

HCO5

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TECHNICAL
DATA



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HCMOS MICROCONTROLLER UNIT

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**SECTION 1
GENERAL DESCRIPTION**

The MC68HC705P6 is a member of the low-cost, high-performance M68HC05 Family of 8-bit microcontroller units (MCUs). The M68HC05 Family is based on the customer-specified integrated circuit (CSIC) design strategy. All MCUs in the family use the popular M68HC05 central processor unit (CPU) and are available with a variety of subsystems, memory sizes and types, and package types.

On-chip memory of the MC68HC705P6 includes 176 bytes of user RAM and 4672 bytes of user erasable, programmable ROM (EPROM). In packages without the transparent window for EPROM erasure, the 4672 EPROM bytes serve as one-time programmable ROM (OTPROM).

1.1 Features

Features of the MC68HC705P6 MCU include the following:

- Popular M68HC05 Central Processor Unit
- Memory-Mapped Input/Output (I/O) Registers
- 4672 Bytes of User EPROM/OTPROM Including 48 Bytes of Page Zero EPROM/OTPROM and 16 User Vector Locations
- 176 Bytes of User RAM
- 20 I/O Port Pins and One Input-Only Port Pin
- On-Chip Oscillator with Crystal or Ceramic Resonator Connections
- 4-Input, 8-Bit Analog-to-Digital Converter (ADC)
- Synchronous Serial I/O Port (SIOP)
- 16-Bit Capture/Compare Timer
- Fully Static Operation with no Minimum Clock Speed
- Bootloader ROM
- Computer Operating Properly (COP) Watchdog
- Power-Saving Stop, Wait, Halt, and Data-Retention Modes
- 8 × 8 Unsigned Multiply Instruction
- 28-Pin Plastic Dual In-Line Package (PDIP)
- 28-Pin Small Outline Integrated Circuit (SOIC)
- 28-Pin Ceramic DIP (Cerdip)

1.2 Programmable Options

The following options are programmable in the mask option register (MOR):

- STOP instruction: enabled or disabled
- SIOPI clock rate: oscillator frequency divided by 8, 16, 32, or 64
- SIOPI data format: MSB-first or LSB-first
- External interrupt pin: edge-triggered or edge- and level-triggered
- COP watchdog: enabled or disabled

1.3 MCU Structure

Figure 1-1 shows the structure of the MC68HC705P6 MCU.

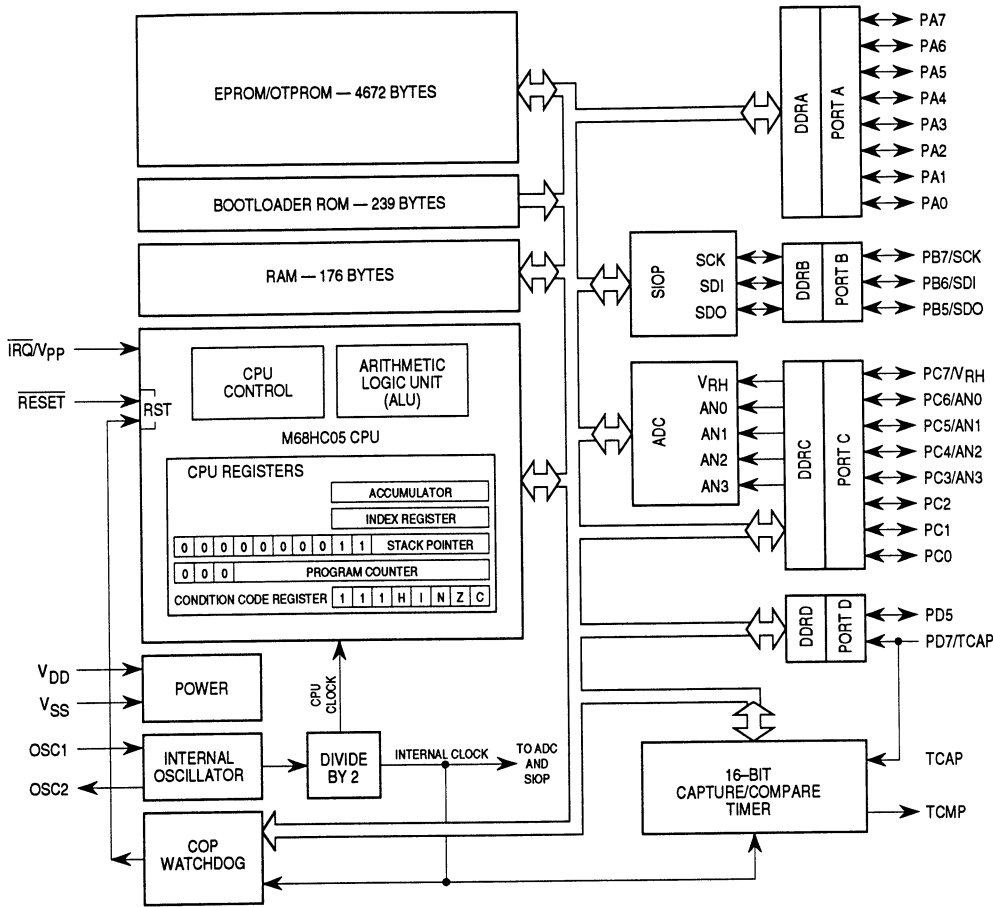


Figure 1-1. MC68HC705P6 Block Diagram

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1.4 Pin Assignments

Figure 1-2 shows the MC68HC705P6 pin assignments.

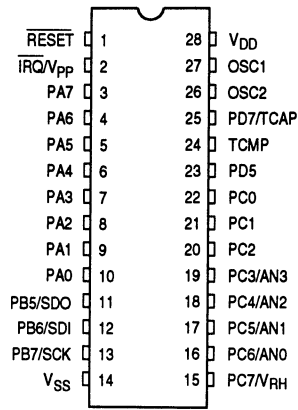


Figure 1-2. Pin Assignments

1.4.1 V_{DD} and V_{SS}

V_{DD} and V_{SS} are the power supply and ground pins. The MCU operates from a single 5 V power supply.

Very fast signal transitions occur on the MCU pins, placing very high short-duration current demands on the power supply. To prevent noise problems, take special care to provide good power supply bypassing at the MCU. Place bypass capacitors as close to the MCU as possible, as Figure 1-3 shows. C2 is an optional bulk current bypass capacitor for use in applications that require the port pins to source high current levels.

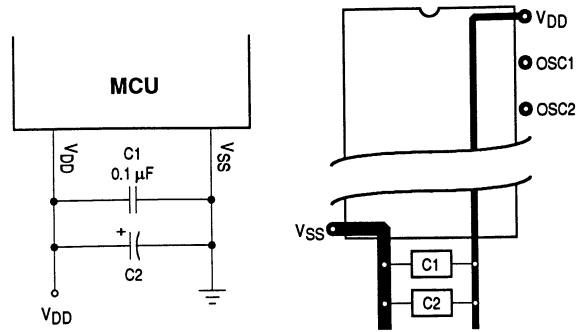


Figure 1-3. Bypassing Layout Recommendation

1.4.2 OSC1 and OSC2

The OSC1 and OSC2 pins are the control connections for the on-chip oscillator. The oscillator can be driven by any of the following:

- Crystal
- Ceramic resonator
- External clock signal

The frequency of the internal oscillator is f_{OSC} . The MCU divides the internal oscillator output by two to produce the internal clock. The frequency of the internal clock is f_{OP} .

1.4.2.1 Crystal

A crystal connected to the OSC1 and OSC2 pins can drive the on-chip oscillator. Figure 1-4 shows a typical crystal oscillator circuit for an AT-cut, parallel resonant crystal. Follow the crystal supplier's recommendations, as the crystal parameters determine the external component values required to provide reliable start-up and maximum stability. The load capacitance values used in the oscillator circuit design should include all stray layout capacitances. To minimize output distortion, mount the crystal and capacitors as close as possible to the pins.

NOTE

Use an AT-cut crystal and not an AT-strip crystal. The MCU may overdrive an AT-strip crystal.

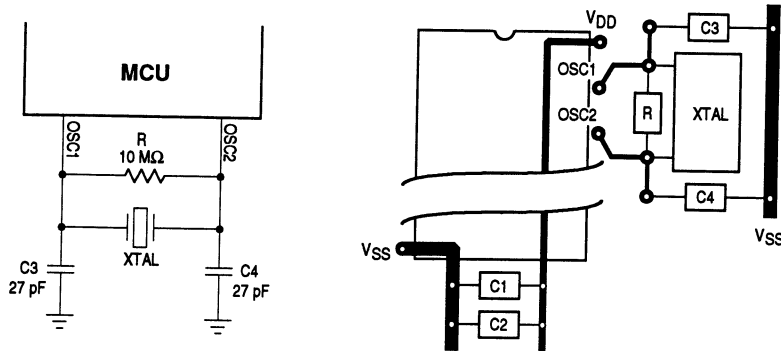


Figure 1-4. Crystal Connections

1.4.2.2 Ceramic Resonator

To reduce cost, use a ceramic resonator in place of the crystal. Use the circuit in Figure 1-5 for a ceramic resonator, and follow the resonator manufacturer's recommendations. The load capacitance values used in the oscillator circuit design should include all stray layout capacitances. To minimize output distortion, mount the resonator as close as possible to the pins.

NOTE

Because the frequency stability of ceramic resonators is not as high as that of crystal oscillators, using a ceramic resonator may degrade the performance of the analog-to-digital converter (ADC).

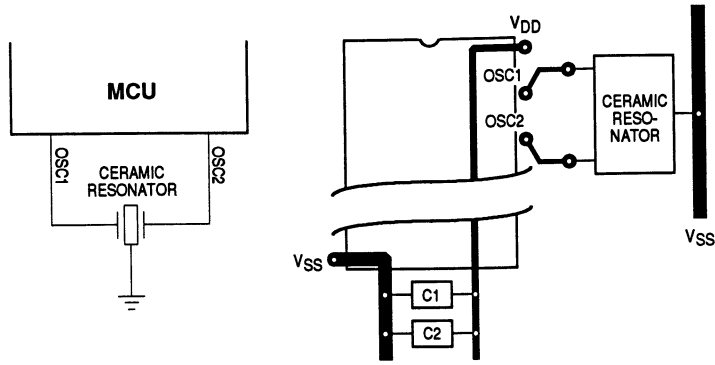


Figure 1-5. Ceramic Resonator Connections

1.4.2.3 External Clock

An external clock from another CMOS-compatible device can drive the OSC1 input. Leave the OSC2 pin unconnected, as Figure 1-6 shows.

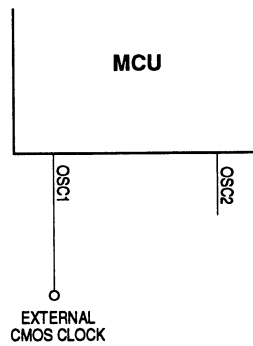


Figure 1-6. External Clock Connections

1.4.3 RESET

A logic zero on the $\overline{\text{RESET}}$ pin forces the MCU to a known start-up state. (See 5.1.2 External Reset for more information.)

1.4.4 $\overline{\text{IRQ}}/\text{V}_{\text{PP}}$

The $\overline{\text{IRQ}}/\text{V}_{\text{PP}}$ pin has the following functions:

- Applying asynchronous external interrupt signals (See 4.1.2 External Interrupt.)
- Applying EPROM programming voltage (See 11.1.1 EPROM Programming Register (EPROG).)

1.4.5 PA7–PA0

PA7–PA0 are the pins of port A, a general-purpose bidirectional I/O port.

1.4.6 PB7/SCK

PB7/SCK is a general-purpose bidirectional port B I/O pin. When the serial I/O port (SIOP) is enabled, PB7/SCK is the serial clock input pin (slave mode) or the serial clock output pin (master mode).

1.4.7 PB6/SDI

PB6/SDI is a general-purpose bidirectional port B I/O pin. When the serial I/O port (SIOP) is enabled, PB6/SDI is the serial data input pin.

1.4.8 PB5/SDO

PB5/SDO is a general-purpose bidirectional port B I/O pin. When the serial I/O port (SIOP) is enabled, PB5/SDO is the serial data output pin.

1.4.9 PC7/ V_{RH}

PC7/ V_{RH} is a general-purpose bidirectional port C I/O pin. When the analog-to-digital converter (ADC) is enabled, PC7/ V_{RH} is the positive reference voltage pin for the ADC.

1.4.10 PC6/AN0

PC6/AN0 is a general-purpose bidirectional port C I/O pin. When the analog-to-digital converter (ADC) is enabled, PC6/AN0 is an analog input pin for the ADC.

1.4.11 PC5/AN1

PC5/AN1 is a general-purpose bidirectional port C I/O pin. When the analog-to-digital converter (ADC) is enabled, PC5/AN1 is an analog input pin for the ADC.

1.4.12 PC4/AN2

PC4/AN2 is a general-purpose bidirectional port C I/O pin. When the analog-to-digital converter (ADC) is enabled, PC4/AN2 is an analog input pin for the ADC.

1.4.13 PC3/AN3

PC3/AN3 is a general-purpose bidirectional port C I/O pin. When the analog-to-digital converter (ADC) is enabled, PC3/AN3 is an analog input pin for the ADC.

1.4.14 PC2–PC0

PC2–PC0 are general-purpose bidirectional port C I/O pins.

1.4.15 PD7/TCAP

PD7/TCAP serves as both a general-purpose input-only port D I/O pin and as the input capture line for the capture/compare timer.

1.4.16 PD5

PD5 is a general-purpose bidirectional port D I/O pin.



1.4.17 TCMP

TCMP is the output pin for the output compare function of the capture/compare timer.

SECTION 2 MEMORY

This section describes the organization of the on-chip memory.

2.1 Memory Map

The CPU can address 8 Kbytes of memory space. The ROM portion of memory holds the program instructions, fixed data, user-defined vectors, and interrupt service routines. The RAM portion of memory holds variable data. I/O registers are memory-mapped so that the CPU can access their locations in the same way that it accesses all other memory locations. Figure 2-1 is a memory map of the MCU.

2.2 Input/Output Section

The first 32 addresses of the memory space, \$0000–\$001F, are the I/O section. These are the addresses of the I/O control registers, status registers, and data registers. (See Figure 2-2.)

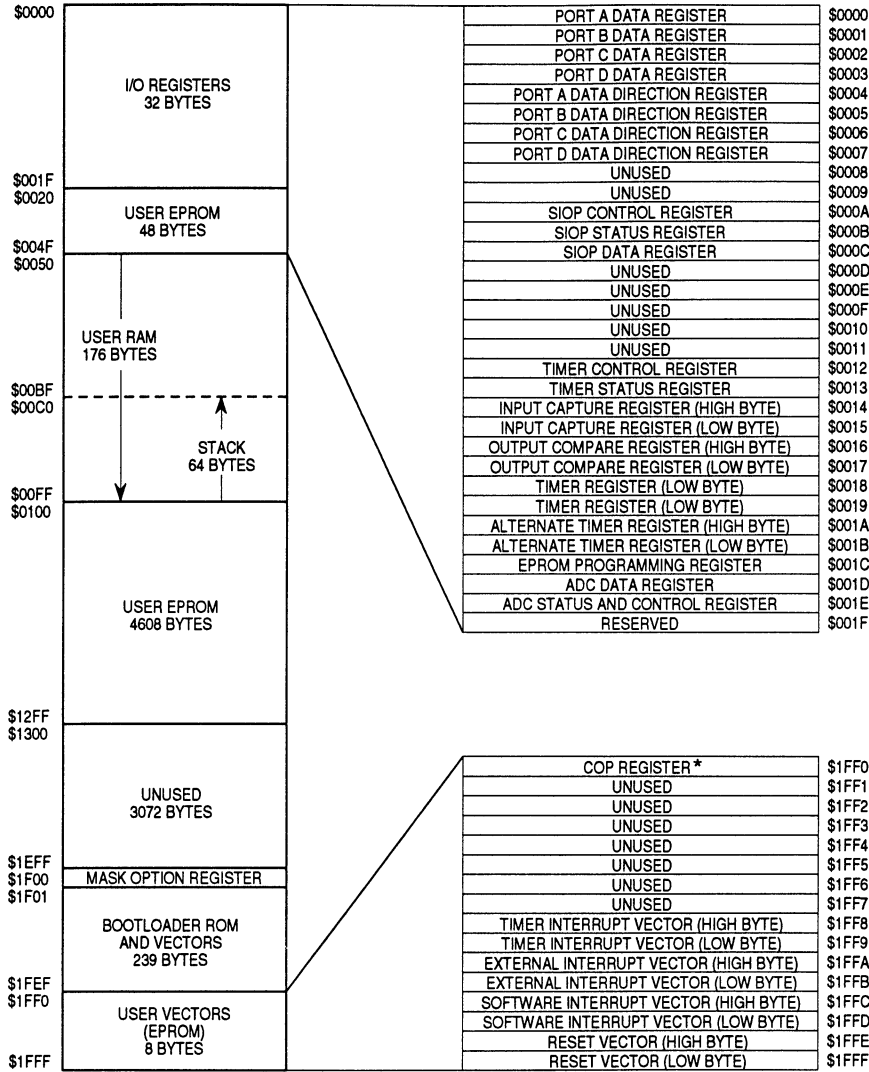
Two of the I/O registers shown in Figure 2-2 are located outside the 32-byte I/O section: the mask option register (MOR) is mapped at \$1F00, and the computer operating properly (COP) register is mapped at \$1FF0.

2.3 RAM

The 176 addresses from \$0050 to \$00FF are RAM locations. The CPU uses the top 64 RAM addresses, \$00C0–\$00FF, as the stack. Before processing an interrupt, the CPU uses five bytes of the stack to save the contents of the CPU registers. During a subroutine call, the CPU uses two stack bytes to store the return address. The stack pointer decrements during pushes and increments during pulls.

NOTE

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



* Writing zero to bit 0 of \$1FF0 clears the COP watchdog timer. Reading \$1FF0 returns user ROM data.

Figure 2-1. Memory Map

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | |
|--------|--------|-------|-------|-------|-------|-------|-------|-------|----------|
| \$0000 | PA7 | PA6 | PA5 | PA4 | PA3 | PA2 | PA1 | PA0 | PORTA |
| \$0001 | PB7 | PB6 | PB5 | 0 | 0 | 0 | 0 | 0 | PORTB |
| \$0002 | PC7 | PC6 | PC5 | PC4 | PC3 | PC2 | PC1 | PC0 | PORTC |
| \$0003 | PD7 | 0 | PD5 | 1 | 0 | 0 | 0 | 0 | PORTD |
| \$0004 | DDRA7 | DDRA6 | DDRA5 | DDRA4 | DDRA3 | DDRA2 | DDRA1 | DDRA0 | DDRA |
| \$0005 | DDRB7 | DDRB6 | DDRB5 | 1 | 1 | 1 | 1 | 1 | DDRB |
| \$0006 | DDRC7 | DDRC6 | DDRC5 | DDRC4 | DDRC3 | DDRC2 | DDRC1 | DDRC0 | DDRC |
| \$0007 | 0 | 0 | DDRD5 | 0 | 0 | 0 | 0 | 0 | DDRD |
| \$0008 | — | — | — | — | — | — | — | — | UNUSED |
| \$0009 | — | — | — | — | — | — | — | — | UNUSED |
| \$000A | 0 | SPE | 0 | MSTR | 0 | 0 | 0 | 0 | SCR |
| \$000B | SPIF | DCOL | 0 | 0 | 0 | 0 | 0 | 0 | SSR |
| \$000C | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | SDR |
| \$000D | | | | | | | | | RESERVED |
| \$000E | — | — | — | — | — | — | — | — | UNUSED |
| \$000F | — | — | — | — | — | — | — | — | UNUSED |
| \$0010 | — | — | — | — | — | — | — | — | UNUSED |
| \$0011 | — | — | — | — | — | — | — | — | UNUSED |
| \$0012 | ICIE | OCIE | TOIE | 0 | 0 | 0 | IEDG | OLVL | TCR |
| \$0013 | ICF | OCF | TOF | 0 | 0 | 0 | 0 | 0 | TSR |
| \$0014 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 | ICRH |
| \$0015 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | ICRL |
| \$0016 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 | OCRH |
| \$0017 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | OCRL |
| \$0018 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 | TCRH |
| \$0019 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | TCRL |
| \$001A | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 | ACRH |
| \$001B | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | ACRL |
| \$001C | 0 | 0 | 0 | 0 | 0 | ELAT | MPGM | EPGM | EPROG |
| \$001D | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 | ADDR |
| \$001E | OC | ADRC | ADON | 0 | 0 | CH2 | CH1 | CH0 | ADSCR |
| \$001F | — | — | — | — | — | — | — | — | RESERVED |
| \$1F00 | | | SWAIT | SPR1 | SPR0 | LSBF | LEVEL | COP | MOR |
| \$1FF0 | | | | | | | | COPC | COPR |

Figure 2-2. I/O Registers

2.4 EPROM/OTPROM

Packages with transparent windows have 4672 bytes of erasable programmable ROM (EPROM). The transparent window allows EPROM erasure with ultraviolet light. Packages without the transparent window do not allow EPROM erasure, and the EPROM serves as one-time programmable ROM (OTPROM). The EPROM/OTPROM is located in three areas of the memory map:

- Addresses \$0020–\$004F contain 48 bytes of page zero EPROM/OTPROM.
- Addresses \$0100–\$12FF contain 4608 bytes of EPROM/OTPROM.
- Addresses \$1FF0–\$1FFF contain 16 bytes of EPROM/OTPROM reserved for vectors.

2.5 Bootloader ROM

Addresses \$1F01–\$1FEF contain the bootloader ROM, which can copy and verify the contents of an external EPROM to the on-chip EPROM/OTPROM. (See 11.1 EPROM/OTPROM Programming.)

SECTION 3 CENTRAL PROCESSOR UNIT

This section describes the CPU registers.

3.1 CPU Registers

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

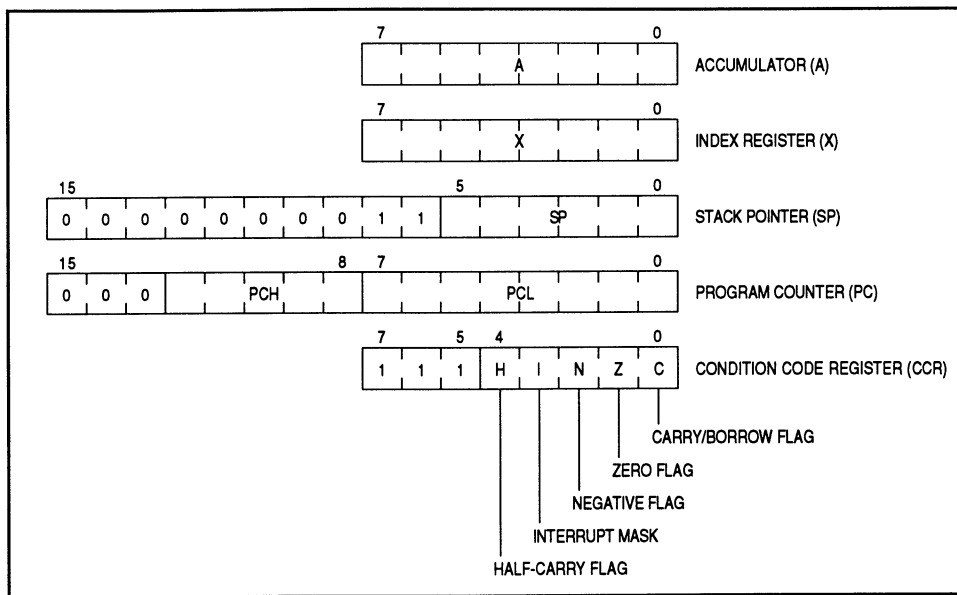


Figure 3-1. Programming Model

3.1.1 Accumulator

The accumulator is a general-purpose 8-bit register. The CPU uses the accumulator to hold operands and results of arithmetic and nonarithmetic operations.

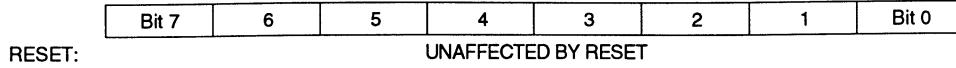


Figure 3-2. Accumulator

3.1.2 Index Register

In the indexed addressing modes, the CPU uses the byte in the index register to determine the conditional address of the operand. (See **12.1 Addressing Modes.**)

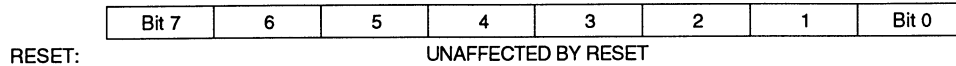


Figure 3-3. Index Register

The 8-bit index register can also serve as a temporary data storage location.

3.1.3 Stack Pointer

The stack pointer is a 16-bit register that contains the address of the next location on the stack. During a reset or after the reset stack pointer (RSP) instruction, the stack pointer is preset to \$00FF. The address in the stack pointer decrements as data is pushed onto the stack and increments as data is pulled from the stack.

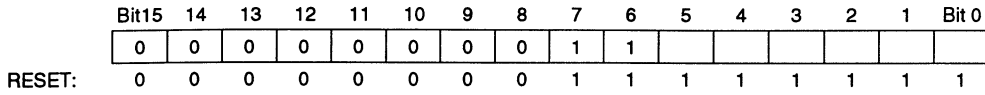


Figure 3-4. Stack Pointer

The ten most significant bits of the stack pointer are permanently fixed at 0000000011, so the stack pointer produces addresses from \$00C0 to \$00FF. If subroutines and interrupts use more than 64 stack locations, the stack pointer wraps around to address \$00FF and begins writing over the previously stored data. A subroutine uses two stack locations; an interrupt uses five locations.

3.1.4 Program Counter

The program counter is a 16-bit register that contains the address of the next instruction or operand to be fetched. The three most significant bits of the program counter are ignored internally and appear as 000.

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

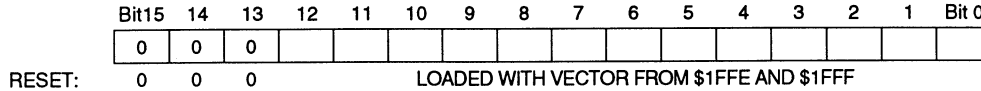


Figure 3-5. Program Counter

3.1.5 Condition Code Register

The condition code register is an 8-bit register whose three most significant bits are permanently fixed at 111. The condition code register contains the interrupt mask and four flags that indicate the results of the instruction just executed. The following paragraphs describe the functions of the condition code register.

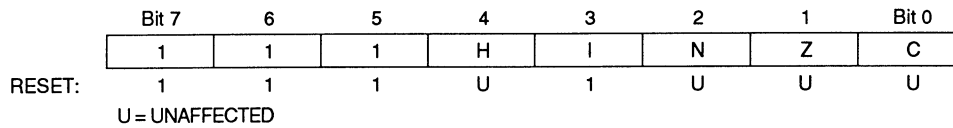


Figure 3-6. Condition Code Register

3.1.5.1 Half-Carry Flag (H)

The CPU sets the half-carry flag when a carry occurs between bits 3 and 4 of the accumulator during an ADD or ADC operation. The half-carry flag is required for binary-coded decimal (BCD) arithmetic operations.

3.1.5.2 Interrupt Mask (I)

Setting the interrupt mask disables interrupts. If an interrupt request occurs while the interrupt mask is logic zero, the CPU saves the CPU registers on the stack, sets the interrupt mask, and then fetches the interrupt vector. If an interrupt request occurs while the interrupt mask is set, the interrupt request is latched. Normally, the CPU processes the latched interrupt as soon as the interrupt mask is cleared again.

A return from interrupt (RTI) instruction pulls the CPU registers from the stack, restoring the interrupt mask to its cleared state. After any reset, the interrupt mask is set and can be cleared only by a software instruction.

3.1.5.3 Negative Flag (N)

The CPU sets the negative flag when an arithmetic operation, logical operation, or data manipulation produces a negative result.

3.1.5.4 Zero Flag (Z)

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

3.1.5.5 Carry/Borrow Flag (C)

The CPU sets the carry/borrow flag when an addition operation produces a carry out of bit 7 of the accumulator or when a subtraction operation requires a borrow. Some logical operations and data manipulation instructions also clear or set the carry/borrow flag.

3.2 Arithmetic/Logic Unit (ALU)

The ALU performs the arithmetic and logical operations defined by the instruction set.

The binary arithmetic circuits decode instructions and set up the ALU for the selected operation. Most binary arithmetic is based on the addition algorithm, carrying out subtraction as negative addition. Multiplication is not performed as a discrete operation but as a chain of addition and shift operations within the ALU. The multiply instruction (MUL) requires 11 internal processor cycles to complete this chain of operations.

SECTION 4 INTERRUPTS

This section describes how interrupts temporarily change the normal processing sequence.

4.1 Interrupt Sources

The following sources can generate interrupt requests:

- SWI instruction
- $\overline{\text{IRQ}}/\text{VPP}$ pin
- Capture/compare timer

An interrupt temporarily stops normal program execution to process a particular event. An interrupt does not stop the execution of the instruction in progress, but takes effect when the current instruction completes its execution. Interrupt processing automatically saves the CPU registers on the stack and loads the program counter with a user-defined interrupt vector address.

4.1.1 Software Interrupt

The software interrupt (SWI) instruction causes a nonmaskable interrupt.

4.1.2 External Interrupt

An interrupt signal on the $\overline{\text{IRQ}}/\text{VPP}$ pin latches an external interrupt request. When the CPU completes its current instruction, it tests the IRQ latch. If the IRQ latch is set, the CPU then tests the I bit in the condition code register. If the I bit is clear, the CPU then begins the interrupt sequence. The CPU clears the IRQ latch while it fetches the interrupt vector, so another external interrupt request can be latched during the interrupt service routine. As soon as the I bit is cleared during the return from interrupt, the CPU can recognize the new interrupt request.

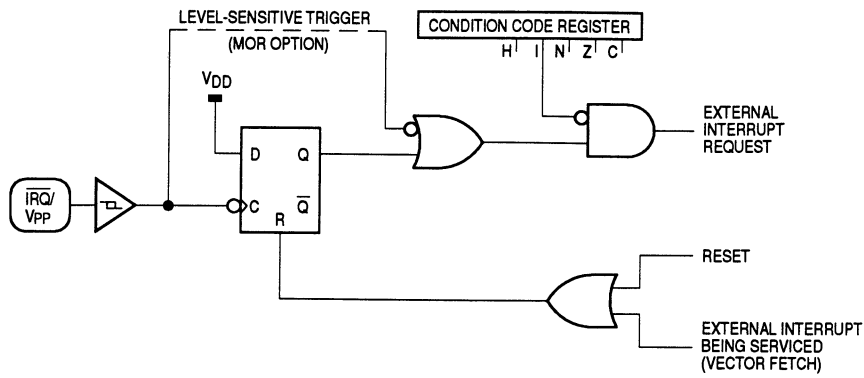


Figure 4-1. External Interrupt Logic

Interrupt triggering sensitivity of the $\bar{I}R\bar{Q}/V_{PP}$ pin is a programmable option. The $\bar{I}R\bar{Q}/V_{PP}$ pin can be negative edge-triggered or negative edge- and low level-triggered. The low level-sensitive triggering option allows the wired-OR use of multiple external interrupt sources. An external interrupt request is latched as long as any source is holding the $\bar{I}R\bar{Q}/V_{PP}$ pin low.

4.1.3 Timer Interrupts

The capture/compare timer can generate the following interrupts:

- Input capture interrupt
- Output compare interrupt
- Timer overflow interrupt

Setting the I bit in the condition code register disables timer interrupts.

4.1.3.1 Input Capture Interrupt

An input capture interrupt request occurs if the input capture flag, ICF, becomes set while the input capture interrupt enable bit, ICIE, is also set. ICF is in the timer status register, and ICIE is in the timer control register. (See **SECTION 8 CAPTURE/COMPARE TIMER.**)

4.1.3.2 Output Compare Interrupt

An output compare interrupt request occurs if the output compare flag, OCF, becomes set while the output compare interrupt enable bit, OCIE, is also set. OCF is in the timer status register, and OCIE is in the timer control register. (See **SECTION 8 CAPTURE/COMPARE TIMER.**)

4.1.3.3 Timer Overflow Interrupt

A timer overflow interrupt request occurs if the timer overflow flag, TOF, becomes set while the timer overflow interrupt enable bit, TOIE, is also set. TOF is in the timer status register, and TOIE is in the timer control register. (See **SECTION 8 CAPTURE/COMPARE TIMER.**)

4.2 Interrupt Processing

The CPU begins servicing an interrupt by taking the following actions:

- Stores the CPU registers on the stack in the order shown in Figure 4-2
- Sets the I bit in the condition code register to prevent further interrupts
- Loads the program counter with the contents of the appropriate interrupt vector locations:
 - \$1FFC and \$1FFD (software interrupt vector)
 - \$1FFA and \$1FFB (external interrupt vector)
 - \$1FF8 and \$1FF9 (timer interrupt vector)

The return from interrupt (RTI) instruction causes the CPU to recover the CPU registers from the stack as shown in Figure 4-2.

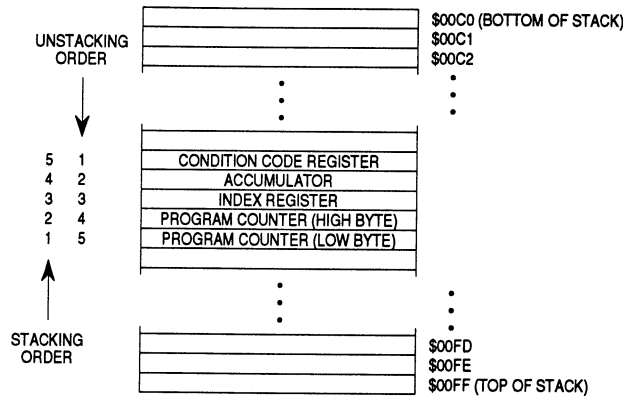


Figure 4-2. Interrupt Stacking Order

Table 4-1 summarizes the reset and interrupt sources and vector assignments.

Table 4-1. Reset/Interrupt Vector Addresses

| Function | Source | Local Mask | Global Mask | Priority (1 = Highest) | Vector Address |
|--------------------------|--|----------------------------------|-------------|------------------------------|----------------|
| Reset | Power-On RESET Pin COP Watchdog* | None | None | 1 1 1 | \$1FFE-\$1FFF |
| Software Interrupt (SWI) | User Code | None | None | Same Priority As Instruction | \$1FFC-\$1FFD |
| External Interrupt | $\overline{\text{IRQ}}/\text{V}_{\text{PP}}$ Pin | None | 1 Bit | 2 | \$1FFA-\$1FFB |
| Timer Interrupts | ICF Bit OCF Bit TOF Bit | ICIE Bit OCIE Bit TOIE Bit | 1 Bit | 3 | \$1FF8-\$1FF9 |

*The COP watchdog is a programmable option.

Figure 4-3 shows the sequence of events caused by an interrupt.

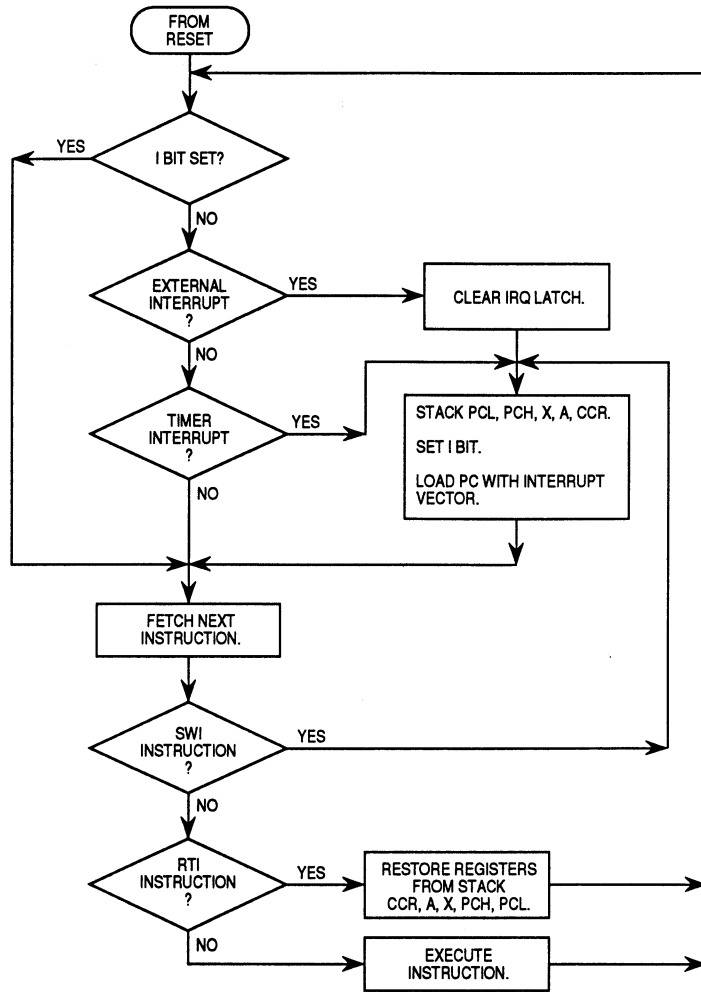


Figure 4-3. Interrupt Flowchart

SECTION 5 RESETS

This section describes the three reset sources and how they initialize the MCU.

5.1 Reset Sources

The following sources can generate resets:

- Power-on reset (POR) circuit
- $\overline{\text{RESET}}$ pin
- COP watchdog

A reset immediately stops the execution of the instruction in progress, initializes certain control bits, and loads the program counter with a user-defined reset vector address. Figure 5-1 is a block diagram of the reset sources.

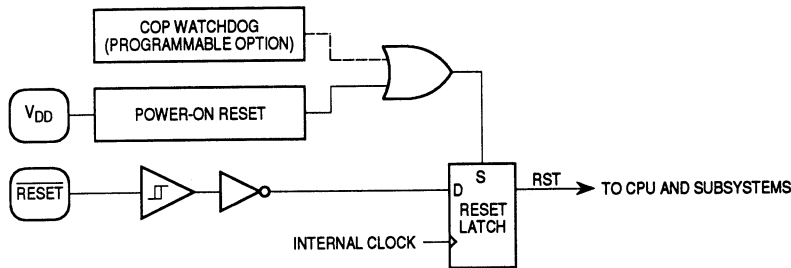


Figure 5-1. Reset Sources

5.1.1 Power-On Reset

A positive transition on the V_{DD} pin generates a power-on reset. The power-on reset is strictly for power-up conditions and cannot be used to detect drops in power supply voltage.

A 4064 t_{CYC} (internal clock cycle) delay after the oscillator becomes active allows the clock generator to stabilize. If the \overline{RESET} pin is at logic zero at the end of 4064 t_{CYC} , the MCU remains in the reset condition until the signal on the \overline{RESET} pin goes to logic one.

5.1.2 External Reset

A logic zero applied to the \overline{RESET} pin for one and one-half t_{CYC} generates an external reset. A Schmitt trigger senses the logic level at the \overline{RESET} pin. Figure 5-2 shows an example of an external reset circuit with an open-collector low voltage inhibit device and a pullup resistor.

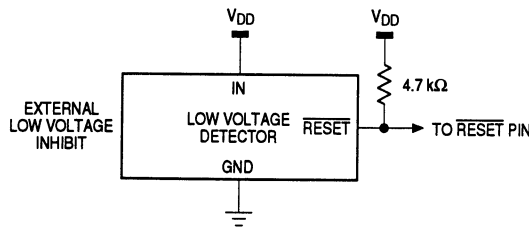


Figure 5-2. Typical External Reset Circuit

5.1.3 Computer Operating Properly (COP) Watchdog Reset

A timeout of the 18-stage ripple counter in the COP watchdog generates a COP reset. The COP watchdog is part of a software error detection system and must be cleared periodically to start a new timeout period. With a 4-MHz oscillator, the COP timeout period is 65.5 ms. To clear the COP watchdog and prevent a COP reset, write a logic zero to bit 0 (COPC) of the COP register at location \$1FF0. The COP register, shown in Figure 5-3, is a write-only register that returns the contents of an EPROM location when read.

The COP watchdog function is programmable in the mask option register.

COPR — COP Register

\$1FF0

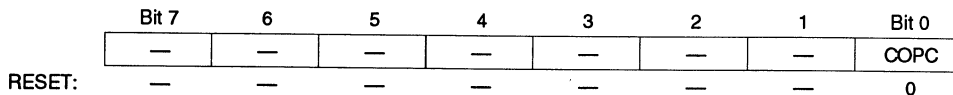


Figure 5-3. COP Register (COPR)

COPC — COP Clear

COPC is a write-only bit. Periodically writing a logic zero to COPC prevents the COP watchdog from resetting the MCU.

5.2 Reset States

The following paragraphs describe how resets initialize the MCU.

5.2.1 CPU

A reset has the following effects on the CPU:

- Loads the stack pointer with \$FF
- Sets the I bit in the condition code register, inhibiting interrupts
- Loads the program counter with the user-defined reset vector from locations \$1FFE and \$1FFF
- Clears the stop latch, enabling the CPU clock
- Clears the wait latch, waking the CPU from the wait mode

5.2.2 I/O Port Registers

A reset has the following effects on I/O port registers:

- Clears data direction registers A, B, C, and D so that all I/O port pins are inputs (PD7/TCAP remains an input-only pin.)
- Has no effect on port A, port B, port C, or port D data registers

5.2.3 Capture/Compare Timer

A reset has the following effects on the capture/compare timer:

- Loads the timer counter with \$FFFC
- Clears the timer control register, except for the IEDG bit, with the following results:
 - Clears the ICIE bit, inhibiting input capture interrupts
 - Clears the OCIE bit, inhibiting output compare interrupts
 - Clears the TOIE bit, inhibiting timer overflow interrupts

- Clears OLVL, the output compare bit
- Clears the TCMP pin
- Has no effect on the ICF, OCF, and TOF flags in the timer status register

5.2.4 Serial I/O Port (SIOP)

A reset clears the SIOP control and status registers and produces the following results:

- Clears the SPE bit, disabling the SIOP
- Clears the MSTR bit, configuring the disabled SIOP for slave mode operation
- Clears the SPIF and DCOL flags

5.2.5 COP Watchdog

A reset clears the COP watchdog counter.

5.2.6 Analog-to-Digital Converter (ADC)

A reset clears the ADC status and control register and produces the following results:

- Clears the ADON bit, disabling the ADC
- Clears the CCF flag
- Clears the ADRC bit, configuring the disabled ADC for operation at internal clock frequency
- Clears bits CH2–CH0, selecting channel 0 as the analog input

SECTION 6 LOW POWER MODES

This section describes the four low power modes:

- Stop mode
- Wait mode
- Halt mode (programmable option)
- Data-retention mode

6.1 Stop Mode

The STOP instruction puts the MCU in its lowest power-consumption mode and has the following effects on the MCU:

- Stops the internal oscillator, the CPU clock, and the internal clock, turning off the capture/compare timer, the COP watchdog, the SIOP, and the ADC
- Clears the I bit in the condition code register, enabling external interrupts
- Clears the ICF, OCF, and TOF interrupt flags in the timer status register, removing any pending timer interrupts
- Clears the ICIE, OCIE, and TOIE bits in the timer control register, disabling further timer interrupts

The STOP instruction does not affect any other registers or any I/O lines.

The following events bring the MCU out of stop mode:

- External interrupt — A high-to-low transition on the \overline{IRQ}/V_{PP} pin loads the program counter with the contents of locations \$1FFA and \$1FFB.
- External reset — A logic zero on the \overline{RESET} pin resets the MCU and loads the program counter with the contents of locations \$1FFE and \$1FFF.

When the MCU exits stop mode, processing resumes after a stabilization delay of 4064 oscillator cycles.

If an external interrupt brings the MCU out of stop mode after an active edge occurred on the PD7/TCAP pin during stop mode, the ICF flag becomes set. An external interrupt also latches the value in the timer registers into the input capture registers.

If an external reset brings the MCU out of stop mode after an active edge occurred on the PD7/TCAP pin during stop mode, the ICF flag does not become set. An external reset has no effect on the input capture registers.

6.2 Wait Mode

The WAIT instruction puts the MCU in an intermediate power-consumption mode and has the following effects on the MCU:

- Clears the I bit in the condition code register, enabling interrupts
- Stops the CPU clock, but allows the internal oscillator and internal clock to continue to run

The WAIT instruction does not affect any other registers or any I/O lines.

The following events restart the CPU clock and bring the MCU out of wait mode:

- External interrupt — A high-to-low transition on the \overline{IRQ}/V_{PP} pin loads the program counter with the contents of locations \$1FFA and \$1FFB.
- Timer interrupt — Input capture, output compare, and timer overflow interrupts load the program counter with the contents of locations \$1FF8 and \$1FF9.

- COP watchdog reset — A timeout of the COP watchdog resets the MCU and loads the program counter with the contents of locations \$1FFE and \$1FFF. Software can enable timer interrupts so that the MCU can periodically exit wait mode to reset the COP watchdog.
- External reset — A logic zero on the $\overline{\text{RESET}}$ pin resets the MCU and loads the program counter with the contents of locations \$1FFE and \$1FFF.

6.3 Halt Mode

If the SWAIT bit in the mask option register is programmed to logic one, a STOP instruction puts the MCU in halt mode. The halt mode is identical to the wait mode, except that a recovery delay of 1–4064 internal clock cycles occurs when the MCU exits the halt mode. If SWAIT is programmed to logic one, the COP watchdog cannot be inadvertently turned off by a STOP instruction.

Figure 6-1 shows the sequence of events in stop, wait, and halt modes.

6.4 Data-Retention Mode

In data-retention mode, the MCU retains RAM contents and CPU register contents at V_{DD} voltages as low as 2.0 Vdc. The data-retention feature allows the MCU to remain in a low power-consumption state during which it retains data, but the CPU cannot execute instructions.

To put the MCU in data-retention mode:

1. Drive the $\overline{\text{RESET}}$ pin to logic zero.
2. Lower the V_{DD} voltage. The $\overline{\text{RESET}}$ pin must remain low continuously during data-retention mode.

To take the MCU out of data-retention mode:

1. Return V_{DD} to normal operating voltage.
2. Return the $\overline{\text{RESET}}$ pin to logic one.

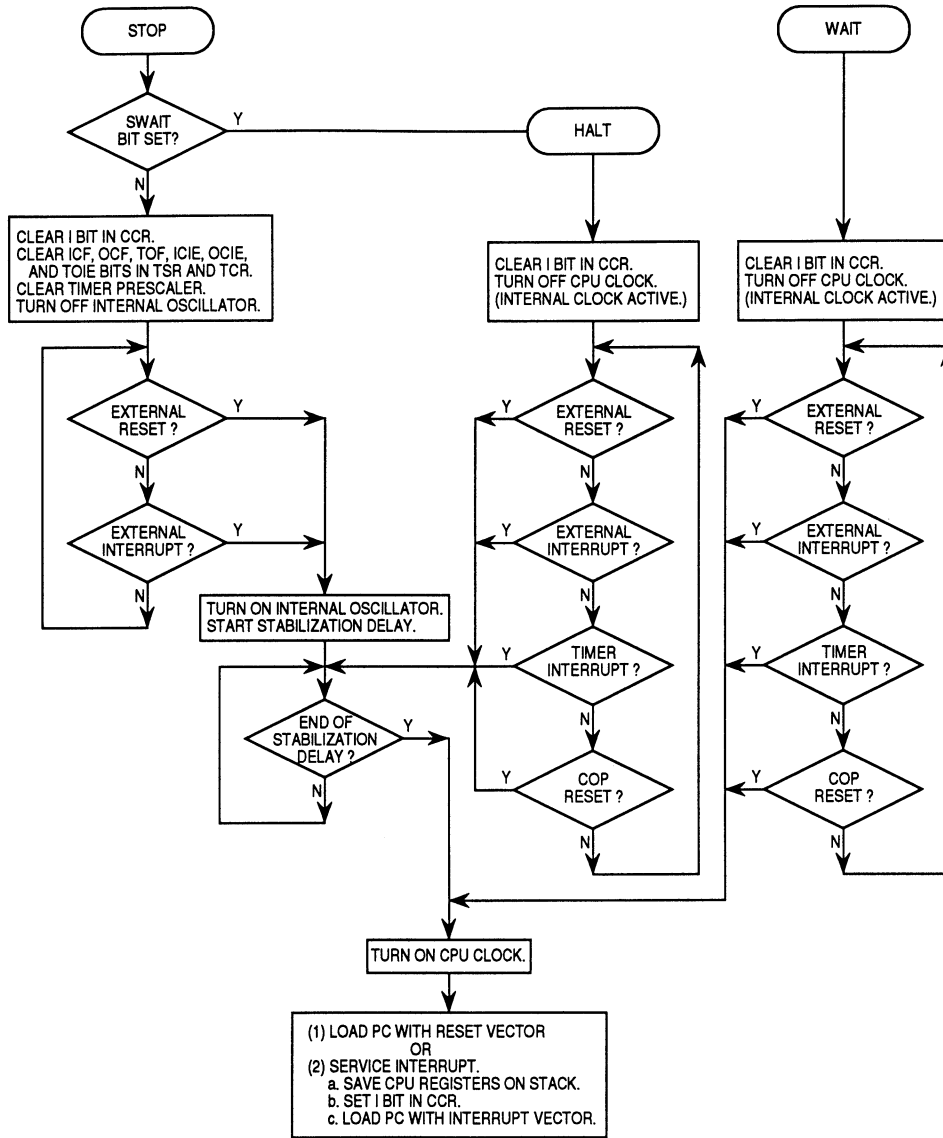


Figure 6-1. STOP/HALT/WAIT Flowchart

SECTION 7 PARALLEL I/O

This section describes the four bidirectional I/O ports.

7.1 I/O Port Function

Twenty bidirectional I/O pins and one input-only pin form four parallel I/O ports. The 20 bidirectional I/O pins are programmable as inputs or outputs through the four data direction registers.

NOTE

Connect any unused inputs and I/O pins to an appropriate logic level, either V_{DD} or V_{SS} . Although the I/O ports do not require termination for proper operation, termination reduces excess current consumption and the possibility of electrostatic damage.

7.2 Port A

Port A is an 8-bit general-purpose bidirectional I/O port.

7.2.1 Port A Data Register (PORTA)

The port A data register, shown in Figure 7-1, contains a data latch for each of the eight port A pins.

PORTA — Port A Data Register

\$0000

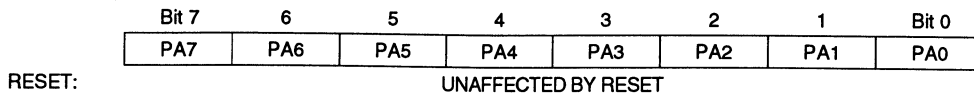


Figure 7-1. Port A Data Register (PORTA)

PA7–PA0 — Port A Data Bits

These read/write bits are software-programmable. Data direction of each bit is under the control of the corresponding bit in data direction register A. Resets have no effect on port A data.

7.2.2 Data Direction Register A (DDRA)

Data direction register A, shown in Figure 7-2, determines whether each port A pin is an input or an output. Writing a logic one to a DDRA bit enables the output buffer for the corresponding port A pin; a logic zero disables the output buffer.

DDRA — Data Direction Register A

\$0004

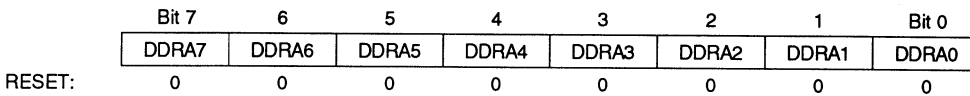


Figure 7-2. Data Direction Register A (DDRA)

DDRA7–DDRA0 — Port A Data Direction Bits

These read/write bits control port A data direction. A reset clears all DDRA bits, configuring all port A pins as inputs.

- 1 = Corresponding port A pin configured as output
- 0 = Corresponding port A pin configured as input

NOTE

Avoid glitches on port A pins by writing to the port A data register before changing data direction register A bits from 0 to 1.

Figure 7-3 shows the port A I/O logic.

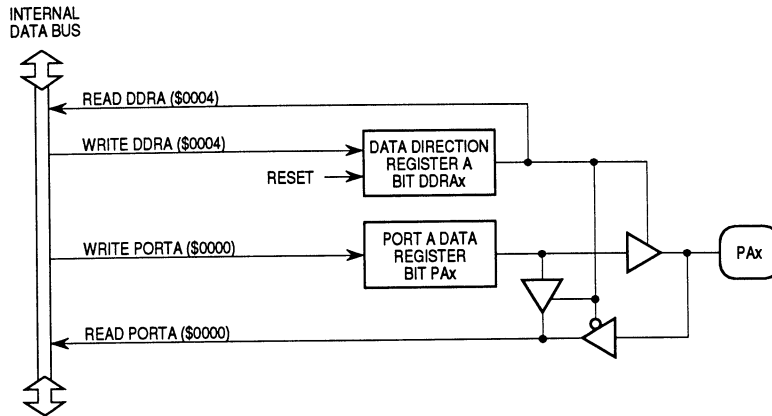


Figure 7-3. Port A I/O Circuit

When a port A pin is programmed as an output, reading the port bit reads the value of the data latch and not the voltage on the pin. When a port A pin is programmed as an input, reading the port bit reads the voltage level on the pin. The data register can always be written, regardless of the state of its DDRA bit. Table 7-1 summarizes the operations of the port A pins.

Table 7-1. Port A Pin Functions

| DDRA Bit | PORTA Bit | I/O Pin Mode | Accesses to DDRA | | Accesses to PORTA | |
|----------|-----------|--------------|------------------|-------|-------------------|--|
| | | | Read/Write | Read | Write | |
| 0 | X | Input, hi-Z | DDRA7-0 | Pin | NOTE 2 | |
| 1 | X | Output | DDRA7-0 | PA7-0 | PA7-0 | |

NOTES:

1. X = don't care.
2. Writing affects data register, but does not affect input.
3. Hi-Z = high impedance.

7.3 Port B

Port B is a 3-bit general-purpose bidirectional I/O port that shares its pins with the serial I/O port (SIOP) subsystem. Port B is available for general-purpose I/O functions when the SIOP is disabled. While the SIOP is enabled and a serial data transmission is in progress, writing to the port B data register or to bits DDRB7-5 of data direction register B can corrupt the SIOP data. (See 9.2.1 SIOP Control Register (SCR).)

7.3.1 Port B Data Register (PORTB)

The port B data register, shown in Figure 7-4, contains a data latch for each of the three port B pins.

PORTB — Port B Data Register

\$0001

| Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|-------|-----|-----|---|---|---|---|-------|
| PB7 | PB6 | PB5 | 0 | 0 | 0 | 0 | 0 |

RESET: UNAFFECTED BY RESET
 ALTERNATE FUNCTION: SCK SDI SDO

Figure 7-4. Port B Data Register (PORTB)

PB7-PB5 — Port B Data Bits

These read/write bits are software-programmable. Data direction of each bit is under the control of the corresponding bit in data direction register B. Resets have no effect on port B data.

Bits 4-0 — Not used

Bits 4-0 always read as logic zeros. Writes to these bits have no effect.

7.3.2 Data Direction Register B (DDRB)

Data direction register B determines whether each port B pin is an input or an output. (See Figure 7-5.) Writing a logic one to a DDRB bit enables the output buffer for the corresponding port B pin; a logic zero disables the output buffer.

DDRC — Data Direction Register B \$0005

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|-------|-------|---|---|---|---|-------|
| | DDRB7 | DDRB6 | DDRB5 | 1 | 1 | 1 | 1 | 1 |
| RESET: | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

Figure 7-5. Data Direction Register B (DDRB)

DDRB7–DDRB5 — Port B Data Direction Bits

These read/write bits control port B data direction. A reset clears DDRB7–DDRB5, configuring pins PB7–PB5 as inputs.

- 1 = Corresponding port B pin configured as output
- 0 = Corresponding port B pin configured as input

Bits 4–0 — Not used

Bits 4–0 always read as logic ones. Writes to these bits have no effect.

NOTE

Avoid glitches on port B pins by writing to the port B data register before changing data direction register B bits from 0 to 1.

Figure 7-6 shows the port B I/O logic.

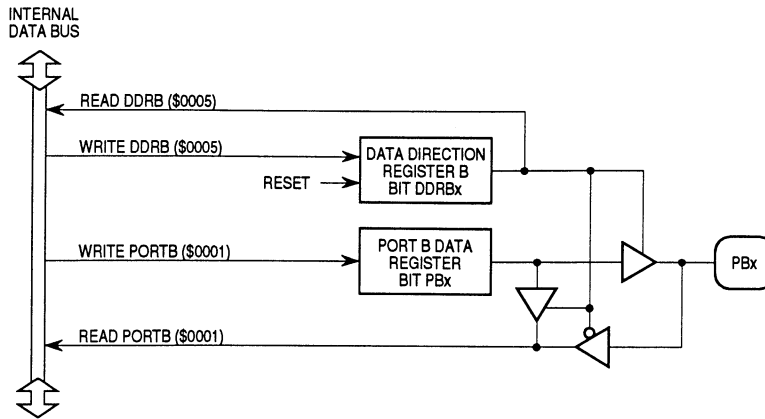


Figure 7-6. Port B I/O Circuit

When a port B pin is programmed as an output, reading the port bit actually reads the value of the data latch and not the voltage on the pin. When a port B pin is programmed as an input, reading the port bit reads the voltage level on the pin. The data latch can always be written, regardless of the state of its DDRB bit. Table 7-2 summarizes the operation of the port B pins.

Table 7-2. Port B Pin Functions

| DDRB Bit | PORTB Bit | I/O Pin Mode | Accesses to DDRB | Accesses to PORTB | |
|----------|-----------|--------------|------------------|-------------------|--------|
| | | | Read/Write | Read | Write |
| 0 | X | Input, hi-Z | DDRB7-5 | Pin | NOTE 2 |
| 1 | X | Output | DDRB7-5 | PB7-5 | PB7-5 |

NOTES:

1. X = don't care.
2. Writing affects data register, but does not affect input.
3. Hi-Z = high impedance.

7.4 Port C

Port C is an 8-bit general-purpose bidirectional I/O port that shares five of its pins with the analog-to-digital converter (ADC) subsystem. The five shared pins are available for general-purpose I/O functions when the ADC is disabled. While the ADC is enabled, writing to bits PC7–3 of the port C data register or to bits DDRC7–3 of data direction register C can produce unpredictable ADC results. (See 10.2.1 ADC Status and Control Register (ADSCR).)

7.4.1 Port C Data Register (PORTC)

The port C data register, shown in Figure 7-7, contains a data latch for each of the eight port C pins.

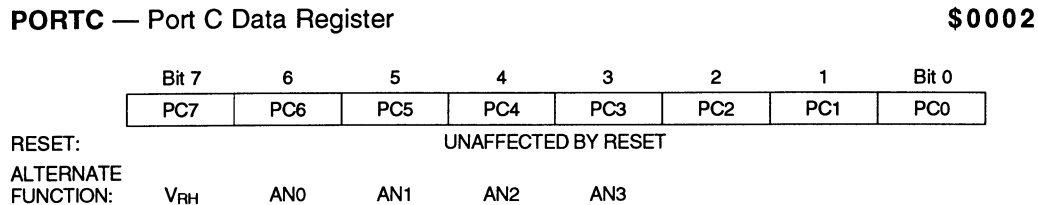


Figure 7-7. Port C Data Register (PORTC)

PC7–PC0 — Port C Data Bits

These read/write bits are software-programmable. Data direction of each bit is under the control of the corresponding bit in data direction register C. Resets have no effect on port C data.

7.4.2 Data Direction Register C (DDRC)

Data direction register C determines whether each port C pin is an input or an output. (See Figure 7-8.) Writing a logic one to a DDRC bit enables the output buffer for the corresponding port C pin; a logic zero disables the output buffer. A reset initializes all DDRC bits to logic zero, configuring all port C pins as inputs.

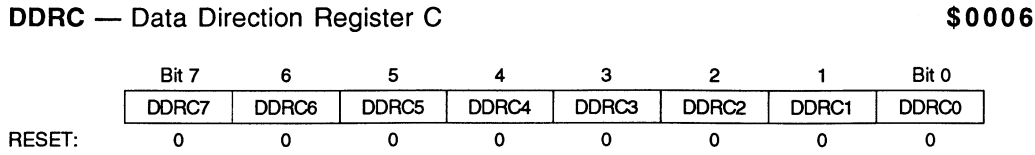


Figure 7-8. Data Direction Register C (DDRC)

DDRC7–DDRC0 — Port C Data Direction Bits

These read/write bits control port C data direction. A reset clears all DDRC bits, configuring all port C pins as inputs.

- 1 = Corresponding port C pin configured as output
- 0 = Corresponding port C pin configured as input

NOTE

Avoid glitches on port C pins by writing to the port C data register before changing data direction register C bits from 0 to 1.

Figure 7-9 shows the port C I/O logic.

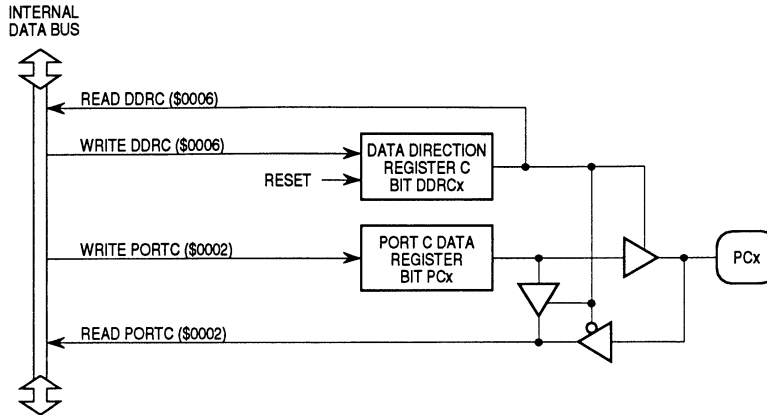


Figure 7-9. Port C I/O Circuit

When a port C pin is programmed as an output, reading the port bit actually reads the value of the data latch and not the voltage on the pin. When a port C pin is programmed as an input, reading the port bit reads the voltage level on the pin. The data register can always be written, regardless of the state of its DDRC bit. Table 7-3 summarizes the operation of the port C pins.

Table 7-3. Port C Pin Functions

| DDRC Bit | PORTC Bit | I/O Pin Mode | Accesses to DDRC | Accesses to PORTC | |
|----------|-----------|--------------|------------------|-------------------|--------|
| | | | Read/Write | Read | Write |
| 0 | X | Input, hi-Z | DDRC7-0 | Pin | NOTE 2 |
| 1 | X | Output | DDRC7-0 | PC7-0 | PC7-0 |

NOTES:

1. X = don't care.
2. Writing affects data register, but does not affect input.
3. Hi-Z = high impedance.

7.5 Port D

Port D is a 2-bit general-purpose I/O port with one bidirectional pin, PD5, and one input-only pin, PD7/TCAP. Port D shares pin PD7/TCAP with the capture/compare timer. PD7/TCAP is always available for general-purpose I/O functions, and the state of the pin can be read from the port D data register at any time.

7.5.1 Port D Data Register (PORTD)

The port D data register, shown in Figure 7-10, contains a data latch for each of the two port D pins.

PORTD — Port D Data Register **\$0003**

| | | | | | | | |
|-------|---|-----|---|---|---|---|-------|
| Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
| PD7 | 0 | PD5 | 1 | 0 | 0 | 0 | 0 |

RESET: UNAFFECTED BY RESET

ALTERNATE
FUNCTION: TCAP

Figure 7-10. Port D Data Register (PORTD)

PD7 — This read/write bit is software-programmable. The PD7/TCAP pin can be a general-purpose input even when the timer is using it as the input capture pin. Resets have no effect on PD7.

PD5 — This read/write bit is software-programmable. Data direction of PD5 is under the control of bit DDRD5 in data direction register D. Resets have no effect on PD5.

Bit 6 and Bits 4–0 — Not used

Bit 6 and bits 4–0 always read as logic zeros. Writes to these bits have no effect.

7.5.2 Data Direction Register D (DDRD)

Bit DDRD5 in data direction register D, shown in Figure 7-11, determines whether pin PD5 is an input or an output. Writing a logic one to bit DDRD5 enables the output buffer for pin PD5; a logic zero disables the output buffer.

DDRD — Data Direction Register D **\$0007**

| | | | | | | | | |
|--------|-------|---|-------|---|---|---|---|-------|
| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
| | 0 | 0 | DDRD5 | 0 | 0 | 0 | 0 | 0 |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 7-11. Data Direction Register D (DDRD)

DDRD5 — PD5 Data Direction Bit

This read/write bit controls pin PD5 data direction. A reset clears DDRD5, configuring pin PD5 as an input.

- 1 = Pin PD5 configured as output
- 0 = Pin PD5 configured as input

Bits 7–6 and bits 4–0 — Not used

Bits 7–6 and 4–0 always read as logic zeros. Writes to these bits have no effect.

NOTE

Avoid glitches on PD5 by writing to PD5 before changing DDRD5 from 0 to 1.

Figure 7-12 shows the port D I/O logic.

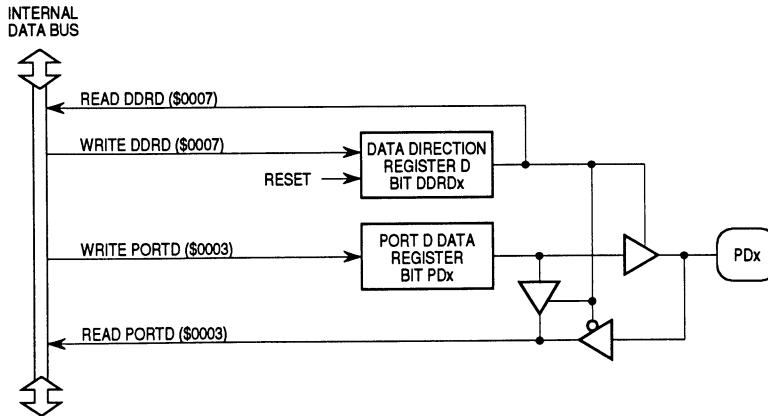


Figure 7-12. Port D I/O Circuit

When pin PD5 is programmed as an output, reading the port bit actually reads the value of the data latch and not the voltage on the pin. When pin PD5 is programmed as an input, reading bit PD5 reads the voltage level on the pin. Bit PD5 can always be written, regardless of the state of bit DDRD5 in data direction register D. Table 7-4 summarizes the operation of the port D pins.

Table 7-4. Port D Pin Functions

| DDRD Bit | PORTD Bit | I/O Pin Mode | Accesses to DDRD | | Accesses to PORTD | |
|----------|-----------|--------------|------------------|--|-------------------|--------|
| | | | Read/Write | | Read | Write |
| 0 | X | Input, hi-Z | DDRD5 | | Pin | NOTE 2 |
| 1 | X | Output | DDRD5 | | PD5 | PD5 |

- NOTES:
1. X = don't care.
 2. Writing affects data register, but does not affect input.
 3. Hi-Z = high impedance.

SECTION 8 CAPTURE/COMPARE TIMER

This section describes the operation of the 16-bit capture/compare timer. Figure 8-1 shows the organization of the capture/compare timer subsystem.

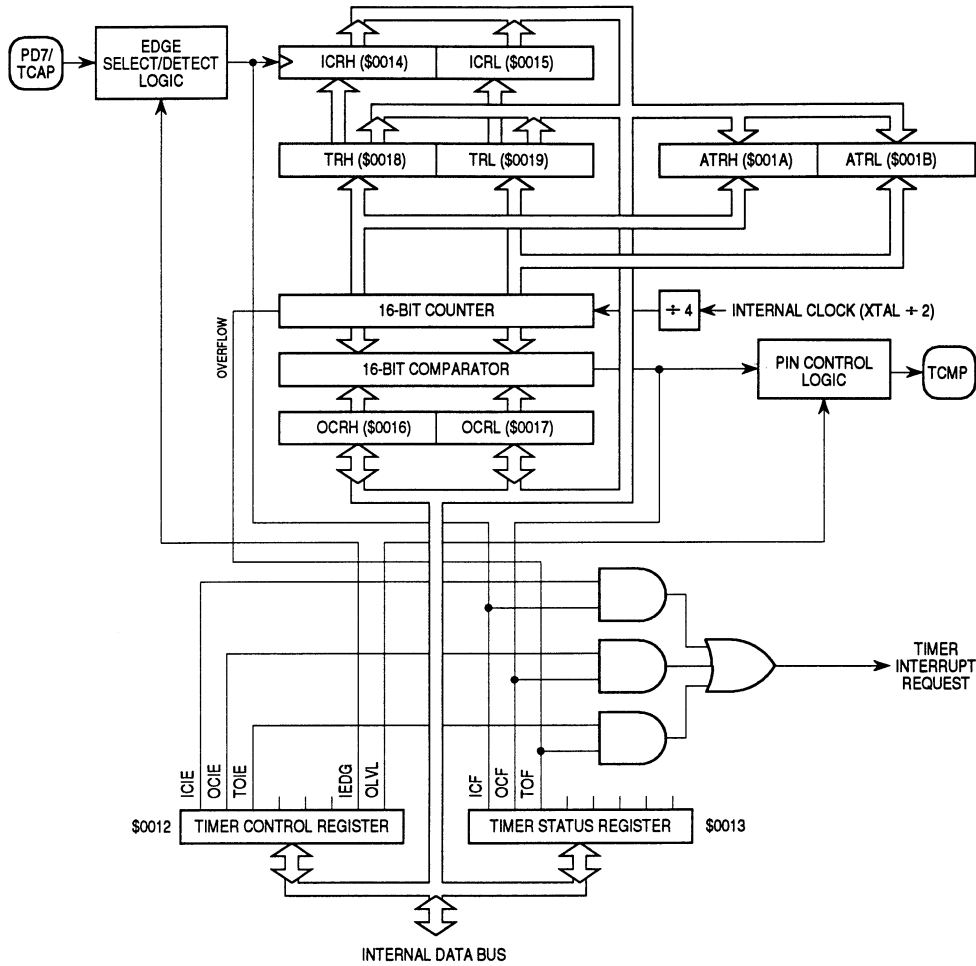


Figure 8-1. Timer Block Diagram

8.1 Timer Operation

The core of the capture/compare timer is a 16-bit free-running counter. The counter is the timing reference for the input capture and output compare functions. The input capture and output compare functions provide a means to latch the times at which external events occur, to measure input waveforms, and to generate output waveforms and timing delays. Software can read the value in the 16-bit free-running counter at any time without affecting the counter sequence.

Because of the 16-bit timer architecture, the I/O registers for the input capture and output compare functions are pairs of 8-bit registers.

Because the counter is 16 bits long and preceded by a fixed divide-by-four prescaler, the counter rolls over every 262,144 internal clock cycles. Timer resolution with a 4-MHz crystal is 2 μ s.

8.1.1 Input Capture

The input capture function is a means to record the time at which an external event occurs. When the input capture circuitry detects an active edge on the PD7/TCAP pin, it latches the contents of the timer registers into the input capture registers. The polarity of the active edge is programmable.

Latching values into the input capture registers at successive edges of the same polarity measures the period of the input signal on the PD7/TCAP pin. Latching the counter values at successive edges of opposite polarity measures the pulse width of the signal. Figure 8-2 shows the logic of the input capture function.

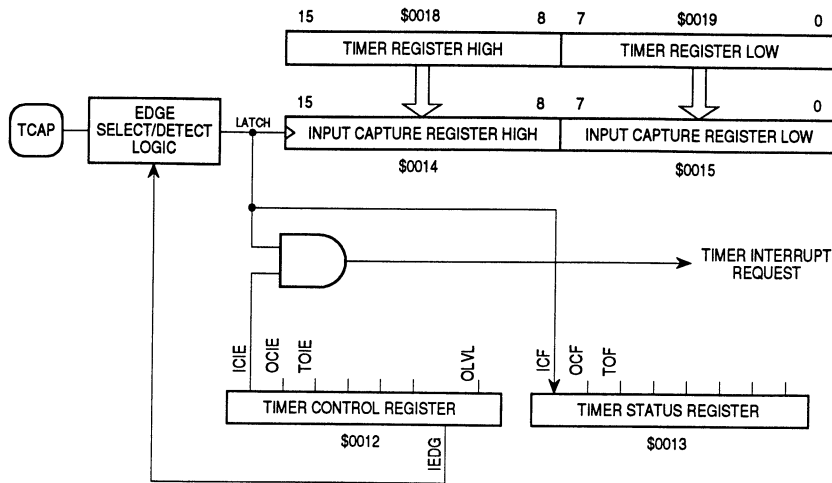


Figure 8-2. Input Capture Operation

8.1.2 Output Compare

The output compare function is a means of generating an output signal when the 16-bit counter reaches a selected value. Software writes the selected value into the output compare registers. On every fourth internal clock cycle the output compare circuitry compares the value of the counter to the value written in the output compare registers. When a match occurs, the timer transfers the programmable output level bit (OLVL) from the timer control register to the TCMP pin.

Software can use the output compare register to measure time periods, to generate timing delays, or to generate a pulse of specific duration or a pulse train of specific frequency and duty cycle on the TCMP pin. Figure 8-3 shows the logic of the output compare function.

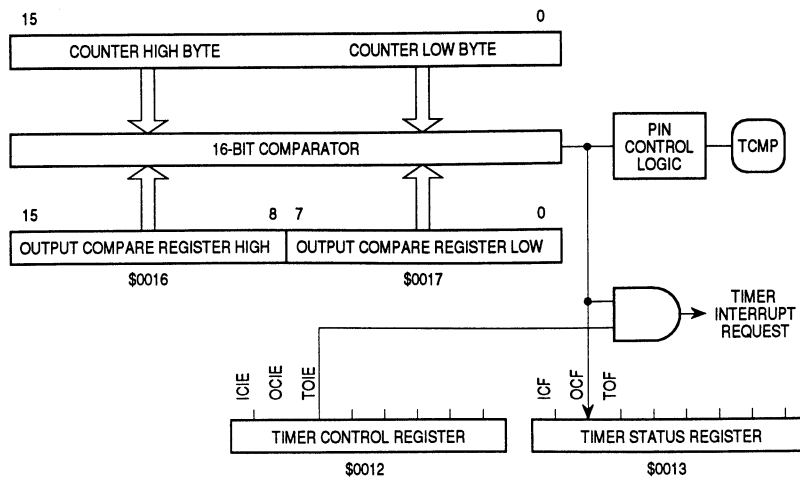


Figure 8-3. Output Compare Operation

8.2 Timer I/O Registers

The following registers control and monitor the operation of the timer:

- Timer control register (TCR)
- Timer status register (TSR)
- Timer registers (TRH and TRL)
- Alternate timer registers (ATRH and ATRL)
- Input capture registers (ICRH and ICRL)
- Output compare registers (OCRH and OCRL)

8.2.1 Timer Control Register (TCR)

The timer control register, shown in Figure 8-4, performs the following functions:

- Enables input capture interrupts
- Enables output compare interrupts
- Enables timer overflow interrupts
- Controls the active edge polarity of the TCAP signal
- Controls the active level of the TCMP output

TCR — Timer Control Register

\$0012

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|------|------|---|---|---|------|-------|
| | ICIE | OCIE | TOIE | 0 | 0 | 0 | IEDG | OLVL |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | U | 0 |

U = UNAFFECTED

Figure 8-4. Timer Control Register (TCR)

ICIE — Input Capture Interrupt Enable

This read/write bit enables interrupts caused by an active signal on the TCAP pin.

Resets clear the ICIE bit.

- 1 = Input capture interrupts enabled
- 0 = Input capture interrupts disabled

OCIE — Output Compare Interrupt Enable

This read/write bit enables interrupts caused by an active signal on the TCMP pin.

Resets clear the OCIE bit.

- 1 = Output compare interrupts enabled
- 0 = Output compare interrupts disabled

TOIE — Timer Overflow Interrupt Enable

This read/write bit enables interrupts caused by a timer overflow. Resets clear the

TOIE bit.

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

IEDG — Input Edge

The state of this read/write bit determines whether a positive or negative transition on the TCAP pin triggers a transfer of the contents of the timer register to the input capture register. Resets have no effect on the IEDG bit.

- 1 = Positive edge (low to high transition) triggers input capture
- 0 = Negative edge (high to low transition) triggers input capture

OLVL — Output Level

The state of this read/write bit determines whether a logic one or a logic zero appears on the TCMP pin when a successful output compare occurs. Resets clear the OLVL bit.

- 1 = TCMP goes high on output compare
- 0 = TCMP goes low on output compare

8.2.2 Timer Status Register (TSR)

The timer status register, shown in Figure 8-5, contains flags for the following events:

- An active signal on the TCAP pin, transferring the contents of the timer registers to the input capture registers
- A match between the 16-bit counter and the output compare registers, transferring the OLVL bit to the TCMP pin
- A timer rollover from \$FFFF to \$0000

TSR — Timer Status Register

\$0012

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|-----|-----|---|---|---|---|-------|
| | ICF | OCF | TOF | 0 | 0 | 0 | 0 | 0 |
| RESET: | U | U | U | 0 | 0 | 0 | 0 | 0 |

U = UNAFFECTED

Figure 8-5. Timer Status Register (TSR)

ICF — Input Capture Flag

The ICF bit is automatically set when an edge of the selected polarity occurs on the TCAP pin. Clear the ICF bit by reading the timer status register with ICF set, and then reading the low byte (\$0015) of the input capture registers. Resets have no effect on ICF.

OCF — Output Compare Flag

The OCF bit is automatically set when the value of the timer registers matches the contents of the output compare registers. Clear the OCF bit by reading the timer status register with OCF set, and then accessing the low byte (\$0017) of the output compare registers. Resets have no effect on OCF.

TOF — Timer Overflow Flag

The TOF bit is automatically set when the 16-bit counter rolls over from \$FFFF to \$0000. Clear the TOF bit by reading the timer status register with TOF set, and then accessing the low byte (\$0019) of the timer registers. Resets have no effect on TOF.

8.2.3 Timer Registers (TRH and TRL)

The timer registers, shown in Figure 8-6, contain the current high and low bytes of the 16-bit counter. Reading TRH before reading TRL causes TRL to be latched until TRL is read. Reading TRL after reading the timer status register clears the timer overflow flag (TOF). Writing to the timer registers has no effect.

TRH and TRL — Timer Register High/Low \$0018 and \$0019

| | | | | | | | | |
|--------|--------|----|----|----|----|----|---|-------|
| \$0018 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 |
| \$0019 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |

Reset initializes the timer registers to \$FFFC.

Figure 8-6. Timer Registers (TRH and TRL)

Reading TRH returns the current value of the high byte of the counter and causes the low byte to be latched into a buffer, as shown in Figure 8-7. The buffer value remains fixed even if the high byte is read more than once. Reading TRL reads the transparent low byte buffer and completes the read sequence of the timer registers.

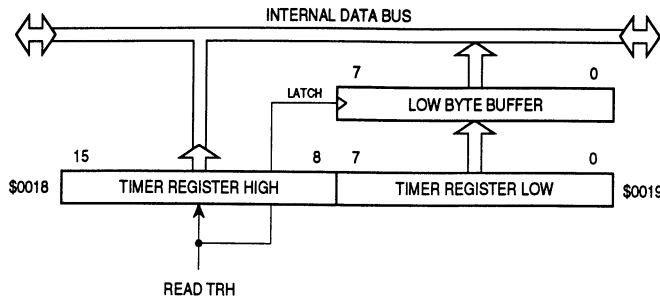


Figure 8-7. Timer Register Reads

NOTE

To prevent interrupts from occurring between readings of TRH and TRL, set the interrupt flag in the condition code register before reading TRH, and clear the flag after reading TRL.

8.2.4 Alternate Timer Registers (ATRH and ATRL)

The alternate timer registers, shown in Figure 8-8, contain the current high and low bytes of the 16-bit counter. Reading ATRH before reading ATRL causes ATRL to be latched until ATRL is read. Reading does not affect the timer overflow flag (TOF). Writing to the alternate timer registers has no effect.

ATRH and ATRL — Alternate Timer Register High/Low \$001A and \$001B

| | | | | | | | | |
|--------|--------|----|----|----|----|----|---|-------|
| \$001A | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 |
| \$001B | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |

Reset initializes the alternate timer registers to \$FFFC.

Figure 8-8. Alternate Timer Registers (ATRH and ATRL)

Reading ATRH returns the current value of the high byte of the counter and causes the low byte to be latched into a buffer, as shown in Figure 8-9. The buffer value remains fixed even if the high byte is read more than once. Reading ATRL reads the transparent low byte buffer and completes the read sequence of the alternate timer registers.

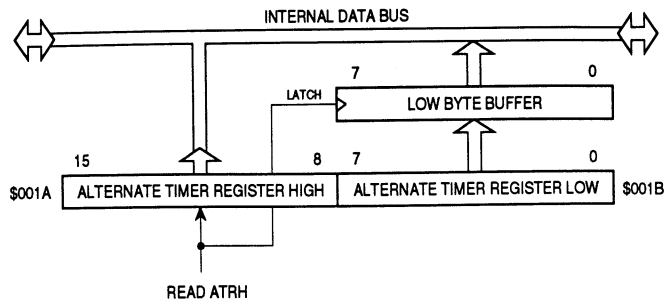


Figure 8-9. Alternate Timer Register Reads

NOTE

To prevent interrupts from occurring between readings of ATRH and ATRL, set the interrupt flag in the condition code register before reading ATRH, and clear the flag after reading ATRL.

8.2.5 Input Capture Registers (ICRH and ICRL)

When a selected edge occurs on the TCAP pin, the current high and low bytes of the 16-bit counter are latched into the input capture registers, as shown in Figure 8-10. Reading ICRH before reading ICRL inhibits further captures until ICRL is read. Reading ICRL after reading the timer status register clears the input capture flag (ICF). Writing to the input capture registers has no effect.

ICRH and ICRL — Input Capture Register High/Low \$0014 and \$0015

| | | | | | | | | |
|--------|--------|----|----|----|----|----|---|-------|
| \$0014 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 |
| \$0015 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |

Reset does not affect the input capture registers.

Figure 8-10. Input Capture Registers (ICRH and ICRL)

NOTE

To prevent interrupts from occurring between readings of ICRH and ICRL, set the interrupt flag in the condition code register before reading ICRH, and clear the flag after reading ICRL.

8.2.6 Output Compare Registers (OCRH and OCRL)

When the value of the 16-bit counter matches the value in the output compare registers, shown in Figure 8-11, the planned TCMP pin action takes place. Writing to OCRH before writing to OCRL inhibits timer compares until OCRL is written. Reading or writing to OCRL after reading the timer status register clears the output compare flag (OCF).

OCRH and OCRL — Output Compare Register High/Low \$0016 and \$0017

| | | | | | | | | |
|--------|--------|----|----|----|----|----|---|-------|
| \$0016 | Bit 15 | 14 | 13 | 12 | 11 | 10 | 9 | Bit 8 |
| \$0017 | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |

Reset does not affect the output compare registers.

Figure 8-11. Output Compare Registers (OCRH and OCRL)

To prevent OCF from being set between the time it is read and the time the output compare registers are updated, use the following procedure:

1. Disable interrupts by setting the I bit in the condition code register.
2. Write to OCRH. Compares are now inhibited until OCRL is written.
3. Clear bit OCF by reading the timer status register (TSR).
4. Enable the output compare function by writing to OCRL.
5. Enable interrupts by clearing the I bit in the condition code register.

SECTION 9 SERIAL I/O PORT (SIOP)

This section describes the operation of the serial I/O port (SIOP). Figure 9-1 shows the structure of the SIOP subsystem.

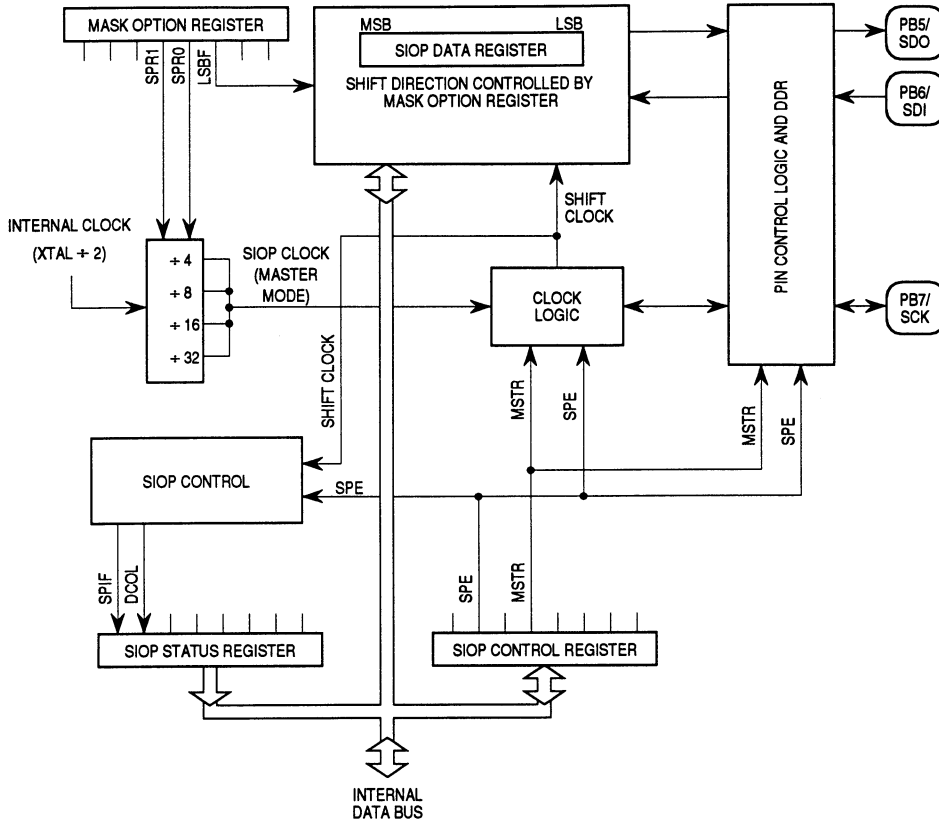


Figure 9-1. SIOP Block Diagram

9.1 SIOP Operation

The SIOP enables high-speed synchronous serial data transmission between the MCU and peripheral devices. Shift registers used with the SIOP can increase the number of parallel I/O pins controlled by the MCU. More powerful peripherals such as analog-to-digital converters and real-time clocks are also compatible with the SIOP. A programmable option allows the SIOP to transmit data MSB-first or LSB-first.

9.1.1 SIOP Pin Functions

The SIOP uses the three port B I/O pins. Setting the SPE bit in the SIOP control register enables the SIOP. When the SPE bit is set, the PB7/SCK, PB6/SDI, and PB5/SDO pins are dedicated to SIOP functions. When the SPE bit is clear, the PB7/SCK, PB6/SDI, and PB5/SDO pins are bidirectional port B I/O pins.

Setting the MSTR bit in the SIOP control register configures the SIOP for master mode. In master mode, the PB7/SCK pin is the serial clock output. PB6/SDI is the serial data input pin, and PB5/SDO is the serial data output pin. The master MCU initiates and controls the transmission of data to and from one or more slave peripheral devices. In master mode, a transmission is initiated by writing to the SIOP data register. Data written to the SIOP data register is parallel-loaded and shifted out serially to the slave device(s).

9.1.2 Serial Clock

The PB7/SCK pin synchronizes the movement of data into and out of the MCU through the PB6/SDI and PB5/SDO pins. In master mode, the PB7/SCK pin is an output. The transmission rate for master mode is programmable through the mask option register. (See **11.3 Mask Option Register (MOR)**.)

In slave mode, the PB7/SCK pin is an input. The maximum serial clock rate for slave mode is the maximum internal clock rate divided by four. There is no minimum serial clock frequency for slave mode.

Figure 9-2 shows the timing relationships between the serial clock, data input, and data output. The state of the serial clock between transmissions is a logic one. The first falling edge on the PB7/SCK pin signals the beginning of a transmission, and data appears at the PB5/SDO pin. Data is captured at the PB6/SDI pin on the rising edge of the serial clock, and the transmission ends on the eighth rising edge of the serial clock.

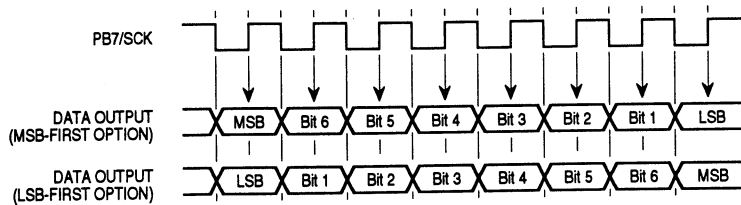


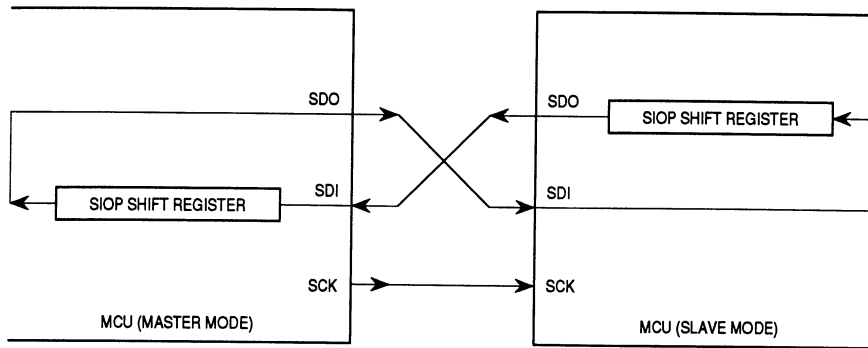
Figure 9-2. SIOP Data/Clock Timing

Valid serial data input (SDI) data must be present for an SDI setup time before the rising edge of the serial clock and must remain valid for an SDI hold time after the rising edge of the serial clock. (See **13.9 SIOP Timing (V_{DD} = 5.0 Vdc)** and **13.10 SIOP Timing (V_{DD} = 3.3 Vdc)**.)

Between transmissions, the state of the PB5/SDO pin reflects the value of the last bit received on the previous transmission. On the first falling edge on the PB7/SCK pin, the first data bit to be shifted out appears at the PB5/SDO pin.

9.1.3 Data Movement

Connecting the SIOPI data register of a master MCU with the SIOPI of a slave MCU forms a 16-bit circular shift register. During a SIOPI transmission, the master shifts out the contents of its SIOPI data register on its PB5/SDO pin. At the same time, the slave MCU shifts out the contents of its SIOPI data register on its SDO pin. Figure 9-3 shows how the master and slave exchange the contents of their data registers.



NOTE: Both MCUs shown are programmed for MSB first data format.

Figure 9-3. Master/Slave SIOPI Shift Register Operation

9.2 SIOPI I/O Registers

The following registers control and monitor SIOPI operation:

- SIOPI control register (SCR)
- SIOPI status register (SSR)
- SIOPI data register (SDR)

9.2.1 SIOPI Control Register (SCR)

The read/write SIOPI control register, shown in Figure 9-4, contains two bits. One bit enables the SIOPI, and the other configures the SIOPI for master mode or for slave mode.

SCR — SIOP Control Register

\$000A

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|-----|---|------|---|---|---|-------|
| | 0 | SPE | 0 | MSTR | 0 | 0 | 0 | 0 |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 9-4. SIOP Control Register (SCR)

SPE — SIOP Enable

This read/write bit enables the SIOP. Clearing the SPE bit during a transmission aborts the transmission and returns port B to its normal I/O function. After clearing the SPE bit, be sure to initialize the port B data direction register for the intended port B I/O use. Resets clear SPE.

- 1 = SIOP enabled
- 0 = SIOP disabled

MSTR — Master Mode Select

This read/write bit configures the SIOP for master mode. Setting MSTR initializes the PB7/SCK pin as the serial clock output. Clearing MSTR initializes the PB7/SCK pin as the serial clock input. Resets clear MSTR.

- 1 = Master mode selected
- 0 = Slave mode selected

9.2.2 SIOP Status Register (SSR)

The read/write SIOP status register, shown in Figure 9-5, contains two bits. One bit indicates that a SIOP transmission is complete, and the other indicates that an access of the SIOP data register occurred while a transmission was in progress.

SSR — SIOP Status Register

\$000B

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|------|---|---|---|---|---|-------|
| | SPIF | DCOL | 0 | 0 | 0 | 0 | 0 | 0 |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 9-5. SIOP Status Register (SSR)

SPIF — SIOP Interrupt Flag

This clearable, read-only bit is set automatically at the end of a transmission. Clear the SPIF bit by reading the SIOP status register with SPIF set, and then reading or writing the SIOP data register. Resets clear the SPIF bit.

- 1 = Serial transmission complete
- 0 = Serial transmission not complete

DCOL — Data Collision

This clearable, read-only bit is set if the SIOP data register is read or written during a transmission. Clear the DCOL bit by reading the SIOP status register with the SPIF bit set, and then reading or writing the SIOP data register. Resets clear the DCOL bit.

- 1 = Invalid access of SIOP data register
- 0 = No invalid access of SIOP data register

9.2.3 SIOP Data Register (SDR)

The SIOP data register, shown in Figure 9-6, is both the transmit data register and the receive data register. To read or write the SIOP data register, the SPE bit in the SIOP control register must be set.

SDR — SIOP Data Register

\$000C

| | | | | | | | | |
|--------|-------|---|---|---|---|---|---|-------|
| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 9-6. SIOP Data Register (SDR)

With the SIOP configured as master, writing to the SIOP data register initiates a serial transmission. This register is not buffered. Writing to the SIOP data register overwrites the previous contents. Reading or writing to the SIOP data register while a transmission is in progress can cause invalid data to be transmitted or received.

SECTION 10 ANALOG-TO-DIGITAL CONVERTER (ADC)

This section describes the four-channel, 8-bit, successive approximation ADC.

10.1 ADC Operation

Figure 10-1 shows the structure of the ADC.

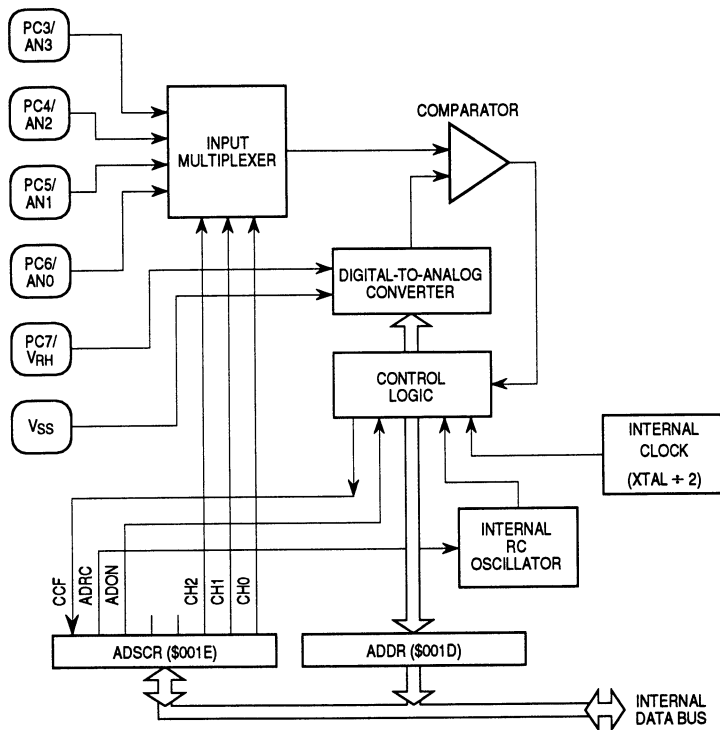


Figure 10-1. ADC Block Diagram

A multiplexer selects one of four external analog signals for sampling. The CH2–CH0 bits in the ADC status and control register (ADSCR) control input selection.

A comparator makes successive comparisons of the selected analog input and the output of a precision digital-to-analog converter (DAC). Control logic changes the input to the DAC one bit at a time, starting with the MSB, until the DAC output matches the selected analog input. The conversion is monotonic and has no missing codes. At the end of 32 internal clock cycles, the conversion complete (CC) flag becomes set, and the digital conversion is readable in the ADC data register (ADDR).

For ratiometric conversion, the supply voltage of the analog source should be the same as V_{RH} and be referenced to V_{SS} . An analog input voltage equal to V_{RH} converts to digital \$FF; an input voltage greater than V_{RH} converts to \$FF with no overflow. An analog input voltage equal to V_{SS} converts to digital \$00.

10.1.1 Pin Functions

Port C shares five of its pins with the ADC. The following paragraphs describe the ADC pin functions.

10.1.1.1 PC7/ V_{RH}

The PC7/ V_{RH} pin supplies the high reference voltage for the ratiometric conversion process. The low reference is connected internally to V_{SS} .

10.1.1.2 PC6/AN0, PC5/AN1, PC4/AN2, and PC3/AN3

PC6/AN0, PC5/AN1, PC4/AN2, and PC3/AN3 are the analog inputs to the ADC.

10.1.2 Conversion Accuracy

Conversion accuracy of ± 1.5 LSB is guaranteed when $V_{RH} = V_{DD}$.

10.1.3 Conversion Time

Each input conversion takes 32 internal clock cycles. The internal clock frequency must be equal to or greater than 1 MHz.

10.1.4 Internal RC Oscillator

If the internal clock frequency is less than 1 MHz, the internal RC oscillator must be used for the ADC clock instead of the internal clock. The nominal frequency of the RC oscillator is 1.5 MHz. Select the internal RC oscillator by setting the ADRC bit in the ADSCR.

Since the RC oscillator is not synchronous with the internal clock, software must rely on the CC bit to determine when each conversion process is complete.

Using the RC oscillator may slightly degrade ADC accuracy. The ADC reads voltages only during the periods when the clock driving it is not changing. But since the RC oscillator and the internal clock are not synchronous, the ADC occasionally reads voltages during internal clock transitions.

When the internal clock frequency is 1 MHz or greater, the RC oscillator must be turned off.

10.2 ADC I/O Registers

The following registers control and monitor operation of the ADC:

- ADC status and control register (ADSCR)
- ADC data register (ADDR)

10.2.1 ADC Status and Control Register (ADSCR)

The ADC status and control register, shown in Figure 10-2, contains a conversion complete flag and performs the following control functions:

- Turns on the ADC
- Turns on the internal RC oscillator
- Selects the analog inputs

Writing to ADSCR clears the conversion complete flag and starts a new conversion sequence.

ADSCR — ADC Status and Control Register

\$001E

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|--------|-------|------|------|---|---|-----|-----|-------|
| | CC | ADRC | ADON | 0 | 0 | CH2 | CH1 | CH0 |
| RESET: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 10-2. ADC Status and Control Register (ADSCR)

CC — Conversion Complete

This read-only bit is automatically set at the end of each conversion process. When CC is set, the result of the conversion is readable in the ADDR. Clear the CC bit by writing to the CH2–CH0 bits or by clearing the ADON bit or by reading the ADDR. Resets clear CC.

- 1 = Conversion complete
- 0 = Conversion not complete

ADRC — ADC RC (Oscillator)

This read/write bit turns on the internal RC oscillator to drive the ADC. If the internal clock frequency (f_{OP}) is less than 1 MHz, ADRC must be set. When the RC oscillator is turned on, it requires a time, t_{ADRC} , to stabilize, and results can be inaccurate during this time. Resets clear ADRC.

- 1 = Internal RC oscillator drives ADC
- 0 = Internal clock drives ADC

ADON — ADC On

This read/write bit turns on the ADC. When the ADC is on, it requires a time, t_{ADON} , for the current sources to stabilize. During this time, results can be inaccurate. Resets clear ADON.

- 1 = ADC turned on
- 0 = ADC turned off

Bits 4–2 — Not used

Bits 4–2 always read as logic zeros.

CH2–CH0 — Channel 2–Channel 0

These read/write bits select one of eight ADC input channels as shown in Table 10-1. Channels 0–3 are the port C input pins, PC3/AN3, PC4/AN2, PC5/AN1, and PC6/AN0. Channels 4–6 can be used for reference measurements. Channel 7 is reserved for factory testing.

Table 10-1. ADC Input Channel Selection

| CH[2:1:0] | Channel | Signal |
|-----------|---------|--|
| 0 0 0 | 0 | AN0 Port C Bit 6 |
| 0 0 1 | 1 | AN1 Port C Bit 5 |
| 0 1 0 | 2 | AN2 Port C Bit 4 |
| 0 1 1 | 3 | AN3 Port C Bit 3 |
| 1 0 0 | 4 | V _{RH} Port C Bit 7 |
| 1 0 1 | 5 | (V _{RH} + V _{SS}) ÷ 2 |
| 1 1 0 | 6 | V _{SS} |
| 1 1 1 | 7 | Reserved |

To prevent excess power dissipation, do not use a port C pin as an analog input and a digital input at the same time.

Using one of the port C pins as the ADC input does not affect the ability to use the remaining port C pins as digital inputs.

Reading a port C pin that is selected as an analog input returns a logic zero.

10.2.2 ADC Data Register (ADDR)

The ADC data register is a read-only register that contains the result of the most recent analog-to-digital conversion.

ADDR — ADC Data Register **\$001D**

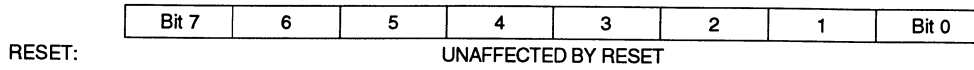


Figure 10-3. ADC Data Register (ADDR)

**SECTION 11
EPROM/OTPROM**

This section describes how to program the 4672-byte EPROM/OTPROM.

11.1 EPROM/OTPROM Programming

There are two ways to program the EPROM/OTPROM:

- Manipulating the control bits in the EPROM programming register to program the EPROM/OTPROM on a byte-by-byte basis.
- Activating the bootloader ROM to download the contents of an external memory device to the on-chip EPROM/OTPROM.

11.1.1 EPROM Programming Register (EPROG)

The EPROM programming register, shown in Figure 11-1, contains the control bits for programming the EPROM/OTPROM.

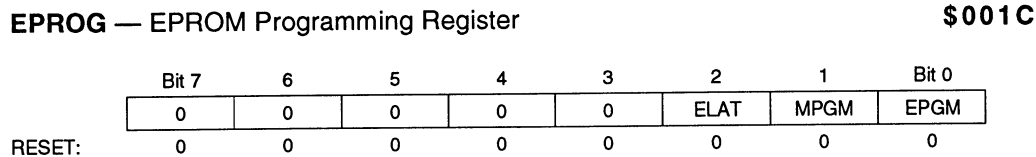


Figure 11-1. EPROM Programming Register (EPROG)

ELAT — EPROM Latch

This read/write bit latches data on the address bus and the data bus for EPROM/OTPROM programming. Clearing the ELAT bit automatically clears the EPGM bit. EPROM/OTPROM data cannot be read while the ELAT bit is set. Resets clear the ELAT bit.

- 1 = Address and data buses configured for EPROM/OTPROM programming
- 0 = Address and data buses configured for normal operation

MPGM — Mask Option Register (MOR) Programming

This read/write bit applies the voltage from the $\overline{\text{IRQ}}/V_{\text{PP}}$ pin to the MOR. Resets clear the MPGM bit.

- 1 = MOR programming power switched on
- 0 = MOR programming power switched off

EPGM — EPROM Programming

This read/write bit applies the voltage from the $\overline{\text{IRQ}}/V_{\text{PP}}$ pin to the EPROM/OTEPROM. To write the EPGM bit, the ELAT bit must already be set. Clearing the ELAT bit also clears the EPGM bit. Resets clear the EPGM bit.

- 1 = EPROM/OTEPROM programming power switched on
- 0 = EPROM/OTEPROM programming power switched off

NOTE

Writing logic ones to both the ELAT and EPGM bits with a single instruction sets ELAT and clears EPGM. ELAT must be set first by a separate instruction.

Bits 7–3 — Reserved

Bits 7–3 are factory test bits that always read as logic zeros.

Take the following steps to program a byte of EPROM/OTEPROM:

1. Apply 16.5 V to the $\overline{\text{IRQ}}/V_{\text{PP}}$ pin.
2. Set the ELAT bit.
3. Write to any EPROM/OTEPROM address.
4. Set the EPGM bit for a time, t_{EPGM} , to apply the programming voltage.
5. Clear the ELAT bit.

11.1.2 Bootloader ROM

The bootloader ROM, located at addresses \$1F01–\$1FEF, contains routines for copying to the on-chip EPROM/OTPROM from an external EPROM.

The bootloader copies to the following MC68HC705P6 EPROM/OTPROM addresses:

- \$0020–\$004F
- \$0100–\$12FF
- \$1F00 (mask option register)
- \$1FF0–\$1FFF

The addresses of the code in the external EPROM must match the MC68HC705P6 addresses. The bootloader ignores all other addresses.

Figure 11-2 shows the circuit used to download to the on-chip EPROM/OTPROM from a 2764 EPROM. The bootloader circuit includes an external 12-bit counter to address the external EPROM. Operation is fastest when unused external EPROM addresses contain \$00. The bootloader function begins when a rising edge occurs on the $\overline{\text{RESET}}$ pin while the $\overline{\text{IRQ/VPP}}$ pin is at $2 \times V_{DD}$ and the PD7/TCAP pin is at V_{DD} .

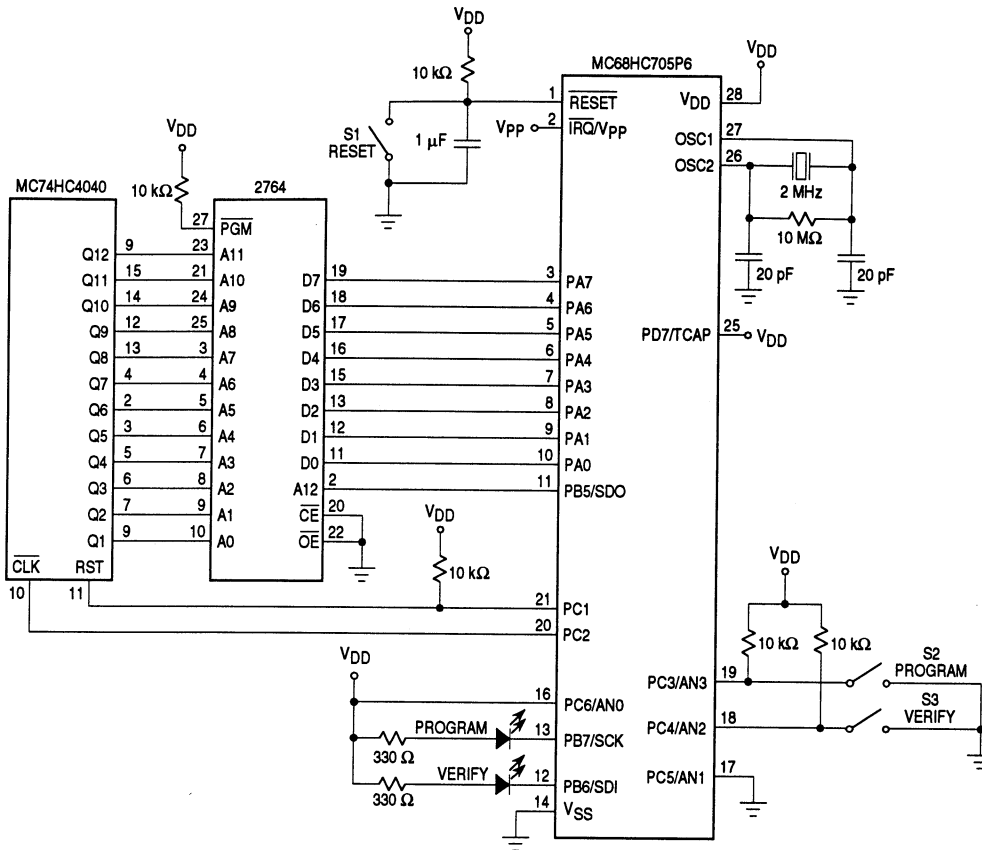


Figure 11-2. Bootloader Circuit

Complete the following steps to bootload the MCU:

1. Turn off all power to the circuit.
2. Install the EPROM containing the code to be downloaded.
3. Install the MCU.
4. Select the bootloader function:
 - a. Open switches S2 and S3 to select the program and verify function.
 - b. Open only switch S3 to select only the verify function.

5. Close switch S1.
6. Turn on the V_{DD} power supply.

CAUTION

Turn on the V_{DD} power supply **before** turning on the V_{PP} power supply. Damage to the MCU can occur if V_{PP} is turned on first.

7. Turn on the V_{PP} power supply.
8. Open switch S1. The bootloader code begins to execute. If the program function is selected, the PROGRAM LED turns on during programming. If the verify function is selected, the VERIFY LED turns on when verification is successful. The program and verify function takes about 40 seconds.
9. Close switch S1.
10. Turn off the V_{PP} power supply.

CAUTION

Turn off the V_{PP} power supply **before** turning off the V_{DD} power supply. Damage to the MCU can occur if V_{DD} is turned off first.

11. Turn off the V_{DD} power supply.

11.2 EPROM Erasing

The erased state of an EPROM bit is zero. Erase the EPROM by exposing it to 15 Ws/cm^2 of ultraviolet light with a wavelength of 2537 angstroms. Position the ultraviolet light source one inch from the EPROM. Do not use a shortwave filter.

Cerdip packages have a transparent window for erasing the EPROM with ultraviolet light. In the windowless PDIP and SOIC packages, the 4672 EPROM bytes function as one-time programmable ROM (OTPROM)

11.3 Mask Option Register (MOR)

The mask option register, shown in Figure 11-3, is an EPROM/OTPROM byte that controls the following options:

- Enabled or disabled STOP instruction
- SIOP clock rate
- MSB first or LSB first SIOP data transfer
- Edge-triggered or edge- and level-triggered external interrupt pin
- Enabled or disabled COP watchdog

MOR — Mask Option Register

\$1F00

| | Bit 7 | 6 | 5 | 4 | 3 | 2 | 1 | Bit 0 |
|---------|-------|---|-------|------|------|------|-------|-------|
| RESET: | 1 | 1 | SWAIT | SPR1 | SPR0 | LSBF | LEVEL | COPE |
| ERASED: | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UNAFFECTED BY RESET

Figure 11-3. Mask Option Register (MOR)

Bits 7 and 6 — Unused

Program bits 7 and 6 to logic zero.

SWAIT — STOP Conversion to WAIT

The SWAIT bit disables the STOP instruction and prevents inadvertently turning off the COP watchdog with a STOP instruction. When the SWAIT bit is set, a STOP instruction puts the MCU in halt mode. Halt mode is a low-power mode similar to wait mode. The internal oscillator continues to run, but the CPU clock stops. When the SWAIT bit is clear, a STOP instruction stops the internal oscillator, the internal clock, and the CPU clock.

- 1 = STOP instruction puts MCU in halt mode
- 0 = STOP instruction puts MCU in stop mode

SPR1, SPR0 — SIOP Rate

SPR1 and SPR0 select the SIOP clock rate, as shown in Table 11-1.

Table 11-1. SIOP Clock Rate Selection

| SPR1:SPR0 | SIOP Clock Rate |
|-----------|-------------------------------|
| 00 | f _{OP} Divided by 32 |
| 01 | f _{OP} Divided by 16 |
| 10 | f _{OP} Divided by 8 |
| 11 | f _{OP} Divided by 4 |

LSBF — Least Significant Bit First

LSBF controls the shift direction into and out of the SIOP shift register.

- 1 = SIOP data transferred LSB first
- 0 = SIOP data transferred MSB first

LEVEL — Level-Sensitive External Interrupt Trigger

The LEVEL bit makes the external interrupt function of the \overline{IRQ}/V_{PP} pin level-triggered as well as edge-triggered.

- 1 = \overline{IRQ}/V_{PP} pin negative edge-triggered and low level-triggered
- 0 = \overline{IRQ}/V_{PP} pin negative edge-triggered only

COPE — COP Watchdog Enable

COPE enables the COP watchdog. In applications that have wait cycles longer than the COP watchdog timeout period, the COP watchdog can be disabled by not programming the COPE bit to logic one.

- 1 = COP watchdog enabled
- 0 = COP watchdog disabled

The STOP instruction turns off the COP watchdog. In applications that depend on the COP watchdog, the STOP instruction can be disabled by programming the SWAIT bit to logic one in the mask option register. Table 11-2 summarizes the recommended conditions for enabling the COP watchdog.

Table 11-2. COP Watchdog Recommendations

| SWAIT Bit | Wait/Halt Time | Recommended COP Watchdog Condition |
|-----------|---------------------------------|------------------------------------|
| 1 | Less than COP Timeout Period | Enabled (COPE = 1) |
| 1 | Greater than COP Timeout Period | Disabled (COPE = 0) |
| 0 | X | Disabled (COPE = 0) |

NOTE: X = don't care.

SECTION 12 INSTRUCTION SET

This section describes the addressing modes and the types of instructions.

12.1 Addressing Modes

The CPU uses eight addressing modes for flexibility in accessing data. These addressing modes define the manner in which the CPU finds the data required to execute an instruction. The eight addressing modes are as follows:

- Inherent
- Immediate
- Direct
- Extended
- Indexed, no offset
- Indexed, 8-bit offset
- Indexed, 16-bit offset
- Relative

12.1.1 Inherent

Inherent instructions are those that have no operand, such as return from interrupt (RTI) and stop (STOP). Some of the inherent instructions act on data in the CPU registers, such as set carry flag (SEC) and increment accumulator (INCA). Inherent instructions require no memory address and are one byte long. Table 12-1 lists the instructions that use inherent addressing.

Table 12-1. Inherent Addressing Instructions

| Instruction | Mnemonic |
|--|-----------------|
| Arithmetic Shift Left | ASLA, ASLX |
| Arithmetic Shift Right | ASRA, ASRX |
| Clear Carry Bit | CLC |
| Clear Interrupt Mask | CLI |
| Clear | CLRA, CLRX |
| Complement | COMA, COMX |
| Decrement | DECA, DECX |
| Increment | INCA, INCX |
| Logical Shift Left | LSLA, LSLX |
| Logical Shift Right | LSRA, LSRX |
| Multiply Index Register by Accumulator (Unsigned) | MUL |
| Negate | NEGA, NEGX |
| No Operation | NOP |
| Rotate Left through Carry | ROLA, ROLX |
| Rotate Right through Carry | RORA, RORX |
| Reset Stack Pointer | RSP |
| Return from Interrupt | RTI |
| Return from Subroutine | RTS |
| Set Carry Bit | SEC |
| Set Interrupt Mask | SEI |
| Enable $\overline{\text{IRQ}}$ and Stop Oscillator | STOP |
| Software Interrupt | SWI |
| Transfer Accumulator to Index Register | TAX |
| Test for Negative or Zero | TSTA, TSTX |
| Transfer Index Register to Accumulator | TXA |
| Enable Interrupts and Halt CPU | WAIT |

12.1.2 Immediate

Immediate instructions are those that contain a value to be used in an operation with the value in the accumulator or index register. Immediate instructions require no memory address and are two bytes long. The opcode is the first byte and the immediate data value is the second byte. Table 12-2 lists the instructions that use immediate addressing.

Table 12-2. Immediate Addressing Instructions

| Instruction | Mnemonic |
|--|-----------------|
| Add Memory and Carry to Accumulator | ADC |
| Add Memory to Accumulator | ADD |
| Logical AND Memory with Accumulator | AND |
| Bit Test Memory with Accumulator (Logical Compare) | BIT |
| Arithmetic Compare Accumulator with Memory | CMP |
| Arithmetic Compare Index Register with Memory | CPX |
| Exclusive OR Memory with Accumulator | EOR |
| Load Accumulator from Memory | LDA |
| Load Index Register from Memory | LDX |
| Logical Inclusive OR Memory with Accumulator | ORA |
| Subtract Memory and Carry from Accumulator | SBC |
| Subtract Memory from Accumulator | SUB |

12.1.3 Direct

Direct instructions can access any of the first 256 memory addresses with two bytes. The first byte is the opcode, and the second is the low byte of the operand address. In direct addressing, the CPU automatically uses \$00 as the high byte of the operand address. BRSET and BRCLR are three-byte instructions that use direct addressing to access the operand and relative addressing to specify a branch destination. Table 12-3 lists the instructions that use direct addressing.

Table 12-3. Direct Addressing Instructions

| Instruction | Mnemonic |
|--|-----------------|
| Add Memory and Carry to Accumulator | ADC |
| Add Memory to Accumulator | ADD |
| Logical AND Memory with Accumulator | AND |
| Arithmetic Shift Left | ASL |
| Arithmetic Shift Right | ASR |
| Clear Bit | BCLR |
| Bit Test Memory with Accumulator (Logical Compare) | BIT |
| Branch if Bit Clear | BRCLR |
| Branch if Bit Set | BRSET |
| Set Bit | BSET |
| Clear | CLR |
| Arithmetic Compare Accumulator with Memory | CMP |
| Complement | COM |
| Arithmetic Compare Index Register with Memory | CPX |
| Decrement | DEC |
| Exclusive OR Memory with Accumulator | EOR |
| Increment | INC |
| Jump | JMP |
| Jump to Subroutine | JSR |
| Load Accumulator from Memory | LDA |
| Load Index Register from Memory | LDX |
| Logical Shift Left | LSL |
| Logical Shift Right | LSR |
| Negate | NEG |
| Logical Inclusive OR Memory with Accumulator | ORA |
| Rotate Left through Carry | ROL |
| Rotate Right through Carry | ROR |
| Subtract Memory and Carry from Accumulator | SBC |
| Store Accumulator in Memory | STA |
| Store Index Register in Memory | STX |
| Subtract Memory from Accumulator | SUB |
| Test for Negative or Zero | TST |

12.1.4 Extended

Extended instructions use only three bytes to access any address in memory. The first byte is the opcode; the second and third bytes are the high and low bytes of the operand address.

When using the Motorola assembler, the programmer does not need to specify whether an instruction is direct or extended. The assembler automatically selects the shortest form of the instruction. Table 12-4 lists the instructions that use extended addressing.

Table 12-4. Extended Addressing Instructions

| Instruction | Mnemonic |
|--|-----------------|
| Add Memory and Carry to Accumulator | ADC |
| Add Memory to Accumulator | ADD |
| Logical AND Memory with Accumulator | AND |
| Bit Test Memory with Accumulator (Logical Compare) | BIT |
| Arithmetic Compare Accumulator with Memory | CMP |
| Arithmetic Compare Index Register with Memory | CPX |
| Exclusive OR Memory with Accumulator | EOR |
| Jump | JMP |
| Jump to Subroutine | JSR |
| Load Accumulator from Memory | LDA |
| Load Index Register from Memory | LDX |
| Logical Inclusive OR Memory with Accumulator | ORA |
| Subtract Memory and Carry from Accumulator | SBC |
| Store Accumulator in Memory | STA |
| Store Index Register in Memory | STX |
| Subtract Memory from Accumulator | SUB |

12.1.5 Indexed, No Offset

Indexed instructions with no offset are one-byte instructions that can access data with variable addresses within the first 256 memory locations. The index register contains the low byte of the conditional address of the operand. The CPU automatically uses \$00 as the high byte, so these instructions can address locations \$0000–\$00FF.

Indexed, no offset instructions are often used to move a pointer through a table or to hold the address of a frequently used RAM or I/O location. Table 12-5 lists the instructions that use indexed, no offset addressing.

12.1.6 Indexed, 8-Bit Offset

Indexed, 8-bit offset instructions are two-byte instructions that can access data with variable addresses within the first 511 memory locations. The CPU adds the unsigned byte in the index register to the unsigned byte following the opcode. The sum is the conditional address of the operand. These instructions can access locations \$0000–\$01FE.

Indexed, 8-bit offset instructions are useful for selecting the kth element in an n-element table. The table can begin anywhere within the first 256 memory locations and could extend as far as location 510 (\$01FE). The k value would typically be in the index register, and the address of the beginning of the table would be in the byte following the opcode. Table 12-5 lists the instructions that use indexed, 8-bit offset addressing.

12.1.7 Indexed, 16-Bit Offset

Indexed, 16-bit offset instructions are three-byte instructions that can access data with variable addresses at any location in memory. The CPU adds the unsigned byte in the index register to the two unsigned bytes following the opcode. The sum is the conditional address of the operand. The first byte after the opcode is the high byte of the 16-bit offset; the second byte is the low byte of the offset. These instructions can address any location in memory.

Indexed, 16-bit offset instructions are useful for selecting the kth element in an n-element table anywhere in memory.

As with direct and extended addressing, the Motorola assembler determines the shortest form of indexed addressing. Table 12-5 lists the instructions that use indexed, 16-bit offset addressing.

Table 12-5. Indexed Addressing Instructions

| Instruction | Mnemonic | No Offset | 8-Bit Offset | 16-Bit Offset |
|--|----------|-----------|--------------|---------------|
| Add Memory and Carry to Accumulator | ADC | √ | √ | √ |
| Add Memory to Accumulator | ADD | √ | √ | √ |
| Logical AND Memory with Accumulator | AND | √ | √ | √ |
| Arithmetic Shift Left | ASL | √ | √ | |
| Arithmetic Shift Right | ASR | √ | √ | |
| Bit Test Memory with Accumulator (Logical Compare) | BIT | √ | √ | √ |
| Clear | CLR | √ | √ | |
| Arithmetic Compare Accumulator with Memory | CMP | √ | √ | √ |
| Complement | COM | √ | √ | |
| Arithmetic Compare Index Register with Memory | CPX | √ | √ | √ |
| Decrement | DEC | √ | √ | |
| Exclusive OR Memory with Accumulator | EOR | √ | √ | √ |
| Increment | INC | √ | √ | |
| Jump | JMP | √ | √ | √ |
| Jump to Subroutine | JSR | √ | √ | √ |
| Load Accumulator from Memory | LDA | √ | √ | √ |
| Load Index Register from Memory | LDX | √ | √ | √ |
| Logical Shift Left | LSL | √ | √ | |
| Logical Shift Right | LSR | √ | √ | |
| Negate | NEG | √ | √ | |
| Logical Inclusive OR Memory with Accumulator | ORA | √ | √ | √ |
| Rotate Left through Carry | ROL | √ | √ | |
| Rotate Right through Carry | ROR | √ | √ | |
| Subtract Memory and Carry from Accumulator | SBC | √ | √ | √ |
| Store Accumulator in Memory | STA | √ | √ | √ |
| Store Index Register in Memory | STX | √ | √ | √ |
| Subtract Memory from Accumulator | SUB | √ | √ | √ |
| Test for Negative or Zero | TST | √ | √ | |

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12.1.8 Relative

Relative addressing is only for branch instructions and bit test and branch instructions. If the branch condition is true, the CPU finds the conditional branch destination by adding the signed byte following the opcode to the contents of the program counter. If the branch condition is not true, the CPU goes to the next instruction. The offset is a signed, two's complement byte that gives a branching range of -128 to +127 bytes from the address of the next location after the branch instruction.

When using the Motorola assembler, the programmer does not need to calculate the offset, because the assembler determines the proper offset and verifies that it is within the span of the branch. Table 12-6 lists the instructions that use relative addressing.

Table 12-6. Relative Addressing Instructions

| Instruction | Mnemonic |
|--------------------------------|----------|
| Branch if Carry Clear | BCC |
| Branch if Carry Set | BCS |
| Branch if Equal | BEQ |
| Branch if Half-Carry Clear | BHCC |
| Branch if Half-Carry Set | BHCS |
| Branch if Higher | BHI |
| Branch if Higher or Same | BHS |
| Branch if Interrupt Line High | BIH |
| Branch if Interrupt Line Low | BIL |
| Branch if Lower | BLO |
| Branch if Lower or Same | BLS |
| Branch if Interrupt Mask Clear | BMC |
| Branch if Minus | BMI |
| Branch if Interrupt Mask Set | BMS |
| Branch if Not Equal | BNE |
| Branch if Plus | BPL |
| Branch Always | BRA |
| Branch if Bit Clear | BRCLR |
| Branch if Bit Set | BRSET |
| Branch Never | BRN |
| Branch to Subroutine | BSR |

12.2 Instruction Types

The MCU instructions fall into the following five categories:

- Register/memory
- Read-modify-write
- Jump/branch
- Bit manipulation
- Control

12.2.1 Register/Memory Instructions

Most of these instructions use two operands. One operand is in either the accumulator or the index register. The CPU finds the other operand in memory. Register/memory instructions use all the addressing modes except relative.

Table 12-7 lists the register/memory instructions.

Table 12-7. Register/Memory Instructions

| Instruction | Mnemonic |
|--|----------|
| Add Memory and Carry to Accumulator | ADC |
| Add Memory to Accumulator | ADD |
| Logical AND Memory with Accumulator | AND |
| Bit Test Memory with Accumulator (Logical Compare) | BIT |
| Arithmetic Compare Accumulator with Memory | CMP |
| Arithmetic Compare Index Register with Memory | CPX |
| Logical Exclusive OR Memory with Accumulator | EOR |
| Load Accumulator from Memory | LDA |
| Load Index Register from Memory | LDX |
| Multiply Index Register by Accumulator (Unsigned) | MUL |
| Logical Inclusive OR Memory with Accumulator | ORA |
| Subtract Memory and Carry from Accumulator | SBC |
| Store Accumulator in Memory | STA |
| Store Index Register in Memory | STX |
| Subtract Memory from Accumulator | SUB |

12.2.2 Read-Modify-Write Instructions

These instructions read a memory location or a register, modify its contents, and write the modified value back to the memory location or to the register. The test for negative or zero (TST) instruction is an exception to the read-modify-write sequence because it does not write a replacement value. Read-modify-write instructions use the following addressing modes:

- Inherent
- Direct
- Indexed, no offset
- Indexed, 8-bit offset

Table 12-8 lists the read-modify-write instructions.

Table 12-8. Read-Modify-Write Instructions

| Instruction | Mnemonic |
|-------------------------------------|-----------------|
| Arithmetic Shift Left (Same as LSL) | ASL |
| Arithmetic Shift Right | ASR |
| Clear Bit in Memory | BCLR |
| Set Bit in Memory | BSET |
| Clear | CLR |
| Complement | COM |
| Decrement | DEC |
| Increment | INC |
| Logical Shift Left (Same as ASL) | LSL |
| Logical Shift Right | LSR |
| Negate (Two's Complement) | NEG |
| Rotate Left through Carry | ROL |
| Rotate Right through Carry | ROR |
| Test for Negative or Zero | TST |

12.2.3 Jump/Branch Instructions

Jump instructions allow the CPU to interrupt the normal sequence of the program counter. The unconditional jump (JMP) and jump to subroutine (JSR) instructions have no register operand. Jump instructions use the following addressing modes:

- Direct
- Extended

- Indexed, no offset
- Indexed, 8-bit offset
- Indexed, 16-bit offset

Branch instructions allow the CPU to interrupt the normal sequence of the program counter when a test condition is met. If the test condition is not met, the branch is not performed. All branch instructions use relative addressing.

Bit test and branch instructions cause a branch based on the state of any readable bit in the first 256 memory locations. These three-byte instructions use a combination of direct addressing and relative addressing. The direct address of the byte to be tested is in the byte following the opcode. The third byte is the signed offset byte. The CPU finds the conditional branch destination by adding the third byte to the program counter if the specified bit tests true. The bit to be tested and its condition (set or clear) is part of the opcode. The span of branching is from -128 to +127 from the address of the next location after the branch instruction. The CPU also transfers the tested bit to the carry/borrow bit of the condition code register. Table 12-9 lists the jump and branch instructions.

Table 12-9. Jump and Branch Instructions

| Instruction | Mnemonic |
|-----------------------------------|----------|
| Branch if Carry Clear | BCC |
| Branch if Carry Set (Same as BLO) | BCS |
| Branch if Equal | BEQ |
| Branch if Half-Carry Bit Clear | BHCC |
| Branch if Half-Carry Bit Set | BHCS |
| Branch if Higher | BHI |
| Branch if Higher or Same | BHS |
| Branch if Interrupt Line High | BIH |
| Branch if Interrupt Line Low | BIL |
| Branch if Lower (Same as BCS) | BLO |
| Branch if Lower or Same | BLS |
| Branch if Interrupt Mask Clear | BMC |
| Branch if Minus | BMI |
| Branch if Interrupt Mask Set | BMS |
| Branch if Not Equal | BNE |
| Branch if Plus | BPL |
| Branch Always | BRA |
| Branch if Bit Clear | BRCLR |
| Branch Never | BRN |
| Branch if Bit Set | BRSET |
| Branch to Subroutine | BSR |
| Jump | JMP |
| Jump to Subroutine | JSR |

12.2.4 Bit Manipulation Instructions

The CPU can set or clear any writable bit in the first 256 bytes of memory. Port registers, port data direction registers, timer registers, and on-chip RAM locations are in the first 256 bytes of memory. The CPU can also test and branch based on the state of any bit in any of the first 256 memory locations. Bit manipulation instructions use direct addressing. Table 12-10 lists these instructions.

Table 12-10. Bit Manipulation Instructions

| Instruction | Mnemonic |
|---------------------|----------|
| Clear Bit | BCLR |
| Branch if Bit Clear | BRCLR |
| Branch if Bit Set | BRSET |
| Set Bit | BSET |

12.2.5 Control Instructions

These register reference instructions control CPU operation during program execution. Control instructions, listed in Table 12-11, use inherent addressing.

Table 12-11. Control Instructions

| Instruction | Mnemonic |
|--|----------|
| Clear Carry Bit | CLC |
| Clear Interrupt Mask | CLI |
| No Operation | NOP |
| Reset Stack Pointer | RSP |
| Return from Interrupt | RTI |
| Return from Subroutine | RTS |
| Set Carry Bit | SEC |
| Set Interrupt Mask | SEI |
| Stop | STOP |
| Software Interrupt | SWI |
| Transfer Accumulator to Index Register | TAX |
| Transfer Index Register to Accumulator | TXA |
| Wait | WAIT |

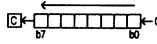
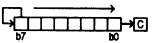
12.3 Instruction Set Summary

Table 12-12 shows all MC68HC705P9 instructions in all possible addressing modes. The table shows the operand construction and the execution time in internal clock cycles (t_{CYC}) of each instruction. One internal clock cycle equals two oscillator input cycles. The following legend summarizes the symbols and abbreviations used in Table 12-12.

Abbreviations and Symbols

| | | | |
|-------|---|------|-------------------------------------|
| A | Accumulator | PCH | Program counter high byte |
| C | Carry/borrow flag | PCL | Program counter low byte |
| CCR | Condition code register | REL | Relative addressing |
| dd | Address of operand in direct addressing | rel | Offset byte for relative addressing |
| dd rr | Address (dd) of operand and offset (rr) of branch instruction for bit test instructions | rr | Offset byte of branch instruction |
| DIR | Direct addressing | SP | Stack pointer |
| ee ff | High (ee) and low (ff) bytes of offset in indexed, 16-bit offset addressing | X | Index register |
| EXT | Extended addressing | Z | Zero flag |
| ff | Offset byte in indexed, 8-bit offset addressing | • | AND |
| H | Half-carry flag | – | Not affected |
| hh ll | High (hh) and low (ll) bytes of operand address in extended addressing | ? | If |
| I | Interrupt mask | — | NOT |
| ii | Operand byte for immediate addressing | () | Contents of |
| IMM | Immediate addressing | ← | Is loaded with |
| INH | Inherent addressing | : | Concatenated with |
| IX | Indexed, no offset addressing | × | Multiplication |
| IX1 | Indexed, 8-bit offset addressing | –() | Negation (two's complement) |
| IX2 | Indexed, 16-bit offset addressing | + | Inclusive OR |
| M | Any memory location (1 byte) | ↕ | Set if true; clear if not true |
| N | Negative flag | ⊕ | Exclusive OR |
| n | Any bit (7,6,5 . . . 0) | + | Addition |
| opr | Operand byte | – | Subtraction |
| PC | Program counter | | |

Table 12-12. Instruction Set (Sheet 1 of 4)

| Source Form | Operation | Description | Addressing Mode for Operand | Machine Coding (hexadecimal) | | Cycles | Condition Code | | | | |
|---|---------------------------------------|---|--|--|--|--------------------------------------|----------------|---|---|---|---|
| | | | | Opcode | Operand | | H | I | N | Z | C |
| ADC #opr ADC opr ADC opr ADC opr,X ADC opr,X ADC X | Add with carry | $A \leftarrow (A) + (M) + C$ | IMM DIR EXT IX2 IX1 IX | A9 B9 C9 D9 E9 F9 | ii dd hh ll ee ff ff ff | 2 3 4 5 4 3 | ‡ | - | ‡ | ‡ | ‡ |
| ADD #opr ADD opr ADD opr ADD opr,X ADD opr,X ADD X | Add without carry | $A \leftarrow (A) + (M)$ | IMM DIR EXT IX2 IX1 IX | AB BB CB DB EB FB | ii dd hh ll ee ff ff ff | 2 3 4 5 4 3 | ‡ | - | ‡ | ‡ | ‡ |
| AND #opr AND opr AND opr AND opr,X AND opr,X AND X | Logical AND | $A \leftarrow (A) \cdot (M)$ | IMM DIR EXT IX2 IX1 IX | A4 B4 C4 D4 E4 F4 | ii dd hh ll ee ff ff ff | 2 3 4 5 4 3 | - | - | ‡ | ‡ | - |
| ASL opr ASLA ASLX ASL opr,X ASL opr,X | Arithmetic shift left (Same as LSL) |  | DIR INH INH IX1 IX | 38 48 58 68 78 | dd dd ff ff | 5 3 3 6 5 | - | - | ‡ | ‡ | ‡ |
| ASR opr ASRA ASRX ASR opr,X ASR opr,X | Arithmetic shift right |  | DIR INH INH IX1 IX | 37 47 57 67 77 | dd dd ff ff | 5 3 3 6 5 | - | - | ‡ | ‡ | ‡ |
| BCC rel | Branch if carry bit clear | ? C = 0 | REL | 24 | rr | 3 | - | - | - | - | - |
| BCLR n opr | Clear bit n | Mn ← 0 | DIR (b0) DIR (b1) DIR (b2) DIR (b3) DIR (b4) DIR (b5) DIR (b6) DIR (b7) | 11 13 15 17 19 1B 1D 1F | dd dd dd dd dd dd dd dd | 5 5 5 5 5 5 5 5 | - | - | - | - | - |
| BCS rel | Branch if carry bit set (Same as BLO) | ? C = 1 | REL | 25 | rr | 3 | - | - | - | - | - |
| BEQ rel | Branch if equal | ? Z = 1 | REL | 27 | rr | 3 | - | - | - | - | - |
| BHCC rel | Branch if half carry bit clear | ? H = 0 | REL | 28 | rr | 3 | - | - | - | - | - |
| BHCS rel | Branch if half carry bit set | ? H = 1 | REL | 29 | rr | 3 | - | - | - | - | - |
| BHI rel | Branch if higher | ? C + Z = 0 | REL | 22 | rr | 3 | - | - | - | - | - |
| BHS rel | Branch if higher or same | ? C = 0 | REL | 24 | rr | 3 | - | - | - | - | - |
| BIH rel | Branch if IRQ pin high | ? IRQ = 1 | REL | 2F | rr | 3 | - | - | - | - | - |
| BIL rel | Branch if IRQ pin low | ? IRQ = 0 | REL | 2E | rr | 3 | - | - | - | - | - |
| BIT rel | Bit test accumulator with memory | (A) • (M) | IMM DIR EXT IX2 IX1 IX | A5 B5 C5 D5 E5 F5 | ii dd hh ll ee ff ff ff | 2 3 4 5 4 3 | - | - | ‡ | ‡ | - |
| BLO rel | Branch if lower (Same as BCS) | ? C = 1 | REL | 25 | rr | 3 | - | - | - | - | - |
| BLS rel | Branch if lower or same | ? C + Z = 1 | REL | 23 | rr | 3 | - | - | - | - | - |
| BMC rel | Branch if interrupt mask clear | ? I = 0 | REL | 2C | rr | 3 | - | - | - | - | - |
| BMI rel | Branch if minus | ? N = 1 | REL | 2B | rr | 3 | - | - | - | - | - |
| BMS rel | Branch if interrupt mask set | ? I = 0 | REL | 2D | rr | 3 | - | - | - | - | - |
| BNE rel | Branch if not equal | ? Z = 0 | REL | 26 | rr | 3 | - | - | - | - | - |
| BPL rel | Branch if plus | ? N = 0 | REL | 2A | rr | 3 | - | - | - | - | - |

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Table 12-12. Instruction Set (Sheet 2 of 4)

| Source Form(s) | Operation | Description | Addressing Mode for Operand | Machine Coding (hexadecimal) | | Cycles | Condition Code | | | | |
|------------------------|--|--|-----------------------------|------------------------------|---------|--------|----------------|---|---|---|---|
| | | | | Opcode | Operand | | H | I | N | Z | C |
| BRA <i>rel</i> | Branch always | ? 1 = 1 | REL | 20 | rr | 3 | - | - | - | - | - |
| BRCLR <i>n opr rel</i> | Branch if bit n clear | ? Mn = 0 | DIR (b0) | 01 | dd rr | 5 | - | - | - | - | ‡ |
| | | | DIR (b1) | 03 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b2) | 05 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b3) | 07 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b4) | 09 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b5) | 0B | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b6) | 0D | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b7) | 0F | dd rr | 5 | - | - | - | - | - |
| BRN <i>rel</i> | Branch never | ? 1 = 0 | REL | 21 | rr | 3 | - | - | - | - | |
| BRSET <i>n opr rel</i> | Branch if bit n set | ? Mn = 1 | DIR (b0) | 00 | dd rr | 5 | - | - | - | - | ‡ |
| | | | DIR (b1) | 02 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b2) | 04 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b3) | 06 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b4) | 08 | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b5) | 0A | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b6) | 0C | dd rr | 5 | - | - | - | - | - |
| | | | DIR (b7) | 0E | dd rr | 5 | - | - | - | - | - |
| BSET <i>n opr</i> | Set bit n | Mn ← 1 | DIR (b0) | 10 | dd | 5 | - | - | - | - | |
| | | | DIR (b1) | 12 | dd | 5 | - | - | - | - | |
| | | | DIR (b2) | 14 | dd | 5 | - | - | - | - | |
| | | | DIR (b3) | 16 | dd | 5 | - | - | - | - | |
| | | | DIR (b4) | 18 | dd | 5 | - | - | - | - | |
| | | | DIR (b5) | 1A | dd | 5 | - | - | - | - | |
| | | | DIR (b6) | 1C | dd | 5 | - | - | - | - | |
| | | | DIR (b7) | 1E | dd | 5 | - | - | - | - | |
| BSR <i>rel</i> | Branch to subroutine | PC ← (PC) + 2; push (PCL) SP ← (SP) - 1; push (PCH) SP ← (SP) - 1 PC ← (PC) + rel | REL | AD | rr | 6 | - | - | - | - | |
| CLC | Clear carry bit | C ← 0 | INH | 98 | | 2 | - | - | - | 0 | |
| CLI | Clear interrupt mask | I ← 0 | INH | 9A | | 2 | - | 0 | - | - | |
| CLR <i>opr</i> | Clear register | M ← \$00 A ← \$00 X ← \$00 M ← \$00 M ← \$00 | DIR | 3F | dd | 5 | - | - | 0 | 1 | |
| CLRA | | | INH | 4F | | 3 | - | - | - | - | |
| CLR X | | | INH | 5F | | 3 | - | - | - | - | |
| CLR <i>opr,X</i> | | | IX1 | 6F | ff | 6 | - | - | - | - | |
| CLR <i>opr,X</i> | | | IX | 7F | | 5 | - | - | - | - | |
| | | | | | | | | | | | |
| CMP # <i>opr</i> | Compare accumulator with memory | (A) - (M) | IMM | A1 | ii | 2 | - | - | ‡ | ‡ | ‡ |
| | | | DIR | B1 | dd | 3 | - | - | - | - | - |
| | | | EXT | C1 | hh ll | 4 | - | - | - | - | - |
| | | | IX2 | D1 | ee ff | 5 | - | - | - | - | - |
| | | | IX1 | E1 | ff | 4 | - | - | - | - | - |
| | | | IX | F1 | | 3 | - | - | - | - | - |
| COM <i>opr</i> | Complement memory or register (one's complement) | M ← M = \$FF - (M) A ← A = \$FF - (A) X ← X = \$FF - (X) M ← M = \$FF - (M) M ← M = \$FF - (M) | DIR | 33 | dd | 5 | - | - | ‡ | ‡ | 1 |
| | | | INH | 43 | | 3 | - | - | - | - | |
| | | | INH | 53 | | 3 | - | - | - | - | |
| | | | IX1 | 63 | ff | 6 | - | - | - | - | |
| | | | IX | 73 | | 5 | - | - | - | - | |
| CPX # <i>opr</i> | Compare index register with memory | (X) - (M) | IMM | A3 | ii | 2 | - | - | ‡ | ‡ | ‡ |
| | | | DIR | B3 | dd | 3 | - | - | - | - | |
| | | | EXT | C3 | hh ll | 4 | - | - | - | - | |
| | | | IX2 | D3 | ee ff | 5 | - | - | - | - | |
| | | | IX1 | E3 | ff | 4 | - | - | - | - | |
| | | | IX | F3 | | 3 | - | - | - | - | |
| DEC <i>opr</i> | Decrement | M ← (M) - 1 A ← (A) - 1 X ← (X) - 1 M ← (M) - 1 M ← (M) - 1 | DIR | 3A | dd | 5 | - | - | ‡ | ‡ | - |
| | | | INH | 4A | | 3 | - | - | - | - | |
| | | | INH | 5A | | 3 | - | - | - | - | |
| | | | IX1 | 6A | ff | 6 | - | - | - | - | |
| | | | IX | 7A | | 5 | - | - | - | - | |
| | | | | | | | | | | | |

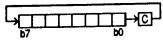
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Table 12-12. Instruction Set (Sheet 3 of 4)

| Source Form(s) | Operation | Description | Addressing Mode for Operand | Machine Coding (hexadecimal) | | Cycles | Condition Code | | | | |
|--|--|---|---------------------------------------|----------------------------------|----------------------------------|----------------------------|----------------|---|---|---|---|
| | | | | Opcode | Operand | | H | I | N | Z | C |
| EOR #opr EOR opr EOR opr EOR opr,X EOR opr,X EOR ,X | Exclusive OR accumulator with memory | $A \leftarrow (A) \oplus (M)$ | IMM DIR EXT IX2 IX1 IX | A8 B8 C8 D8 E8 F8 | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↕ | ↕ | - |
| INC opr INCA INCX INC opr,X INC opr,X INC ,X | Increment memory or register | $M \leftarrow (M) + 1$ $A \leftarrow (A) + 1$ $X \leftarrow (X) + 1$ $M \leftarrow (M) + 1$ $M \leftarrow (M) + 1$ | DIR INH INH IX1 IX | 3C 4C 5C 6C 7C | dd | 5 3 3 6 5 | - | - | ↕ | ↕ | - |
| JMP opr JMP opr JMP opr,X JMP opr,X JMP ,X | Unconditional jump | $PC \leftarrow \text{jump address}$ | DIR EXT IX2 IX1 IX | BC CC DC EC FC | dd hh ll ee ff ff | 2 3 4 3 2 | - | - | - | - | - |
| JSR opr JSR opr JSR opr,X JSR opr,X JSR ,X | Jump to subroutine | $PC \leftarrow (PC) + n$ ($n = 1, 2, \text{ or } 3$) Push (PCL); $SP \leftarrow (SP) - 1$ Push (PCH); $SP \leftarrow (SP) - 1$ $PC \leftarrow \text{conditional address}$ | DIR EXT IX2 IX1 IX | BD CD DD ED FD | dd hh ll ee ff ff | 5 6 7 6 5 | - | - | - | - | - |
| LDA #opr LDA opr LDA opr LDA opr,X LDA opr,X LDA ,X | Load accumulator from memory | $A \leftarrow (M)$ | IMM DIR EXT IX2 IX1 IX | A6 B6 C6 D6 E6 F6 | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↕ | ↕ | - |
| LDX #opr LDA opr LDA opr LDA opr,X LDA opr,X LDA ,X | Load index register from memory | $X \leftarrow (M)$ | IMM DIR EXT IX2 IX1 IX | AE BE CE DE EE FE | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↕ | ↕ | - |
| LSL opr LSLA LSLX LSL opr,X LSL ,X | Logical shift left (Same as ASL) | | DIR INH INH IX1 IX | 38 48 58 68 78 | dd | 5 3 3 6 5 | - | - | ↕ | ↕ | ↕ |
| LSR opr LSRA LSRX LSR opr,X LSR ,X | Logical shift right | | DIR INH INH IX1 IX | 34 44 54 64 74 | dd | 5 3 3 6 5 | - | - | 0 | ↕ | ↕ |
| MUL | Unsigned multiply | $X : A \leftarrow (X) \times (A)$ | INH | 42 | | 11 | 0 | - | - | - | 0 |
| NEG opr NEGA NEGX NEG opr,X NEG ,X | Negate memory or register (two's complement) | $M \leftarrow \sim(M) = \$00 - (M)$ $A \leftarrow \sim(A) = \$00 - (A)$ $X \leftarrow \sim(X) = \$00 - (X)$ $M \leftarrow \sim(M) = \$00 - (M)$ $M \leftarrow \sim(M) = \$00 - (M)$ | DIR INH INH IX1 IX | 30 40 50 60 70 | dd | 5 3 3 6 5 | - | - | ↕ | ↕ | ↕ |
| NOP | No operation | | INH | 9D | | 2 | - | - | - | - | - |
| ORA #opr ORA opr ORA opr ORA opr,X ORA opr,X ORA ,X | Inclusive OR accumulator with memory | $A \leftarrow (A) + (M)$ | IMM DIR EXT IX2 IX1 IX | AA BA CA DA EA FA | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↕ | ↕ | - |
| ROL opr ROLA ROLX ROL opr,X ROL ,X | Rotate left through carry | | DIR INH INH IX1 IX | 39 49 59 69 79 | dd | 5 3 3 6 5 | - | - | ↕ | ↕ | ↕ |

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Table 12-12. Instruction Set (Sheet 4 of 4)

| Source Form | Operation | Description | Addressing Mode for Operand | Machine Coding (hexadecimal) | | Cycles | Condition Code | | | | |
|--|--|---|---------------------------------------|----------------------------------|----------------------------------|----------------------------|----------------|---|---|---|---|
| | | | | Opcode | Operand | | H | I | N | Z | C |
| ROR <i>opr</i> RORA RORX ROR <i>opr,X</i> ROR <i>X</i> | Rotate right through carry |  | DIR INH INH IX1 IX | 36 46 56 66 76 | dd ff | 5 3 3 6 5 | - | - | ↓ | ↓ | ↓ |
| RSP | Reset stack pointer | SP ← \$00FF | INH | 9C | | 2 | - | - | - | - | - |
| RTI | Return from interrupt | SP ← (SP) + 1; pull (CCR) SP ← (SP) + 1; pull (A) SP ← (SP) + 1; pull (X) SP ← (SP) + 1; pull (PCH) SP ← (SP) + 1; pull (PCL) | INH | 80 | | 9 | From Stack | | | | |
| RTS | Return from subroutine | SP ← (SP) + 1; pull (PCH) SP ← (SP) + 1; pull (PCL) | INH | 81 | | 6 | - | - | - | - | - |
| SBC # <i>opr</i> SBC <i>opr</i> SBC <i>opr</i> SBC <i>opr,X</i> SBC <i>opr,X</i> SBC <i>X</i> | Subtract memory and carry bit from accumulator | A ← (A) - (M) - C | IMM DIR EXT IX2 IX1 IX | A2 B2 C2 D2 E2 F2 | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↓ | ↓ | ↓ |
| SEC | Set carry bit | C ← 1 | INH | 99 | | 2 | - | - | - | - | 1 |
| SEI | Set interrupt mask | I ← 1 | INH | 9B | | 2 | - | 1 | - | - | - |
| STA <i>opr</i> STA <i>opr</i> STA <i>opr,X</i> STA <i>opr,X</i> STA <i>X</i> | Store accumulator in memory | M ← (A) | DIR EXT IX2 IX1 IX | B7 C7 D7 E7 F7 | dd hh ll ee ff ff | 4 5 6 5 4 | - | - | ↓ | ↓ | - |
| STOP | Enable \overline{IRQ} ; stop oscillator | | INH | 8E | | 2 | - | 0 | - | - | - |
| STX <i>opr</i> STX <i>opr</i> STX <i>opr,X</i> STX <i>opr,X</i> STX <i>X</i> | Store index register in memory | M ← (X) | DIR EXT IX2 IX1 IX | BF CF DF EF FF | dd hh ll ee ff ff | 4 5 6 5 4 | - | - | ↓ | ↓ | - |
| SUB # <i>opr</i> SUB <i>opr</i> SUB <i>opr</i> SUB <i>opr,X</i> SUB <i>opr,X</i> SUB <i>X</i> | Subtract memory from accumulator | A ← (A) - (M) | IMM DIR EXT IX2 IX1 IX | A0 B0 C0 D0 E0 F0 | ii dd hh ll ee ff ff | 2 3 4 5 4 3 | - | - | ↓ | ↓ | ↓ |
| SWI | Software interrupt | PC ← (PC) + 1; push (PCL) SP ← (SP) - 1; push (PCH) SP ← (SP) - 1; push (X) SP ← (SP) - 1; push (A) SP ← (SP) - 1; push (CCR) SP ← (SP) - 1; I ← 1 PCH ← Interrupt vector hi byte PCL ← Int. vector low byte | INH | 83 | | 10 | - | 1 | - | - | - |
| TAX | Transfer accumulator to index register | X ← (A) | INH | 97 | | 2 | - | - | - | - | - |
| TST <i>opr</i> TSTA TSTX TST <i>opr,X</i> TST <i>X</i> | Test memory or register for negative or zero | (M) - \$00 | DIR INH INH IX1 IX | 3D 4D 5D 6D 7D | dd ff | 4 3 3 5 4 | - | - | ↓ | ↓ | - |
| TXA | Transfer index register to accumulator | A ← (X) | INH | 9F | | 2 | - | - | - | - | - |
| WAIT | Enable interrupts; halt CPU | | INH | 8F | | 2 | - | 0 | - | - | - |

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12.4 Opcode Map

Table 12-13 is an opcode map of the M68HC05 instruction set.

Table 12-13. Opcode Map

| HI LO | Bit Manipulation | | | Branch | | | Read-Modify-Write | | | Control | | | Register/Memory | | | HI LO | | | |
|----------|------------------|-------|---------|---------|-----------|---------|-------------------|-----|-----|---------|----|------|-----------------|-----|-----|----------|-----|-----|-----|
| | DIR | DIR | REL | DIR | REL | REL | DIR | INH | INH | IX1 | IX | INH | INH | IMM | DIR | | EXT | IX2 | IX1 |
| 0 | BRSET0 | BSET0 | BRA | NEG | NEGA | NEG | DIR | INH | INH | IX1 | IX | INH | INH | A | SUB | SUB | SUB | SUB | SUB |
| 1 | BRCLR0 | BCLR0 | BRN | | | | DIR | INH | INH | | | INH | INH | CMP | CMP | CMP | CMP | CMP | CMP |
| 2 | BRSET1 | BSET1 | BHI | | MUL | | DIR | INH | INH | | | | | SBC | SBC | SBC | SBC | SBC | SBC |
| 3 | BRCLR1 | BCLR1 | BLS | COM | COMA | COM | DIR | INH | INH | IX1 | IX | INH | INH | CPX | CPX | CPX | CPX | CPX | CPX |
| 4 | BRSET2 | BSET2 | BCC | LSR | LSRA | LSR | DIR | INH | INH | IX1 | IX | | | AND | AND | AND | AND | AND | AND |
| 5 | BRCLR2 | BCLR2 | BCS/BLO | | | | DIR | INH | INH | | | | | BIT | BIT | BIT | BIT | BIT | BIT |
| 6 | BRSET3 | BSET3 | BNE | ROR | RORA | ROR | DIR | INH | INH | IX1 | IX | | | LDA | LDA | LDA | LDA | LDA | LDA |
| 7 | BRCLR3 | BCLR3 | BEQ | ASR | ASRA | ASR | DIR | INH | INH | IX1 | IX | TAX | | STA | STA | STA | STA | STA | STA |
| 8 | BRSET4 | BSET4 | BHCC | ASL/LSL | ASLX/LSLX | ASL/LSL | DIR | INH | INH | IX1 | IX | CLC | | EOR | EOR | EOR | EOR | EOR | EOR |
| 9 | BRCLR4 | BCLR4 | BHCS | ROL | ROLA | ROL | DIR | INH | INH | IX1 | IX | SEC | | ADC | ADC | ADC | ADC | ADC | ADC |
| A | BRSET5 | BSET5 | BPL | DEC | DECA | DEC | DIR | INH | INH | IX1 | IX | CLI | | ORA | ORA | ORA | ORA | ORA | ORA |
| B | BRCLR5 | BCLR5 | BMI | | | | DIR | INH | INH | | | SEI | | ADD | ADD | ADD | ADD | ADD | ADD |
| C | BRSET6 | BSET6 | BMC | INC | INCA | INC | DIR | INH | INH | IX1 | IX | RSP | | JMP | JMP | JMP | JMP | JMP | JMP |
| D | BRCLR6 | BCLR6 | BMS | TST | TSTA | TST | DIR | INH | INH | IX1 | IX | NOP | | BSR | JSR | JSR | JSR | JSR | JSR |
| E | BRSET7 | BSET7 | BIL | | | | DIR | INH | INH | | | STOP | | LDX | LDX | LDX | LDX | LDX | LDX |
| F | BRCLR7 | BCLR7 | BIH | CLR | CLRA | CLR | DIR | INH | INH | IX1 | IX | WAIT | TXA | STX | STX | STX | STX | STX | STX |

ABBREVIATIONS FOR ADDRESSING MODES

INH Inherent
IMM Immediate
DIR Direct
EXT Extended
REL Relative
IX Indexed, No Offset
IX1 Indexed, 8-Bit Offset
IX2 Indexed, 16-Bit Offset

LEGEND

Number of Cycles
Opcode Memory
Number of Bytes/Addressing Mode
High Byte of Opcode in Hexadecimal
Low Byte of Opcode in Hexadecimal

SECTION 13 ELECTRICAL SPECIFICATIONS

This section contains MCU electrical specifications and timing information.

13.1 Maximum Ratings

CAUTION

To avoid damage to the MCU, do not exceed the values listed in Table 13-1 Maximum Ratings. Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN} \text{ or } V_{OUT}) \leq V_{DD}$.

Table 13-1. Maximum Ratings

| Rating | Symbol | Value | Unit |
|--|----------|----------------------------------|------|
| Supply Voltage | V_{DD} | -0.3 to +7.0 | V |
| Input Voltage | V_{IN} | $V_{SS} - 0.3$ to $V_{DD} + 0.3$ | V |
| EPROM Programming Voltage (\overline{IRQ}/V_{PP} Pin) | V_{PP} | 16.75 | V |
| Current Drain per Pin (Excluding V_{DD} and V_{SS}) | I | 25 | mA |

NOTE: Maximum values are not guaranteed operating values.

13.2 Thermal Characteristics

Table 13-2. Thermal Characteristics

| Characteristic | Symbol | Value | Unit |
|--|-----------------|--|---------------|
| Thermal Resistance Plastic SOIC | $R_{\theta JA}$ | 60 60 | $^{\circ}C/W$ |
| Operating Temperature Range MC68HC705P6P, DW, S (Standard) MC68HC705P6CP, CDW, CS (Extended) MC68HC705P6VP, VDW, VS (Automotive) MC68HC705P6MP, MDW, MS (Automotive) | T_A | 0 to +70 -40 to +85 -40 to +105 -40 to +125 | $^{\circ}C$ |
| Storage Temperature Range | T_{STG} | -65 to +150 | $^{\circ}C$ |

NOTES:

- | | |
|---|---|
| <ol style="list-style-type: none"> 1. P = Plastic dual in-line package (PDIP) 2. DW = Small outline integrated circuit (SOIC) 3. S = Ceramic dual in-line package (Cerdip) | <ol style="list-style-type: none"> 4. C = Extended temp. range (-40 to +85 $^{\circ}C$) 5. V = Automotive temp. range (-40 to +105 $^{\circ}C$) 6. M = Automotive temp. range (-40 to +125 $^{\circ}C$) |
|---|---|

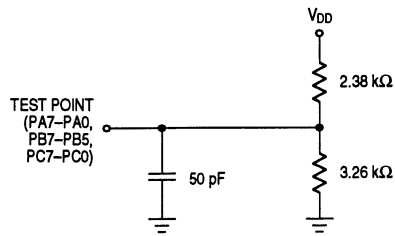


Figure 13-1. Test Load

13.3 Power Considerations

The average chip junction temperature, T_J , in $^{\circ}\text{C}$ can be obtained from:

$$T_J = T_A + (P_D \times \theta_{JA}) \quad (1)$$

where:

T_A = Ambient temperature in $^{\circ}\text{C}$

θ_{JA} = Package thermal resistance, junction to ambient in $^{\circ}\text{C}/\text{W}$

$P_D = P_{INT} + P_{I/O}$

$P_{INT} = I_{CC} \times V_{CC}$, watts — chip internal power

$P_{I/O}$ = Power dissipation on input and output pins — user-determined

For most applications $P_{I/O} \ll P_{INT}$ and can be neglected.

The following is an approximate relationship between P_D and T_J (if $P_{I/O}$ is neglected):

$$P_D = K + (T_J + 273 \text{ }^{\circ}\text{C}) \quad (2)$$

Solving equations (1) and (2) for K gives:

$$K = P_A \times (T_A + 273 \text{ }^{\circ}\text{C}) + R_{\theta JA} \times P_D \quad (3)$$

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 .

13.4 DC Electrical Characteristics ($V_{DD} = 5.0$ Vdc)
Table 13-3. DC Electrical Characteristics ($V_{DD} = 5.0$ Vdc)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|-----------------------|---------------------------------|----------------------------------|--------------------------------------|---|
| Output Voltage $I_{LOAD} = 10.0 \mu A$ $I_{LOAD} = -10.0 \mu A$ | V_{OL} V_{OH} | — $V_{DD} - 0.1$ | — — | 0.1 — | V V |
| Output High Voltage ($I_{LOAD} = -0.8$ mA) PA7-PA0, PB7/SCK-PB5/SDO, PC7/ V_{RH} -PC3/AN3, PC2-PC0, PD5, TCMP | V_{OH} | $V_{DD} - 0.8$ | — | — | V |
| Output Low Voltage ($I_{LOAD} = 1.6$ mA) PA7-PA0, PB7/SCK-PB5/SDO, PC7/ V_{RH} -PC3/AN3, PC2-PC0, PD5, TCMP | V_{OL} | — | — | 0.4 | V |
| Input High Voltage PA7-PA0, PB7/SCK-PB5/SDO, PC7/ V_{RH} -PC3/AN3, PC2-PC0, PD5, PD7/TCAP, IRQ/ V_{PP} , RESET, OSC1 | V_{IH} | $0.7 \times V_{DD}$ | — | V_{DD} | V |
| Input Low Voltage PA7-PA0, PB7/SCK-PB5/SDO, PC7/ V_{RH} -PC3/AN3, PC2-PC0, PD5, PD7/TCAP, IRQ/ V_{PP} , RESET, OSC1 | V_{IL} | V_{SS} | — | $0.2 \times V_{DD}$ | V |
| Supply Current (NOTES 3-6) RUN WAIT (A/D Converter On) WAIT (A/D Converter Off) STOP 25 °C 0 to 70 °C (Standard) -40 to 125 °C | I_{DD} | — — — — — — — | 4.0 2.0 1.3 2 — — | 7.0 4.0 2.0 30 50 100 | mA mA mA μA μA μA |
| I/O Ports Hi-Z Leakage Current PA7-PA0, PB7-PB5, PC7-PC0, PD5 | I_{IL} | — | — | ± 10 | μA |
| A/D Ports Hi-Z Leakage Current | I_{OZ} | — | — | ± 1 | μA |
| Input Current RESET, IRQ/ V_{PP} , OSC1, PD7/TCAP | I_{IN} | — | — | ± 1 | μA |
| Capacitance Ports (as Input or Output) RESET, IRQ/ V_{PP} | C_{OUT} C_{IN} | — — | — — | 12 8 | pF pF |
| Programming Voltage | V_{PP} | 16.25 | 16.5 | 16.75 | V |
| Programming Current | I_{PP} | — | 5 | 10 | mA |
| Programming Time per Byte | t_{EPGM} | 4 | — | — | ms |

NOTES:

- $V_{DD} = 5.0$ Vdc $\pm 10\%$, $V_{SS} = 0$ Vdc, $T_A = T_L$ to T_H , unless otherwise noted.
- Typical values at midpoint of voltage range, 25°C only.
- RUN (operating) I_{DD} and WAIT I_{DD} measured using external square wave clock source ($f_{OSC} = 4.2$ MHz); all inputs 0.2 V from rail; no dc loads; less than 50 pF on all outputs; $C_L = 20$ pF on OSC2.
- WAIT I_{DD} and STOP I_{DD} : all ports configured as inputs; $V_{IL} = 0.2$ V; $V_{IH} = V_{DD} - 0.2$ V.
- STOP I_{DD} measured with OSC1 = V_{SS} .
- WAIT I_{DD} is affected linearly by the OSC2 capacitance.

13.5 DC Electrical Characteristics (V_{DD} = 3.3 Vdc)
Table 13-4. DC Electrical Characteristics (V_{DD} = 3.3 Vdc)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|--|-------------------------------------|----------------------------|--------|-----------------------|----------|
| Output Voltage (I _{LOAD} ≤ 10.0 μA) | V _{OL} V _{OH} | — V _{DD} - 0.1 | — — | 0.1 — | V |
| Output High Voltage (I _{LOAD} = -0.2 mA) PA7-PA0, PB7/SCK-PB5/SDO, PC7/V _{RH} -PC3/AN3, PC2-PC0, PD5, TCOMP | V _{OH} | V _{DD} - 0.3 | — | — | V |
| Output Low Voltage (I _{LOAD} = 0.4 mA) PA7-PA0, PB7/SCK-PB5/SDO, PC7/V _{RH} -PC3/AN3, PC2-PC0, PD5, TCOMP | V _{OL} | — | — | 0.3 | V |
| Input High Voltage PA7-PA0, PB7/SCK-PB5/SDO, PC7/V _{RH} -PC3/AN3, PC2-PC0, PD5, PD7/TCAP, IRQ/V _{PP} , RESET, OSC1 | V _{IH} | 0.7 × V _{DD} | — | V _{DD} | V |
| Input Low Voltage PA7-PA0, PB7/SCK-PB5/SDO, PC7/V _{RH} -PC3/AN3, PC2-PC0, PD5, PD7/TCAP, IRQ/V _{PP} , RESET, OSC1 | V _{IL} | V _{SS} | — | 0.2 × V _{DD} | V |
| Data-Retention Mode Supply Voltage | V _{RM} | 2.0 | — | — | V |
| Supply Current (NOTES 3-6) | I _{DD} | | | | |
| RUN | | — | 1.8 | 2.5 | mA |
| WAIT (A/D Converter On) | | — | 1.0 | 1.4 | mA |
| WAIT (A/D Converter Off) | | — | 0.6 | 1.0 | mA |
| STOP | | — | — | — | — |
| 25°C | | — | 2.0 | 20 | μA |
| 0 to 70 °C (Standard) | | — | — | 40 | μA |
| -40 to +125 °C | | — | — | 50 | μA |
| I/O Ports Hi-Z Leakage Current PA7-PA0, PB7/SCK-PB5/SDO, PC7/V _{RH} -PC3/AN3, PC2-PC0, PD5 | I _{IL} | — | — | ±10 | μA |
| Input Current RESET, IRQ/V _{PP} , OSC1, PD5, PD7/TCAP | I _{IN} | — | — | ±1 | μA |
| Capacitance Ports (as Input or Output) RESET, IRQ/V _{PP} , PD5, PD7/TCAP | C _{OUT} C _{IN} | — — | — — | 12 8 | pF pF |

NOTES:

- V_{DD} = 3.3 Vdc ± 10%, V_{SS} = 0 Vdc, T_A = T_L to T_H unless otherwise noted.
- Typical values at midpoint of voltage range, 25 °C only.
- RUN (operating) I_{DD} and WAIT I_{DD} measured using external square wave clock source (f_{OSC} = 2.1 MHz); all inputs 0.2 V from rail; no dc loads; less than 50 pF on all outputs; C_L = 20 pF on OSC2.
- WAIT I_{DD} and STOP I_{DD}: all ports configured as inputs; V_{IL} = 0.2 V, V_{IH} = V_{DD} - 0.2 V.
- STOP I_{DD} measured with OSC1 = V_{SS}.
- WAIT I_{DD} is affected linearly by the OSC2 capacitance.

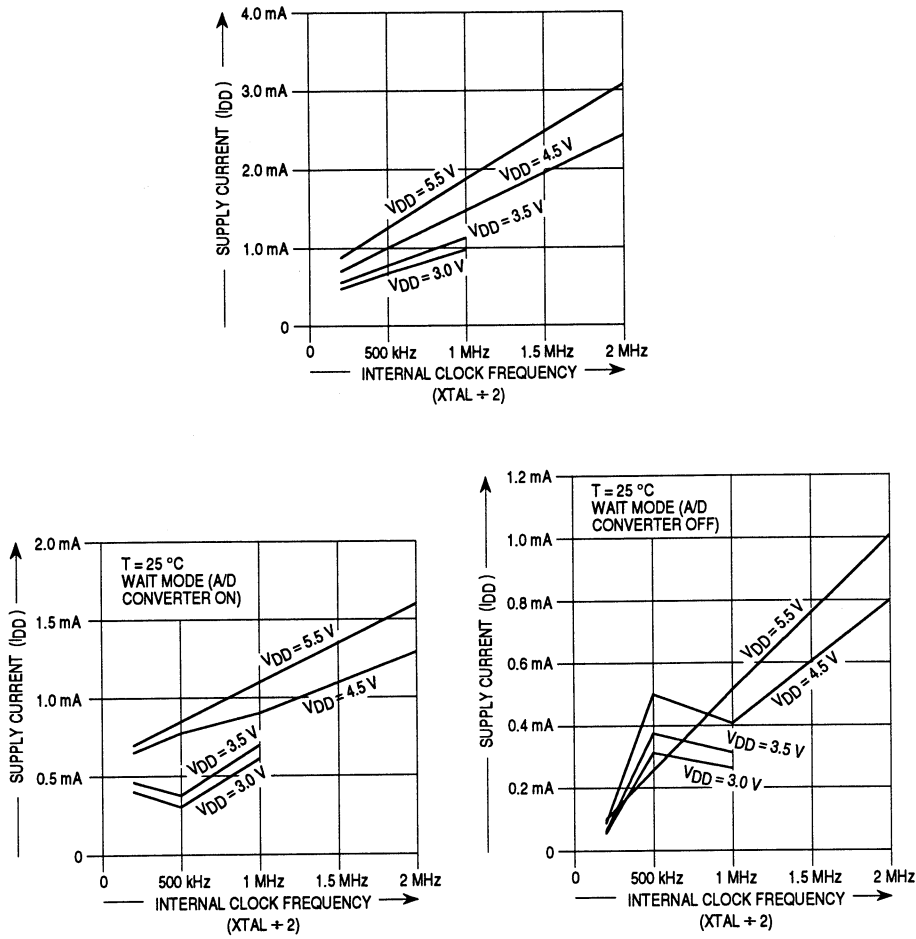


Figure 13-2. Typical I_{DD} vs Internal Clock Frequency ($T = 25\text{ }^{\circ}\text{C}$)

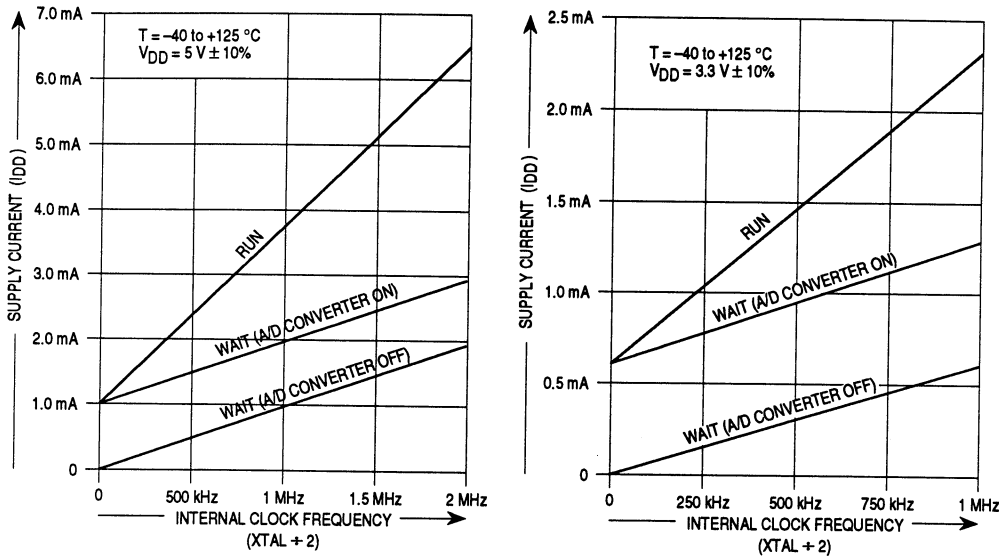


Figure 13-3. Typical I_{DD} vs Internal Clock Frequency ($T = -40$ °C to $+125$ °C)

13.6 A/D Converter Characteristics
Table 13-5. A/D Converter Characteristics

| Characteristic | Min | Max | Unit |
|--|-------------------------------|-------------|----------|
| Resolution | 8 | 8 | Bit |
| Absolute Accuracy ($4.0 > V_{RH} > V_{DD}$) (NOTE 2) | — | $\pm 1-1/2$ | LSB |
| Conversion Range (V_{RH} Pin) | V_{SS} | V_{DD} | V |
| Conversion Time (Includes Sampling Time) | | | |
| External Clock (XTAL) | 32 | 32 | t_{AD} |
| Internal RC Oscillator (ADRC = 1) | 32 | 32 | μs |
| Monotonicity | Inherent (Within Total Error) | | |
| Zero Input Reading ($V_{IN} = 0 V$) | 00 | 01 | Hex |
| Full-Scale Reading ($V_{IN} = V_{RH}$) | FF | FF | Hex |
| Sample Acquisition Time (NOTE 3) | | | |
| External Clock (XTAL) | 12 | 12 | t_{AD} |
| Internal RC Oscillator (ADRC) = 1 | — | 12 | μs |
| Input Capacitance | | | |
| PC6/AN0, PC5/AN1, PC4/AN2, PC3/AN3 | — | 12 | pF |
| Analog Input Voltage | V_{SS} | V_{RH} | V |
| Input Leakage (NOTE 5) | | | |
| PC6/AN0, PC5/AN1, PC4/AN2, PC3/AN3 | — | ± 1 | μA |
| V_{RH} | — | ± 1 | μA |

NOTES:

1. $V_{DD} = 5.0 Vdc \pm 10 \%$, $V_{SS} = 0 Vdc$, $T_A = T_L$ to T_H , unless otherwise noted.
2. A/D accuracy may decrease proportionately as V_{RH} is reduced below 4.0 V.
3. Source impedances greater than 10 kohm adversely affect internal RC charging time during input sampling.
4. $t_{AD} = t_{CYC}$ if clock source is MCU.
5. The external system error caused by input leakage current is approximately equal to the product of R source and input current.

13.7 Control Timing ($V_{DD} = 5.0$ Vdc)
Table 13-6. Control Timing ($V_{DD} = 5.0$ Vdc)

| Characteristic | Symbol | Min | Max | Unit |
|---|----------|----------|------------|------------|
| Oscillator Frequency Crystal Option External Clock Option | fosc | — dc | 4.2 4.2 | MHz MHz |
| Internal Operating Frequency Crystal (fosc + 2) External Clock (fosc + 2) | fop | — dc | 2.1 2.1 | MHz MHz |
| Cycle Time | tcyc | 480 | — | ns |
| Crystal Oscillator Startup Time | toxov | — | 100 | ms |
| STOP Recovery Startup Time (Crystal Oscillator) | tILCH | — | 100 | ms |
| RESET Pulse Width | tRL | 1.5 | — | tcyc |
| Timer Resolution (NOTE 2) | tRESL | 4.0 | — | tcyc |
| Interrupt Pulse Width Low (Edge-Triggered) | tILIH | 125 | — | ns |
| Interrupt Pulse Period | tILIL | (NOTE 3) | — | tcyc |
| OSC1 Pulse Width | tOH, tOL | 90 | — | ns |
| A/D On Current Stabilization Time | tADON | — | 100 | μ s |

NOTES:

1. $V_{DD} = 5.0$ Vdc \pm 10%, $V_{SS} = 0$ Vdc, $T_A = T_L$ to T_H , unless otherwise noted.
2. Since a 2-bit prescaler in the timer must count four internal cycles (tcyc), this is the limiting minimum factor in determining the timer resolution.
3. The minimum period tILIL should not be less than the number of cycle times it takes to execute the interrupt service routine plus 19 tcyc.

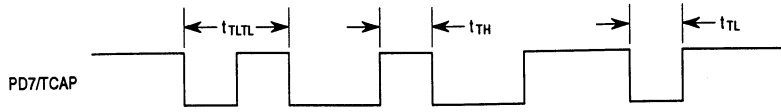
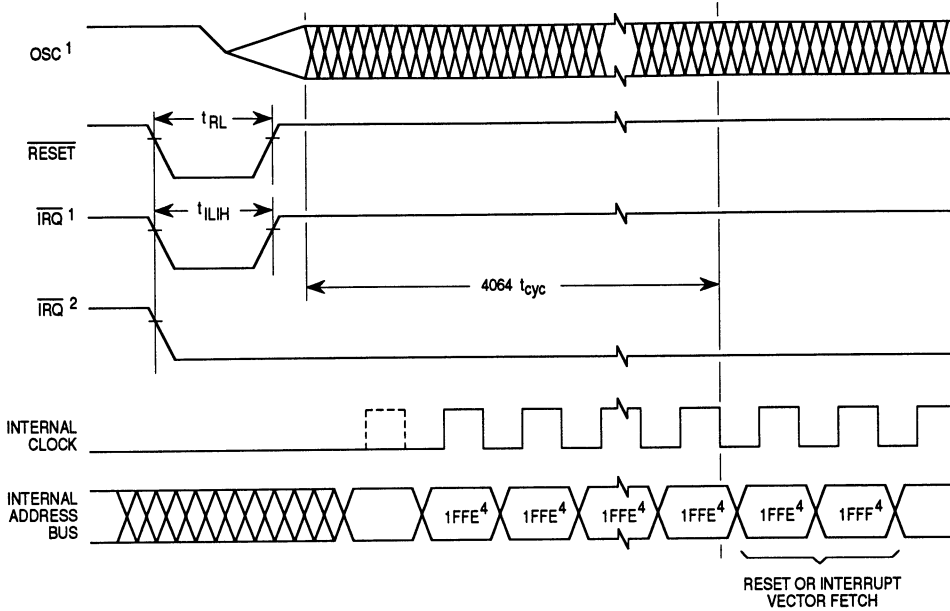


Figure 13-4. TCAP Timing



NOTES:

1. Represents the internal clocking of OSC1 pin.
2. External interrupt edge-triggered mask option.
3. External interrupt edge- and level-triggered mask option.
4. Reset vector shown for timing example.

Figure 13-5. STOP Recovery Timing

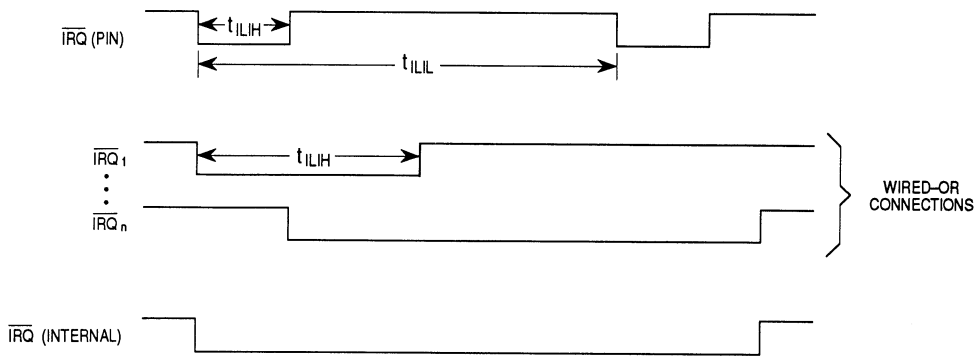


Figure 13-6. External Interrupt Timing

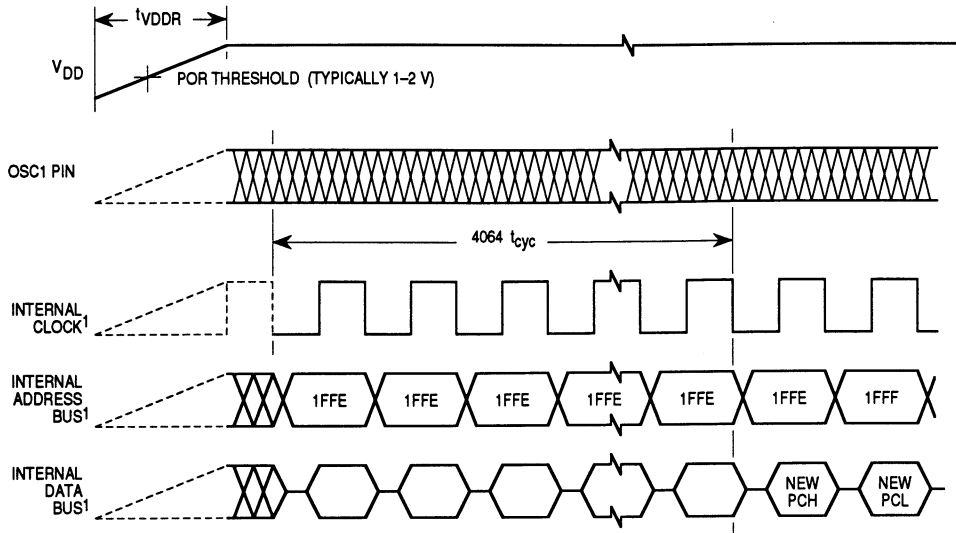
13.8 Control Timing ($V_{DD} = 3.3 \text{ Vdc}$)

Table 13-7. Control Timing ($V_{DD} = 3.3 \text{ Vdc}$)

| Characteristic | Symbol | Min | Max | Unit |
|---|------------------|----------|-----|-----------|
| Oscillator Frequency | f_{osc} | – | 2.0 | MHz |
| Crystal Option | | dc | 2.0 | MHz |
| External Clock Option | | | | |
| Internal Operating Frequency | f_{OP} | – | 1.0 | MHz |
| Crystal ($f_{osc} + 2$) | | dc | 1.0 | MHz |
| External Clock ($f_{osc} + 2$) | | | | |
| Cycle Time | t_{CYC} | 1 | – | ms |
| Crystal Oscillator Startup Time | t_{OXOV} | – | 100 | ms |
| STOP Recovery Startup Time (Crystal Oscillator) | t_{ILCH} | – | 100 | ms |
| RESET Pulse Width | t_{RL} | 1.5 | – | t_{CYC} |
| Timer Resolution (NOTE 2) | t_{RESL} | 4.0 | – | t_{CYC} |
| Interrupt Pulse Width Low (Edge-Triggered) | t_{ILIH} | 250 | – | ns |
| Interrupt Pulse Period | t_{ILIL} | (NOTE 3) | – | t_{CYC} |
| OSC1 Pulse Width | t_{OH}, t_{OL} | 200 | – | ns |

NOTES:

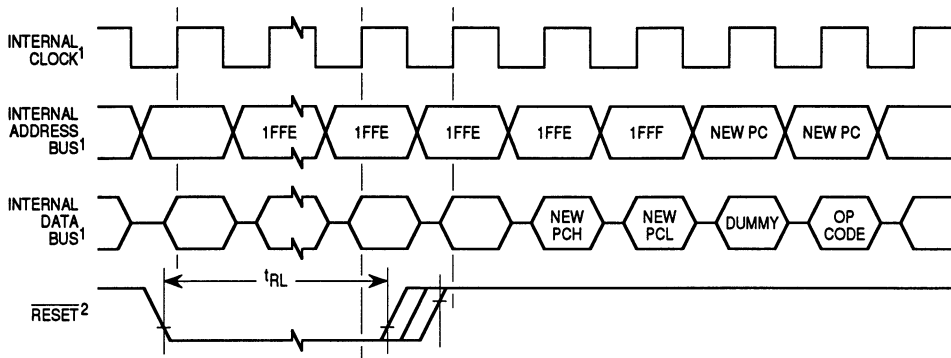
- $V_{DD} = 3.3 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H , unless otherwise noted.
- Because a 2-bit prescaler in the timer must count four internal cycles (t_{CYC}), this is the limiting minimum factor in determining the timer resolution.
- The minimum period t_{ILIL} should not be less than the number of cycle times it takes to execute the interrupt service routine plus $19 t_{CYC}$.



NOTES:

1. Internal clock, internal address bus, and internal data bus are not available externally.

Figure 13-7. Power-On Reset Timing



NOTES:

1. Internal clock, internal address bus, and internal data bus signals are not available externally.
2. Next rising edge of internal clock after rising edge of RESET initiates reset sequence.

Figure 13-8. External Reset Timing

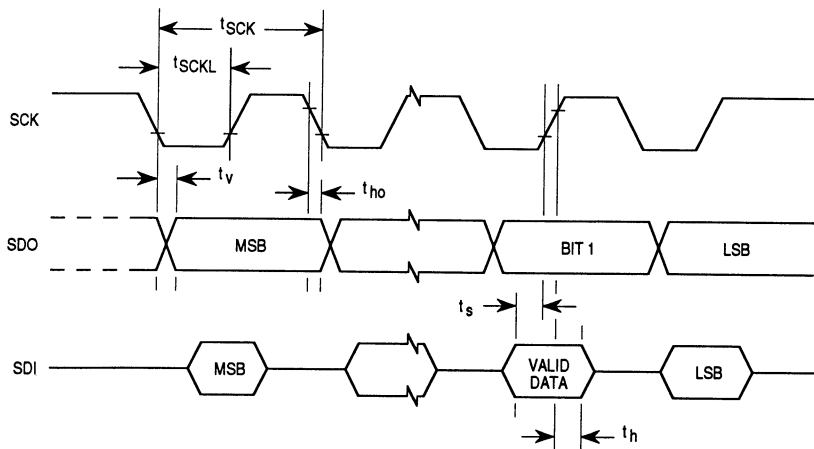
13.9 SIOP Timing ($V_{DD} = 5.0 \text{ Vdc}$)

Table 13-8. SIOP Timing ($V_{DD} = 5.0 \text{ Vdc}$)

| Characteristic | Symbol | Min | Max | Unit |
|---|--------------------------------|------------|-------------|-----------------|
| Frequency of Operation Master Slave | $f_{SIOP(M)}$ $f_{SIOP(S)}$ | 0.25 dc | 0.25 525 | f_{OP} kHz |
| Cycle Time Master Slave | $t_{SCK(M)}$ $t_{SCK(S)}$ | 4.0 — | 4.0 1920 | t_{CYC} ns |
| Clock (SCK) Low Time ($f_{OP} = 2.1 \text{ MHz}$) | t_{SCKL} | 932 | — | ns |
| SDO Data Valid Time | t_v | — | 200 | ns |
| SDO Hold Time | t_{HO} | 0 | — | ns |
| SDI Setup Time | t_s | 100 | — | ns |
| SDI Hold Time | t_h | 100 | — | ns |

NOTES:

- $V_{DD} = 5.0 \text{ Vdc} \pm 10\%$, $V_{SS} = 0 \text{ Vdc}$, $T_A = T_L$ to T_H , unless otherwise noted.
- $f_{OP} = f_{OSC} + 2 = 2.1 \text{ MHz}$ maximum; $t_{CYC} = 1 + f_{OP}$.
- In master mode, SCK is generated by dividing the internal clock (f_{OP}) by 4.



NOTES:

- This diagram applies to both the master and slave modes of the SIOP.
- Bit order is shown for MSB first option.

Figure 13-9. SIOP Timing

13.10 SIOP Timing ($V_{DD} = 3.3$ Vdc)
Table 13-9. SIOP Timing ($V_{DD} = 3.3$ Vdc)

| Characteristic | Symbol | Min | Max | Unit |
|--|--------------------------------|------------|-------------|-----------------|
| Frequency of operation Master Slave | $f_{SIOP(M)}$ $f_{SIOP(S)}$ | 0.25 dc | 0.25 250 | f_{OP} kHz |
| Cycle Time Master Slave | $t_{SCK(M)}$ $t_{SCK(S)}$ | 4.0 – | 4.0 4000 | t_{CYC} ns |
| Clock (SCK) Low Time ($f_{OP} = 1.0$ MHz) | t_{SCKL} | 1980 | – | ns |
| SDO Data Valid Time | t_V | – | 400 | ns |
| SDO Hold Time | t_{HO} | 0 | – | ns |
| SDI Setup Time | t_S | 200 | – | ns |
| SDI Hold Time | t_H | 200 | – | ns |

NOTES:

- $V_{DD} = 3.3$ Vdc \pm 10%, $V_{SS} = 0$ Vdc, $T_A = T_L$ to T_H , unless otherwise noted.
- $f_{OP} = 1.0$ MHz maximum.



MOTOROLA
13-14

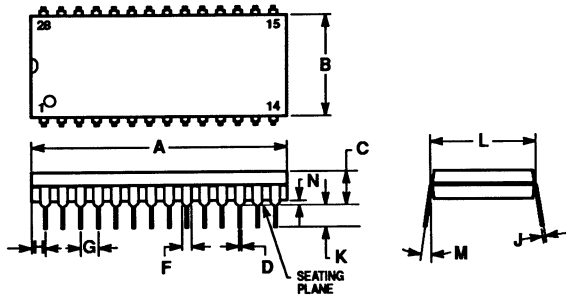
ELECTRICAL SPECIFICATIONS

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**SECTION 14
MECHANICAL SPECIFICATIONS**

This section gives the dimensions of the plastic dual in-line package (PDIP), ceramic dual in-line package (cerdip), and small outline integrated circuit (SOIC) package.

14.1 PDIP



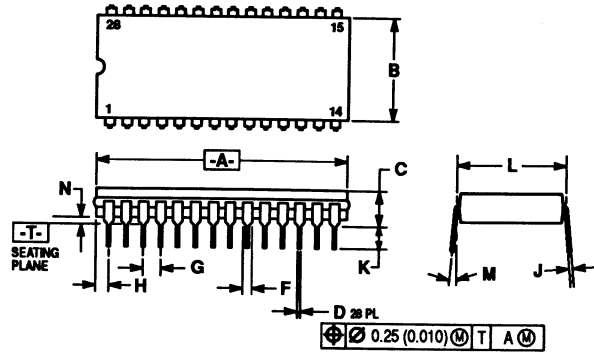
- NOTES:
1. POSITIONAL TOLERANCE OF LEADS (D), SHALL BE WITHIN 0.25mm (0.010) AT MAXIMUM MATERIAL CONDITION, IN RELATION TO SEATING PLANE AND EACH OTHER.
 2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
 3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

| DIM | MILLIMETERS | | INCHES | |
|-----|-------------|-------|-----------|-------|
| | MIN | MAX | MIN | MAX |
| A | 36.45 | 37.21 | 1.435 | 1.465 |
| B | 13.72 | 14.22 | 0.540 | 0.560 |
| C | 3.94 | 5.08 | 0.155 | 0.200 |
| D | 0.36 | 0.56 | 0.014 | 0.022 |
| F | 1.02 | 1.52 | 0.040 | 0.060 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 1.65 | 2.16 | 0.065 | 0.085 |
| J | 0.20 | 0.38 | 0.008 | 0.015 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 15.24 BSC | | 0.600 BSC | |
| M | 0° | 15° | 0° | 15° |
| N | 0.51 | 1.02 | 0.020 | 0.040 |

CASE 710-02
ISSUE B

Figure 14-1.

14.2 Cerdip



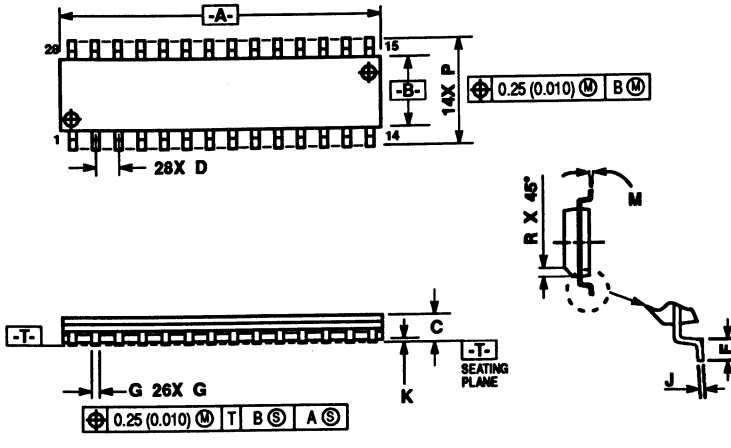
- NOTES:
1. DIM A AND B INCLUDES MENISCUS.
 2. DIM L TO CENTER OF LEADS WHEN FORMED PARALLEL.
 3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
 4. CONTROLLING DIM: INCH.

| DIM | INCHES | | MILLIMETERS | |
|-----|-----------|-------|-------------|-------|
| | MIN | MAX | MIN | MAX |
| A | 1.435 | 1.490 | 36.45 | 37.84 |
| B | 0.500 | 0.605 | 12.70 | 15.36 |
| C | 0.160 | 0.230 | 4.06 | 5.84 |
| D | 0.015 | 0.022 | 0.38 | 0.55 |
| F | 0.050 | 0.065 | 1.27 | 1.65 |
| G | 0.100 BSC | | 2.54 BSC | |
| J | 0.008 | 0.012 | 0.20 | 0.30 |
| K | 0.125 | 0.160 | 3.18 | 4.06 |
| L | 0.600 BSC | | 15.24 BSC | |
| M | 0° 15° | | 0° 15° | |
| N | 0.020 | 0.050 | 0.51 | 1.27 |

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ISSUE B

Figure 14-2.

14.3 SOIC



- NOTES:
1. DIMENSIONS "A" AND "B" ARE DATUMS AND "T" IS A DATUM SURFACE.
 2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
 3. CONTROLLING DIMENSION: MILLIMETER.
 4. DIMENSION "A" AND "B" DO NOT INCLUDE MOLD PROTRUSION.
 5. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
 6. DIMENSION "D" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF "D" DIMENSION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS | | INCHES | |
|-----|-------------|-------|--------|--------|
| | MIN | MAX | MIN | MAX |
| A | 17.80 | 18.05 | 0.701 | 0.711 |
| B | 7.40 | 7.60 | 0.292 | 0.299 |
| C | 2.35 | 2.65 | 0.093 | 0.104 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.41 | 0.90 | 0.016 | 0.035 |
| G | 1.27 | BSC | 0.050 | BSC |
| J | 0.229 | 0.317 | 0.0090 | 0.0125 |
| K | 0.127 | 0.292 | 0.0050 | 0.0115 |
| M | 0° | 8° | 0° | 8° |
| P | 10.05 | 10.55 | 0.395 | 0.415 |
| R | 0.25 | 0.75 | 0.010 | 0.029 |

CASE 751F-04
ISSUE E

Figure 14-3.

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MOTOROLA
14-4

MECHANICAL SPECIFICATIONS

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