under test.

TSTMSRB — Master Shift Register B

\$YFFA32

Master shift register B collects the response data shifted from the module under test to the test submodule.

TSTSCA — Shift Count Register A and Shift Counter A

\$YFFA34

Shift count register A is an 8-bit shift register that can be accessed by the bus master. Shift counter A is an 8-bit counter that is loaded by shift count register A and is not accessible to the bus master.

TSTSCB — Shift Count Register B and Shift Counter B

\$YFFA35

Shift count register B is an 8-bit shift register that can be accessed by the bus master. Shift counter B is an 8-bit counter that is loaded by shift count register B and is not accessible to the bus master.



TSTRC — Test Module Repetition Counter**\$YFFA36**

The repetition counter determines the number of psuedo-random vectors generated in the automatic mode of operation.

CREG — Test Submodule Control Register**\$YFFA38**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BUSY	TMARM	COMP	IMBTST	CPUTR	QBIT	MUXEL	—	—	—	—	ACUT	SCONT	SSHOP	SATO	ETM

RESET:

1	TSTME	U	0	0	0	0	0	0	0	0	0	0	0	0	0
---	-------	---	---	---	---	---	---	---	---	---	---	---	---	---	---

ETM — Enter Test Mode

1 = Enter test mode

0 = Stay in normal mode

SATO — Start Automatic Test Operation

1 = Start an automatic test operation

0 = Stay in normal mode

SSHOP — Start Shifting Operation

1 = Start a shifting operation

0 = Stay in normal mode

SCONT — Start Continuous Operation

1 = Start continuous operation

0 = Stop continuous operation

ACUT — Activate Circuit Under Test

1 = Assert the ACUTL line

0 = Stay in normal mode

MUXSEL — Multiplexer Select Bit

1 = Shift in source for master shift register B (MSRB) is the external interrupt pin

0 = Shift in source for MSRB is the internal test line

QBIT — Quotient Bit

1 = The least significant bit of master shift register B is available at the quotient/freeze (FREEZE/QUOT) pin

0 = The internal freeze status is available at the FREEZE/QUOT pin

CPUTR — CPU Test Register

1 = Scan lines connected to the CPU test register

0 = Scan lines disconnected from the CPU test register

IMBTST — Intermodule Bus Test

1 = Internal interconnect lines are configured as test lines

0 = Internal interconnect lines have normal function

COMP — Compare Status Bit

- 1 = Master shift register B contains the correct answer for the user basic self-test
- 0 = Master shift register B does not contain the correct answer for the basic user self-test

TMARM — Test Mode Armed Status Bit

- 1 = TSTME pin is asserted; test mode can be entered by setting the ETM control bit
- 0 = TSTME pin is negated; test mode cannot be entered; bit can be read at any time, but cannot be written

BUSY — Test Submodule Busy Status Bit

- 1 = Test submodule is busy
- 0 = Test submodule is not busy

DREG — Distributed Register

\$YFFA3A

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
—	—	—	—	—	WAIT3	WAIT2	WAIT1	MSRA18	MSRA17	MSRA16	MSRAC	MSRB18	MSRB17	MSRB16	MSRBC

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

WAIT3–WAIT1 — Wait Counter Preset 3–1

These bits program the delay time between automatic test sequences.

MSRA18–MSRA16 — Master Shift Register A Bits 18–16

MSRAC — Master Shift Register A Configuration

- 1 = Master shift register A configured as a 19-bit serial pattern generator
- 0 = Master shift register A configured as a 16-bit shift register

MSRB18–MSRB16 — Master Shift Register B Bits 18–16

MSRBC — Master Shift Register B Configuration

- 1 = Master shift register B configured as a 19-bit serial signature analyzer
- 0 = Master shift register B configured as a 16-bit shift register



CSPDR — Chip-Select Pin Data Register

\$YFFA41

7	6	5	4	3	2	1	0
0	DO6	DO5	DO4	DO3	DO2	DO1	DO0

RESET:

0 1 1 1 1 1 1 1

D6–0 — Pin Data

CSPAR0 — Chip-Select Pin Assignment Register 0

\$YFFA44

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	CS5 (FC2)	CS4 (FC1)	CS3 (FC0)	CS2 (BGACK)	CS1 (BG)	CS0 (BR)	CSBOOT							

RESET:

0	0	DB2	1	DB2	1	DB2	1	DB1	1	DB1	1	DB1	1	1	DB0
---	---	-----	---	-----	---	-----	---	-----	---	-----	---	-----	---	---	-----

Bits 15, 14 — Not Used

These bits always read zero; write has no effect.

CSPAR1 — Chip-Select Pin Assignment Register 1

\$YFFA46

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	CS10 (A23)	CS9 (A22)	CS8 (A21)	CS7 (A20)	CS6 (A19)					

RESET:

0	0	0	0	0	0	DB7	1	DB6	1	DB5	1	DB4	1	DB3	1
---	---	---	---	---	---	-----	---	-----	---	-----	---	-----	---	-----	---

Bits 15–10 — Not Used

These bits always read zero; write has no effect.

Hierarchical Selection Structure of CSPAR1

Data Bus Pins At Reset					Default/Alternate Function				
DB7	DB6	DB5	DB4	DB3	CS10/A23	CS9/A22	CS8/A21	CS7/A20	CS6/A19
1	1	1	1	1	CS10	CS9	CS8	CS7	CS6
1	1	1	1	0	CS10	CS9	CS8	CS7	A19
1	1	1	0	X	CS10	CS9	CS8	A20	A19
1	1	0	X	X	CS10	CS9	A21	A20	A19
1	0	X	X	X	CS10	A22	A21	A20	A19
0	X	X	X	X	A23	A22	A21	A20	A19

Pin Assignment Register Bit Encoding

Bits	Description
00	Discrete Output (E Clock on A23)*
01	Alternate Function
10	Chip-Select (8-Bit Port)
11	Chip-Select (16-Bit Port)

*Except for BR, BG, and BGACK

CSBARBT — Chip-Select Base Address Register Boot**\$YFFA48**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A23	A22	A21	A20	A19	A18	A17	A16	A15	A14	A13	A12	A11	BLKSZ		

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1

CSBAR0–CSBAR10 — Chip-Select Base Address Registers**\$YFFA4C–YFFA74**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A23	A22	A21	A20	A19	A18	A17	A16	A15	A14	A13	A12	A11	BLKSZ		

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

BLKSZ — Block Size Field

Block Size Field	Block Size	Address Lines Compared
000	2K	A23–A11
001	8K	A23–A13
010	16K	A23–A14
011	64K	A23–A16
100	128K	A23–A17
101	256K	A23–A18
110	512K	A23–A19
111	1M	A23–A20

Bits 15–3 — Base Address Field

In supervisor/user space, this field sets the starting address of a particular address space.

Option Register Functions Summary

MODE	BYTE	R/W	STRB	DSACK	SPACE	IPL	AVEC
0 = ASYNC	00 = Off	00 = Rsvd	0 = AS	0000 = 0 WAIT	00 = CPU SP	000 = All	0 = Off
1 = SYNC	01 = Lower	01 = Read	1 = DS	0001 = 1 WAIT	01 = User SP	001 = Level 1	1 = On
	10 = Upper	10 = Write		0010 = 2 WAIT	10 = Supv SP	010 = Level 2	
	11 = Both	11 = Both		0011 = 3 WAIT	11 = S/U SP	011 = Level 3	
				0100 = 4 WAIT		100 = Level 4	
				0101 = 5 WAIT		101 = Level 5	
				0110 = 6 WAIT		110 = Level 6	
				0111 = 7 WAIT		111 = Level 7	
				1000 = 8 WAIT			
				1001 = 9 WAIT			
				1010 = 10 WAIT			
				1011 = 11 WAIT			
				1100 = 12 WAIT			
				1101 = 13 WAIT			
				1110 = F term			
				1111 = External			

CSORBT — Chip-Select Option Register Boot

\$YFFA4A

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODE	BYTE	R/W	STRB	DSACK			SPACE			IPL			AVEC		

RESET:

0 1 1 1 1 0 1 1 0 1 1 1 0 0 0 0

MODE — Asynchronous/Synchronous Mode

1 = Synchronous mode selected

0 = Asynchronous mode selected

BYTE — Upper/Lower Byte Option

This field is used when the chip-select 16-bit port option in the pin assignment register is selected.

Bits	Description
00	Disable
01	Lower Byte
10	Upper Byte
11	Both Bytes

$\overline{R/W}$ — Read/Write

This option causes the chip-select to be asserted only for a read, only for a write, or for both read and write.

Bits	Description
00	Reserved
01	Read Only
10	Write Only
11	Read/Write

STRB — Address Strobe/Data Strobe

1 = Data strobe

0 = Address strobe

This option controls the timing for assertion of a chip-select in asynchronous mode.

\overline{DSACK} — Data Strobe Acknowledge

In asynchronous mode, this option field specifies the source of the \overline{DSACK} (externally or internally generated).

Bits	Description
0000	No Wait States
0001	1 Wait State
0010	2 Wait States
0011	3 Wait States
0100	4 Wait States
0101	5 Wait States
0110	6 Wait States
0111	7 Wait States
1000	8 Wait States
1001	9 Wait States
1010	10 Wait States
1011	11 Wait States
1100	12 Wait States
1101	13 Wait States
1110	Fast Termination
1111	External \overline{DSACK}

SPACE — Address Space

This option field checks the address spaces indicated by the function codes generated by the CPU.

Bits	Description
00	CPU Space
01	User Space
10	Supervisor Space
11	Supervisor/User Space



IPL — Interrupt Priority Level

In an IACK cycle, the chip-select logic checks the acknowledged interrupt level on address lines A3–A1. If that level matches the level set in the IPL field, the chip-select can be asserted if the match conditions in the other fields are met.

Bits	Description
000	Any Level
001	IPL1
010	IPL2
011	IPL3
100	IPL4
101	IPL5
110	IPL6
111	IPL7

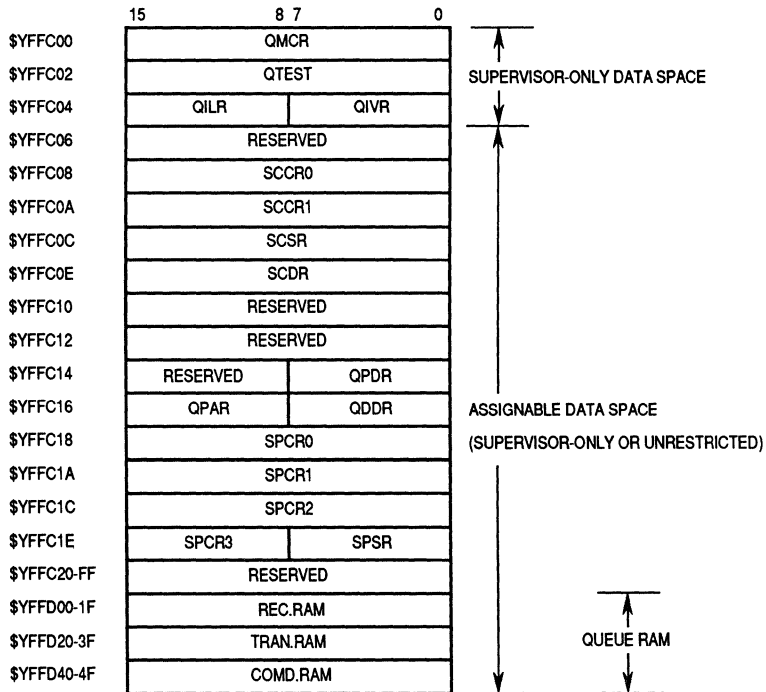
AVEC — Autovector Enable

1 = Autovector enabled

0 = External interrupt vector enabled

APPENDIX D QUEUED SERIAL MODULE (QSM) MEMORY MAP and REGISTERS

D.1 QSM Memory Map



Y = m111 where m is the modmap bit in the SIM MCR (Y = \$7 or \$F).

D

D.2 QSM Registers

QMCR — QSM Configuration Register

\$YFFC00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STOP	FRZ1	FRZ0	0	0	0	0	0	SUPV	0	0	0	IARB			

RESET:

0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0

STOP — Stop Enable

1 = QSM clock operation stopped

0 = Normal QSM clock operation

FRZ1 — Freeze 1

1 = Halt the QSM (on a transfer boundary)

0 = Ignore the FREEZE signal on the IMB

FRZ0 — Freeze 0

Reserved for future enhancement.

Bits 12–8 — Not Implemented

SUPV — Supervisor/Unrestricted

1 = Supervisor access

0 = User access

Bits 6–4 — Not Implemented

IARB — Interrupt Arbitration Identification Number

System software should initialize the IARB field to a value between \$F (top priority) and \$1 (lowest priority). Otherwise, any interrupts generated are identified by the CPU as spurious.

QTEST — QSM Test Register

\$YFFC02

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	TSBD	SYNC	TQSM	TMM

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

TSBD — SPI Test Scan Path Select

1 = Enable delay to SCK scan path

0 = Enable SPI baud clock scan path

SYNC — SCI Baud Clock Synchronization Signal

1 = Inhibit SCI source signal (QCSC11)

0 = Activate SCI source signal

SCCR1 — SCI Control Register 1

\$YFFC0A

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	LOOPS	WOMS	ILT	PT	PE	M	WAKE	TIE	TCIE	RIE	ILIE	TE	RE	RWU	SBK

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Bit 15 — Not Implemented

LOOPS — LOOP Mode

LOOPS controls a feedback path on the data serial shifter.

1 = Test SCI operation, looping, feedback path enabled

0 = Normal SCI operation, no looping, feedback path disabled

WOMS — Wired-OR Mode for SCI Pins

1 = If configured as an output, TXD is an open-drain output

0 = If configured as an output, TXD is a normal CMOS output

ILT — Idle-Line Detect Type

1 = Long idle-line detect (starts counting when the first one is received after a stop bit(s))

0 = Short idle-line detect (starts counting when the first one is received)

PT — Parity Type

1 = Odd parity

0 = Even parity

PE — Parity Enable

1 = SCI parity enabled

0 = SCI parity disabled

M	PE	Result
0	0	8 Data Bits
0	1	7 Data Bits, 1 Parity Bit
1	0	9 Data Bits
1	1	8 Data Bits, 1 Parity Bit

M — Mode Select

1 = SCI frame: 1 start bit, 9 data bits, 1 stop bit (11 bits total)

0 = SCI frame: 1 start bit, 8 data bits, 1 stop bit (10 bits total)

WAKE — Wakeup by Address Mark

1 = SCI receiver awakened by address mark (eighth or ninth (last) bit set)

0 = SCI receiver awakened by idle-line detection

TIE — Transmit Interrupt Enable

1 = SCI TDRE interrupts enabled

0 = SCI TDRE interrupts inhibited

TCIE — Transmit Complete Interrupt Enable

1 = SCI TC interrupts enabled

0 = SCI TC interrupts inhibited

RIE — Receiver Interrupt Enable

1 = SCI RDRF interrupts enabled

0 = SCI RDRF interrupts inhibited

ILIE — Idle-Line Interrupt Enable

1 = SCI IDLE interrupts enabled

0 = SCI IDLE interrupts inhibited

TE — Transmitter Enable

1 = SCI transmitter enabled; TXD pin dedicated to the SCI transmitter

0 = SCI transmitter disabled; TXD pin can be used as general-purpose I/O

RE — Receiver Enable

1 = SCI receiver enabled

0 = SCI receiver disabled

RWU — Receiver Wakeup

1 = Wakeup mode enabled; all received data ignored until awakened

0 = Normal receiver operation; all received data recognized

SBK — Send Break

1 = Break frame(s) are transmitted after completion of the current frame

0 = Normal operation

SCSR — SCI Status Register

\$YFFC0C

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	TDRE	TC	RDRF	RAF	IDLE	OR	NF	FE	PF

RESET:

0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0

Bits 15–9 — Not Implemented

TDRE — Transmit Data Register Empty Flag

1 = A new character can now be written to register TDR

0 = Register TDR still contains data to be sent to the transmit serial shifter

TC — Transmit Complete Flag
 1 = SCI transmitter is idle
 0 = SCI transmitter is busy

RDRF — Receive Data Register Full Flag
 1 = Register RDR contains new data
 0 = Register RDR is empty or contains previously read data

RAF — Receiver Active Flag
 1 = SCI receiver is busy
 0 = SCI receiver is idle

IDLE — Idle-Line Detected Flag
 1 = SCI receiver detected an idle-line condition
 0 = SCI receiver did not detect an idle-line condition

OR — Overrun Error Flag
 1 = RDRF is not cleared before new data arrives
 0 = RDRF is cleared before new data arrives

NF — Noise Error Flag
 1 = Noise occurred on the received data
 0 = No noise detected on the received data

FE — Framing Error Flag
 1 = Framing error or break occurred on the received data
 0 = No framing error on the received data

PF — Parity Error Flag
 1 = Parity error occurred on the received data
 0 = No parity error on the received data

SCDR — SCI Data Register **\$YFFC0E**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	R8/T8	R7/T7	R6/T6	R5/T5	R4/T4	R3/T3	R2/T2	R1/T1	R0/T0

RESET:

0 0 0 0 0 0 0 0 U U U U U U U U U

R8/T8 — Receive 8/Transmit 8

R0–R7/T0–T7 — Receive 0–7/Transmit 0–7

D

QPDR — QSM Port Data Register**\$YFFC15**

15		7	6	5	4	3	2	1	0	
RESERVED			D7 (TXD)	D6 (PCS3)	D5 (PCS2)	D4 (PCS1)	D3 (PCS0/SS)	D2 (SCK)	D1 (MOSI)	D0 (MISO)

RESET:

0 0 0 0 0 0 0 0 0

D7–0 — Pin Data

TXD-MISO — Pin Function

QPAR — QSM Pin Assignment Register**\$YFFC16**

15	14	13	12	11	10	9	8	7		0
0	PCS3	PCS2	PCS1	PCS0/SS	0	MOSI	MISO	QDDR*		

RESET:

0 0 0 0 0 0 0 0

0 = General-purpose I/O

1 = QSPI module

*QDDR — QSM Data Direction Register

Bit 15 — Not Implemented

PCS3–PCS1 — Peripheral Chip-Selects 3–1

PCS0/SS — Peripheral Chip-Select 0/Slave Select

Bit 10 — Not Implemented

MOSI — Master Out Slave In

MISO — Master In Slave Out

These bits determine whether the associated QSM port pin functions as a general-purpose I/O pin or is assigned to the QSPI submodule.

QDDR — QSM Data Direction Register**\$YFFC17**

15		8	7	6	5	4	3	2	1	0	
QPAR*				TXD	PCS3	PCS2	PCS1	PCS0/SS	SCK	MOSI	MISO

RESET:

0 0 0 0 0 0 0 0

0 = Input

1 = Output

*QPAR — QSM Pin Assignment Register

TXD — Transmit Data

PCS1 — Peripheral Chip-Selects 3–1

PCS0/SS — Peripheral Chip-Select 0/Slave Select

SCK — Serial Clock

MOSI — Master Out Slave In



SPCR0 — QSPI Control Register 0

\$YFFC18

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSTR	WOMQ	BITS				CPOL	CPHA	SPBR							

RESET:

0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0

MSTR — Master/Slave Mode Select

- 1 = QSPI is system master and can initiate transmission to external SPI devices
- 0 = QSPI is a slave device, and only responds to externally generated serial MSTR

WOMQ — Wired-OR Mode for QSPI Pins

- 1 = All QSPI port pins designated as output by QDDR function as open-drain outputs
- 0 = Output pins have normal outputs instead of open-drain outputs

BITS — Bits Per Transfer

In master mode, BITS determines the number of data bits transferred for each serial transfer in the queue.

Bit 13	Bit 12	Bit 11	Bit 10	Bits per Transfer
0	0	0	0	16
0	0	0	1	Reserved
0	0	1	0	Reserved
0	0	1	1	Reserved
0	1	0	0	Reserved
0	1	0	1	Reserved
0	1	1	0	Reserved
0	1	1	1	Reserved
1	0	0	0	8
1	0	0	1	9
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

CPOL — Clock Polarity

- 1 = The inactive state value of SCK is high
- 0 = The inactive state value of SCK is low

D

CPHA — Clock Phase

- 1 = Data is changed on the leading edge of SCK and captured on the following edge of SCK
- 0 = Data is captured on the leading edge of SCK and changed on the following edge of SCK

SPBR — Serial Clock Baud Rate

The QSPI internally generates the baud rate for SCK, the frequency of which is programmable by the user. The following equation determines the SCK baud rate:

$$\text{SCK Baud Rate} = \text{System Clock} / (2 * \text{SPBR})$$

or

$$\text{SPBR} = \text{System Clock} / (2 * \text{SCK Baud Rate Desired})$$

where SPBR equals {2, 3, 4, . . . , 255}.

SPCR1— QSPI Control Register

\$YFFC1A

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPE		DSCKL							DTL						

RESET:

0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0

SPE — QSPI Enable

- 1 = The QSPI is enabled and the pins allocated by QSM register QPAR are controlled by the QSPI
- 0 = The QSPI is disabled and the seven QSPI pins can be used as general-purpose I/O pins, regardless of the values in QPAR

DSCKL — Delay before SCK

This bit determines the length of time the QSPI delays from peripheral chip-select (PCS) valid to SCK transition for serial transfers in which the command control bit, DSCK of the QSPI RAM, equals one.

$$\text{PCS to SCK Delay} = (\text{DSCKL} / \text{System Clock Frequency})$$

where DSCKL equals {1,2,3, . . . 127}.

DTL — Length of Delay after Transfer

These bits determine the length of time that the QSPI delays after each serial transfer in which the command control bit, DT of the QSPI RAM, equals one.

$$\text{Delay after Transfer} = (32 * \text{DTL}) / \text{System Clock Frequency}$$

where DTL equals {1,2,3, . . . 255}.



SPCR2 — QSPI Control Register 2**\$YFFC1C**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPIFIE	WREN	WRTO	0	ENDQP				0	0	0	0	NEWQP			

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

SPIFIE — SPI Finished Interrupt Enable

1 = QSPI interrupts enabled

0 = QSPI interrupts disabled

WREN — Wrap Enable

1 = Wraparound mode enabled

0 = Wraparound mode disabled

WRTO — Wrap To

1 = Wrap to address found in NEWQP

0 = Wrap to address \$0

Bit 12 — Not Implemented

ENDQP — Ending Queue Pointer

This field determines the last absolute address in the queue to be completed by the QSPI.

Bits 7–4 — Not Implemented

NEWQP — New Queue Pointer Value

NEWQP determines which queue entry the QSPI transfers first.

SPCR3 — QSPI Control Register**\$YFFC1E**

15	14	13	12	11	10	9	8	7	0						
0	0	0	0	0	LOOPQ	HMIE	HALT	SPSR*							

RESET:

0 0 0 0 0 0 0 0

*SPSR — QSPI Status Register

D

Bits 15–11 — Not Implemented

LOOPQ — QSPI Loop Mode

1 = Feedback path enabled

0 = Feedback path disabled

HMIE — HALTA and MODF Interrupt Enable

1 = HALTA and MODF interrupts enabled

0 = HALTA and MODF interrupts disabled

HALT — Halt

1 = Halt enabled

0 = Halt not enabled

This bit is used by the CPU to stop the QSPI on a queue boundary.

SPSR — QSPI Status Register

\$YFFC1F

15	8	7	6	5	4	3	2	1	0
SPCR3*				SPIF	MODF	HALTA	0	CPTQP	

RESET:

0 0 0 0 0 0 0 0 0

*SPCR3 — QSPI Control Register 3

SPIF — QSPI Finished Flag

1 = QSPI finished

0 = QSPI not finished

SPIF is set when the QSPI finishes executing the last command determined by the address contained in ENDQP in SPCR2.

MODF — Mode Fault Flag

1 = Another SPI node requested to become the network SPI master while the QSPI was enabled in master mode (MSTR = 1), or the PCS0/SS pin was incorrectly pulled low by external hardware

0 = Normal operation

HALTA — Halt Acknowledge Flag

1 = QSPI halted

0 = QSPI not halted

HALTA is asserted by the QSPI when it has come to an orderly halt at the request of the CPU, through the assertion of HALT.

Bit 4 — Not Implemented

CPTQP — Completed Queue Pointer

CPTQP contains the queue pointer value of the last command in the queue that was completed.

COMD.RAM — Command Ram

\$YFFD40

7	6	5	4	3	2	1	0
CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*
—	—	—	—	—	—	—	—
CONT	BITSE	DT	DSCK	PCS3	PCS2	PCS1	PCS0*

\$YFFD4F

COMMAND CONTROL

PERIPHERAL CHIP-SELECT

*The PCS0 bit represents the dual-function PCS0/SS.



CONT — Continue

- 1 = Keeps peripheral chip-selects asserted after transfer is complete
- 0 = Returns control of peripheral chip-selects to QPDR after transfer is complete

BITSE — Bits Enable

- 1 = Number of bits to transfer defined in BITS field of SPCR0
- 0 = 8 bits to transfer

DT — Delay After Transfer

- 1 = Delay
- 0 = No delay

DSCK — PCS to SCK Delay

- 1 = DSCKL field in SPCR1 specifies value of delay from PCS valid to SCK
- 0 = PCS valid to SCK transition is 1/2 SCK

PCS3–PCS0/ \overline{SS} — Peripheral Chip-Select

The four peripheral chip-select bits can be used directly to select one of four external chips for the serial transfer, or decoded by external hardware to select one of 16 chip-select patterns for a serial transfer.

APPENDIX E GENERAL-PURPOSE TIMER (GPT) MEMORY MAP and REGISTERS

E.1 GPT Memory Map

		WORD			
	ADDRESS	15	8	7	0
		BYTE n		BYTE n + 1	
S	\$YFF900	MCR			
S	\$YFF902	RESERVED			
S	\$YFF904	ICR			
U	\$YFF906	PDDR		PDR	
U	\$YFF908	OC1M		OC1D	
U	\$YFF90A	TCNT			
U	\$YFF90C	PACTL		PACNT	
U	\$YFF90E	TIC1			
U	\$YFF910	TIC2			
U	\$YFF912	TIC3			
U	\$YFF914	TOC1			
U	\$YFF916	TOC2			
U	\$YFF918	TOC3			
U	\$YFF91A	TOC4			
U	\$YFF91C	TI4O5			
U	\$YFF91E	TCTL1		TCTL2	
U	\$YFF920	TMSK1		TMSK2	
U	\$YFF922	TFLG1		TFLG2	
U	\$YFF924	CFORC		PWMC	
U	\$YFF926	PWMA		PWMB	
U	\$YFF928	PWMCNT			
U	\$YFF92A	PWMABUF		PWMBBUF	
U	\$YFF92C	PRESCL (Lower 9 bits)			
	\$YFF92E	RESERVED			
	\$YFF93F				

S = Supervisor accessible only

U = User or Supervisor depending on state of SUPV in the MCR

Y = m111, where m is the state of the modmap bit in the module configuration register of the system integration module (Y = \$7 or \$F)

E

E.2 GPT Registers

MCR — GPT Module Configuration Register

\$YFF900

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STOP	FRZ1	FRZ0	STOPP	INCP	0	0	0	SUPV	0	0	0	IARB3	IARB2	IARB1	IARB0

RESET:

0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0

STOP — Stop Clocks

0 = Internal clocks are not shut down

1 = Internal clocks are shut down

FRZ1, FRZ0 — FREEZE Response

0 = Ignore FREEZE

1 = Freeze the current state of the GPT

STOPP — Stop Prescaler

0 = Normal operation

1 = Stop the prescaler and pulse accumulator from incrementing; ignore changes to input pins

INCP — Increment Prescaler

0 = Has no meaning

1 = If STOPP is asserted, increment the prescaler once and clock the input synchronizers once

SUPV — Supervisor/Unrestricted Data Space

0 = Registers with access controlled by the SUPV bit are unrestricted (FC2 is a don't care)

1 = Registers with access controlled by the SUPV bit are restricted to supervisor access only when FC2 = 1

IARB3–0 — Interrupt Arbitration ID

The interrupt structure of the IMB supports a total of 15 internal interrupt sources. External interrupts are grouped as one of the internal sources. Each source supports 7 interrupt levels. A level 7 interrupt has the highest priority. Each of the 15 internal sources is assigned a unique ID, the interrupt arbitration ID, which is used to determine which interrupt will be serviced if two or more interrupts of the same priority occur at the same time.

These sources must arbitrate for the interrupt during the IACK cycle. The module with the higher ID wins the arbitration. System software must set this field to \$F–\$1; \$F being the highest priority. This field is initialized to zero during reset which disables arbitration and causes any interrupts generated by the module to be treated as spurious.

E

MTR — GPT Module Test Register**\$YFF902**

No module test register is implemented on the GPT. However, this address location is reserved for future needs.

ICR — GPT Interrupt Configuration Register**\$YFF904**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PAB				0	IRL			IVBA			0	0	0	0	

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

PAB — Priority Adjust Bits

The GPT has 11 sources capable of generating an interrupt. These bits specify the single interrupt source which is to be advanced to the highest priority level. All of the other interrupt sources maintain their relative priority.

Interrupt Source		Priority Level	Vector Address
Name	Function		
—	Adjusted Channel	0 (Highest)	\$X0
IC1	Input Capture 1	1	\$X1
IC2	Input Capture 2	2	\$X2
IC3	Input Capture 3	3	\$X3
OC1	Output Compare 1	4	\$X4
OC2	Output Compare 2	5	\$X5
OC3	Output Compare 3	6	\$X6
OC4	Output Compare 4	7	\$X7
IC4/OC5	Input Capture 4/Output Compare 5	8	\$X8
TOF	Timer Overflow Flag	9	\$X9
PAOVF	Pulse Accumulator Overflow Flag	10	\$XA
PAIF	Pulse Accumulator Input Flag	11 (Lowest)	\$XB

X = Four-bit Vector Base Address (VBA)

IRL — Interrupt Request Level

These bits specify the priority level of the GPT module's interrupts. The GPT can have any of 8 priority levels, with level 7 being the highest and level 0 disabling interrupts. The interrupt request level specifies the priority level presented to the CPU. The interrupt request level is initialized to zero during reset.

All GPT internal interrupts are prioritized as shown in the above table. The interrupt with the highest priority will generate the interrupt level to the IMB specified by this field.

E

IVBA — Interrupt Vector Base Address

This field specifies the most significant nibble of all the vector numbers that can be generated by the different interrupt sources of the GPT module. This value, concatenated with the vector address shown in the above table, is the module interrupt vector.

PDDR/PDR — Parallel Data Direction Register/Parallel Data Register \$YFF906

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DDRI4O5	DDRO4	DDRO3	DDRO2	DDRO1	DDRI3	DDRI2	DDRI1	IC4/OC5	OC4	OC3	OC2	OC1	IC3	IC2	IC1

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

DDR_x — Data Direction for Input Capture/Output Compare pins

0 = Input only

1 = Output

IC4/OC5, OC4–1, IC3–1 — Parallel Data Port

OC1M/OC1D — OC1 Action Mask Register/OC1 Action Data Register \$YFF908

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC1M7	OC1M6	OC1M5	OC1M4	OC1M3	0	0	0	OC1D7	OC1D6	OC1D5	OC1D4	OC1D3	0	0	0

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

OC1M_x — OC1 Mask Bits

0 = Corresponding bit in the parallel data port is not affected by OC1 compare

1 = Corresponding bit in the parallel data port is affected by OC1 compare

OC1D_x — OC1 Data Bits

0 = If OC1M_x is set, store 0 on the corresponding parallel data port bit on OC1 match

1 = If OC1M_x is set, store 1 on the corresponding parallel data port bit on OC1 match

TCNT — Timer Counter Register \$YFF90A

TCNT is the 16-bit free-running counter associated with the input capture, output compare, and pulse accumulator functions of the GPT module.

E

PACTL/PACNT — Pulse Accumulator Control Register/Pulse Accumulator Counter \$YFF90C

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PAIS	PAEN	PAMOD	PEDGE	PCLKS	I4/O5	PACLK1	PACLK0	PULSE ACCUMULATOR COUNTER							

RESET:

U 0 0 0 U 0 0 0 0 0 0 0 0 0 0 0

PAIS — PAI Pin State (Read-Only)

PAEN — Pulse Accumulator System Enable

0 = Pulse accumulator disabled

1 = Pulse accumulator enabled

PAMOD — Pulse Accumulator Mode

0 = External event counting

1 = Gated time accumulation

PEDGE — Pulse Accumulator Edge Control

This bit has different meanings based on the state of the PAMOD bit.

PAMOD	PEDGE	Action on Clock
0	0	PAI falling edge increments counter.
0	1	PAI rising edge increments counter.
1	0	A zero on PAI inhibits counting (Gated Mode).
1	1	A one on PAI inhibits counting (Gated Mode).

PCLKS — PCLK Pin State (Read-Only)

I4/O5 — Input Capture 4/Output Compare 5

0 = Output compare 5 function enabled

1 = Input capture 4 function enabled

PACLK1–0 — Pulse Accumulator Clock Select (Gated Mode)

PACLK1	PACLK0	Pulse Accumulator Clock Selected
0	0	System Clock Divided by 512
0	1	Same Clock Used to Increment TCNT
1	0	TOF Flag from TCNT
1	1	External Clock, PCLK

Pulse Accumulator Counter

This is an 8-bit read/write counter used for external event counting or gated time accumulation.

TIC1–TIC3 — Input Capture Registers 1–3

\$YFF90E, \$YFF910, \$YFF912

The input capture registers are 16-bit read-only registers which are used to latch the value of TCNT when a specified transition is detected on the corresponding input capture pin. They are reset to \$FFFF.

E

TOC1–TOC4 — Output Compare Registers 1–4 **\$YFF914, \$YFF916, \$YFF918, \$YFF91A**

The output compare registers are 16-bit read/write registers which can be used as output waveform controls or as elapsed time indicators. For output compare functions, they are written to a desired match value and compared against TCNT to control specified pin actions. They are reset to \$FFFF.

TI4O5 — Input Capture 4/Output Compare 5 Register **\$YFF91C**

This register serves either as input capture register 4 or output compare register 5, depending on the function chosen for the I4/O5 pin.

TCTL1/TCTL2 — Timer Control Registers 1-2 **\$YFF91E**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OM5	OL5	OM4	OL4	OM3	OL3	OM2	OL2	EDGE4 B	EDGE4 A	EDGE3 B	EDGE3 A	EDGE2 B	EDGE2 A	EDGE1 B	EDGE1 A

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

OMx — Output Compare Mode Bits

OLx — Output Compare Level Bits

These bits are encoded to specify the output action to be taken as a result of a successful OCx compare.

OMx–OLx	Action Taken on Successful Compare
00	Timer Disconnected from Output Logic
01	Toggle OCx Output Line
10	Clear OCx Output Line to 0
11	Set OCx Output Line to 1

EDGExA, EDGExB — Input Capture Edge Control Bits

These bits are encoded to configure the input sensing logic for the corresponding input capture.

EDGExB–A	Configuration
00	Capture Disabled
01	Capture on Rising Edge Only
10	Capture on Falling Edge Only
11	Capture on Any (Rising or Falling) Edge



TMSK1/TMSK2 — Timer Interrupt Mask Registers 1–2**\$YFF920**

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I4O5I	OC4I	OC3I	OC2I	OC1I	IC3I	IC2I	IC1I	TOI	0	PAOVI	PAII	CPROUT	CPR2	CPR1	CPR0

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

OCxI — Output Compare x Interrupt Enable

0 = OCx interrupts disabled

1 = OCx interrupts requested when OCxF flag is set

ICxI — Input Capture x Interrupt Enable

0 = ICx interrupts disabled

1 = ICx interrupts requested when ICxF flag is set

I4O5I — Input Capture 4/Output Compare 5 Interrupt Enable

0 = IC4 or OC5 interrupt disabled (depending on I4/O5 pin function)

1 = IC4 or OC5 interrupt requested when I4O5I flag is set (depending on I4/O5 pin function)

TOI — Timer Overflow Interrupt Enable

0 = Timer overflow interrupts disabled

1 = Interrupts requested when TOF flag is set

PAOVI — Pulse Accumulator Overflow Interrupt Enable

0 = Pulse accumulator overflow interrupts disabled

1 = Interrupts requested when PAOVF flag is set

PAII — Pulse Accumulator Interrupt Enable

0 = Pulse accumulator interrupts disabled

1 = Interrupts requested when PAIF flag is set

CPROUT — Compare/Capture Unit Clock Output Enable

0 = Normal operation for OC1 pin

1 = Output of prescaler mux for compare/capture unit (TCNT clock) is driven out on OC1 pin

CPR2–0 — Timer Prescaler Select Bits

These bits select a prescaler tap or the external clock (PCLK) to be the input to TCNT.

E

CPR2 — 0	System Clock Divide-By Factor
000	4
001	8
010	16
011	32
100	64
101	128
110	256
111	PCLK*

* PCLK is an external clock input pin.

TFLG1/TFLG2 — Timer Interrupt Flag Registers 1-2

\$YFF922

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I4O5F	OC4F	OC3F	OC2F	OC1F	IC3F	IC2F	IC1F	TOF	0	PAOVF	PAIF	0	0	0	0

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

OCxF — Output Compare x Flag

This flag is set each time TCNT matches the value in output compare register x.

ICxF — Input Capture x Flag

This flag is set each time a selected edge is detected at the input capture x pin.

I4O5F — Input Capture 4/Output Compare 5 Flag

If the I4/O5 pin is configured as input capture 4, this flag is set each time a selected edge is detected at the I4/O5 pin. If the I4/O5 pin is configured as output compare 5, this flag is set each time TCNT matches the value in output compare register 5.

TOF — Timer Overflow Flag

This flag is set each time TCNT advances from a value of \$FFFF to \$0000.

PAOVF — Pulse Accumulator Overflow Flag

This flag is set each time the pulse accumulator counter advances from a value of \$FF to \$00.

PAIF — Pulse Accumulator Flag

In event counting mode, this bit is set when an active edge is detected on the PAI pin. In gated time accumulation mode, this bit is set at the end of the timed period when going from the active (counting) state to the inactive (no longer counting) state.

E

CFORC/PWMC — Compare Force Register/PWM Control Register

\$YFF924

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FOC5	FOC4	FOC3	FOC2	FOC1	0	FPWMA	FPWMB	PPROUT	PPR2	PPR1	PPR0	SFA	SFB	F1A	F1B

RESET:

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

FOCx — Force Output Compare Bits

0 = Has no meaning

1 = Causes pin action programmed for OCx, except that the OCxF flag is not set

FPWMx — Force PWM Value

0 = PWM pin x is used for PWM functions; normal operation.

1 = PWM pin x is used for discrete output. The value of the F1x bit will be driven out on the PWMx pin. This is true for PWMA regardless of the state of the PPROUT bit.

PPROUT — PWM Prescaler Clock Output Enable

0 = Normal PWM operation on PWMA

1 = Output of prescaler mux for PWM counter is driven out on the PWMA pin

PPR2-0 — PWM Prescaler

These bits select a prescaler tap or the external clock (PCLK) to be the input to PWMCNT.

PPR2 — 0	System Clock Divide-By Factor
000	2
001	4
010	8
011	16
100	32
101	64
110	128
111	PCLK*

* PCLK is an external clock input pin.

SF_x — Slow/Fast Bits

0 = The higher speed of PWM_x is selected. (The PWM_x period is 256 PWMCNT increments long.)

1 = The slower speed of PWM_x is selected. (The PWM_x period is 32,768 PWMCNT increments long.)



F1x — Force Logic One on PWMx

0 = Normal PWMx operation or force a zero on the PWMx pin for discrete output

1 = Force one on the PWMx pin; a 100% duty cycle PWM or discrete output

PWMA/PWMB — PWM Registers A/B

\$YFF926, \$YFF927

These registers are associated with the pulse-width value of the PWM output on the corresponding PWM pin. A value of \$00 loaded into one of these registers results in a continuously low output on the corresponding pin. A value of \$80 results in a 50% duty cycle output, and so on, to the maximum value of \$FF. This maximum value corresponds to an output which is high for 255/256 of the period.

PWMCNT — PWM Count Register

\$YFF928

PWMCNT is the 16-bit free-running counter associated with the PWM functions of the GPT module.

PWMABUF/PWMBBUF — PWM Buffer Registers A/B

\$YFF92A, \$YFF92B

These read-only registers contain the values associated with the duty cycles of the corresponding PWMs in progress.

PRESCL — GPT Prescaler

\$YFF92C

The value of the 9-bit prescaler can be read at this address. The value of the prescaler will be reflected in bits 8–0; whereas, bits 15–9 are unimplemented and will always read as zeros.

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