80296SA Microcontroller User's Manual

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80296SA Microcontroller User's Manual

September 1996

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Guide to This Manual

CHAPTER 1
GUIDE TO THIS MANUAL

This manual describes the 80296SA embedded microcontroller. It is intended for use by both software and hardware designers familiar with the principles of microcontrollers. This chapter describes what you'll find in this manual, lists other documents that may be useful, and explains how to access the support services we provide to help you complete your design.

1.1 MANUAL CONTENTS

This manual contains several chapters and appendixes, a glossary, and an index. This chapter, Chapter 1, provides an overview of the manual. This section summarizes the contents of the remaining chapters and appendixes. The remainder of this chapter describes notational conventions and terminology used throughout the manual, provides references to related documentation, describes customer support services, and explains how to access information and assistance.

Chapter 2 — Architectural Overview — provides an overview of the device hardware. It describes the core, internal timing, internal peripherals, and special operating modes. It also describes the chip configuration bytes (CCBs) and the chip configuration registers (CCRs), which control many aspects of the microcontroller's operation.

Chapter 3 — Digital Signal Processing — describes the advanced mathematical features of the 80296SA that enable it to perform digital signal processing functions. The 80296SA incorporates enhanced instructions for multiplication, shifting, and multiply-accumulate operations. It also has a dedicated 32-bit barrel shifter for manipulating data and a 40-bit accumulator register for storing the results. The instructions and accumulator support signed and unsigned integers as well as signed fractional data.

Chapter 4 — Programming Considerations — provides an overview of the instruction set, describes general standards and conventions, and defines the operand types and addressing modes supported by the MCS® 96 microcontroller family. (For additional information about the instruction set, see Appendix A.)

Chapter 5 — Memory Partitions — describes the addressable memory space of the device. It describes the memory partitions, explains how to use windows to increase the amount of memory that can be accessed with direct addressing, and lists all special-function registers (SFRs) with their addresses.

Chapter 6 — Interrupts — describes the interrupt controller and programmable priority scheme. It also explains interrupt programming and control.

Chapter 7 — I/O Ports — describes the input/output ports and explains how to configure the pins for general-purpose input/output or for special functions.

Chapter 8 — Serial I/O (SIO) Port — describes the asynchronous/synchronous serial I/O (SIO) port and explains how to program it.

Chapter 9 — Pulse-width Modulator — provides a functional overview of the pulse width modulator (PWM) modules, describes how to program them, and provides sample circuitry for converting the PWM outputs to analog signals.

Chapter 10 — Event Processor Array (EPA) — describes the event processor array, a timer/counter-based, high-speed input/output unit. It describes the timer/counters and explains how to program the EPA and how to use the EPA to produce pulse-width modulated (PWM) outputs.

Chapter 11 — Minimum Hardware Considerations — describes options for providing the basic requirements for device operation within a system, discusses other hardware considerations, and describes device reset options.

Chapter 12 — Special Operating Modes — provides an overview of the idle, powerdown, standby, and on-circuit emulation (ONCE) modes and describes how to enter and exit each mode.

Chapter 13 — Interfacing with External Memory — lists the signals and registers used for interfacing to external devices. It discusses the bus width and memory configurations, the bus-hold protocol, write-control modes, and internal wait states and ready control. Finally, it provides timing information for the system bus.

Appendix A — Instruction Set Reference — provides reference information for the instruction set. It describes each instruction; defines the processor status word (PSW) flags; shows the relationships between instructions and PSW flags; and lists hexadecimal opcodes, instruction lengths, and execution times. (For additional information about the instruction set, see Chapter 4, "Programming Considerations.")

Appendix B — Signal Descriptions — provides reference information for the device pins, including descriptions of the pin functions, reset status of the I/O and control pins, and package pin assignments.

Appendix C — Registers — provides a compilation of all special-function registers (SFRs), arranged alphabetically by register mnemonic. It also includes tables that list the windowed direct addresses for all SFRs in each possible window.

Glossary — defines terms with special meaning used throughout this manual.

Index — lists key topics with page number references.

1.2 NOTATIONAL CONVENTIONS AND TERMINOLOGY

The following notations and terminology are used throughout this manual. The Glossary defines other terms with special meanings.

— The pound symbol (#) has either of two meanings, depending on the context. When used with a signal name, the symbol means that the signal is active low. When used in an instruction, the symbol prefixes an immediate value in immediate addressing mode.

addresses — In this manual, both internal and external addresses use the number of hexadecimal digits that correspond with the number of available address bits. For example, the highest possible internal address is shown as FFFFFFH, while the highest possible external address is shown as FFFFFH.

When writing code, use the appropriate address conventions for the software tool you are using. (In general, assemblers require a zero preceding an alphabetic hexadecimal character and an “H” following any hexadecimal value, so FFFFFFH must be written as 0FFFFFFH. ANSI ‘C’ compilers require a zero plus an “x” preceding a hexadecimal value, so FFFFFFH must be written as 0xFFFFFF.) Consult the manual for your assembler or compiler to determine its specific requirements.

assert and deassert — The terms *assert* and *deassert* refer to the act of making a signal active (enabled) and inactive (disabled), respectively. The active polarity (low or high) is defined by the signal name. Active-low signals are designated by a pound symbol (#) suffix; active-high signals have no suffix. To assert RD# is to drive it low; to assert ALE is to drive it high; to deassert RD# is to drive it high; to deassert ALE is to drive it low.

clear and set — The terms *clear* and *set* refer to the value of a bit or the act of giving it a value. If a bit is clear, its value is “0”; clearing a bit gives it a “0” value. If a bit is set, its value is “1”; setting a bit gives it a “1” value.

f — Lowercase “f” represents the internal operating frequency. See “Internal Timing” on page 2-8 for details.

instructions — Instruction mnemonics are shown in upper case to avoid confusion. In general, you may use either upper case or lower case when programming. Consult the manual for your assembler or compiler to determine its specific requirements.

italics Italics identify variables and introduce new terminology. The context in which italics are used distinguishes between the two possible meanings.

Variables in registers and signal names are commonly represented by *x* and *y*, where *x* represents the first variable and *y* represents the second variable. For example, in register P*x*_MODE.*y*, *x* represents the variable that identifies the specific port associated with the register, and *y* represents the register bit variable (7:0 or 15:0). Variables must be replaced with the correct values when configuring or programming registers or identifying signals.

numbers Hexadecimal numbers are represented by a string of hexadecimal digits followed by the character *H*. Decimal and binary numbers are represented by their customary notations. (That is, 255 is a decimal number and 1111 1111 is a binary number. In some cases, the letter *B* is appended to binary numbers for clarity.)

register bits Bit locations are indexed by 7:0 (or 15:0), where bit 0 is the least-significant bit and bit 7 (or 15) is the most-significant bit. An individual bit is represented by the register name, followed by a period and the bit number. For example, WSR.7 is bit 7 of the window selection register. In some discussions, bit names are used.

register names Register mnemonics are shown in upper case. For example, TIMER2 is the timer 2 register; timer 2 is the timer. A register name containing a lowercase italic character represents more than one register. For example, the *x* in P*x*_REG indicates that the register name refers to any of the port data registers.

reserved bits Certain bits are described as *reserved* bits. In illustrations, reserved bits are indicated with a dash (—). These bits are not used in this device, but they may be used in future implementations. To help ensure that a current software design is compatible with future implementations, reserved bits should be cleared (given a value of "0") or left in their default states, unless otherwise noted. Do not rely on the values of reserved bits; consider them undefined.

reserved registers Certain special-function register (SFR) locations are described as *reserved*. These locations are not used in this microcontroller, but they may be used in future implementations. To help ensure that a current software design is compatible with future implementations, do not use these locations.

signal names Signal names are shown in upper case. When several signals share a common name, an individual signal is represented by the signal name followed by a number. For example, the EPA signals are named EPA0, EPA1, EPA2, etc. Port pins are represented by the port abbreviation, a period, and the pin number (e.g., P2.0, P2.1); a range of pins is represented by P*x*.*y*:*z* (e.g., P2.4:0 represents five port pins: P2.4, P2.3, P2.2, P2.1, P2.0). A pound symbol (#) appended to a signal name identifies an active-low signal.

t Lowercase "t" represents the internal operating period. See "Internal Timing" on page 2-8 for details.

units of measure The following abbreviations are used to represent units of measure:

A	amps, amperes
DCV	direct current volts
Kbytes	kilobytes
kHz	kilohertz
kΩ	kilo-ohms
mA	milliamps, milliamperes
Mbytes	megabytes
MHz	megahertz
ms	milliseconds
mW	milliwatts
ns	nanoseconds
pF	picofarads
W	watts
V	volts
µA	microamps, microamperes
µF	microfarads
µs	microseconds
µW	microwatts

x Lowercase *x* (italic) represents a variable. Variables must be replaced with the correct values when configuring or programming registers or identifying signals.

X Uppercase X (no italics) represents an unknown value or an irrelevant ("don't care") state or condition. The value may be either binary or hexadecimal, depending on the context. For example, 2XAFH (hex) indicates that bits 11:8 are unknown; 10XXB (binary) indicates that the two least-significant bits are unknown.

y Lowercase *y* (italic) represents a variable. Variables must be replaced with the correct values when configuring or programming registers or identifying signals.

1.3 RELATED DOCUMENTS

The tables in this section list additional documents that you may find useful in designing systems incorporating MCS 96 microcontrollers. These are not comprehensive lists, but are a representative sample of relevant documents. For a complete list of available printed documents, please order the literature catalog (order number 210621). To order documents, please call the Intel literature center for your area (see Table 1-4 on page 1-8).

Table 1-1. Handbooks and Product Information

Title and Description	Order Number
Intel Embedded Quick Reference Guide	272439
Solutions for Embedded Applications Guide	240691
Data on Demand fact sheet	240952
Data on Demand annual subscription (6 issues; Windows* version) Complete set of Intel handbooks on CD-ROM.	240897
Handbook Set — handbooks and product overview Intel's product line handbooks containing datasheets, application notes, article reprints and other design information on microprocessors, peripherals, embedded controllers, memory components, single-board computers, microcommunications, software development tools, and operating systems.	231003
Embedded Microcontrollers † Datasheets and architecture descriptions for Intel's three industry-standard microcontrollers, the MCS 48, MCS 51, and MCS 96 microcontrollers.	270646
Peripheral Components † Comprehensive information on Intel's peripheral components, including datasheets, application notes, and technical briefs.	296467
Flash Memory (2 volume set) † A collection of datasheets and application notes devoted to techniques and information to help design semiconductor memory into an application or system.	210830
Packaging † Detailed information on the manufacturing, applications, and attributes of a variety of semiconductor packages.	240800
Automotive Products Application notes and article reprints on topics including the MCS 51 and MCS 96 microcontrollers. Documents in this handbook discuss hardware and software implementations and present helpful design techniques.	231792
Embedded Applications (1995/96) Datasheets, architecture descriptions, and application notes on topics including flash memory devices, networking chips, and MCS 51 and MCS 96 microcontrollers. Documents in this handbook discuss hardware and software implementations and present helpful design techniques.	270648
Development Tools Handbook Information on third-party hardware and software tools that support Intel's embedded microcontrollers.	272326

† Included in handbook set (order number 231003)

Table 1-2. Application Notes

Title	Order Number
AP-125, *Designing Microcontroller Systems for Electrically Noisy Environments* †††	210313
AP-155, *Oscillators for Microcontrollers* †††	230659
AP-406, *MCS® 96 Analog Acquisition Primer* †††	270365
AP-445, *8XC196KR Peripherals: A User's Point of View* †	270873
AP-477, *Low Voltage Embedded Design* ††	272324
AP-715, *Interfacing an I²C Serial EEPROM to an MCS® 96 Microcontroller*	272680
AP-717, *Migration from the 8XC196Nx to the 80296SA*	272730

† Included in *Automotive Products* handbook (order number 231792)

†† Included in *Embedded Applications* handbook (order number 270648)

††† Included in *Automotive Products* and *Embedded Applications* handbooks

Table 1-3. MCS® 96 Microcontroller Datasheets

Title	Order Number
8XC196NP Commercial CHMOS 16-Bit Microcontroller †	272459
80C196NU Commercial CHMOS 16-Bit Microcontroller †	272644
80296SA Commercial CHMOS 16-Bit Microcontroller	272748

† Included in *Embedded Microcontrollers* handbook (order number 270646)

1.4 APPLICATION SUPPORT SERVICES

You can get up-to-date technical information from a variety of electronic support systems: the World Wide Web, CompuServe, the FaxBack* service, and Intel's Brand Products and Applications Support bulletin board service (BBS). These systems are available 24 hours a day, 7 days a week, providing technical information whenever you need it.

In the U.S. and Canada, technical support representatives are available to answer your questions between 5 a.m. and 5 p.m. Pacific Standard Time (PST). Outside the U.S. and Canada, please contact your local distributor. You can order product literature from Intel literature centers and sales offices.

Table 1-4 lists the information you need to access these services.

Table 1-4. Intel Application Support Services

Service	U.S. and Canada	Asia-Pacific and Japan	Europe
World Wide Web	URL: http://www.intel.com/	URL: http://www.intel.com/	URL: http://www.intel.com/
CompuServe	go intel	go intel	go intel
FaxBack*	800-525-3019	503-264-6835 916-356-3105	+44(0)1793-496646
BBS	503-264-7999 916-356-3600	503-264-7999 916-356-3600	+44(0)1793-432955
Help Desk	800-628-8686 916-356-7999	Please contact your local distributor.	Please contact your local distributor.
Literature	800-548-4725	708-296-9333 +81(0)120 47 88 32	+44(0)1793-431155 England +44(0)1793-421777 France +44(0)1793-421333 Germany

1.4.1 World Wide Web

We offer a variety of technical and product information through the World Wide Web (URL: http://www.intel.com/design/mcs96). Also visit Intel's Web site for financials, history, and news.

1.4.2 CompuServe Forums

Intel maintains several CompuServe forums that provide a means for you to gather information, share discoveries, and debate issues. Type "go intel" for access. The INTELC forum is set up to support designers using various Intel components. For information about CompuServe access and service fees, call CompuServe at 1-800-848-8199 (U.S.) or 614-529-1340 (outside the U.S.).

1.4.3 FaxBack Service

The FaxBack service is an on-demand publishing system that sends documents to your fax machine. You can get product announcements, change notifications, product literature, device characteristics, design recommendations, and quality and reliability information from FaxBack 24 hours a day, 7 days a week.

Think of the FaxBack service as a library of technical documents that you can access with your phone. Just dial the telephone number and respond to the system prompts. After you select a document, the system sends a copy to your fax machine.

Each document is assigned an order number and is listed in a subject catalog. The first time you use FaxBack, you should order the appropriate subject catalogs to get a complete listing of document order numbers. Catalogs are updated twice monthly. In addition, daily update catalogs list the title, status, and order number of each document that has been added, revised, or deleted during the past eight weeks. The daily update catalogs are numbered with the subject catalog number followed by a zero. For example, for the complete microcontroller and flash catalog, request document number 2; for the daily update to the microcontroller and flash catalog, request document number 20.

The following catalogs and information are available at the time of publication:

1. *Solutions OEM* subscription form
2. Microcontroller and flash catalog
3. Development tools catalog
4. Systems catalog
5. Multimedia catalog
6. Multibus and iRMX® software catalog and BBS file listings
7. Microprocessor, PCI, and peripheral catalog
8. Quality and reliability and change notification catalog
9. iAL (Intel Architecture Labs) technology catalog

1.4.4 Bulletin Board System (BBS)

Intel's Brand Products and Applications Support bulletin board system (BBS) lets you download files to your PC. The BBS has the latest *Ap*BUILDER software, hypertext manuals and datasheets, software drivers, firmware upgrades, application notes and utilities, and quality and reliability data.

Any customer with a PC and modem can access the BBS. The system provides automatic configuration support for 1200- through 19200-baud modems. Use these modem settings: no parity, 8 data bits, and 1 stop bit (N, 8, 1).

To access the BBS, just dial the telephone number (see Table 1-4 on page 1-8) and respond to the system prompts. During your first session, the system asks you to register with the system operator by entering your name and location. The system operator will set up your access account within 24 hours. At that time, you can access the files on the BBS.

NOTE

In the U.S. and Canada, you can get a BBS user's guide, a master list of BBS files, and lists of FaxBack documents by calling 1-800-525-3019. Use these modem settings: no parity, 8 data bits, and 1 stop bit (N, 8, 1).

2

Architectural Overview

CHAPTER 2
ARCHITECTURAL OVERVIEW

The 16-bit 80296SA CHMOS microcontroller is designed to handle high-speed calculations and fast input/output (I/O) operations. The core of the 80296SA differs from that of earlier MCS® 96 microcontroller cores. It was designed to provide a significant performance increase while maintaining object-code compatibility with earlier MCS 96 microcontrollers. Major contributors to the performance increase are the 80296SA's pipelined architecture, improved math performance, and new hardware and instructions to support embedded digital signal processing applications. The 80296SA is pin-compatible with the 8XC196NP and 80C196NU, allowing you to place an 80296SA into a socket designed for the 8XC196NP or 80C196NU and improve your system's performance.

2.1 TYPICAL APPLICATIONS

MCS 96 microcontrollers are typically used for high-speed event control systems. Commercial applications include modems, motor-control systems, printers, photocopiers, air conditioner control systems, disk drives, and medical instruments. Automotive customers use MCS 96 microcontrollers in engine-control systems, airbags, suspension systems, and antilock braking systems (ABS). The 80296SA is especially well suited to applications that benefit from its fast instruction execution times and digital signal processing functions, such as mass storage applications.

Table 2-1 lists the features of the 80296SA, and Figure 2-1 shows a detailed block diagram.

Table 2-1. Features of the 80296SA

Device	Pins	Register RAM (Note 1)	Code/Data RAM	I/O Pins (Note 2)	EPA Pins	SIO Ports	PWM Channels	Chip-select Pins	External Interrupt Pins
80296SA	100	512 bytes	2 Kbytes	64	4	1	3	6	4

NOTES:
1. Register RAM amount includes the 24 bytes allocated to core special-function registers (SFRs) and the stack pointer.
2. I/O pins include address, data, and bus control pins and 32 I/O port pins.

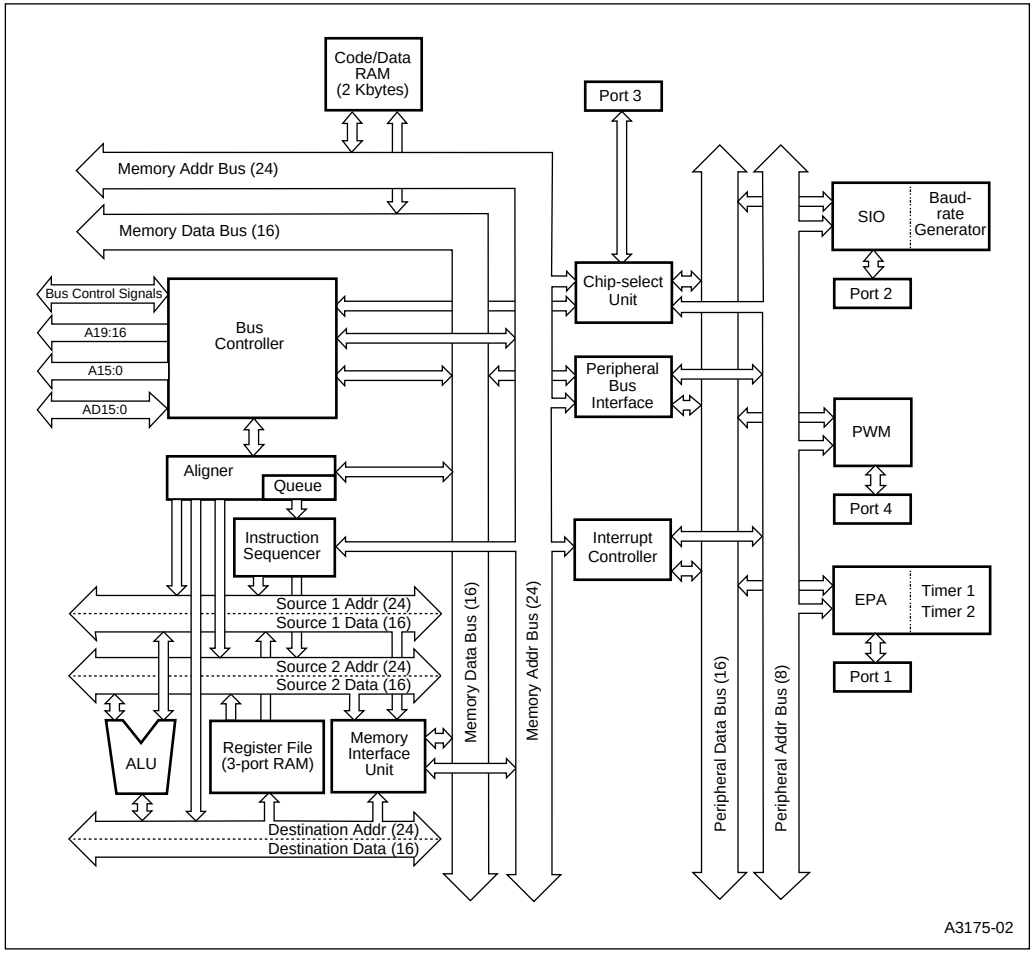


Figure 2-1. 80296SA Detailed Block Diagram

2.2 FUNCTIONAL OVERVIEW

Figure 2-2 is a simplified block diagram that shows the major blocks within the microcontroller. The shaded area of Figure 2-2 encompasses the core, clock and power management logic, internal code/data RAM, the bus controller, and the chip-select unit. All communication among these blocks takes place through the 24-bit memory address bus. Outside the shaded area are the internal peripherals: general-purpose input/output (I/O) ports, serial input/output (SIO) port, pulse-width modulator (PWM), event processor array (EPA), and programmable interrupt controller. The peripheral interface communicates through the 8-bit peripheral address bus.

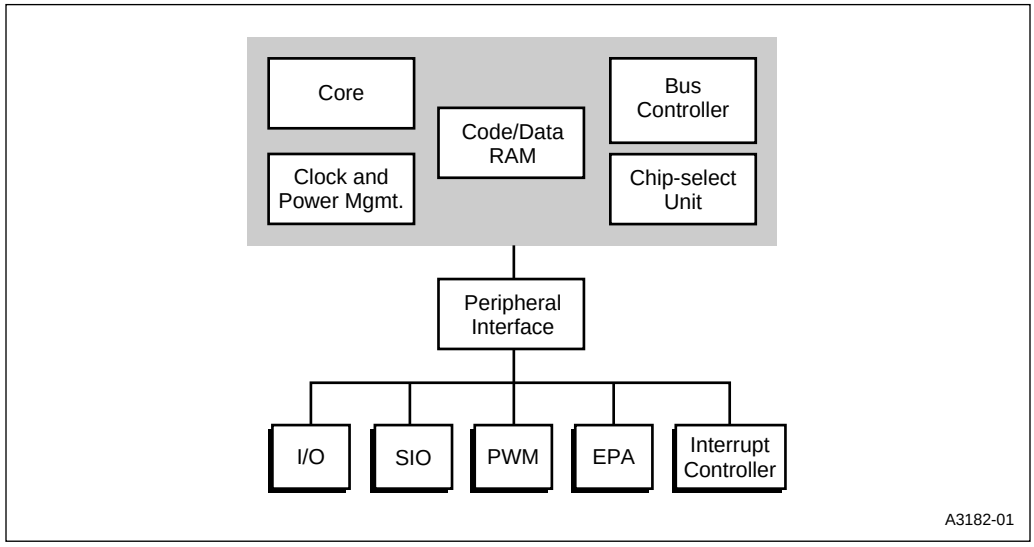


Figure 2-2. 80296SA Block Diagram

2.2.1 Core

The core of the 80296SA (Figure 2-3) consists of the central processing unit (CPU) and memory interface unit. The CPU contains the aligner and instruction sequencer, the execution unit, and the register file. A 24-bit memory address bus connects the CPU and memory interface unit; an extension of this bus connects the memory interface unit to the bus controller. An 8-bit peripheral address bus allows communication with the interrupt controller and internal peripherals.

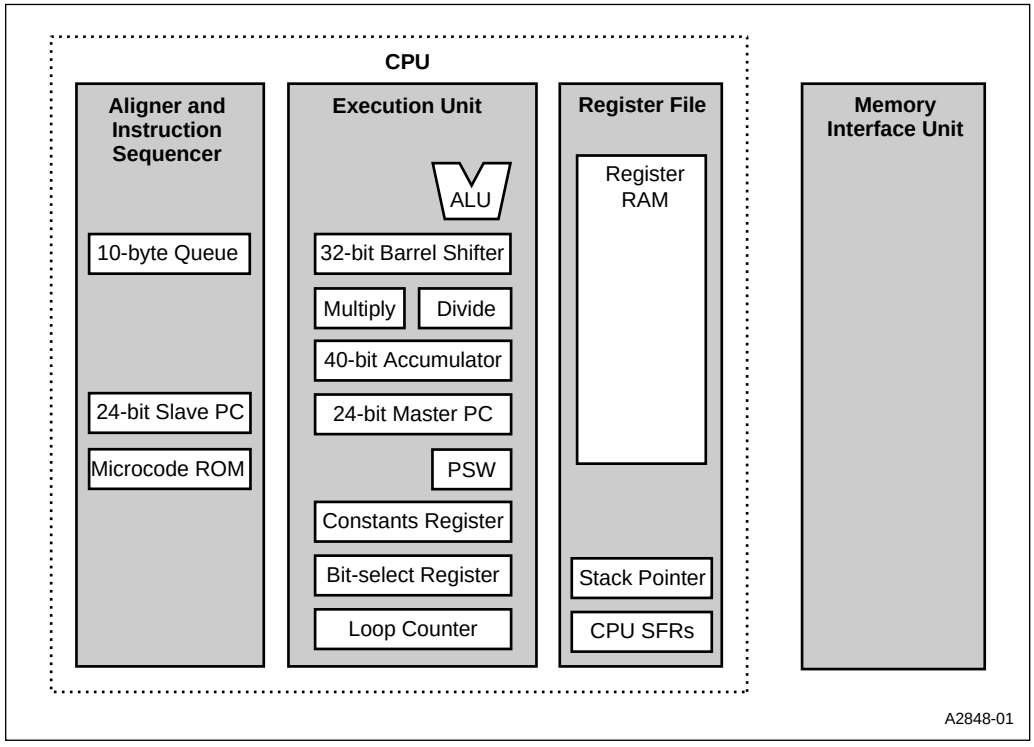


Figure 2-3. Block Diagram of the Core

2.2.1.1 CPU

The 80296SA implements a pipelined architecture. The pipelined microcode engine controls the CPU, instructing the execution unit to perform operations using bytes, words, or double-words from either the 256-byte lower register file or through a *window* that directly accesses higher memory. (See Chapter 5, "Memory Partitions," for more information about the register file and windowing.) In addition, two automatic indexing registers (IDX0 and IDX1) provide indirect access to the entire 16-Mbyte internal address space. CPU instructions move from the memory interface unit into the queue, then into the instruction sequencer, and finally into the execution pipeline. The aligner and instruction sequencer maintain a steady flow of instructions into the pipeline. The pipeline has four stages: fetch, decode, read-execute, and execute-write. Instructions move sequentially through the pipeline stages, as shown in Figure 2-4.

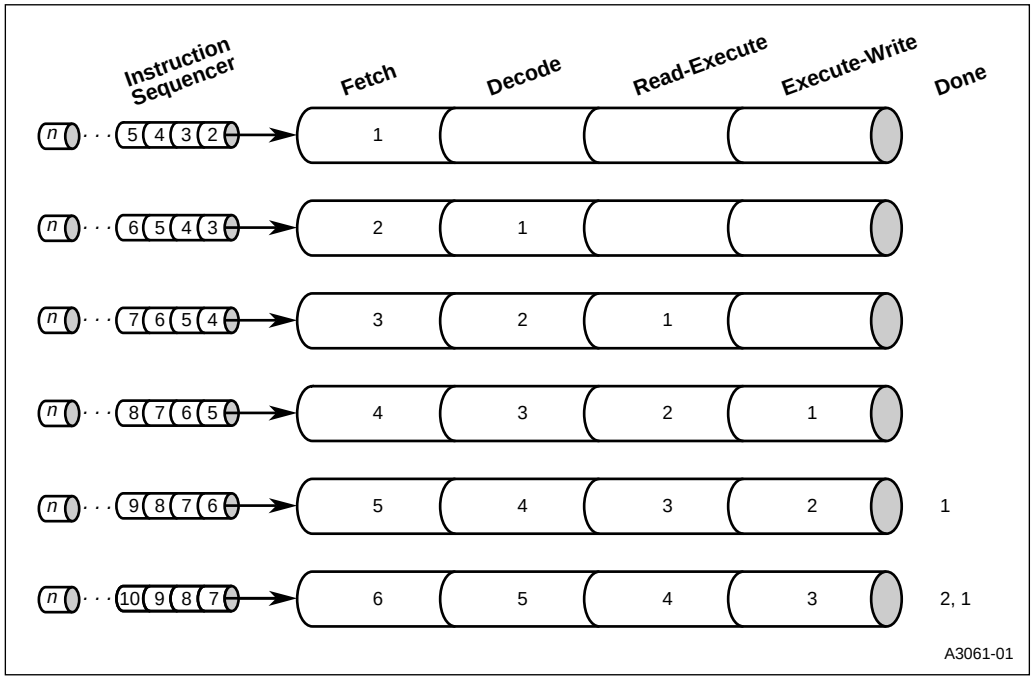


Figure 2-4. Instruction Pipeline

2.2.1.2 Register File

The register file is divided into an upper and a lower file. In the lower register file, the lowest 24-byte section is allocated to the CPU's special-function registers (SFRs) and the stack pointer, while the remainder is available as general-purpose register RAM. The upper register file contains only general-purpose register RAM. The register RAM can be accessed as bytes, words, or double-words.

The execution unit accesses the upper and lower register files differently. The lower register file is always directly accessible with direct addressing (see "Addressing Modes" on page 4-8). The upper register file is accessible with direct addressing only when *windowing* is enabled. Otherwise, the upper register file is accessed indirectly, through the memory interface unit. Windowing is a technique that maps blocks of the upper register file into a *window* in the lower register file. See Chapter 5, "Memory Partitions," for more information about the register file and windowing.

2.2.2 Execution Unit

The execution unit contains the 16-bit arithmetic logic unit (ALU), the divide unit, the multiply unit, the 32-bit barrel shifter, and the 40-bit hardware accumulator. It also contains the master program counter (PC), the processor status word (PSW), a constants register, a bit-selection register, and a loop counter.

The ALU handles general arithmetic and logical operations. The divide unit processes division instructions independently. The multiply unit processes both normal multiplication instructions and multiply-accumulate (MAC) operations. The barrel shifter processes all shifts, and the accumulator is used for all multiply-accumulate operations.

The 24-bit master program counter (PC) provides a linear, nonsegmented 16-Mbyte memory space. The master PC contains the address of the next instruction and has a built-in incrementer that automatically loads the next sequential address. However, if a jump, interrupt, call, or return changes the address sequence, the ALU loads the appropriate address into the master PC.

The PSW contains one bit that globally enables or disables servicing of all maskable interrupts, and six Boolean flags that reflect the state of your program. (Table A-2 on page A-4 describes the status flags.) The execution unit speeds up calculations by storing constants (e.g., 0, 1, and 2) in the constants register so that they are readily available when complementing, incrementing, or decrementing bytes or words. In addition, the constants register generates single-bit masks, based on the bit-selection register, for bit-test instructions. The six-bit loop counter counts repetitive shifts.

2.2.3 Memory Interface Unit

All memory except the register file is accessed through the memory interface unit. The memory interface unit drives the memory bus, which consists of an internal memory bus and the external address/data bus. It receives memory-access requests from either the register file or the prefetch queue. Data accesses have priority over instruction prefetches. Instruction prefetches are transparent to the register file. When the memory interface unit receives a request from the prefetch queue, it fetches the code from the address contained in the slave program counter (PC). Having the next instruction immediately available in the queue can increase execution performance, since the processor need not wait for the master PC to update the address. If a jump, interrupt, call, or return changes the address sequence, however, the master PC loads the new address into the slave PC, the CPU flushes both the instruction queue and the pipeline, the memory interface unit fetches the code from the new address, and processing resumes.

NOTE

When using a logic analyzer to debug code, remember that instructions are preloaded into the prefetch queue and are not necessarily executed immediately after they are fetched. Also remember that up to four instructions can be executing in different stages of the pipeline.

2.2.4 Bus Controller and Chip-select Unit

The memory interface unit accesses the internal code/data RAM through the bus controller unless the RAM is *windowed* into the register file. It also accesses the chip-select unit through the bus controller. The peripheral bus interface enables access to the internal peripherals.

In addition to its 16-bit address/data bus, the 80296SA has an extended addressing port consisting of 4 external address pins, for a total of 20 address pins. With 20 address pins, this microcontroller can access up to 1 Mbyte of external address space. Like the 8XC196NP and 80C196NU, the 80296SA incorporates a chip-select unit to simplify access to external memory devices. Unlike the chip-select unit of the earlier microcontrollers, which decoded only the lower 20 address bits,

the 80296SA's chip-select unit decodes all 24 bits of the internal address. You can assign each chip-select a range of addresses in up to 1-Mbyte segments. Therefore, with 6 chip-select outputs, the 80296SA can access up to 6 Mbytes of memory. Refer to "Memory Map Overview" on page 5-1 and "The Chip-select Unit" on page 13-8 for details.

2.3 INTERNAL TIMING

This section describes the internal clock circuitry and power management logic.

2.3.1 Clock and Power Management Logic

The 80296SA's clock circuitry (Figure 2-5) implements phase-locked loop and clock multiplier circuitry, which can substantially increase the CPU clock rate while using a lower-frequency input clock.

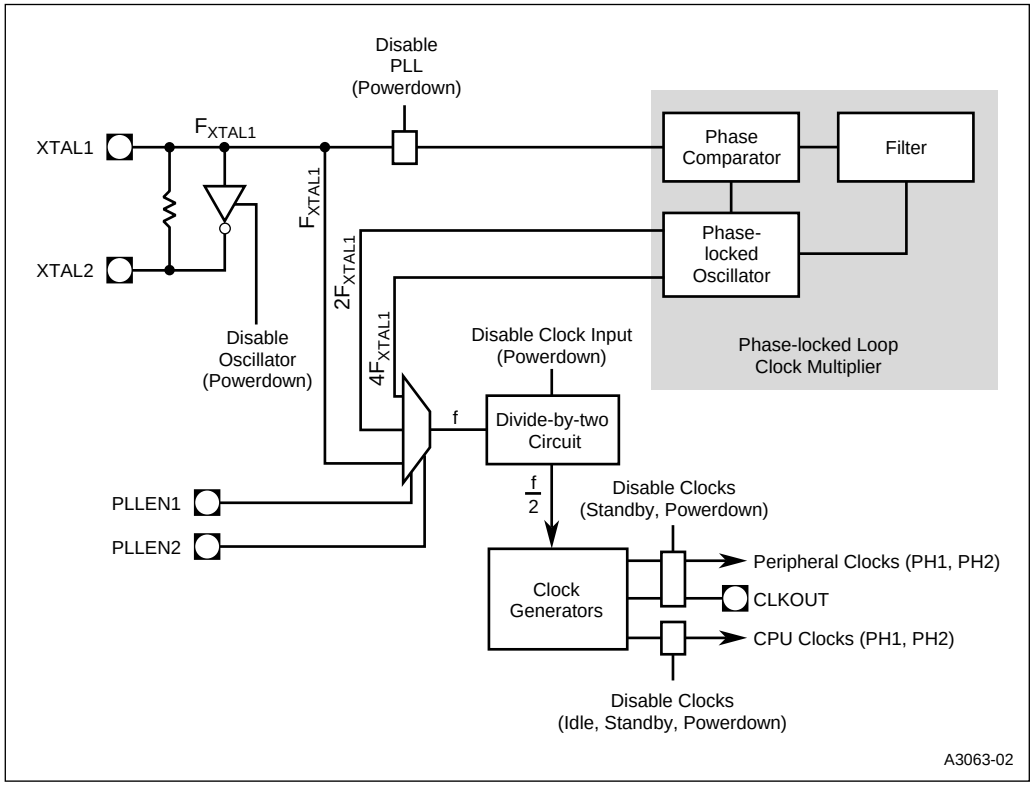


Figure 2-5. Clock Circuitry

NOTE

This manual uses lowercase "f" to represent the internal clock frequency. For the 80296SA, f is equal to either F_{XTAL1} , $2F_{XTAL1}$, or $4F_{XTAL1}$, depending on the clock multiplier mode, which is controlled by the PLLEN1 and PLLEN2 input pins. The "f" frequency is routed through the divide-by-two circuit to the clock generators, which produce the two nonoverlapping internal timing signals, PH1 and PH2.

2.3.2 Internal Timing

The clock circuitry accepts an input clock signal on XTAL1 provided by an external crystal or oscillator. This frequency is routed either through the phase-locked loop and multiplier circuitry or directly to the divide-by-two circuit. The multiplier circuitry can double or quadruple the input frequency (F_{XTAL1}). The frequency (f) input to the divide-by-two circuit is either F_{XTAL1}, $2F_{XTAL1}$, or $4F_{XTAL1}$, depending on the PLLEN1 and PLLEN2 pins. The clock generators accept the frequency (f/2) from the divide-by-two circuit and produce two active-high, nonoverlapping internal timing signals, PH1 and PH2. The clock circuitry routes separate internal clock signals to the CPU and the peripherals for flexibility in power management.

The rising edges of PH1 and PH2 generate the internal CLKOUT signal (Figure 2-6). It also outputs the CLKOUT signal on the CLKOUT pin. Because of the complex logic in the clock circuitry, the signal on the CLKOUT pin is a delayed version of the internal CLKOUT signal. This delay varies with temperature and voltage.

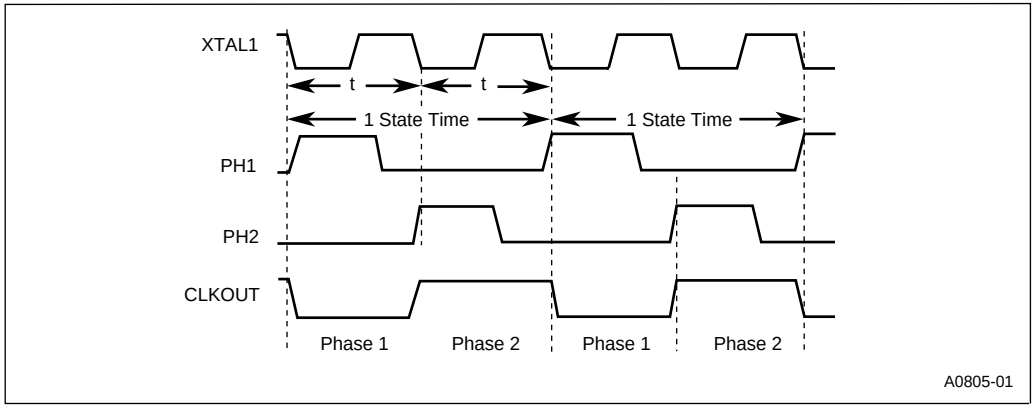


Figure 2-6. Internal Clock Phases (Assuming PLL is Bypassed)

The combined period of phase 1 and phase 2 of the internal CLKOUT signal defines the basic time unit known as a *state time* or *state*. Table 2-2 lists state time durations at various frequencies.

Table 2-2. State Times at Various Frequencies

f (Frequency Input to the Divide-by-two Circuit)	State Time
12.5 MHz	160 ns
25 MHz	80 ns
50 MHz	40 ns

The following formulas calculate the frequency of PH1 and PH2, the duration of a state time, and the duration of a clock period (t).

$$PH1 = \frac{f}{2} = PH2 \qquad \text{State Time} = \frac{2}{f} \qquad t = \frac{1}{f}$$

Because the microcontroller can operate at many frequencies, this manual defines time requirements (such as instruction execution times) in terms of state times rather than specific measurements. Datasheets list AC characteristics in terms of clock periods (t).

Table 2-3 details the relationships between the input frequency (F_{XTAL1}), the configuration of PLLEN1 and PLLEN2, the operating frequency (f), the clock period (t), and state times.

Table 2-3. Relationships Between Input Frequency, Clock Multiplier, and State Times

F_{XTAL1} (Frequency on XTAL1)	PLLEN2:1	Multiplier	f (Input Frequency to the Divide-by-two Circuit)	t (Clock Period)	State Time
50 MHz †	00	1	50 MHz	20 ns	40 ns
25 MHz	00	1	25 MHz	40 ns	80 ns
	01	2	50 MHz	20 ns	40 ns
12.5 MHz	00	1	12.5 MHz	80 ns	160 ns
	01	2	25 MHz	40 ns	80 ns
	11	4	50 MHz	20 ns	40 ns

† Assumes an external clock. The maximum frequency for an external crystal oscillator is 25 MHz.

Figure 2-7 illustrates the timing relationships between the input frequency (F_{XTAL1}), the operating frequency (f), and the CLKOUT signal with each of the three valid PLLEN*x* pin configurations. (Since the maximum operating frequency is 50 MHz, only a 12.5 MHz external clock frequency allows all three clock multiplier modes.)

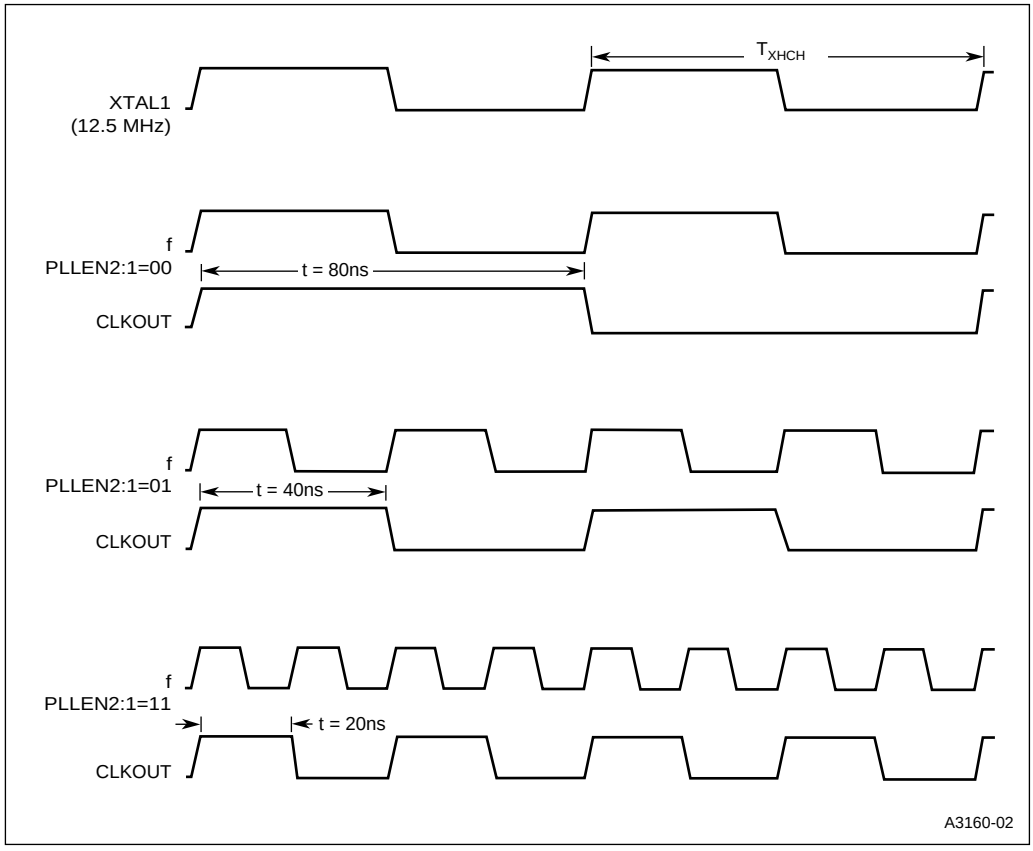


Figure 2-7. Effect of Clock Mode on CLKOUT Frequency

2.3.2.1 Power Management Options

The power saving modes selectively disable internal clocks to conserve power when the microcontroller is inactive. This microcontroller has three power-saving modes: idle, standby, and powerdown. If the power-saving modes are enabled in CCB0, the microcontroller enters a power-saving mode after executing the IDLPD instruction with a valid key (an invalid key causes a device reset). Figure 2-5 on page 2-7 illustrates the clock circuitry of the 80296SA.

In idle mode, the CPU stops executing instructions, but the peripheral clocks remain active. Power consumption drops to about 40% of normal execution mode consumption. Either a hardware reset or any enabled interrupt source will bring the microcontroller out of idle mode.

In standby mode, all internal clocks are frozen at logic state zero, but the oscillator and phase-locked loop continue to run. Power consumption drops to about 10% of normal execution mode consumption. Either a hardware reset or any enabled external interrupt source will bring the microcontroller out of standby mode.

In powerdown mode, all internal clocks are frozen at logic state zero and the internal oscillator is shut off. The register file, internal code and data RAM, and most peripherals retain their data if V_{CC} is maintained. Power consumption drops into the µW range.

You can conserve additional power by disabling the serial I/O port's baud-rate counter and the pulse-width modulator's duty-cycle counter when the peripherals are not being used. See "Chapter 8, "Serial I/O Port," and Chapter 9, "Pulse-width Modulator," for details.

2.4 INTERNAL PERIPHERALS

The internal peripheral modules provide special functions for a variety of applications. This section provides a brief description of the peripherals; subsequent chapters describe them in detail.

2.4.1 I/O Ports

80296SA has five I/O ports, ports 1–4 and the EPORT. In general, you can configure individual port pins to serve as general-purpose I/O or to carry special-function signals associated with on-chip peripherals or off-chip components.

Ports 1–4 are eight-bit, bidirectional I/O ports. Only the lower nibble of port 4 is implemented in current package offerings. Port 1 provides I/O pins for the four event processor array (EPA) modules and the two timers. Port 2 is used for the serial I/O (SIO) port, two external interrupts, and bus hold functions. Port 3 is used for chip-select functions and two external interrupts. Port 4 (functionally only a 4-bit port) provides I/O pins associated with the three on-chip pulse-width modulators. The EPORT provides address lines A19:16 to support extended addressing. See Chapter 7, "I/O Ports," for more information.

2.4.2 Serial I/O (SIO) Port

The serial I/O (SIO) port is an asynchronous/synchronous port that includes a universal asynchronous receiver and transmitter (UART). The UART has one synchronous mode (mode 0) and three asynchronous modes (modes 1, 2, and 3) for both transmission and reception. The asynchronous modes are full duplex, meaning that they have dedicated receive and transmit data signals. The receiver is buffered, so the reception of a second byte can begin before the first byte is read. The transmitter is also buffered, allowing continuous transmissions. See Chapter 8, "Serial I/O (SIO) Port," for details.

2.4.3 Event Processor Array (EPA) and Timer/Counters

The event processor array (EPA) performs high-speed input and output functions associated with its timer/counters. In the input mode, the EPA monitors an input for signal transitions. When an event occurs, the EPA records the timer value associated with it. This is a *capture* event. In the output mode, the EPA monitors a timer until its value matches that of a stored time value. When a match occurs, the EPA triggers an output event, which can set, clear, or toggle an output pin. This is a *compare* event. Both capture and compare events can initiate interrupts, which can be serviced by either the interrupt controller or the PTS.

Timer 1 and timer 2 are 16-bit up/down timer/counters that can be clocked internally or externally. Each timer/counter is called a *timer* if it is clocked internally and a *counter* if it is clocked externally. See Chapter 10, "Event Processor Array (EPA)," for additional information on the EPA and timer/counters.

2.4.4 Pulse-width Modulator (PWM)

The output waveform from each PWM channel is a variable duty-cycle pulse with a programmable frequency that occurs every 256, 512, or 1024 state times, as programmed. Several types of motors require a PWM waveform for most efficient operation. When filtered, the PWM wave-

form produces a DC level that can change in 256 steps by varying the duty cycle. The number of steps per PWM period is also programmable (8 bits). See Chapter 9, “Pulse-width Modulator,” for more information.

2.4.5 Interrupt Controller

The 80296SA’s interrupt controller differs from that of earlier MCS 96 microcontrollers. This enhanced interrupt controller features two priority methods. The first method is compatible with earlier MCS 96 microcontrollers. For this method, the interrupt vector table begins at FF2000H, and you use the mask registers to modify the default interrupt priorities. The second method allows you to program the priority of each maskable interrupt. For this method, the interrupt controller generates a unique vector for the assigned priority level. You can also choose to relocate the interrupt vector table. See Chapter 6, “Interrupts,” for more information.

2.5 SPECIAL OPERATING MODES

In addition to the normal execution and power-saving modes, the microcontroller operates in special-purpose mode. On-circuit emulation (ONCE) mode electrically isolates the microcontroller from the system. By invoking the ONCE mode, you can test the printed circuit board while the microcontroller is soldered onto the board. See Chapter 12, “Special Operating Modes,” for more information about power-saving and ONCE modes.

2.6 CHIP CONFIGURATION REGISTERS

Two chip configuration bytes (CCBs) located in ROM control the basic configuration of the microcontroller. These bytes are loaded into the chip configuration registers (CCRs) as part of the reset sequence. Once they are loaded, the CCRs control many aspects of the microcontroller’s operation. Figures 2-8 and 2-9 illustrate the CCRs and describe their functions.

CCR0 no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7							0
1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5:4	WS1:0	Wait States These bits, along with the READY pin, control the number of wait states that are used for an external fetch of chip configuration byte 1 (CCB1). **WS1 WS0** 0 0 0 wait states 0 1 5 wait states 1 0 10 wait states 1 1 15 wait states If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.
3	DEMUX	Select Demultiplexed Bus Selects the demultiplexed bus mode for an external fetch of CCB1: 0 = multiplexed — address and data are multiplexed on AD15:0. 1 = demultiplexed — data only on AD15:0.
2	BHE#	Write-control Mode Selects the write-control mode, which determines the functions of the BHE#/WRH# and WR#/WRL# pins for external bus cycles: 0 = write strobe mode: the BHE#/WRH# pin operates as WRH#, and the WR#/WRL# pin operates as WRL#. 1 = standard write-control mode: the BHE#/WRH# pin operates as BHE#, and the WR#/WRL# pin operates as WR#.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 2-8. Chip Configuration 0 (CCR0) Register

CCR0 (Continued) no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7							0
1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
1	BW16	Buswidth Control Selects the bus width for an external fetch of CCB1: 0 = 8-bit bus 1 = 16-bit bus
0	PD	Powerdown Enable Enables or disables the IDLPD #2 and IDLPD #3 instructions. When enabled, the IDLPD #2 instruction causes the microcontroller to enter powerdown mode and the IDLPD #3 instruction causes the microcontroller to enter standby mode. 0 = disable powerdown and standby modes 1 = enable powerdown and standby modes If your design uses powerdown or standby mode, set this bit when you program the CCBs. If it does not, clearing this bit when you program the CCBs will prevent accidental entry into powerdown or standby mode. (Chapter 12, “Special Operating Modes,” discusses powerdown and standby modes.)

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 2-8. Chip Configuration 0 (CCR0) Register (Continued)

CCR1 no direct access†

The chip configuration 1 (CCR1) register selects the 64-Kbyte or 1-Mbyte addressing mode.

7							0
1	1	0	1	1	0	MODE64	0

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5	0	To guarantee proper operation, write zero to this bit.
4:3	1	To guarantee proper operation, write ones to these bits.

The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 2-9. Chip Configuration 1 (CCR1) Register

CCR1 (Continued) no direct access†

The chip configuration 1 (CCR1) register selects the 64-Kbyte or 1-Mbyte addressing mode.

7							0
1	1	0	1	1	0	MODE64	0

Bit Number	Bit Mnemonic	Function
2	0	To guarantee proper operation, write zero to this bit.
1	MODE64	Addressing Mode Selects 64-Kbyte or 1-Mbyte addressing. 0 = selects 1-Mbyte addressing 1 = selects 64-Kbyte addressing In 1-Mbyte mode, code can execute from almost anywhere in the address space. In 64-Kbyte mode, code can execute only from page FFH. (See "Fetching Code and Data in the 1-Mbyte and 64-Kbyte Modes" on page 5-22 for more information.)
0	0	Reserved; for compatibility with future devices, write zero to this bit.

The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 2-9. Chip Configuration 1 (CCR1) Register (Continued)

2.7 DESIGN CONSIDERATIONS FOR 80C196NU TO 80296SA CONVERSIONS

This section summarizes differences to consider when converting your design requirements from the 80C196NU to the 80296SA.

- Instructions will execute more quickly on the 80296SA than on the 80C196NU. If your software uses timing loops, you will need to analyze them for proper timing.
- Because of the pipelined architecture, instruction execution does not stall on the 80296SA to allow for wait states when writing to an external device. If an external write is followed by an external read, the read can occur before the write completes. To avoid this possibility if it is an issue in your system, use no-operation (NOP) instructions between the store and load instructions to cover the wait states required for the write.
- For the 80296SA, opcodes 10H, EEH, EDH, and ECH will generate an illegal opcode interrupt. Opcode E5H is an illegal opcode in the 80C196NU, but is the opcode for the return-from-interrupt (RETI) instruction in the 80296SA.
- The 80296SA has several new and enhanced instructions to support embedded digital signal processing applications.
- The 80296SA's accumulator is 40 bits, while the 80C196NU's is 32 bits.

- The 80296SA's register file is 512 bytes (00–1FFH), while the 80C196NU's is 1 Kbyte (00–3FFH). If your software expects memory in the upper 512 bytes of the register file (200–3FFH), or if you window higher memory into that area, you must provide external memory in those locations.
- The 80296SA has 2 Kbytes of internal code/data RAM (FFF800–FFFFFFH in 1-Mbyte mode, FFF800–FFFFFFH and 00F800–00FFFFH in 64-Kbyte mode). We recommend that you use this RAM for time-critical code (e.g., interrupt service routines) or time-critical data (e.g., data tables for digital signal processing, the stack, or the interrupt vector table).
- The 80296SA's CPU special-function registers and stack pointer (00–19H) must be accessed with direct addressing.
- The 80296SA can window additional memory (including two segments of external memory) into the lower register file via window selection register 1 (WSR1). The 80C196NU can window sections of the upper register file or special-function registers with WSR1, but cannot window external memory.
- The 80296SA has a 10-byte prefetch queue, while the 80C196NU has an 8-byte queue.
- The 80296SA's chip-select unit decodes all 24 internal address bits, allowing unique access to 6 Mbytes of external memory. In addition, the chip-select unit uses a priority method to prevent two chip-select outputs from being active at the same time.
- The 80296SA's chip configuration bytes and chip-select unit configuration registers select either 5, 10, or 15 internal wait states, while the 80C196NU's select either 1, 2, or 3.
- The 80296SA's deferred bus mode is controlled by the chip-select unit, while the 80C196NU's is controlled by the chip configuration bytes.
- The 80296SA's external interrupt inputs can be programmed as either edge-triggered or level-sensitive inputs.
- When the 80296SA's timers are operated independently (rather than cascaded), they overflow only on the 0000–FFFFH or FFFF–0000H boundary. If you implemented a workaround to check the overflow boundaries on an 80C196NU design, you will need to verify it for the 80296SA.
- For additional power conservation, the 80296SA allows you to individually disable the serial I/O port's baud-rate counter and the pulse-width modulator's duty-cycle counter when those peripherals are not being used.
- Indirect and indexed PUSH and POP operations relative to the stack pointer work differently on the 80296SA than on the 8XC196NP and 80C196NU. The 8XC196NP and 80C196NU microcontrollers calculate the address based on the value of the SP **after** it is updated, but the 80296SA calculates the address based on the value of the SP **before** it is updated.

3

Digital Signal Processing

CHAPTER 3
DIGITAL SIGNAL PROCESSING

Several digital signal processing (DSP) enhancements were made to the 80296SA architecture. These enhancements increase the 80296SA's overall math performance compared to previous MCS® 96 microcontrollers.

Together with the architectural enhancements, new and modified instructions manipulate the 80296SA's 40-bit accumulator efficiently to reduce execution cycle time. The instructions support signed and unsigned integers as well as signed fractional numbers. The overall impact of the microcontroller's enhanced digital signal processing functionality, combined with the register-to-register flexibility of the MCS 96 architecture, offers an efficient, math-intensive platform incorporated into a single-chip solution.

This chapter describes the new and modified instruction set, the 40-bit accumulator, and the index registers. Examples for using the signal processing hardware and software algorithms are provided where needed for clarification.

3.1 DIGITAL SIGNAL PROCESSING OVERVIEW

Digital signal processing (DSP) is a methodology that uses mathematical algorithms to analyze and extract information from complex digital signals.

The 80296SA's signal processing enhancements and increased mathematical computation resources, together with appropriate software algorithms, enable it to perform digital signal processing functions with precision. The 80296SA can search and retrieve data from lookup tables more quickly, with less CPU overhead, than earlier MCS 96 microcontrollers. (See "Application Example" on page 3-19.)

3.2 DSP REGISTERS

Table 3-1 describes the control and status registers associated with digital signal processing.

Table 3-1. DSP Control and Status Registers

Mnemonic	Address	Description
ACC_00 ACC_02 ACC_04	000CH 000EH 0006H	Accumulator Value These registers specify the current count of the accumulator. You can write to this register to clear or preload a value into the accumulator.
ACC_STAT	000BH	Accumulator Control and Status This register enables and disables fractional and saturation modes and contains three status flags that indicate the status of the accumulator's contents.
ICB0 ICB1	1FC3H 1FC7H	Index Control These registers control the automatic increment and decrement feature of the index pointers.

Table 3-1. DSP Control and Status Registers (Continued)

Mnemonic	Address	Description
ICX0 ICX1	0010H 0016H	Index Reference These registers allow you to indirectly access the address location being pointed to by the index register.
IDX0 IDX1	1FC0H 1FC4H	Index Pointer These 24-bit registers serve as pointers to any location within the address space.
RPT_CNT	0004H	Repeat Counter This register specifies the count value for the next instruction following the repeat instruction.

3.3 ENHANCED INSTRUCTION SET

There are 17 new and modified instructions for the 80296SA, each listed in Table 3-2. These instructions for handling digital signal processing routines can be divided into four basic categories:

- Add and subtract instructions — ADDC and SUBC
- Multiply-accumulate (MAC) instructions — MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, and SMACZ
- Move instructions — MSAC and MVAC
- Repeat instructions — RPT, RPT*xxx*, RPTI, and RPTI*xxx*

Additionally, the return from interrupt (RETI) instruction reduces interrupt overhead to aid in implementing multiply-accumulate operations.

Table 3-2. Enhanced Instruction Set for the 80296SA

Instruction		Description
Add/Sub	ADDC	Add word operands with carry
	SUBC	Subtract word operands with borrow
Multiply-Accumulate	MAC	Unsigned multiply-accumulate
	MACR	Unsigned multiply-accumulate with automatic data relocation
	MACRZ	Unsigned multiply-accumulate with zeroed accumulator and automatic data relocation
	MACZ	Unsigned multiply-accumulate and zeroed accumulator
	SMAC	Signed multiply-accumulate
	SMACR	Signed multiply-accumulate with automatic data relocation
	SMACRZ	Signed multiply-accumulate with zeroed accumulator and automatic data relocation
	SMACZ	Signed multiply-accumulate with zeroed accumulator
Move	MSAC	Move saturated long-word from accumulator
	MVAC	Move long-word from accumulator
Repeat	RPT	Unconditional uninterruptible repeat of next instruction
	RPTxxx	Conditional uninterruptible repeat of next instruction
	RPTI	Unconditional interruptible repeat of next instruction
	RPTIxxx	Conditional interruptible repeat of next instruction
	RETI	Return from interrupt

3.3.1 Addition and Subtraction (ADDC and SUBC) Instructions

The add with carry (ADDC) and subtract with borrow (SUBC) instructions are used to add and subtract constants to and from the accumulator.

3.3.1.1 ADDC Instruction

ADDC (add signed word to accumulator with carry) adds the source and destination word operands and the carry flag, and stores the sum into the destination address.

If the destination address is the accumulator, the word is added to (ACC_02).

If the destination address is the accumulator, and saturation is enabled in the accumulator control and status (ACC_STAT) register, then a saturated addition is performed. (Refer to “Saturation Mode (SME)” on page 3-15.)

3.3.1.2 SUBC Instruction

SUBC (subtract signed word from accumulator with borrow) subtracts the source word operand from the destination word operand, stores the result in the destination operand, and sets the carry flag as the complement of borrow.

If the destination address is the accumulator, the word is subtracted from (ACC_02).

If the destination address is the accumulator, and saturation is enabled in the accumulator control and status (ACC_STAT) register, then a saturated subtraction is performed.

3.3.2 Multiply-Accumulate (MAC) Instructions

There are eight multiply-accumulate (MAC) instructions for the 80296SA. Their basic functions are to:

- clear the accumulator before execution (denoted by a "Z" suffix on the core MAC mnemonic)
- relocate the source 2 (SRC2) word within a data table (denoted by an "R" suffix on the core MAC mnemonic)
- operate on signed numbers (denoted by an "S" prefix on the core MAC mnemonic)

The new multiply-accumulate instructions have the same opcodes as the multiply instructions, MUL and MULU. The 80296SA differentiates the instructions by the destination operand. If the destination operand address is less than 10H (0–FH), the 80296SA executes a multiply-accumulate instruction and automatically stores the result in the accumulator. If the destination operand is equal to or greater than 10H, the 80296SA executes a basic multiplication instruction.

The four least-significant bits of the destination operand address determine what operation a given instruction will execute (see Table 3-3). All the possible functional combinations of the multiply-accumulate instruction set are listed in Table 3-4 with detailed descriptions.

Table 3-3. Multiply-Accumulate Instruction Bit Definition

Bit Number	Bit Mnemonic (if bit = 1)	Function	
		Bit = 1	Bit = 0
3	Z	Zero accumulator after multiply	Do not zero accumulator
2	R	Relocate SRC2 after operation	Do not relocate SRC2
1	—	Reserved for future expansion; write zero to this bit	
0	S	Signed MAC operation	Unsigned MAC operation

Table 3-4. Multiply-Accumulate Instruction Set

Destination Address (Accumulator)					Instruction Mnemonic	Description
Bit 3	Bit 2	Bit 1†	Bit 0	Hex		
0	0	0	0	00H	MAC	Multiplies two unsigned 16-bit operands and adds the 32-bit result to the value currently in the accumulator.
0	0	0	1	01H	SMAC	Multiplies two signed 16-bit operands and adds the 32-bit result to the value currently in the accumulator.
0	1	0	0	04H	MACR	Multiplies two unsigned 16-bit operands and adds the 32-bit result to the value currently in the accumulator. The SRC2 data is relocated in memory to the SRC2 address plus two.
0	1	0	1	05H	SMACR	Multiplies two signed 16-bit operands and adds the 32-bit result to the value currently in the accumulator. The SRC2 data is relocated in memory to the SRC2 address plus two.
1	0	0	0	08H	MACZ	Multiplies two unsigned 16-bit operands, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
1	0	0	1	09H	SMACZ	Multiplies two signed 16-bit operands, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
1	1	0	0	0CH	MACRZ	Multiplies two unsigned 16-bit operands, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The SRC2 data is relocated in memory to the SRC2 address plus two.
1	1	0	1	0DH	SMACRZ	Multiplies two signed 16-bit operands, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The SRC2 data is relocated in memory to the SRC2 address plus two.

† Reserved for future expansion; write zero to this bit.

As previously stated, the multiplication instructions, MUL and MULU, share opcodes with the multiply-accumulate instructions. When you execute a MAC-related instruction (i.e., a destination address in the range of 00–0FH), the 80296SA automatically stores the result in the accumulator. The examples in Table 3-5 illustrate the results of consecutive multiply-accumulate instructions. Listed for each row of the table below are the three-operand multiply-accumulate instruction syntax, the equivalent three-operand multiply instruction syntax, the result, and the updated accumulator register value.

Table 3-5. Accumulator Usage Examples

MAC Syntax† (3-operand)	Equivalent 3-operand Multiply Instruction	SRC1×SRC2	Accumulator Value
MAC r1, r2	MULU **00H**, r1, r2	0200H	0200H
MACZ r3, #28H	MULU **08H**, r3, #28H	0780H	0780H
SMAC r3, r2	MULU **01H**, r3, r2	0600H	0D80H
MACRZ r5, r4	MULU **0CH**, r5, r4	1400H	1400H
SMACZ r5, r6	MULU **09H**, r5, r6	1800H	1800H
SMAC r1, #14H	MULU **01H**, r1, #14H	0140H	1940H

† Initial register values: ACC = 0, r1 = 10H, r2 = 20H, r3 = 30H, r4 = 40H, r5 = 50H, r6 = 60H

NOTE

The multiply-accumulate operation syntax does not include a destination operand because the accumulator is always the destination address.

3.3.3 Move (MSAC and MVAC) Instructions

There are two move instructions for the 80296SA — MSAC and MVAC. They are used to save accumulator values to other locations in memory when necessary. When you use these instructions, the 80296SA saves the accumulator results to a temporary register without modifying the accumulator.

The MSAC and MVAC instructions are barrel shifter-related instructions. This is because they are supported by the "left and right shift normalize" function that the barrel shifter unit performs.

3.3.3.1 Move Saturated Integer From Accumulator (MSAC) Instruction

The move saturated integer from accumulator (MSAC) instruction allows a 32-bit signed value to be rotated from the accumulator to a register or memory location at a double-word boundary address using a 32-bit barrel shifter.

Case studies one and two below illustrate the MSAC operation when the accumulator contains the positive value 0123 ABCDH:

```
CASE 1:   MSAC    r2,#27      ;rotate right 12, result in r2 is BCD0 123AH
CASE 2:   MSAC    r2,#23      ;rotate right 8, result in r2 is CD01 7FFFH
```

The syntax for this instruction shows the result destination address followed by the bit pointer. (The bit pointer is the position of the bit that will assume the most-significant bit (MSB) position of the low destination word (bit 15), the destination sign bit.)

To conceptualize the wrapping affect of the 32-bit barrel shifter and determine the rotation direction and shift count for all 32 bits, you must first subtract the value fifteen (for bit position 15) from the bit pointer.

- If the result is negative, a shift left is performed.
- If the result is positive, a shift right is performed.

If a saturation is detected, the latched saturation bit in the ACC_STAT register is set. (MSAC is valid only for signed values.)

In case study one above, for example, the bit pointer, minus fifteen, equals the value twelve. This is interpreted as shift accumulator bit #27 twelve positions to the right (see Figure 3-1). In this case, the extracted result after all bits have been shifted is BCD0 123AH.

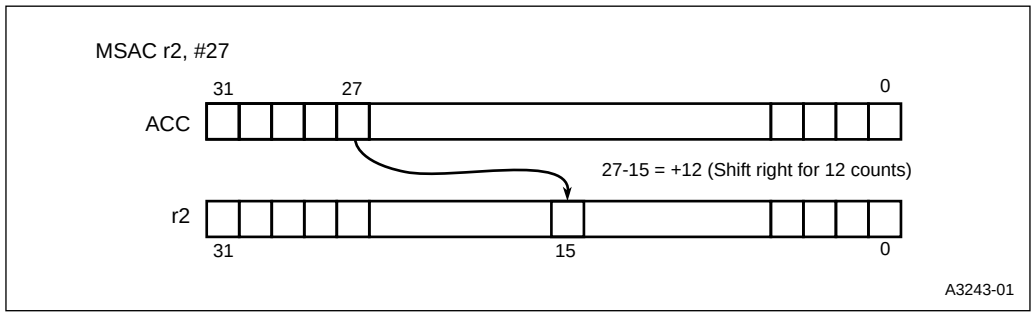


Figure 3-1. MSAC Instruction Example

NOTE

The bit pointer is specified either as an immediate value in the range 0–31 or as a register in the range 20–FFH. The value in the register must be in the range 0–31.

If a positive value is to be extracted from the accumulator, the sign bit of the accumulator (bit 31), the destination sign bit, and all of the bits between them, must be zero.

- If not, the extracted number will not accurately represent the value in the accumulator. As a result, the value in the low destination word of the extracted number will saturate to the maximum positive number 7FFFH, as in case study two, above.

If a negative value is to be extracted from the accumulator, the sign bit of the accumulator (bit 31), the destination sign bit, and all of the bits between them, must be one.

- If not, the extracted number will not accurately represent the value in the accumulator and the value in the low destination word of the extracted number will saturate to the maximum negative number 8000H.

Cases studies three and four below illustrate the MSAC operation when the accumulator contains the negative value F865 ABCDH:

```
CASE 3:   MSAC   r2,#27      ;BCDF 865AH accurately represents the
                             ;accumulator
CASE 4:   MSAC   r2,#7       ;zeros left of bit 7 force saturation of
                             ;65AB CDF8H, result is saturated to
                             ;65AB 8000H
```

NOTE

The high destination word is not modified by the saturation logic. The saturation adjustment affects only the low destination word.

3.3.3.2 Move Double-word from Accumulator (MVAC) Instruction

The move double-word from accumulator (MVAC) instruction allows a 32-bit value to be rotated from the accumulator to a register or memory location at a double-word boundary address utilizing a 32-bit barrel shifter.

The MVAC instruction does not make adjustments for saturation (as the MSAC instruction does). As a result, the extracted result value is never altered. The accumulator control and status register do not become modified during operation.

Case study five below illustrates the MVAC operation when the accumulator contains the value 0123 ABCDH:

```
CASE 5:   MVAC    r2,#11       ;rotate left 4, result in r2 is 123A BCD0H
```

When MVAC is executed with a shift value of eleven, bit 11 of the accumulator is placed in bit position 15 of the destination low word, and bit 12 of the accumulator becomes bit position 0 of the destination high word. The remaining bits wrap in a similar fashion.

3.3.4 Repeat (RPT, RPTI, RPT*xxx*, RPTI*xxx*) Instructions

There are four repeat instructions for the 80296SA — RPT, RPTI, RPT*xxx*, and RPTI*xxx*. You can use these instructions to operate on the repeat counter (RPT_CNT) register and on the instruction following the repeat instruction (see Table 3-6).

Repeat instructions affect the operation of the next instruction executed in code, and vary only in exit conditions and interruptibility.

An instruction following a repeat instruction is limited to non-branching instructions only. Examples of instructions not permitted for repeating are jumps, calls, and returns.

The opcode for the repeat instructions is the same opcode as the AND instructions. The 80296SA differentiates the instructions by the destination operand.

Table 3-6. Repeat Instructions

Instruction	Decode	Description
RPT	00H	Unconditional uninterruptible repeat of next instruction
RPT*xxx*	10–1FH	Conditional uninterruptible repeat of next instruction
RPTI	20H	Unconditional interruptible repeat of next instruction
RPTI*xxx*	30–3FH	Conditional interruptible repeat of next instruction

3.3.4.1 Repeat Next (RPT) Instruction

The unconditional uninterruptible repeat next instruction (RPT) is useful for data block moves, but requires considerable execution time without a chance for interrupt servicing.

The instruction following a RPT instruction code line is repeated the number of times specified by the word count value in the repeat counter (RPT_CNT) register located at address 04H.

For example, the following lines of code perform a block move of 1,024 words from ICX1 to ICX0.

```
RPT     #1024       ;repeat next instruction 1,024 times
LD      ICX0,ICX1   ;move data
```

In this example, the RPT_CNT register is decremented from 1,024 by a count of one after each load instruction. The repeat sequence is completed when the load instruction is executed with RPT_CNT decremented to zero.

The machine code for this example of a repeat operation would appear as follows:

```
41 0004 00 04    RPT  #1024
```

The manner in which the CPU processes the repeat instruction differentiates this operation from the AND instruction operation. In the machine code example above:

- The first two characters (41H) of the machine code could represent either an immediate AND or an immediate RPT instruction, because both instructions share the same opcode.
- Following the opcode is the word source operand (0004H), which is the repeat count value 1,024 represented in hexadecimal. Because of the manner in which the stack builds, with the low byte pushed on the stack followed by the high byte, the number 400H appears as 0004 in the machine code.
- The next two characters following the source operand decode the specific repeat instruction used. In the example, the decode value for the RPT instruction is (00H). (Refer to Table 3-6 for the full range of repeat instruction decode values.)
- The remaining two characters (04H) represent the destination word special function register into which the source word is loaded. It is the destination word machine code that differentiates the RPT instruction from the AND instruction.

The maximum repeat count is 65,536. This is achieved by initializing the RPT_CNT register with a count of 0000H.

3.3.4.2 Repeat Next Conditional (RPT*xxx*) Instruction

The conditional uninterruptible repeat next instruction (RPT*xxx*) is similar to the RPT instruction with the added flexibility of an exit condition from the repeat loop.

The instruction following the RPT*xxx* instruction is executed until either the RPT_CNT decrements to zero or an exit condition is satisfied.

Conditional exiting of the repeat loop is enabled by selecting one of the sixteen standard branch suffix conditions and appending it to the root RPT instruction mnemonic. Examples are RPTC, RPTLE, RPTNE, and so on. Table 3-7 details the entire listing of exit conditions.

Table 3-7. Repeat Instruction Exit Conditions

RPT*xxx* Instruction	Decode (Hex)	RPTI*xxx* Instruction	Decode (Hex)	Repeat next instruction until
RPTNST	10	RPTINST	30	negative and sticky bit flags are set
RPTNH	11	RPTINH	31	not higher
RPTGT	12	RPTIGT	32	greater than
RPTNC	13	RPTINC	33	negative and carry flags are set

Table 3-7. Repeat Instruction Exit Conditions (Continued)

RPT*xxx* Instruction	Decode (Hex)	RPTI*xxx* Instruction	Decode (Hex)	Repeat next instruction until
RPTNVT	14	RPTINVT	34	negative and overflow-trap flags are set
RPTNV	15	RPTINV	35	negative and overflow flags are set
RPTGE	16	RPTIGE	36	greater than or equal
RPTNE	17	RPTINE	37	not equal
RPTST	18	RPTIST	38	sticky bit flag is set
RPTH	19	RPTIH	39	higher
RPTLE	1A	RPTILE	3A	less than or equal
RPTC	1B	RPTIC	3B	carry flag is set
RPTVT	1C	RPTIVT	3C	overflow-trap flag is set
RPTV	1D	RPTIV	3D	overflow flag is set
RPTLT	1E	RPTILT	3E	less than
RPTE	1F	RPTIE	3F	equal

3.3.4.3 Repeat Next Interruptible (RPTI) Instruction

This instruction is the same as the RPT instruction with an added functionality; you can use it to interrupt between iterations of a repeated instruction.

With the interruptible repeat of the next instruction (RPTI), the interrupt servicing and recovery is left up to you. This is because, upon interrupt return, the repeat loop will continue operation at the location following the repeated instruction.

The following example illustrates a 1,024 word data block move from ICX1 to ICX0 using an RPTI instruction with interrupt recovery.

- The routine first checks whether the count has expired.
- If the count has not expired, the repeat loop must have been interrupted. An interruption halts execution of the code until the interrupt is serviced. Notice that the repeat instruction can use a register as well as an immediate value.

```
        LD      r0,#1024     ;load repeat count value into register
  MOVE:RPTI     r0           ;repeat number of times in r0
        LD      ICX0,ICX1    ;move data
        CMP     RPT_CNT,0    ;check if repeat count equals zero
        JZ      DONE         ;all done if zero
        LD      r0,RPT_CNT   ;repeat was interrupted, reload remaining
                             ;count
        SJMP    MOVE         ;jump back to repeat to continue
DONE:...                     ;execution continues
```

3.3.4.4 Repeat Next Conditional Interruptible (RPTI*xxx*) Instruction

The RPTI*xxx* instruction is the same as the RPT*xxx* instruction with an added functionality: you can use it to interrupt between iterations of the repeated instruction.

This means there is one more condition to be checked upon exit from the repeat loop. The instruction following the RPTI*xxx* instruction is thus executed until either the RPT_CNT decrements to zero or the exit condition is satisfied (see Table 3-7).

The following example illustrates a 1,024 word data block move using the RPTIV instruction.

- The routine first checks whether the overflow condition is met.
- If the condition is not met, the routine determines whether the count has expired.
- If neither the overflow nor the expired count condition is true, the repeat loop must have been interrupted. An interruption halts execution of the code until the interrupt is serviced.

```
      LD      r0,#1024     ;load repeat count value into register
LOOP:RPTIV    r0           ;repeat r0 times, or until overflow occurs
      ADD     r1,[r2]+     ;add [r2] to r1, increment r2
      JV      MET          ;check if condition has been met
      CMP     RPT_CNT,0    ;check if repeat count has expired
      JZ      DONE         ;if so, exit the loop
      LD      r0,RPT_CNT   ;repeat was interrupted, reload remaining
                           ;count
      SJMP    LOOP         ;jump back to repeat to continue
MET:...                    ;execution continues
.
.
.
DONE:...                   ;execution continues
```

3.3.5 Return from Interrupt (RETI) Instruction

The return from interrupt (RETI) instruction executes a return by popping the program status word (PSW) and program counter (PC) from the stack and resetting interrupts of a lower or equal priority.

Upon completion of an interrupt service routine, the RETI instruction causes the program counter and status flags to be reloaded from the stack and program execution to resume. At the same time, the RETI instruction clears the highest priority interrupt bit that is set in the in-progress (IN_PROG*x*) register.

This instruction allows new interrupt requests of a priority greater than the highest priority currently being serviced. It also ensures that there will be no more than 16 levels of nested maskable interrupts. The RETI instruction must be used when priority programming is enabled.

3.4 REPEAT COUNTER (RPT_CNT) REGISTER

The repeat counter (RPT_CNT) register is a 16-bit word value initialized by the repeat instructions (see Figure 3-2). The RPT_CNT value is decremented by one and then tested for zero after each execution of the repeated instruction.

RPT_CNT Address: 0004H
Reset State: XXXXH

The repeat counter (RPT_CNT) register contains a counter for the repeat instruction set.

15	0
Repeat Counter Value	

Bit Number	Function
15:0	Repeat Counter Value This register contains the count value for the instruction following the repeat instruction. An initial count of zero repeats the next instruction 65,536 times. An initial count of FFFFH will repeat 65,535 times.

Figure 3-2. Repeat Counter (RPT_CNT) Register

3.5 ACCUMULATOR

The accumulator is a 40-bit register that stores the results of mathematical operations. It can increase the mathematical precision of multiplication instructions while decreasing the overall instruction execution time. The 40-bit accumulator is composed of 32 bits, addressable as two words, and another eight bits for overflow occurences.

However, the accumulator can only perform 40-bit accumulation during unsigned arithmetic operations with saturation disabled. The most significant byte (39:32) of the accumulator is not defined for signed or saturated MAC operations. The accumulator register can be addressed as a normal special function register (SFR).

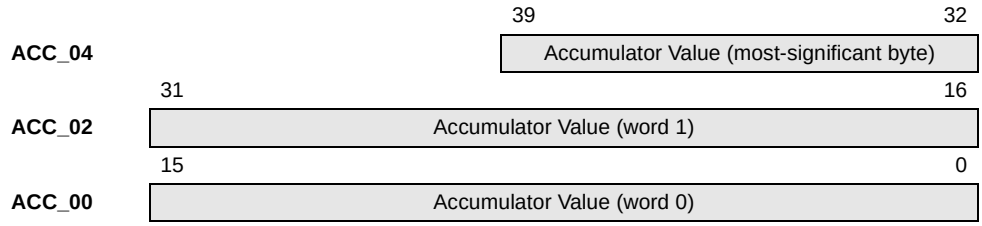
3.5.1 Accumulator Register (ACC_0*x*)

The ACC_0*x* register (Figure 3-3) can be used to either determine the current value of the accumulator or to preload a value into the accumulator.

ACC_0*x*
***x* = 0, 2, 4**

Address: 0CH, 0EH, 06H
Reset State: 00H

The 40-bit accumulator register (ACC_0*x*) resides at locations 0C–0FH. You must read from or write to the accumulator register as two words at locations 0CH and 0EH, and as one byte at location 06H.



Bit Number	Function
39:0	Accumulator Value You can read this register to determine the current value of the accumulator. You can write to this register to clear or preload a value into the accumulator.

Figure 3-3. Accumulator (ACC_0*x*) Register

Hardware considerations on the 80296SA have restricted the number of instructions that can operate on the accumulator.

- Instructions valid for the lower 32 bits of the accumulator (ACC_00 and ACC_02) are as follows:
  - — All eight MAC-related instructions
  - — LD/ST instructions on words starting at ACC_00 and ACC_02
  - — ADD/SUB instructions on the word starting at ACC_00
  - — ADDC/SUBC instructions on the word starting at ACC_02
  - — MSAC and MVAC instructions
  - — CMPL, SHLL, SHRAL, and NORML instructions
- Instructions valid for the upper 8 bits of the accumulator (ACC_04) are as follows:
  - — LDB/STB instructions on ACC_04 to a word-aligned boundary
  - — MAC, MACR, MACRZ, and MACZ instructions in conjunction with the lower 32 bits of the accumulator

3.5.2 Accumulator Control and Status Register (ACC_STAT)

The ACC_STAT register (Figure 3-4) controls the operating mode and reflects the status of the accumulator.

The mode bits, saturation mode enable (SME) and fractional mode enable (FME), are effective only for signed multiplication. Table 3-8 describes the 80296SA's operation with each of the four possible configurations of these bits.

ACC_STAT

Address: 0BH
Reset State: 38H

The accumulator control and status (ACC_STAT) register enables and disables fractional and saturation modes and contains three status flags that indicate the status of the accumulator's contents.

7							0
FME	SME	—	—	—	STOVF	OVF	STSAT

Bit Number	Bit Mnemonic	Function
7	FME	Fractional Mode Enable Set this bit to enable fractional mode (see Table 3-8 on page 3-15). In this mode, the result of a signed multiplication instruction is shifted left by one bit before it is added to the contents of the accumulator. For unsigned multiplication, this bit is ignored.
6	SME	Saturation Mode Enable Set this bit to enable saturation mode (see Table 3-8 on page 3-15). In this mode, the result of a signed multiplication operation is **not** allowed to overflow or underflow. For unsigned multiplication, this bit is ignored.
5:3	—	Reserved; for compatibility with future devices, write zeros to these bits.
2	STOVF	Sticky Overflow Flag For unsigned multiplication, this bit is set if a carry out of bit 31 occurs. Unless saturation mode is enabled, this bit is set for signed multiplication to indicate that the sign bit of the accumulator and the sign bit of the addend are equal, but the sign bit of the result is the opposite (see Table 3-8 on page 3-15). Software can clear this flag; hardware does **not** clear it.
1	OVF	Overflow Flag This bit indicates that an overflow occurred during the preceding accumulation (see Table 3-8 on page 3-15). This flag is dynamic; it can change after each accumulation.
0	STSAT	Sticky Saturation Flag This bit indicates that a saturation has occurred during accumulation with saturation mode enabled (see Table 3-8 on page 3-15). Software can clear this flag; hardware does **not** clear it.

Figure 3-4. Accumulator Control and Status (ACC_STAT) Register

Table 3-8. Effect of SME and FME Bit Combinations

SME	FME	Description
0	0	Sets the OVF and STOVF flags if the sign bits of the accumulator and the addend (the number to be added to the contents of the accumulator) are equal, but the sign bit of the result is the opposite.
0	1	Shifts the addend (the number to be added to the contents of the accumulator) left by one bit before adding it to the accumulator. Sets the OVF and STOVF flags if the sign bits of the accumulator and the addend are equal, but the sign bit of the result is the opposite.
1	0	Accumulates a signed integer value up or down to saturation and sets the STSAT flag. Positive saturation changes the accumulator value to 7FFFFFFFH; negative saturation changes the accumulator value to 80000000H. Accumulation proceeds normally after saturation, which means that the accumulator value can increase from a negative saturation or decrease from a positive saturation.
1	1	Shifts the addend (the number to be added to the contents of the accumulator) left by one bit before adding it to the accumulator. Accumulates a signed integer value up or down to saturation and sets the STSAT flag. Positive saturation changes the accumulator value to 7FFFFFFFH; negative saturation changes the accumulator value to 80000000H. Accumulation proceeds normally after saturation, which means that the accumulator value can increase from a negative saturation or decrease from a positive saturation.

3.5.2.1 Saturation Mode (SME)

Saturation mode (SME) is one of two operating modes that allows you to control the results of operations on signed numbers.

Saturation occurs when the result of two positive numbers generates a negative sign bit or the result of two negative numbers generates a positive sign bit. Without saturation mode, an underflow or overflow occurs and the overflow (OVF) flag is set. Saturation mode prevents an underflow or overflow of the accumulated value.

In saturation mode, the accumulator's value is changed to 7FFFFFFFH for a positive saturation or 80000000H for a negative saturation and the sticky saturation (STSAT) flag is set.

The following two examples illustrate the contents of the accumulator as a result of positive and negative saturation, respectively:

$$7FFFFFFFH = 0111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111 = 2^{31} - 1 = +2147483647$$

$$80000000H = 1000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000 = -2147483648$$

3.5.2.2 Fractional Mode

Fractional mode is the other operating mode that allows you to control the results of operations on signed numbers. A *signed fractional* contains an imaginary decimal point between the sign bit (the MSB) and the adjacent bit. These examples illustrate the representation of 32-bit signed fractional numbers:

$$0.111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111 = \frac{2147483647}{2147483648} = 1$$

0.000 0000 0000 0000 0000 0000 0000 0000 = 0

$$1.111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111 = \frac{-1}{2147483648} = -0$$

1.000 0000 0000 0000 0000 0000 0000 0000 = –1

Fractional mode shifts the result of a multiplication instruction left by one bit before writing the result to the accumulator. This left shift eliminates the extra sign bit when both operands are signed, leaving a correctly signed result and the correct decimal placement.

3.5.3 Accumulator Operation Limit

The most-significant byte of the 40-bit accumulator is not defined for signed or saturated arithmetic operations, so only a 32-bit value can be added to, or subtracted from, the accumulator using the ADDC and SUBC instructions. Illustrated below are examples of two-operand and three-operand addition and subtraction operations:

```
ADD     ACC_00,#0123H          ;add #22330123H to the accumulator
ADDC    ACC_02,#2233H          ;using two-operand instructions
ADD     ACC_00,ACC_00,#0123H   ;three-operand version of above
ADDC    ACC_02,ACC_02,#2233H   ;addition
SUB     ACC_00,#0AABBH         ;subtract #4433AABBH from the
SUBC    ACC_02,#4433H          ;accumulator using two-operand
                               ;instructions
SUB     ACC_00,ACC_00,#0AABBH  ;three-operand version of above
SUBC    ACC_02,ACC_02,#4433H   ;subtraction
```

3.6 INDEX REGISTERS

The 80296SA has three pairs of index registers:

- index pointer registers IDX0 and IDX1
- index control byte registers ICB0 and ICB1
- index reference registers ICX0 and ICX1

The index pointer registers, IDX0 and IDX1, are 24-bit pointers to any location within the 16-Mbyte address range.

The index control byte registers, ICB0 and ICB1, act as indirect address references with an automatic increment and decrement feature. Use these registers when you want to program the index pointer registers to automatically increment or decrement at the end of an instruction.

The index reference registers, ICX0 and ICX1, act as indirect address references. Use these index registers as destination and source addresses when you want to access the index pointer address locations.

3.6.1 Index Pointer (IDX0 and IDX1) Registers

The index registers, IDX0 and IDX1, are 24-bit pointers to any locations within the address space. (See Figure 3-5).

IDX*x*
***x* = 0–1**

Address: 1FC0H, 1FC4H
Reset State: XXXXXXH

The 24-bit index register (IDX*x*) serves as a pointer to any location within the 16-Mbyte address space. The following restrictions apply:

- IDX0 and IDX1 must be accessed with windowed direct addressing.
- IDX0 must point to either a source 1 (SRC1) or a destination (DEST) address.
- IDX1 must point to a source 2 (SRC2) address.

24	0
Index Pointer	

Bit Number	Function
24:0	Index Pointer This register contains 24 bits of data that point to a location within the address range.

Figure 3-5. Index Pointer (IDX*x*) Registers

To use these pointers, you must first load the index registers with the appropriate 24-bit starting address of the locations being pointed to. The example below illustrates the loading of IDX0 and IDX1 registers:

```
LDB     WSR,#7EH          ;Select window 7EH
LD      IDX0_7E,#4321H    ;load IDX0 to point to 654321H
LDB     IDX0_7E+2,#65H    ;load upper byte

LD      IDX1_7E,#0DCBAH   ;load IDX1 to point to 0FEDCBAH
LDB     IDX1_7E+2,#0FEH   ;load upper byte
```

3.6.2 Index Control Byte (ICB0 and ICB1) Registers

The index control byte registers, ICB0 and ICB1, are used to control the sequencing of the index registers (see Figure 3-6). You can program the index registers to automatically increment or decrement at the end of an instruction by any value ranging from 0 to 15.

ICB*x*
***x* = 0–1**

Address: 1FC3H, 1FC7H
Reset State: 00H

The index control byte (ICB*x*) register controls the automatic increment and decrement feature of the index pointers.

7			4	3	0
—	—	—	ID	Count	

Bit Number	Bit Mnemonic	Function
7:5	—	Reserved; for compatibility with future devices, write zeros to these bits.
4	ID	Increment or Decrement This bit allows the index pointer to increment and decrement. 0 = increment 1 = decrement
3:0	Count	Count Value These bits specify a count value ranging from 0H to 0FH (15 decimal).

Figure 3-6. Index Control Byte (ICB*x*) Registers

To enable the automatic increment or decrement feature, you must program the control bytes as illustrated below:

```
LDB     WSR,#7EH          ;Select window 7EH
LDB     ICB0_7E,#3H       ;auto-increment IDX0 by 3 bytes
LDB     ICB1_7E,#1EH      ;auto-decrement IDX1 by 14 bytes
```

NOTE

The increment or decrement operation takes place only once per instruction, and at the effective end of the instruction.

3.6.3 Index Reference (ICX0 and ICX1) Registers

The index pointer registers can be accessed indirectly using the index reference registers, ICX0 and ICX1 (see Figure 3-7). Using ICX0 as a destination or source address and ICX1 as a source address enables the index registers to act as indirect address references.

ICX*x*
***x* = 0–1**

Address: 0010H, 0016H
Reset State: XXXXH

The index reference register (ICX*x*) allows you to indirectly access the address location being pointed to by the index pointer.

15	0
Index Reference	

Bit Number	Function
15:0	Index Reference This register contains a word of data that indirectly addresses the index pointer.

Figure 3-7. Index Reference (ICX*x*) Registers

In the following example the index pointers, IDX0 and IDX1, are accessed via the index reference registers, ICX0 and ICX1. This example is a continuation of the previous examples used in the explanation of the index registers and control bytes:

```
LD      ICX0,#20H         ;loads 20H into location 654321H and
                          ;increments IDX0 by 3 bytes
LD      r20,ICX1          ;loads content in location 0FEDCBAH into
                          ;r20 and decrements IDX1 by 14 bytes
LD      ICX0,ICX1         ;loads content in location 0FEDCACH into
                          ;location 654324H and increments IDX0
                          ;3 bytes and decrements IDX1 by 14 bytes
ADD     ICX0,ICX0,ICX1    ;adds content in locations 654327H and
                          ;0FEDC9EH and stores result in location
                          ;654327H. Increments IDX0 by 3 bytes,
                          ;even though it is used twice, and
                          ;decrements IDX1 by 14 bytes
```

3.7 APPLICATION EXAMPLE

The following code segment incorporates the multiply-accumulate and repeat instructions, and utilizes register indexing to perform a multiply-accumulate of two 100-entry word tables.

In the example:

- the coefficient (C1) table is located at address 112233H
- the sample (S1) table is located at address 445566H and is to be rotated upward during the operation

```
LDB     WSR,#7EH          ;Select window 7EH
LD      IDX0_7E,#22FBH    ;load C1 table pointer to the top of C1
LDB     IDX0_7E+2,#11H
LD      IDX1_7E,#562EH    ;load S1 table pointer to the top of S1
LDB     IDX1_7E+2,#44H
LDB     ICB0_7E,#12H      ;set-up auto-decrement of IDX0 by 2 bytes
                          ;for word contents in C1
LDB     ICB1_7E,#12H      ;set-up auto-decrement of IDX1 by 2 bytes
                          ;for word contents in S1
```

```
SMAC    ICX0,ICX1       ;multiply-accumulate first entry at top of
                        ;tables and store result in the accumulator
RPT     #99             ;set-up unconditional uninterruptible repeat
                        ;loop of next instruction
SMACR   ICX0,ICX1       ;multiply-accumulate remaining table entries
                        ;and add results to the accumulator. Rotate
                        ;S2 word entries in address memory
```

The initial six lines of code simply establish the two data tables in address memory and initialize the table pointers. The remaining code sets up a 100-iteration, uninterrupted multiply-accumulate loop.

The accumulator stores the results while the contents of table S1 are physically rotated in address memory from 445566–44562EH to 445568–445630H (see Figure 3-8).

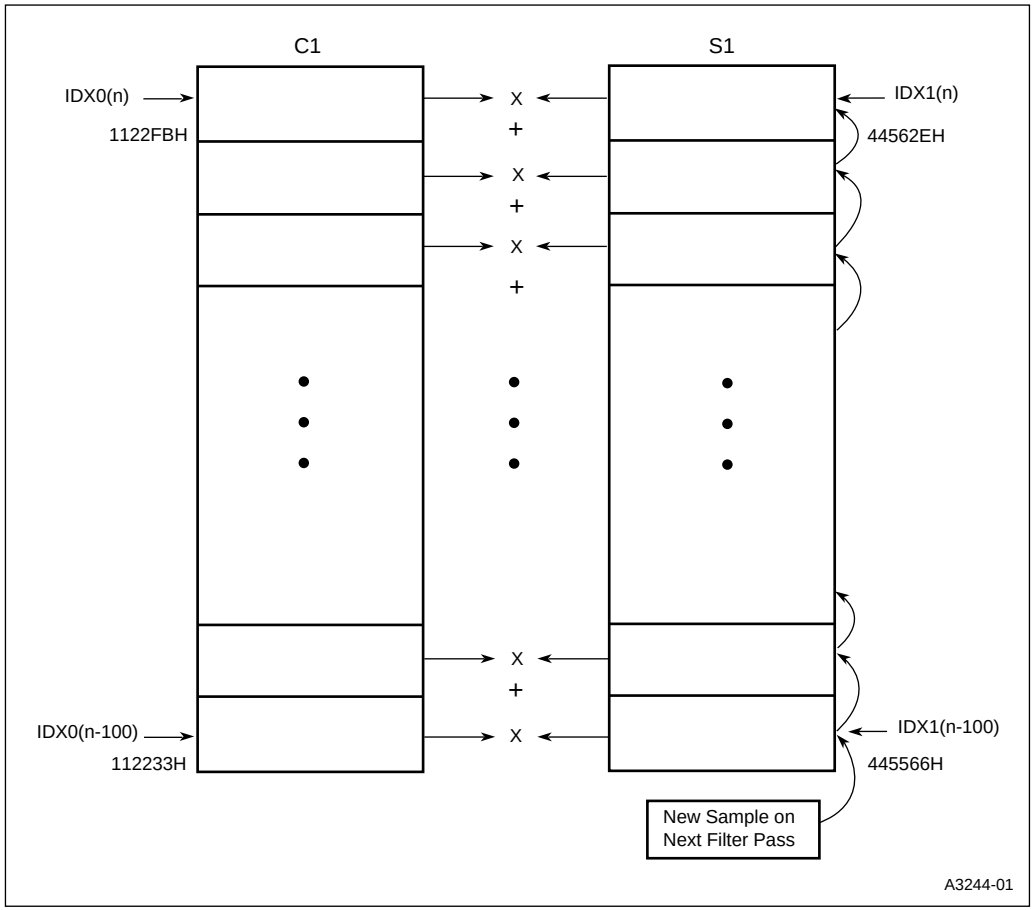


Figure 3-8. Application Code Illustration

In Figure 3-8, table C1 contains your coefficients and table S1 contains your input samples. Each iteration loop through the table represents one filter pass. (In our example, a filter pass comprises 100 filter taps.) As new data is rotated into the sample table on successive filter passes, the signal waveform is further interpreted until all the data has been introduced and processed.

The usefulness of such code can be found in signal processing applications where a finite-impulse-response (FIR) filter is used for processing sampled data (see Figure 3-9).

Figure 3-9. FIR Filter Block Diagram

The FIR filter function is represented in equation form as follows:

$$y(n) = a(0)x(n) + a(1)x(n-1) + \ldots + a(N)x(n-N)$$

where: N = number of filter taps
n = number of samples
a = coefficient
x = input sample
y = filter pass (accumulator)

In our example, the output y(100) is the summation of x(100) to x(0) input samples, where the first sample x(100) is multiplied by coeffient a(0), the second sample x(99) is multiplied by coeffient a(1), and so on.

4

Programming Considerations

CHAPTER 4
PROGRAMMING CONSIDERATIONS

This section provides an overview of the instruction set of the MCS® 96 microcontrollers and offers guidelines for program development. For detailed information about specific instructions, see Appendix A.

4.1 OVERVIEW OF THE INSTRUCTION SET

The instruction set supports a variety of data types likely to be useful in control applications (see Table 4-1).

NOTE

The data-type variables are shown in all capitals to avoid confusion. For example, a *BYTE* is an unsigned 8-bit variable in an instruction, while a *byte* is any 8-bit unit of data (either signed or unsigned).

Table 4-1. Data Type Definitions

Data Type	No. of Bits	Signed	Possible Values	Addressing Restrictions
BIT	1	No	True (1) or False (0)	As components of bytes
BYTE	8	No	0 through 2^8–1 (0 through 255)	None
SHORT-INTEGER	8	Yes	-2^7 through $+2^7$–1 (–128 through +127)	None
WORD	16	No	0 through 2^{16}–1 (0 through 65,535)	Even byte address
INTEGER	16	Yes	-2^{15} through $+2^{15}$–1 (–32,768 through +32,767)	Even byte address
DOUBLE-WORD (Note 1)	32	No	0 through 2^{32}–1 (0 through 4,294,967,295)	An address in the lower register file that is evenly divisible by four
LONG-INTEGER (Note 1)	32	Yes	-2^{31} through $+2^{31}$–1 (–2,147,483,648 through +2,147,483,647)	An address in the lower register file that is evenly divisible by four
QUAD-WORD (Note 2)	64	No	0 through 2^{64}–1	An address in the lower register file that is evenly divisible by eight

NOTES:
1. The 32-bit operands are supported only in shift operations, as the dividend in 32-by-16 division, and as the product of 16-by-16 multiplication.
2. QUAD-WORD variables are supported only as the operand for the EBMOVI instruction.

Table 4-2 lists the equivalent data-type names for both C programming and assembly language.

Table 4-2. Equivalent Data Types for Assembly and C Programming Languages

Data Types	Assembly Language Equivalent	C Programming Language Equivalent
BYTE	BYTE	unsigned char
SHORT-INTEGER	BYTE	char
WORD	WORD	unsigned int
INTEGER	WORD	int
DOUBLE-WORD	LONG	unsigned long
LONG-INTEGER	LONG	long
QUAD-WORD	—	—

4.1.1 BIT Operands

A BIT is a single-bit variable that can have the Boolean values, "true" and "false." The architecture requires that BITs be addressed as components of BYTEs or WORDs. It does not support the direct addressing of BITs. (You can, however, test the state of a single bit. For example, the JBC and JBS instructions are conditional jump instructions that test a specified bit.)

4.1.2 BYTE Operands

A BYTE is an unsigned, 8-bit variable that can take on values from 0 through 255 (2^8–1). Arithmetic and relational operators can be applied to BYTE operands, but the result must be interpreted in modulo 256 arithmetic. Logical operations on BYTEs are applied bitwise. Bits within BYTEs are labeled from 0 to 7; bit 0 is the least-significant bit. There are no alignment restrictions for BYTEs, so they may be placed anywhere in the address space.

4.1.3 SHORT-INTEGER Operands

A SHORT-INTEGER is an 8-bit, signed variable that can take on values from –128 ($–2^7$) through +127 ($+2^7$–1). Arithmetic operations that generate results outside the range of a SHORT-INTEGER set the overflow flags in the processor status word (PSW). The numeric result is the same as the result of the equivalent operation on BYTE variables. There are no alignment restrictions on SHORT-INTEGERs, so they may be placed anywhere in the address space.

4.1.4 WORD Operands

A WORD is an unsigned, 16-bit variable that can take on values from 0 through 65,535 (2^{16}–1). Arithmetic and relational operators can be applied to WORD operands, but the result must be interpreted in modulo 65536 arithmetic. Logical operations on WORDs are applied bitwise. Bits within WORDs are labeled from 0 to 15; bit 0 is the least-significant bit.

WORDs must be aligned at even byte boundaries in the address space. The least-significant byte of the WORD is in the even byte address, and the most-significant byte is in the next higher (odd) address. The address of a WORD is that of its least-significant byte (the even byte address). WORD operations to odd addresses are not guaranteed to operate in a consistent manner.

4.1.5 INTEGER Operands

An INTEGER is a 16-bit, signed variable that can take on values from –32,768 (-2^{15}) through +32,767 ($+2^{15}$–1). Arithmetic operations that generate results outside the range of an INTEGER set the overflow flags in the processor status word (PSW). The numeric result is the same as the result of the equivalent operation on WORD variables.

INTEGERs must be aligned at even byte boundaries in the address space. The least-significant byte of the INTEGER is in the even byte address, and the most-significant byte is in the next higher (odd) address. The address of an INTEGER is that of its least-significant byte (the even byte address). INTEGER operations to odd addresses are not guaranteed to operate in a consistent manner.

4.1.6 DOUBLE-WORD Operands

A DOUBLE-WORD is an unsigned, 32-bit variable that can take on values from 0 through 4,294,967,295 (2^{32}–1). The architecture directly supports DOUBLE-WORD operands only as the operand in shift operations, as the dividend in 32-by-16 divide operations, and as the product of 16-by-16 multiply operations. For these operations, a DOUBLE-WORD variable must reside in the lower register file and must be aligned at an address that is evenly divisible by four. The address of a DOUBLE-WORD is that of its least-significant byte (the even byte address). The least-significant word of the DOUBLE-WORD is always in the lower address, even when the data is in the stack. This means that the most-significant word must be pushed onto the stack first.

DOUBLE-WORD operations that are not directly supported can be easily implemented with two WORD operations. For example, the following sequences of 16-bit operations perform a 32-bit addition and a 32-bit subtraction, respectively.

```
ADD  REG1,REG3                    ; (2-operand addition)
ADDC REG2,REG4

SUB  REG1,REG3                    ; (2-operand subtraction)
SUBC REG2,REG4
```

4.1.7 LONG-INTEGER Operands

A LONG-INTEGER is a 32-bit, signed variable that can take on values from –2,147,483,648 (-2^{31}) through +2,147,483,647 ($+2^{31}-1$). The architecture directly supports LONG-INTEGER operands only as the operand in shift operations, as the dividend in 32-by-16 divide operations, and as the product of 16-by-16 multiply operations. For these operations, a LONG-INTEGER variable must reside in the lower register file and must be aligned at an address that is evenly divisible by four. The address of a LONG-INTEGER is that of its least-significant byte (the even byte address).

LONG-INTEGER operations that are not directly supported can be easily implemented with two INTEGER operations. See the example in "DOUBLE-WORD Operands" on page 4-3.

4.1.8 QUAD-WORD Operands

A QUAD-WORD is a 64-bit, unsigned variable that can take on values from 0 through $2^{64}-1$. The architecture directly supports the QUAD-WORD operand only as the operand of the EBMOVI instruction. For this operation, the QUAD-WORD variable must reside in the lower register file and must be aligned at an address that is evenly divisible by eight.

4.1.9 Converting Operands

The instruction set supports conversions between the data types (Table 4-3). The LDBZE (load byte, zero extended) instruction converts a BYTE to a WORD. CLR (clear) converts a WORD to a DOUBLE-WORD by clearing (writing zeros to) the upper WORD of the DOUBLE-WORD. LDBSE (load byte, sign extended) converts a SHORT-INTEGER into an INTEGER. EXT (sign extend) converts an INTEGER to a LONG-INTEGER.

Table 4-3. Converting Data Types

To convert from …	to…	Use this instruction…	Which performs this function.
BYTE	WORD	LDBZE	Writes zeros to the upper byte.
WORD	DOUBLE-WORD	CLR	Writes zeros to the upper word.
SHORT-INTEGER	INTEGER	LDBSE	Writes the sign bit to the upper byte.
INTEGER	LONG-INTEGER	EXT	Writes the sign bit to the upper word.

4.1.10 Conditional Jumps

The instructions for addition, subtraction, and comparison do not distinguish between unsigned (BYTE, WORD) and signed (SHORT-INTEGER, INTEGER) data types. However, the conditional jump instructions allow you to treat the results of these operations as signed or unsigned quantities. For example, the CMP (compare) instruction is used to compare both signed and unsigned 16-bit quantities. Following a compare operation, you can use the JH (jump if higher) instruction for unsigned operands or the JGT (jump if greater than) instruction for signed operands.

4.1.11 Floating Point Operations

The hardware does not directly support operations on REAL (floating point) variables. Those operations are supported by floating point libraries from third-party tool vendors. (See the *Development Tools Handbook*.) The performance of these operations is significantly improved by the NORML instruction and by the sticky bit (ST) flag in the processor status word (PSW). The NORML instruction normalizes a 32-bit variable; the sticky bit (ST) flag can be used in conjunction with the carry (C) flag to achieve finer resolution in rounding.

4.1.12 Extended Instructions

This section briefly describes the instructions that enable code execution and data access anywhere in the address space. These instructions are implemented for all MCS 96 microcontrollers that have extended addressing ports (currently the 8XC196NT, 8XC196NP, 80C196NU, and 80296SA, microcontrollers). They function only in extended addressing modes.

In general, you should avoid creating tables or arrays that cross page boundaries. For example, if you are building a large array, start it at a base address that will accommodate the entire array within the same page. If you cannot avoid crossing a page boundary, keep in mind that you must use extended instructions to access data outside page 00H.

NOTE

In 1-Mbyte mode, ECALL, LCALL, and SCALL always push two words onto the stack; therefore, a RET must always pop two words from the stack. Because of the extra push and pop operations, interrupt routines and subroutines take slightly longer to execute in 1-Mbyte mode than in 64-Kbyte mode.

EBMOVI — **Extended interruptible block move**. Moves a block of word data from one memory location to another. This instruction allows you to move blocks of up to 64K words between any two locations in the address space. It uses two 24-bit autoincrementing pointers and a 16-bit counter.

EBR — **Extended branch**. This instruction is an unconditional indirect jump to anywhere in the address space.

ECALL — **Extended call**. This instruction is an unconditional relative call to anywhere in the address space.

EJMP — **Extended jump**. This instruction is an unconditional relative jump to anywhere in the address space.

ELD, ELDB — **Extended load word, extended load byte**. Loads the value of the source operand into the destination operand. This instruction allows you to move data from anywhere in the address space into the lower register file.

EST, ESTB — **Extended store word, extended store byte**. Stores the value of the source **(leftmost)** operand into the destination **(rightmost)** operand. This instruction allows you to move data from the lower register file to anywhere in the address space.

4.1.13 Instructions That Were Removed from the 80296SA

The instructions that enable and disable the peripheral transaction server (PTS) were removed from the 80296SA because it has no PTS.

DPTS, EPTS — **Disable PTS, enable PTS**.

4.1.14 Instructions That Were Enhanced for the 80296SA

Several mathematical instructions were enhanced for the 80296SA.

ADDC — **Add signed word to accumulator with carry**. Adds the source and destination operands and the carry flag and stores the sum into the destination operand. If the accumulator is the destination and saturation is enabled in the ACC_STAT register, a saturated addition is performed.

DIV, DIVB — **Signed divide word, signed divide byte**. Divides the destination operand by the contents of the source operand, using signed arithmetic. It stores the quotient into the low-order word of the destination and the remainder into the high-order word. The 80296SA does not require the FEH opcode prefix. The tools use the sign extension bit (bit 0) in the destination operand register. For compatibility with earlier MCS 96 microcontrollers, the 80296SA supports both methods. DIVU with the sign bit is functionally equivalent to DIV with the sign-extension opcode (FEH).

MUL, MULB — **Signed multiply word, signed multiply byte**. Multiplies the source and destination operands, using signed arithmetic, and stores the result in the destination operand. The 80296SA does not require the FEH opcode prefix. The tools use the sign extension bit (bit 0) in the destination operand register. For compatibility with earlier MCS 96 microcontrollers, the 80296SA supports both methods. MULU with the sign bit is functionally equivalent to MUL with the sign-extension opcode (FEH).

SUBC — **Subtract signed words with borrow**. Subtracts the source word operand from the destination word operand. If the carry flag was clear, SUBC subtracts 1 from the result. It stores the result in the destination operand and sets the carry flag as the complement of borrow. If the accumulator is the destination and saturation is enabled in the ACC_STAT register, a saturated subtraction is performed.

4.1.15 Instructions That Were Added for the 80296SA

Several instructions were added to the 80296SA to support embedded digital signal processing applications.

MAC — **Unsigned multiply-accumulate**. Multiplies two unsigned 16-bit operands and adds the 32-bit result to the value currently in the accumulator.

MACR — **Unsigned multiply-accumulate and relocate source 2**. Multiplies two unsigned 16-bit operands, adds the 32-bit result to the value currently in the accumulator, and moves the source 2 data to (source 2 + 2).

MACRZ — **Unsigned multiply-accumulate, clear accumulator, and relocate source 2**. Multiplies two unsigned 16-bit operands, clears the accumulator, stores the 32-bit result to the accumulator, and moves the source 2 data to (source 2 + 2).

MACZ — **Unsigned multiply-accumulate and clear accumulator**. Multiplies two unsigned 16-bit operands, clears the accumulator, and stores the 32-bit result to the accumulator.

MSAC — **Move saturated integer from accumulator**. Copy (rotate) the signed value from the accumulator to the specified destination, through the barrel shifter. If the value in the accumulator is greater than or less than the extracted low word, then the low word is replaced by the saturated value.

MVAC	**Move double-word from accumulator**. Copy (rotate) the signed value from the accumulator to the specified destination, through the barrel shifter.
RETI	**Return from interrupt subroutine**. Execute a return by popping the PSW and PC from the stack and resetting the highest priority set bit in the in-progress (IN_PROG*x*) register.
RPT, RPT*xxx*	**Repeat, conditional repeat**. Repeats the next instruction the number of times specified in the RPT_CNT register. This instruction can be used in conjunction with a conditional instruction (RPTC, RPTVT, etc).
RPTI, RPTI*xxx*	**Interruptible repeat, interruptible conditional repeat**. Repeats the next instruction the number of times specified in the RPT_CNT register. This instruction can be used in conjunction with a conditional instruction (RPTIC, RPTIVT, etc).
SMAC	**Signed multiply-accumulate**. Multiplies two signed 16-bit operands and adds the 32-bit result to the value currently in the accumulator.
SMACR	**Signed multiply-accumulate and relocate source 2**. Multiplies two signed 16-bit operands, adds the 32-bit result to the value currently in the accumulator, and moves the source 2 data to (source 2 + 2).
SMACRZ	**Signed multiply-accumulate, clear accumulator, and relocate source 2**. Multiplies two signed 16-bit operands, clears the accumulator, stores the 32-bit result to the accumulator, and moves the source 2 data to (source 2 + 2).
SMACZ	**Signed multiply-accumulate and clear accumulator**. Multiplies two signed 16-bit operands, clears the accumulator, and stores the 32-bit result to the accumulator.

4.2 ADDRESSING MODES

This section describes the addressing modes as they are handled by the hardware. An understanding of these details will help programmers to take full advantage of the architecture. Most software tools have features that simplify the choice of addressing modes. Please consult the documentation for your assembler or compiler for details.

The instruction set uses four basic addressing modes:

- direct
- immediate
- indirect (with or without autoincrement)
- indexed (short-, long-, or zero-indexed)

The stack pointer can be used with indirect addressing to access the top of the stack, and it can also be used with short-indexed addressing to access data within the stack. The zero register can be used with long-indexed addressing to access any memory location.

Extended variations of the indirect and indexed modes support the extended load and store instructions. An extended load instruction moves a word (ELD) or a byte (ELDB) from any location in the address space into the lower register file. An extended store instruction moves a word (EST) or a byte (ESTB) from the lower register file into any location in the address space. An instruction can contain only one immediate, indirect, or indexed reference; any remaining operands must be direct references.

The examples in this section assume that temporary registers are defined as shown in Table 4-4.

Table 4-4. Definition of Temporary Registers

Temporary Register	Description
AX	word-aligned 16-bit register; AH is the high byte of AX and AL is the low byte
BX	word-aligned 16-bit register; BL is the low byte of BX
CX	word-aligned 16-bit register; CH is the high byte of CX and CL is the low byte
DX	word-aligned 16-bit register; DH is the high byte of DX and DL is the low byte
EX	double-word-aligned 24-bit register

4.2.1 Direct Addressing

Direct addressing directly accesses a location in the 256-byte lower register file, without involving the memory controller. Windowing allows you to remap other sections of memory into the lower register file for direct access (see Chapter 5, “Memory Partitions,” for details). You specify the registers as operands within the instruction. The register addresses must conform to the alignment rules for the operand type. Depending on the instruction, up to three registers can take part in a calculation. The following instructions use direct addressing:

```
ADD  AX,BX,CX          ; AX ← BX + CX
ADDB AL,BL,CL          ; AL ← BL + CL
MULB AX,BL             ; AX ← AX × BL
INCB CL                ; CL ← CL + 1
```

4.2.2 Immediate Addressing

Immediate addressing mode accepts one immediate value as an operand in the instruction. You specify an immediate value by preceding it with a number symbol (#). An instruction can contain only one immediate value; the remaining operands must be direct references. The following instructions use immediate addressing:

```
ADD  AX,#340        ; AX ← AX + 340
PUSH #1234H         ; SP ← SP - 2
                    ; MEM_WORD(SP) ← 1234H
DIVB AX,#10         ; AL ← AX/10
                    ; AH ← AX MOD 10
```

4.2.3 Indirect Addressing

The indirect addressing mode accesses an operand by obtaining its address from a WORD register in the lower register file. You specify the register containing the indirect address by enclosing it in square brackets ([ ]). The indirect address can refer to any location within the address space, including the register file. The register that contains the indirect address must be word-aligned, and the indirect address must conform to the rules for the operand type. An instruction can contain only one indirect reference; any remaining operands must be direct references. The following instructions use indirect addressing:

```
LD   AX,[BX]            ; AX ← MEM_WORD(BX)
ADDB AL,BL,[CX]         ; AL ← BL + MEM_BYTE(CX)
POP  [AX]               ; MEM_WORD(AX) ← MEM_WORD(SP)
                        ; SP ← SP + 2
```

4.2.3.1 Extended Indirect Addressing

Extended load and store instructions can use indirect addressing. The only difference is that the register containing the indirect address must be a word-aligned 24-bit register to allow access to the entire 1-Mbyte address space. The following instructions use extended indirect addressing:

```
ELD  AX,[EX]        ; AX ← MEM_WORD(EX)
ELDB AL,[EX]        ; AL ← MEM_BYTE(EX)
EST  AX,[EX]        ; MEM_WORD(EX) ← AX
ESTB AL,[EX]        ; MEM_BYTE(EX) ← AL
```

4.2.3.2 Indirect Addressing with Autoincrement

You can choose to automatically increment the indirect address after the current access. You specify autoincrementing by adding a plus sign (+) to the end of the indirect reference. In this case, the instruction automatically increments the indirect address (by one if the destination is an 8-bit register or by two if it is a 16-bit register). When your code is assembled, the assembler automatically sets the least-significant bit of the indirect address register. The following instructions use indirect addressing with autoincrement:

```
LD   AX,[BX]+        ; AX ← MEM_WORD(BX)
                     ; BX ← BX + 2
ADDB AL,BL,[CX]+     ; AL ← BL + MEM_BYTE(CX)
                     ; CX ← CX + 1
PUSH [AX]+           ; SP ← SP - 2
                     ; MEM_WORD(SP) ← MEM_WORD(AX)
                     ; AX ← AX + 2
```

4.2.3.3 Extended Indirect Addressing with Autoincrement

The extended load and store instructions can also use indirect addressing with autoincrement. The only difference is that the register containing the indirect address must be a word-aligned 24-bit register to allow access to the entire 1-Mbyte address space. The following instructions use extended indirect addressing with autoincrement:

```
ELD  AX,[EX]+        ; AX ← MEM_WORD(EX)
                     ; EX ← EX + 2
ELDB AL,[EX]+        ; AL ← MEM_BYTE(EX)
                     ; EX ← EX + 1
EST  AX,[EX]+        ; MEM_WORD(EX) ← AX
                     ; EX ← EX + 2
ESTB AL,[EX]+        ; MEM_BYTE(EX) ← AL
                     ; EX ← EX + 1
```

4.2.3.4 Indirect Addressing with the Stack Pointer

You can also use indirect addressing to access the top of the stack by using the stack pointer as the WORD register in an indirect reference. The following instruction uses indirect addressing with the stack pointer:

```
PUSH [SP]      ; duplicate top of stack
               ; SP ← SP – 2
```

Indirect and indexed PUSH and POP operations relative to the stack pointer work differently on the 80296SA than on the 8XC196NP and 80C196NU. The 8XC196NP and 80C196NU microcontrollers calculate the address based on the value of the SP **after** it is updated. The 80296SA works like the 8096BH. That is, it calculates the address based on the value of the SP **before** it is updated.

4.2.4 Indexed Addressing

Indexed addressing calculates an address by adding an offset to a base address. There are three variations of indexed addressing: short-indexed, long-indexed, and zero-indexed. Both short- and long-indexed addressing are used to access a specific element within a structure. Short-indexed addressing can access up to 256 byte locations, long-indexed addressing can access up to 65,536 byte locations, and zero-indexed addressing can access a single location. An instruction can contain only one indexed reference; any remaining operands must be direct references.

4.2.4.1 Short-indexed Addressing

In a short-indexed instruction, you specify the offset as an 8-bit constant and the base address as an indirect address register (a WORD). The following instructions use short-indexed addressing.

```
LD   AX,12H[BX]     ; AX ← MEM_WORD(BX + 12H)
MULB AX,BL,3[CX]    ; AX ← BL ×MEM_BYTE(CX + 3)
```

The instruction LD AX,12H[BX] loads AX with the contents of the memory location that resides at address BX+12H. That is, the instruction adds the constant 12H (the offset) to the contents of BX (the base address), then loads AX with the contents of the resulting address. For example, if BX contains 1000H, then AX is loaded with the contents of location 1012H. Short-indexed addressing is typically used to access elements in a structure, where BX contains the base address of the structure and the constant (12H in this example) is the offset of a specific element in a structure.

You can also use the stack pointer in a short-indexed instruction to access a particular location within the stack, as shown in the following instruction.

```
LD   AX,2[SP]
```

4.2.4.2 Long-indexed Addressing

In a long-indexed instruction, you specify the base address as a 16-bit variable and the offset as an indirect address register (a WORD). The following instructions use long-indexed addressing.

```
LD   AX,TABLE[BX]        ; AX ← MEM_WORD(TABLE + BX)
AND  AX,BX,TABLE[CX]     ; AX ← BX AND MEM_WORD(TABLE + CX)
ST   AX,TABLE[BX]        ; MEM_WORD(TABLE + BX) ← AX
ADDB AL,BL,LOOKUP[CX]    ; AL ← BL + MEM_BYTE(LOOKUP + CX)
```

The instruction LD AX, TABLE[BX] loads AX with the contents of the memory location that resides at address TABLE+BX. That is, the instruction adds the contents of BX (the offset) to the constant TABLE (the base address), then loads AX with the contents of the resulting address. For example, if TABLE equals 4000H and BX contains 12H, then AX is loaded with the contents of location 4012H. Long-indexed addressing is typically used to access elements in a table, where TABLE is a constant that is the base address of the structure and BX is the scaled offset ($n \times$ element size, in bytes) into the structure.

4.2.4.3 Extended Indexed Addressing

The extended load and store instructions can use extended indexed addressing. The only difference from long-indexed addressing is that both the base address and the offset must be 24 bits to support access to the entire 1-Mbyte address space. The following instructions use extended indexed addressing. (In these instructions, OFFSET is a 24-bit variable containing the offset, and EX is a double-word aligned 24-bit register containing the base address.)

```
ELD  AX,OFFSET[EX]        ; AX ← MEM_WORD(EX+OFFSET)
ELDB AL,OFFSET[EX]        ; AL ← MEM_BYTE(EX+OFFSET)
EST  AX,OFFSET[EX]        ; MEM_WORD(EX+OFFSET) ← AX
ESTB AL,OFFSET[EX]        ; MEM_BYTE(EX+OFFSET) ← AL
```

4.2.4.4 Zero-indexed Addressing

In a zero-indexed instruction, you specify the address as a 16-bit variable; the offset is zero, and you can express it in one of three ways: [0], [ZERO_REG], or nothing. Each of the following load instructions loads AX with the contents of the variable THISVAR.

```
LD   AX,THISVAR[0]
LD   AX,THISVAR[ZERO_REG]
LD   AX,THISVAR
```

The following instructions also use zero-indexed addressing:

```
ADD  AX,1234H[ZERO_REG]        ; AX ← AX + MEM_WORD(1234H)
POP  5678H[ZERO_REG]           ; MEM_WORD(5678H) ← MEM_WORD(SP)
                               ; SP ← SP + 2
```

4.2.4.5 Extended Zero-indexed Addressing

The extended instructions can also use zero-indexed addressing. The only difference is that you specify the address as a 24-bit constant or variable. The following extended instruction uses zero-indexed addressing. ZERO_REG acts as a 32-bit fixed source of the constant zero for an extended indexed reference.

```
ELD  AX,23456H[ZERO_REG]       ; AX ← MEM_WORD(23456H)
```

4.3 CONSIDERATIONS FOR CROSSING PAGE BOUNDARIES

In general, you should avoid creating tables or arrays that cross page boundaries. For example, if you are building a large array, start it at a base address that will accommodate the entire array within the same page. If you cannot avoid crossing a page boundary, keep in mind that you must use extended instructions to access data outside page 00H.

4.4 SOFTWARE PROTECTION FEATURES AND GUIDELINES

The microcontroller has several features to assist in recovering from hardware and software errors. The unimplemented opcode interrupt provides protection from executing unimplemented opcodes. The hardware reset instruction (RST) can cause a reset if the program counter goes out of bounds. The RST instruction opcode is FFH, so the processor will reset itself if it tries to fetch an instruction from unprogrammed locations in nonvolatile memory or from bus lines that have been pulled high.

We recommend that you fill unused areas of code with NOPs and periodic jumps to an error routine or RST instruction. This is particularly important in the code surrounding lookup tables, since accidentally executing from lookup tables will cause undesired results. Wherever space allows, surround each table with seven NOPs (because the longest device instruction has seven bytes) and a RST or a jump to an error routine. Since RST is a one-byte instruction, the NOPs are unnecessary if RSTs are used instead of jumps to an error routine. This will help to ensure a speedy recovery from a software error.

5

Memory Partitions

CHAPTER 5
MEMORY PARTITIONS

This chapter describes the organization of the address space, its major partitions, and the 1-Mbyte and 64-Kbyte operating modes. *1-Mbyte* refers to the address space defined by the 20 external address pins. In 1-Mbyte mode, code can execute from almost anywhere in the 1-Mbyte space. In 64-Kbyte mode, code can execute only from the 64-Kbyte area FF0000–FFFFFFH. The 64-Kbyte mode provides compatibility with software written for previous 16-bit MCS® 96 microcontrollers. In either mode, nearly all of the 1-Mbyte address space is available for data storage.

Other topics covered in this chapter include the following:

- the relationship between the 1-Mbyte address space defined by the 20 external address pins and the 16-Mbyte address space defined by the 24 internal address bits
- a *windowing* technique for accessing the upper register file, peripheral SFRs, internal code RAM, and sections of external memory with register-direct instructions
- extended and nonextended data accesses

5.1 MEMORY MAP OVERVIEW

With 24 internal address bits, the microcontroller can address 16 Mbytes of memory. However, only 20 of the 24 address bits are implemented by external pins: A19:0 in demultiplexed mode, or A19:16 and AD15:0 in multiplexed mode. If, for example, an internal 24-bit address is FF2080H, the 20 external-address pins output F2080H. Further, the address seen by an external device depends on how many of the extended address pins are connected to the device. (See “Internal and External Addresses” on page 13-1.)

The 20 external-address pins can address 1 Mbyte of external memory. For purposes of discussion only, it is convenient to view this 1-Mbyte address space as sixteen 64-Kbyte pages, numbered 00H–0FH (see Figure 5-1 on page 5-2). The 4 upper address pins select a 64-Kbyte page (00H–0FH), and the lower 16 address pins select a particular location within a 64-Kbyte page.

Because the 4 most-significant bits (MSBs) of the internal address can take any values without changing the external address, these 4 bits effectively produce 16 copies of the 1-Mbyte address space, for a total of 16 Mbytes in 256 pages, 00H–FFH (Figure 5-1). For example, page 01H has 15 duplicates: 11H, 21H, …, F1H. The shaded areas in Figure 5-1 represent the overlaid areas.

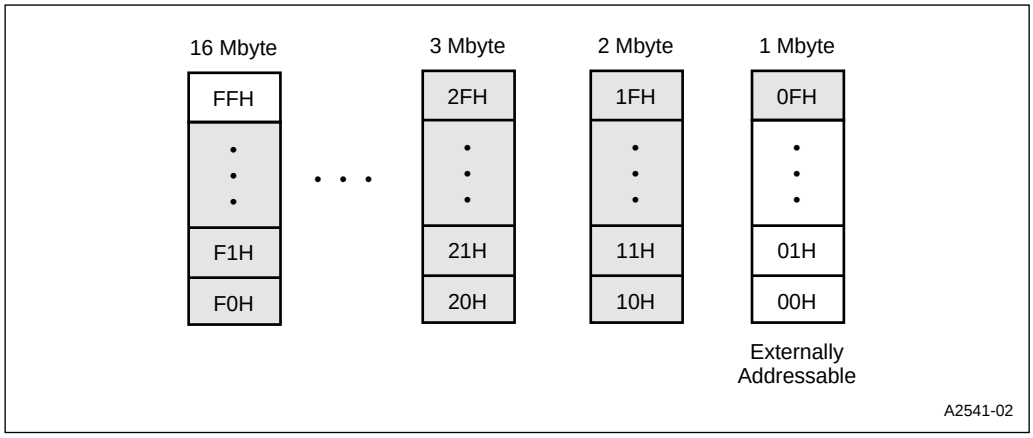


Figure 5-1. 16-Mbyte Address Space

The memory pages of interest are 00H–0EH and FFH. Pages 01H–0EH are external memory with unspecified contents; they can store either code or data. Pages 00H and FFH, shown in Figure 5-2, have special significance. Page 00H contains the register file and the special-function registers (SFRs), while page FFH contains special-purpose memory (chip configuration bytes and interrupt vectors) and program memory. The microcontroller fetches its first instruction from location FF2080H.

Like the 8XC196NP and 80C196NU, the 80296SA incorporates a chip-select unit to simplify access to external memory devices. The chip-select unit of the earlier devices decoded only the lower 20 address bits, enabling unique access to addresses in pages 00H–0EH and FFH. By decoding all 24 bits of the internal address, the 80296SA's enhanced chip-select unit provides a method for uniquely addressing external memory devices in pages 0FH–FEH, as well. You can assign each chip-select a range of addresses in up to 1 Mbyte segments. Therefore, with six chip-select outputs, the 80296SA can access up to 6 Mbytes of memory. Refer to "The Chip-select Unit" on page 13-8 for details.

NOTE

Because the microcontroller has 24 bits of address internally, all programs must be written as though it uses all 24 bits. The microcontroller resets from page FFH, so all code must originate from this page. (Use the assembler directive, "cseg at 0FF*xxxx*H.") This is true even though your code is actually stored in external memory.

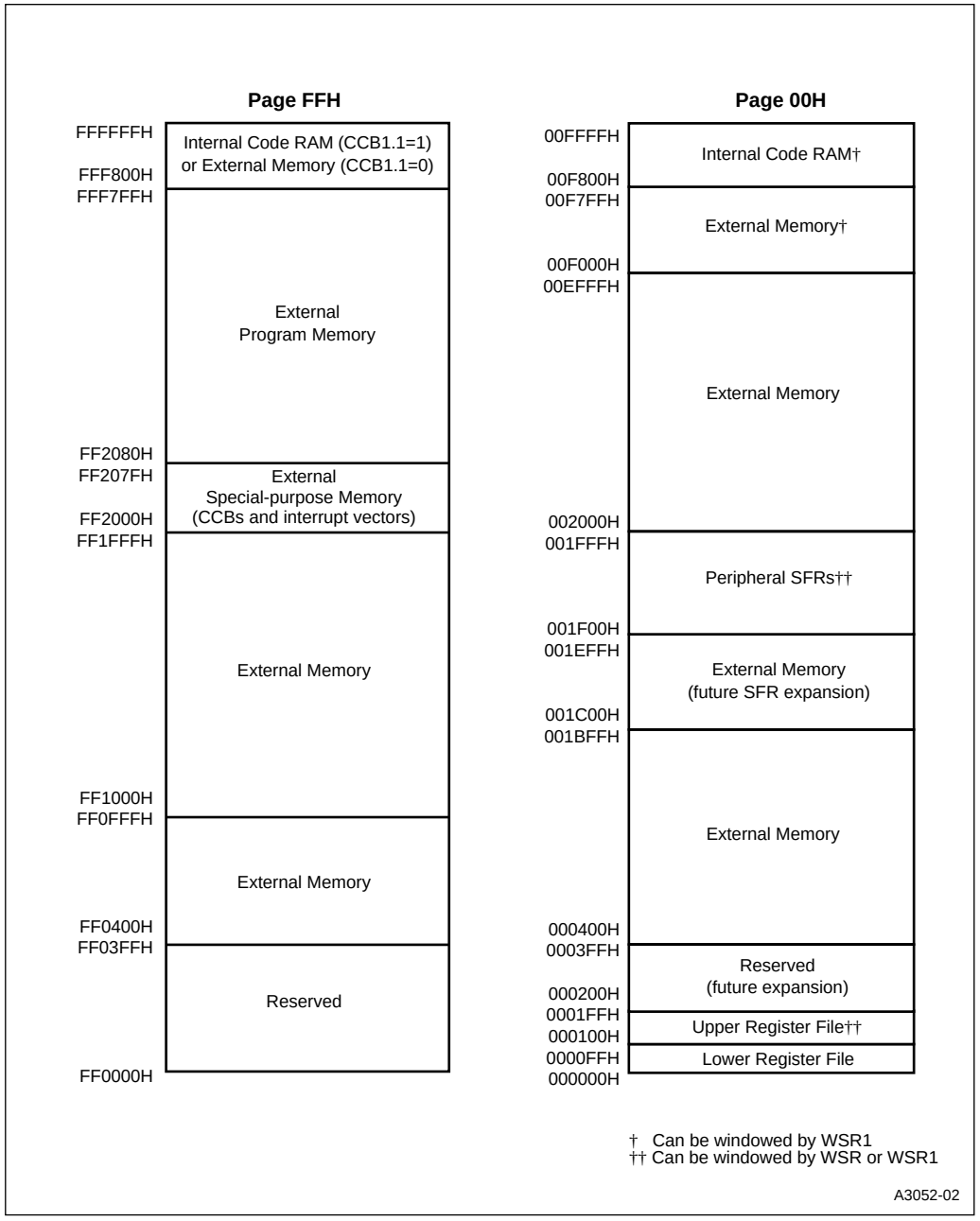


Figure 5-2. Pages FFH and 00H

5.2 MEMORY PARTITIONS

Table 5-1 is a memory map of the 80296SA. This section describes the partitions.

Table 5-1. 80296SA Memory Map

Hex Address	Description (Note 1, Note 2)	Addressing Modes for Data Accesses
FFFFFF FFF800	External device (memory or I/O) in 1-Mbyte mode (CCB1.1=0) A copy of internal code RAM in 64-Kbyte mode (CCB1.1=1)	Extended
FFF7FF FF2080	External program memory (Note 3)	Extended
FF207F FF2000	External special-purpose memory (CCBs and interrupt vectors)	Extended
FF1FFF FF0400	External device (memory or I/O) connected to address/data bus	Extended
FF03FF FF0000	Reserved for in-circuit emulators	—
FEFFFF 0F0000	Overlaid memory (reserved for future devices); locations *x*F0000–*x*F03FFH are reserved for in-circuit emulators	—
0EFFFF 010000	External device (memory or I/O) connected to address/data bus	Extended
00FFFF 00F800	Internal code RAM (code or data); can be windowed by WSR1. In 64-Kbyte mode, code RAM is identically mapped into page FFH.	Indirect, indexed, extended, windowed direct
00F7FF 00F000	External device (memory or I/O) connected to address/data bus; can be windowed by WSR1	Indirect, indexed, extended, windowed direct
00EFFF 002000	External device (memory or I/O) connected to address/data bus	Indirect, indexed, extended
001FFF 001F00	Internal peripheral special-function registers (SFRs); can be windowed by WSR or WSR1	Indirect, indexed, extended, windowed direct
001EFF 001C00	Reserved (future SFR expansion)	—
001BFF 000400	External device (memory or I/O) connected to address/data bus	Indirect, indexed, extended
0003FF 000200	Reserved (future register file expansion)	—
0001FF 000100	Upper register file (general-purpose register RAM) can be windowed by WSR or WSR1	Indirect, indexed, extended windowed direct
0000FF 00001A	Lower register file (general-purpose register RAM)	Direct, indirect, indexed, extended
000019 000000	Lower register file (stack pointer and CPU SFRs)	Direct

NOTES:
1. Unless otherwise noted, write 0FFH to reserved memory locations and write 0 to reserved SFR bits.
2. The contents or functions of reserved locations may change in future device revisions, in which case a program that relies on one or more of these locations might not function properly.
3. External memory occupies the boot memory partition, FF2080–FF7FFH. After reset, the default chip-select line (CS0#) is active; the first instruction fetch is from FF2080H.

5.2.1 External Memory

Several partitions in pages 00H and FFH and all of pages 01H–0EH are assigned to external memory (see Table 5-1). Data can be stored in any part of this memory. Instructions can be stored in any part of this memory in 1-Mbyte mode, but can be stored only in page FFH in 64-Kbyte mode. Chapter 13, “Interfacing with External Memory,” describes the external memory interface and shows examples of external memory configurations.

5.2.2 Program and Special-purpose Memory

Program memory and special-purpose memory occupy a 56-Kbyte memory partition from FF2000–FFFFFFH.

5.2.2.1 Program Memory in Page FFH

The program memory in page FFH is implemented by external memory devices. Nearly all of page FFH is available for storing executable code:

- FFF800–FFFFFFH in 1-Mbyte mode only (occupied by code RAM in 64-Kbyte mode)
- FF2080–FFF7FFH (after a reset, the first instruction fetch is from FF2080H)
- FF0400–FF1FFFH

The 1-Kbyte section FF0000–FF03FFH is reserved for in-circuit emulators, and the 128-byte section FF2000–FF207FH is used for special-purpose memory (the chip configuration bytes and interrupt vectors). In 1-Mbyte mode, the remainder of page FFH is available for storing code. In 64-Kbyte mode, however, the upper 2-Kbyte region FFF800–FFFFFFH is occupied by an identical copy of the internal code RAM from page 00H. In 64-Kbyte mode, code must execute from page FFH and data must reside in page 00H for nonextended instructions. Mapping the internal code RAM into both pages allows you to access data and constants as *near data* and *near constants* in page 00H and execute code in page FFH.

The memory device that contains code also commonly contains constants or lookup tables. To access these tables and constants as *near data* and *near constants*, you can configure a chip-select output to select the corresponding address range in the memory device. Refer to “The Chip-select Unit” on page 13-8 for details.

NOTE

We recommend that you write FFH (the opcode for the RST instruction) to unused program memory locations. This causes a reset if a program begins to execute in unused memory.

5.2.2.2 Special-purpose Memory

Special-purpose memory resides in locations FF2000–FF207FH (Table 5-2). It contains several reserved memory locations, the chip configuration bytes (CCBs), and the interrupt vectors.

Table 5-2. 80296SA Special-purpose Memory Addresses

Hex Address	Description
FF207F FF2040	Reserved (each byte must contain FFH)
FF203F FF2030	Upper interrupt vectors
FF202F FF201C	Reserved (each byte must contain FFH)
FF201B	Reserved (must contain 20H)
FF201A	CCB1
FF2019	Reserved (must contain 20H)
FF2018	CCB0
FF2017 FF2010	Reserved (each byte must contain FFH)
FF200F FF2000	Lower interrupt vectors

5.2.2.3 Reserved Memory Locations

Several memory locations are reserved for testing or for use in future products. Do not read or write these locations except to initialize them to the values shown in Table 5-2. The function or contents of these locations may change in future revisions; software that uses reserved locations may not function properly.

5.2.2.4 Interrupt Vectors

The upper and lower interrupt vectors must contain the addresses of interrupt service routines for the interrupt controller. See Table 6-3, "Interrupt Sources, Vectors, and Priorities," on page 6-6 for more information.

5.2.2.5 Chip Configuration Bytes

The chip configuration bytes (CCB0 and CCB1) specify the operating environment. They specify the bus width, bus mode (multiplexed or demultiplexed), write-control mode, wait states, power-down enabling, and the operating mode (1-Mbyte or 64-Kbyte mode). The chip-select control registers can change some of these parameters.

The chip configuration bytes are the first bytes fetched from memory when the microcontroller leaves the reset state. The post-reset sequence loads the CCBs into the chip configuration registers (CCRs). Once they are loaded, the CCRs cannot be changed until the next reset. Typically, the CCBs are programmed once when your program is compiled and are not redefined during normal operation. “Chip Configuration Registers and Chip Configuration Bytes” on page 13-17 describes the CCBs and CCRs.

5.2.3 Internal RAM (Code RAM)

The 80296SA has 2 Kbytes of internal RAM at 00F800–00FFFFH. Although it is called *code RAM* to distinguish it from *register RAM*, this internal RAM can store both executable code and data. This memory is typically used for the stack or for time-critical code and data.

In 64-Kbyte mode, code must execute from page FFH, so this partition is mapped identically into page FFH. Mapping this partition into both pages allows you to access *near constants* and *near data* in page 00H and execute code in page FFH. In 1-Mbyte mode, code can execute from any page, so this partition resides only in page 00H, leaving FFF800–FFFFFFH available for an external memory or I/O device.

The 80296SA allows you to *window* 64-byte segments of this internal RAM into the lower register file. Accesses to the code RAM take two states longer than accesses to register RAM, but one state faster than accesses to external memory. (See “Windowing” on page 5-13.)

5.2.4 Peripheral Special-function Registers (SFRs)

Locations 1F00–1FFFH provide access to the peripheral SFRs (see Table 5-3). Locations in this range that are omitted from the table are reserved. The peripheral SFRs are I/O control registers; they are physically located in the on-chip peripherals. Peripheral SFRs can be windowed and they can be addressed as bytes, except as noted in the table.

Table 5-3. Peripheral SFRs

Interrupt SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
†1FF0H	VECT_ADDR (H)	VECT_ADDR (L)
†1FEEH	INT_CON3 (H)	INT_CON3 (L)
†1FECH	INT_CON2 (H)	INT_CON2 (L)
†1FEAH	INT_CON1 (H)	INT_CON1 (L)
†1FE8H	INT_CON0 (H)	INT_CON0 (L)
Ports 1–4 SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1FDEH	P4_PIN	P3_PIN
1FDCH	P4_REG	P3_REG
1FDAH	P4_DIR	P3_DIR
1FD8H	P4_MODE	P3_MODE
1FD6H	P2_PIN	P1_PIN
1FD4H	P2_REG	P1_REG
1FD2H	P2_DIR	P1_DIR
1FD0H	P2_MODE	P1_MODE
1FCEH	Reserved	Reserved
Auto-Indexing and Interrupt SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1FCCH	Reserved	EXTINT_CON
†1FCAH	INT_PROG1 (H)	INT_PROG1 (L)
1FC8H	NMI_PEND	INT_PROG0
1FC6H	ICB1	IDX1 (H)††
1FC4H	IDX1 (M)††	IDX1 (L)††
1FC2H	ICB0	IDX0 (H)††
1FC0H	IDX0 (M)††	IDX0 (L)††

EPORT SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1FE6H	EP_PIN	Reserved
1FE4H	EP_REG	Reserved
1FE2H	EP_DIR	Reserved
1FE0H	EP_MODE	Reserved
Serial I/O and PWM SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1FBEH	Reserved	Reserved
1FBCH	SP_BAUD (H)	SP_BAUD (L)
1FBAH	SP_CON	SBUF_TX
1FB8H	SP_STATUS	SBUF_RX
1FB6H	Reserved	CON_REG0
1FB4H	Reserved	PWM2_CONTROL
1FB2H	Reserved	PWM1_CONTROL
1FB0H	Reserved	PWM0_CONTROL
1FAEH	Reserved	Reserved
Reserved Locations		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1FACH	Reserved	Reserved
1FAAH	Reserved	Reserved
1FA8H	Reserved	Reserved
1FA6H	Reserved	Reserved
1FA4H	Reserved	Reserved
1FA2H	Reserved	Reserved
1FA0H	Reserved	Reserved

† Must be addressed as a word.

†† These 24-bit registers must be accessed with windowed direct addressing. Use a word instruction to access the lower word and a byte instruction to access the upper byte.

Table 5-3. Peripheral SFRs (Continued)

EPA, Timer 1, and Timer 2 SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1F9EH	Reserved	EPA_PEND
1F9CH	Reserved	EPA_MASK
1F9AH	Reserved	Reserved
1F98H	Reserved	Reserved
†1F96H	TIMER2 (H)	TIMER2 (L)
1F94H	Reserved	T2CONTROL
†1F92H	TIMER1 (H)	TIMER1 (L)
1F90H	Reserved	T1CONTROL
†1F8EH	EPA3_TIME (H)	EPA3_TIME (L)
†1F8CH	EPA3_CON (H)	EPA3_CON (L)
†1F8AH	EPA2_TIME (H)	EPA2_TIME (L)
1F88H	Reserved	EPA2_CON
EPA, Timer 1, and Timer 2 SFRs (Continued)		
Address	**High (Odd) Byte**	**Low (Even) Byte**
†1F86H	EPA1_TIME (H)	EPA1_TIME (L)
†1F84H	EPA1_CON (H)	EPA1_CON (L)
†1F82H	EPA0_TIME (H)	EPA0_TIME (L)
1F80H	Reserved	EPA0_CON
1F7EH	Reserved	Reserved
1F7CH	Reserved	Reserved
1F7AH	Reserved	Reserved
1F78H	Reserved	Reserved
1F76H	Reserved	Reserved
1F74H	Reserved	Reserved
1F72H	Reserved	Reserved
1F70H	Reserved	Reserved

Chip-select SFRs		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1F6EH	Reserved	Reserved
1F6CH	Reserved	BUSCON5
†1F6AH	ADDRMSK5 (H)	ADDRMSK5 (L)
†1F68H	ADDRCOM5 (H)	ADDRCOM5 (L)
1F66H	Reserved	Reserved
1F64H	Reserved	BUSCON4
†1F62H	ADDRMSK4 (H)	ADDRMSK4 (L)
†1F60H	ADDRCOM4 (H)	ADDRCOM4 (L)
1F5EH	Reserved	Reserved
1F5CH	Reserved	BUSCON3
†1F5AH	ADDRMSK3 (H)	ADDRMSK3 (L)
†1F58H	ADDRCOM3 (H)	ADDRCOM3 (L)
Chip-select SFRs (Continued)		
Address	**High (Odd) Byte**	**Low (Even) Byte**
1F56H	Reserved	Reserved
1F54H	Reserved	BUSCON2
†1F52H	ADDRMSK2 (H)	ADDRMSK2 (L)
†1F50H	ADDRCOM2 (H)	ADDRCOM2 (L)
1F4EH	Reserved	Reserved
1F4CH	Reserved	BUSCON1
†1F4AH	ADDRMSK1 (H)	ADDRMSK1 (L)
†1F48H	ADDRCOM1 (H)	ADDRCOM1 (L)
1F46H	Reserved	Reserved
1F44H	Reserved	BUSCON0
†1F42H	ADDRMSK0 (H)	ADDRMSK0 (L)
†1F40H	ADDRCOM0 (H)	ADDRCOM0 (L)

† Must be addressed as a word.

†† These 24-bit registers must be accessed with windowed direct addressing. Use a word instruction to access the lower word and a byte instruction to access the upper byte.

5.2.5 Register File

The register file is divided into an upper register file and a lower register file (Figure 5-3). The upper register file consists of general-purpose register RAM. The lower register file contains additional general-purpose register RAM along with the stack pointer (SP) and the CPU special-function registers (SFRs). The 80296SA is the first MCS 96 microcontroller to use three-port RAM for the register file. This enhancement allows the CPU to read two source operands at the same time it writes the destination operand from the previous instruction.

Table 5-4 on page 5-11 lists the register file memory addresses. The RALU accesses the lower register file directly, without the use of the memory controller. It also accesses a *windowed* location directly (see "Windowing" on page 5-13). Registers in the lower register file and registers being windowed can be accessed with direct addressing.

NOTE

The register file must not contain code. An attempt to execute an instruction from a location in the register file causes the memory controller to fetch the instruction from external memory.

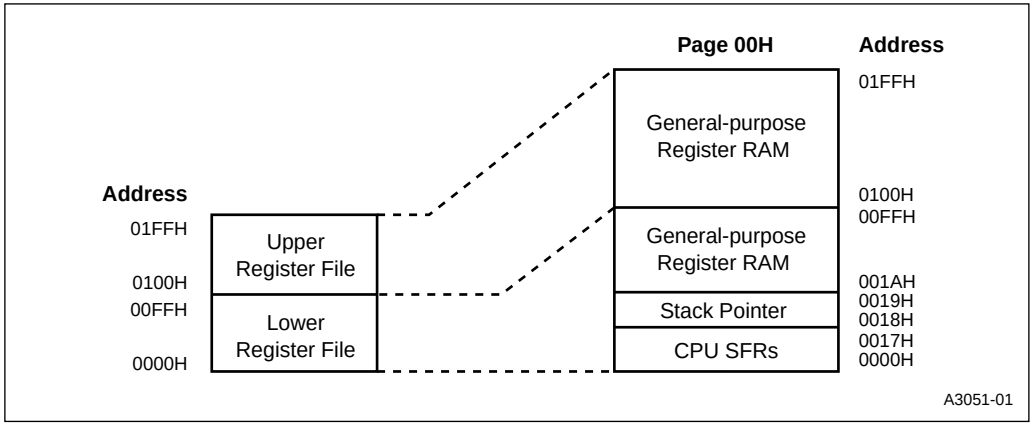


Figure 5-3. Register File Memory Map

Table 5-4. Register File Memory Addresses

Address Range	Description	Addressing Modes
01FFH 0100H	General-purpose register RAM; upper register file	Indirect, indexed, extended, windowed direct
00FFH 001AH	General-purpose register RAM; lower register file	Direct, indirect, indexed, extended
0019H 0018H	Stack pointer (SP); lower register file	Direct
0017H 0000H	CPU special-function registers (SFRs); lower register file	Direct

5.2.5.1 General-purpose Register RAM

The lower register file contains general-purpose register RAM. The stack pointer locations can also be used as general-purpose register RAM when stack operations are not being performed. The RALU can access this memory directly, using direct addressing.

The upper register file also contains general-purpose register RAM. The RALU normally uses indirect or indexed addressing to access the RAM in the upper register file. Windowing enables the RALU to use direct addressing to access this memory, providing fast context switching of interrupt tasks and faster program execution. (Refer to Chapter 4, "Programming Considerations," for a discussion of addressing modes, and see "Windowing" on page 5-13 for details on windowing.) The stack is most efficient when located in the internal code RAM or the upper register file.

NOTE

The upper register file of some earlier MCS® 96 microcontrollers extends from 0100–03FFH (768 bytes), while the 80296SA's extends only from 0100–01FFH (512 bytes). If you are migrating your design from an earlier device to the 80296SA, check your software to determine whether you need to modify it to relocate data from the top 256 bytes of the upper register file to another area.

5.2.5.2 Stack Pointer (SP)

Memory locations 0018H and 0019H contain the stack pointer (SP). The SP contains the address of the stack. The SP must point to a word (even) address that is two bytes (for 64-Kbyte mode) or four bytes (for 1-Mbyte mode) greater than the desired starting address. Before the CPU executes a subroutine call or interrupt service routine, it decrements the SP (by two in 64-Kbyte mode; by four in 1-Mbyte mode). Next, it copies (PUSHes) the address of the next instruction

from the program counter onto the stack. It then loads the address of the subroutine or interrupt service routine into the program counter. When it executes the return-from-subroutine (RET or RETI) instruction at the end of the subroutine or interrupt service routine, the CPU loads (POPs) the contents of the top of the stack (that is, the return address) into the program counter. Finally, it increments the SP (by two in 64-Kbyte mode; by four in 1-Mbyte mode).

Subroutines may be nested. That is, each subroutine may call others. The CPU PUSHes the contents of the program counter onto the stack each time it executes a subroutine call. The stack grows downward as entries are added. The only limit to the nesting depth is the amount of available memory. As the CPU returns from each nested subroutine, it POPs the address off the top of the stack, and the next return address moves to the top of the stack.

Your program must load a word-aligned (even) address into the stack pointer. Select an address that is two bytes (for 64-Kbyte mode) or four bytes (for 1-Mbyte mode) greater than the desired starting address because the CPU automatically decrements the stack pointer before it pushes the first byte of the return address onto the stack. Remember that the stack grows downward, so allow sufficient room for the maximum number of stack entries. The stack must be located in page 00H, in either the internal register file, the internal code RAM, or external RAM. The stack can be used most efficiently when it is located in the upper register file or internal code RAM.

The following examples initialize the stack at the top of the upper register file and at the top of the internal code RAM, respectively.

```
LD   SP, #200H          ;Stack begins at 01FEH and grows downward
LD   SP, #0000H         ;Stack begins at FFFEH and grows downward
```

The following example causes a linker/locator to initialize the stack at a location it chooses:

```
LD   SP, #STACK         ;Stack begins where the linker/locator places it
```

Consult the documentation for your specific development tools for further information.

5.2.5.3 CPU Special-function Registers (SFRs)

Locations 0000–0017H in the lower register file are the CPU SFRs. Table 5-5 lists the CPU SFRs for the 80296SA, and Appendix C describes them.

Table 5-5. 80296SA CPU SFRs

Address	High (Odd) Byte	Low (Even) Byte
0016H	ICX1 (H)	ICX1 (L)
0014H	WSR1	WSR
0012H	INT_MASK1	INT_PEND1
†0010H	ICX0 (H)	ICX0 (L)
†000EH	ACC_03	ACC_02
†000CH	ACC_01	ACC_00
000AH	ACC_STAT	Reserved
0008H	INT_PEND	INT_MASK
0006H	Reserved	ACC_04
†0004H	RPT_CNT (H)	RPT_CNT (L)
0002H	ONES_REG (H)	ONES_REG (L)
0000H	ZERO_REG (H)	ZERO_REG (L)

† Must be addressed as a word.

5.3 WINDOWING

Windowing expands the amount of memory that is accessible with direct addressing. Direct addressing can access the lower register file with short, fast-executing instructions. With windowing, direct addressing can also access the upper register file and peripheral SFRs.

Windowing maps a segment of higher memory (the upper register file, peripheral SFRs, internal code RAM, or external memory) into the lower register file. The 80296SA has two window selection registers, WSR and WSR1. WSR selects a 32-, 64-, or 128-byte segment of the upper register file or peripheral SFRs to be windowed into the top of the lower register file space. WSR1 selects a 32- or 64-byte segment of internal memory (the upper register file or peripheral SFRs), or a 64-byte segment of internal RAM or external memory to be mapped into the middle of the lower register file. (Figure 5-2 on page 5-3 shows the memory locations that can be windowed.)

Because the areas in the lower register file do not overlap, two windows can be in effect at the same time. This allows you to directly address a block of peripheral SFRs in one window and a block of register RAM in another. For example, you can activate a 128-byte window using WSR and a 64-byte window using WSR1 (Figure 5-4). These two windows occupy locations 0040–00FFH in the lower register file, leaving locations 001A–003FH for use as general-purpose register RAM, locations 0018–0019H for the stack pointer or general-purpose register RAM, and locations 0000–0017H for the CPU SFRs.

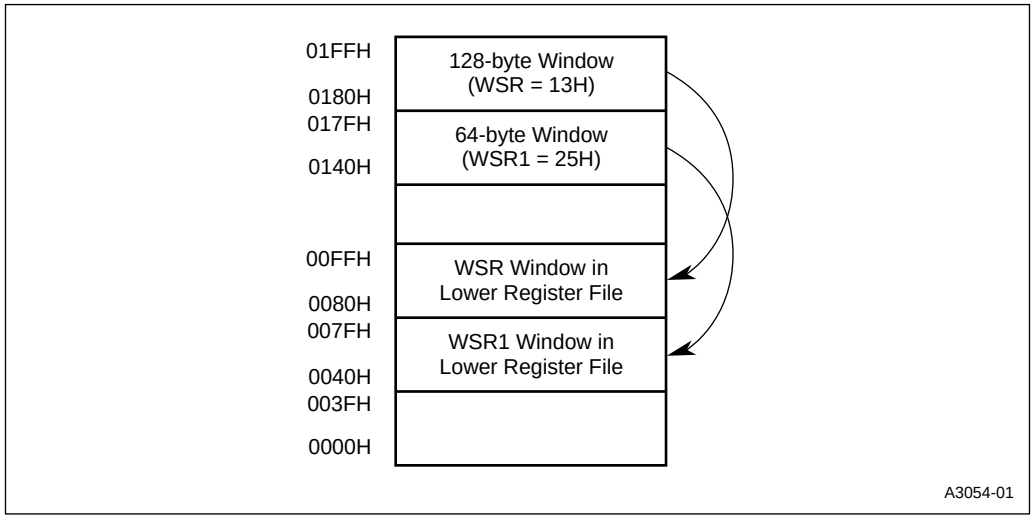


Figure 5-4. Windowing

5.3.1 Selecting a Window

The window selection register (Figure 5-5) has two functions. The HLDEN bit (WSR.7) enables and disables the bus-hold protocol (see Chapter 13, "Interfacing with External Memory"); it is unrelated to windowing. The remaining bits select a window to be mapped into the top of the lower register file. Window selection register 1 (Figure 5-6) selects a second window to be mapped into the middle of the lower register file.

Table 5-6 provides a quick reference of WSR values for windowing the peripheral SFRs. Table 5-7 on page 5-16 lists the WSR values for windowing the upper register file. Table 5-8 and Table 5-9 on page 5-17 list the WSR values for windowing internal code RAM and external memory, respectively.

WSR Address: 0014H
Reset State: 00H

The window selection register (WSR) has two functions. One bit enables and disables the bus-hold protocol. The remaining bits select windows. Windows map sections of RAM into the top of the lower register file, in 32-, 64-, or 128-byte increments. PUSHA saves this register on the stack and POPA restores it.

7							0
HLDEN	W6	W5	W4	W3	W2	W1	W0

Bit Number	Bit Mnemonic	Function
7	HLDEN	HOLD#, HLDA# Protocol Enable This bit enables and disables the bus-hold protocol (see Chapter 13, “Interfacing with External Memory”). It has no effect on windowing. 0 = disable 1 = enable
6:0	W6:0	Window Selection These bits specify the window size and number. See Table 5-6 on page 5-16 or Table 5-7 on page 5-16.

Figure 5-5. Window Selection (WSR) Register

WSR1 Address: 0015H
Reset State: 00H

Window selection 1 (WSR1) register selects a 32- or 64-byte segment of the upper register file or peripheral SFRs, or a 64-byte segment of code RAM or external memory, to be windowed into the middle of the lower register file.

NOTE: The PUSHA and POPA instructions do **not** save and restore WSR1.

7							0
W7	W6	W5	W4	W3	W2	W1	W0

Bit Number	Bit Mnemonic	Function
7:0	W7:0	Window Selection These bits specify the window location, size, and number. See Table 5-6 for peripheral SFR windows. Table 5-7 for upper register file windows, Table 5-8 for internal code RAM windows, or Table 5-9 for external memory windows.

Figure 5-6. Window Selection 1 (WSR1) Register

Table 5-6. Selecting a Window of Peripheral SFRs

Peripherals	SFR Locations (Hex)	WSR or WSR1 Value for 32-byte Window (00E0–00FFH or 0060–007FH)	WSR or WSR1 Value for 64-byte Window (00C0–00FFH or 0040–007FH)	WSR Value for 128-byte Window (0080–00FFH)
EPORT, interrupts	1FE0–1FFF	7FH		
Ports 1–4, interrupts, auto-indexing	1FC0–1FDF	7EH	3FH	
PWM and SIO	1FA0–1FBF	7DH		
EPA and timers	1F80–1F9F	7CH	3EH	1FH
Chip selects 4–5	1F60–1F7F	7BH		
Chip selects 0–3	1F40–1F5F	7AH	3DH	1EH

Table 5-7. Selecting a Window of the Upper Register File

Register RAM Locations (Hex)	WSR or WSR1 Value for 32-byte Window (00E0–00FFH or 0060–007FH)	WSR or WSR1 Value for 64-byte Window (00C0–00FFH or 0040–007FH)	WSR Value for 128-byte Window (0080–00FFH)
01E0–01FF	4FH		
01C0–01DF	4EH	27H	
01A0–01BF	4DH		
0180–019F	4CH	26H	13H
0160–017F	4BH		
0140–015F	4AH	25H	
0120–013F	49H		
0100–011F	48H	24H	12H

Table 5-8. Selecting a Window of the Internal Code RAM

Internal Code RAM Locations (Hex)	WSR1 Value for 64-byte Window (0040–007FH)	Internal Code RAM Locations (Hex)	WSR1 Value for 64-byte Window (0040–007FH)
FFC0–FFFF	BFH	FBC0–FBFF	AFH
FF80–FFBF	BEH	FB80–FBBF	AEH
FF40–FF7F	BDH	FB40–FB7F	ADH
FF00–FF3F	BCH	FB00–FB3F	ACH
FEC0–FEFF	BBH	FAC0–FAFF	ABH
FE80–FEBF	BAH	FA80–FABF	AAH
FE40–FE7F	B9H	FA40–FA7F	A9H
FE00–FE3F	B8H	FA00–FA3F	A8H
FDC0–FDFF	B7H	F9C0–F9FF	A7H
FD80–FDBF	B6H	F980–F9BF	A6H
FD40–FD7F	B5H	F940–F97F	A5H
FD00–FD3F	B4H	F900–F93F	A4H
FCC0–FCFF	B3H	F8C0–F8FF	A3H
FC80–FCBF	B2H	F880–F8BF	A2H
FC40–FC7F	B1H	F840–F87F	A1H
FC00–FC3F	B0H	F800–F83F	A0H

Table 5-9. Selecting a Window of External Memory

External Memory Locations (Hex)	WSR1 Value for 64-byte Window (0040–007FH)	External Memory Locations (Hex)	WSR1 Value for 64-byte Window (0040–007FH)
F7C0–F7FF	9FH	F3C0–F3FF	8FH
F780–F7BF	9EH	F380–F3BF	8EH
F740–F77F	9DH	F340–F37F	8DH
F700–F73F	9CH	F300–F33F	8CH
F6C0–F6FF	9BH	F2C0–F2FF	8BH
F680–F6BF	9AH	F280–F2BF	8AH
F640–F67F	99H	F240–F27F	89H
F600–F63F	98H	F200–F23F	88H
F5C0–F5FF	97H	F1C0–F1FF	87H
F580–F5BF	96H	F180–F1BF	86H
F540–F57F	95H	F140–F17F	85H
F500–F53F	94H	F100–F13F	84H
F4C0–F4FF	93H	F0C0–F0FF	83H
F480–F4BF	92H	F080–F0BF	82H
F440–F47F	91H	F040–F07F	81H
F400–F43F	90H	F000–F03F	80H

5.3.2 Addressing a Location Through a Window

After you have selected the desired window, you need to know the direct address of the memory location (the address in the lower register file). For SFRs, refer to the WSR tables in Appendix C. For other memory locations, calculate the direct address as follows:

1. Subtract the base address of the area to be remapped from the address of the desired location. This gives you the offset of that particular location.
2. Add the offset to the base address of the window (from Table 5-10). The result is the direct address.

Table 5-10. Windowed Base Addresses

Window Size	WSR Windowed Base Address (Base Address in Lower Register File)	WSR1 Windowed Base Address (Base Address in Lower Register File)
32-byte	00E0H	0060H
64-byte	00C0H	0040H
128-byte	0080H	—

Appendix C includes a table of the windowable SFRs with the window selection register values and direct addresses for each window size. The following examples explain how to determine the WSR value and direct address for any windowable location. An additional example shows how to set up a window by using the linker locator.

5.3.2.1 32-byte Windowing Example

Assume that you wish to access location 014BH (a location in the upper register file used for general-purpose register RAM) with direct addressing through a 32-byte window. Table 5-7 on page 5-16 shows that you need to write 4AH to the window selection register. It also shows that the base address of the 32-byte memory area is 0140H. To determine the offset, subtract that base address from the address to be accessed (014BH – 0140H = 000BH). Add the offset to the base address of the window in the lower register file (from Table 5-10). The direct address is 00EBH (000BH + 00E0H) for a WSR window or 006BH (000BH + 0060H) for a WSR1 window.

5.3.2.2 64-byte Windowing Example

Assume that you wish to access the SFR at location 1F8CH with direct addressing through a 64-byte window. Table 5-6 on page 5-16 shows that you need to write 3EH to the window selection register. It also shows that the base address of the 64-byte memory area is 1F80H. To determine the offset, subtract that base address from the address to be accessed (1F8CH – 1F80H = 000CH). Add the offset to the base address of the window in the lower register file (from Table 5-10). The direct address is 00CCH (000CH + 00C0H) for a WSR window or 004CH (000CH + 0040H) for a WSR1 window.

5.3.2.3 128-byte Windowing Example

Assume that you wish to access the SFR at location 1F82H with direct addressing through a 128-byte window. Table 5-6 on page 5-16 shows that you need to write 1FH to the window selection register. It also shows that the base address of the 128-byte memory area is 1F80H. To determine the offset, subtract that base address from the address to be accessed (1F82H – 1F80H = 0002H). Add the offset to the base address of the window in the lower register file (from Table 5-10). The direct address is 0082H (0002H + 0080H).

5.3.2.4 Using the Linker Locator to Set Up a Window

In this example, the linker locator is used to set up a window. The linker locator locates the window in the upper register file and determines the value to load in the WSR for access to that window. (Please consult the manual provided with the linker locator for details.)

```
*********  mod1  **************
mod1 module main              ;Main module for linker
public function1
extrn  ?WSR                   ;Must declare ?WSR as external

wsr  equ   14h:byte
sp   equ   18h:word

oseg
     var1:   dsw  1            ;Allocate variables in an overlayable segment
     var2:   dsw  1
     var3:   dsw  1

cseg

function1:
     push  wsr                ;Prolog code for wsr
```

```
     ldb   wsr, #?WSR         ;Prolog code for wsr

     add var1, var2, var3     ;Use the variables as registers
     ;
     ;
     ;

     ldb  wsr, [sp]           ;Epilog code for wsr
     add sp, #2               ;Epilog code for wsr
     ret
end

********  mod2  **************
public function2
extrn  ?WSR

wsr  equ   14h:byte
sp   equ   18h:word

oseg
     var1:   dsw  1
     var2:   dsw  1
     var3:   dsw  1

cseg

function2:
     push  wsr                ;Prolog code for wsr
     ldb   wsr, #?WSR         ;Prolog code for wsr

     add var1, var2, var3
     ;
     ;
     ;

     ldb  wsr, [sp]           ;Epilog code for wsr
     add sp, #2               ;Epilog code for wsr
     ret
end
*****************************
```

The following is an example of a linker invocation to link and locate the modules and to determine the proper windowing.

```
RL196 MOD1.OBJ, MOD2.OBJ registers(100h-01ff) windowsize(32)
```

The above linker controls tell the linker to use registers 0100–01FFH for windowing and to use a window size of 32 bytes. (These two controls enable windowing.)

The following is the map listing for the resultant output module (MOD1 by default):

```
SEGMENT MAP FOR mod1(MOD1):

            TYPE          BASE    LENGTH   ALIGNMENT    MODULE NAME
            ----          ----    ------   ---------    -----------
**RESERVED*               0000H     001AH
            STACK         001AH     0006H   WORD
*** GAP ***               0020H     00E0H
            OVRLY         0100H     0006H   WORD         MOD2
            OVRLY         0106H     0006H   WORD         MOD1
*** GAP ***               010CH     1F74H
            CODE          2080H     0011H   BYTE         MOD2
            CODE          2091H     0011H   BYTE         MOD1
*** GAP ***               20A2H     DF5EH
```

This listing shows the disassembled code:

```
2080H         ;C814               | PUSH  WSR
2082H         ;B14814             | LDB   WSR,#48H
2085H         ;44E4E2E0           | ADD   E0H,E2H,E4H
2089H         ;B21814             | LDB   WSR,[SP]
208CH         ;65020018           | ADD   SP,#02H
2090H         ;F0                 | RET
2091H         ;C814               | PUSH  WSR
2093H         ;B14814             | LDB   WSR,#48H
2096H         ;44EAE8E6           | ADD   E6H,E8H,EAH
209AH         ;B21814             | LDB   WSR,[SP]
209DH         ;65020018           | ADD   SP,#02H
20A1H         ;F0                 | RET
```

5.3.3 Windowing and Addressing Modes

Once windowing is enabled, the windowed locations can be accessed both through the window using direct addressing and through the actual addresses using indirect or indexed addressing. The lower register file locations that are covered by the window are always accessible by indirect or indexed operations. To re-enable direct access to the entire lower register file, clear bits 6:0 of the WSR and all bits of WSR1. To enable direct access to a particular location in the lower register file, you may select a smaller window that does not cover that location.

When windowing is enabled:

- a direct instruction that uses an address within the lower register file actually accesses the window in the upper register file;
- an indirect or indexed instruction that uses an address within either the lower register file or the upper register file accesses the actual location in memory.

The following sample code illustrates the difference between direct and indexed addressing when using windowing.

```
PUSHA                   ; Pushes the contents of WSR onto the stack
LDB WSR, #13H           ; Selects window 13H, a 128-byte block
                        ; (windows 0180–01FFH into 0080–00FFH)
                        ; The next instruction uses direct addr
ADD  40H, 80H           ; mem_word(40H)←mem_word(40H) + mem_word(180H)
                        ; The next two instructions use indirect addr
ADD  40H, 80H[0]        ; mem_word(40H)←mem_word(40H) + mem_word(80H +0)
ADD  40H, 180H[0]       ; mem_word(40H)←mem_word(40H) + mem_word(180H +0)
POPA                    ; reloads the previous contents into WSR
```

5.4 FETCHING CODE AND DATA IN THE 1-MBYTE AND 64-KBYTE MODES

When the microcontroller leaves reset, the MODE64 bit (CCB1.1) selects the 1-Mbyte or 64-Kbyte mode. The mode cannot be changed until the next reset.

In 64-Kbyte mode, code must execute from page FFH. In 1-Mbyte mode, code can execute from any page. In either mode, data must reside in page 00H for nonextended instructions, but it can reside in any page for extended instructions. In either mode, data and constants that reside in page 00H are called *near data* and *near constants*. Data and constants outside page 00H are called *far data* and *far constants*.

6

Interrupts

CHAPTER 6
INTERRUPTS

The 80296SA's interrupt controller can be programmed to either emulate the defined priority scheme of the 80C196NU or support a programmable priority scheme. This chapter describes the interrupt control circuitry, priority schemes, and latency.

6.1 OVERVIEW OF THE INTERRUPT CONTROL CIRCUITRY

The interrupt control circuitry within a microcontroller permits real-time events to control program flow. When an event generates an interrupt, the microcontroller suspends the execution of current instructions while it performs some service in response to the interrupt. When the interrupt is serviced, program execution resumes at the point where the interrupt occurred. An internal peripheral, an external signal, or an instruction can generate an interrupt request. In the simplest case, the microcontroller receives the request, performs the service, and returns to the task that was interrupted.

The interrupt sources fall into two categories. The unimplemented opcode, software trap, and NMI interrupt sources have a set priority and are always enabled. All other sources can be individually enabled and programmed to one of fourteen priority levels.

Upon reset, the 80296SA is configured to emulate the fixed priority scheme of the 80C196NU. In this mode, interrupts have a predefined priority scheme and vector address. Interrupts are serviced by interrupt service routines that you provide (Figure 6-2). The lower 16 bits of the addresses of these interrupt service routines are stored in the upper and lower interrupt vectors in special-purpose memory (Figure 5-2). The CPU automatically adds FF0000H to the 16-bit vector in special-purpose memory to calculate the address of the interrupt service routine, and then executes the routine.

The 80296SA can also operate in a programmable priority mode. When this mode is enabled, your software defines the priority of each programmable interrupt. A multiplexer is associated with interrupt priorities 0–14 (Figure 6-1). (Interrupt priority 2 is undefined and reserved for compatibility with future devices.) The interrupt control registers (INT_CON*x*) select the interrupt input that passes through the multiplexer. When an interrupt request occurs, it sets the corresponding bit in the interrupt pending register (INT_PEND or INT_PEND1). The interrupt mask registers (INT_MASK or INT_MASK1) enable or disable each interrupt request. When the CPU acknowledges an interrupt, hardware sets the corresponding bit in the in-progress registers (IN_PROG*x*) and clears the bit in the interrupt pending register. To decrease the execution time of interrupt service routines, the 80296SA allows you to copy the interrupt vector table into internal code RAM where it can be accessed directly (see "Internal RAM (Code RAM)" on page 5-7). Hardware generates an 8-bit jump address and adds it to the base address in the interrupt vector register (VECT_ADDR) to generate the complete vector address.

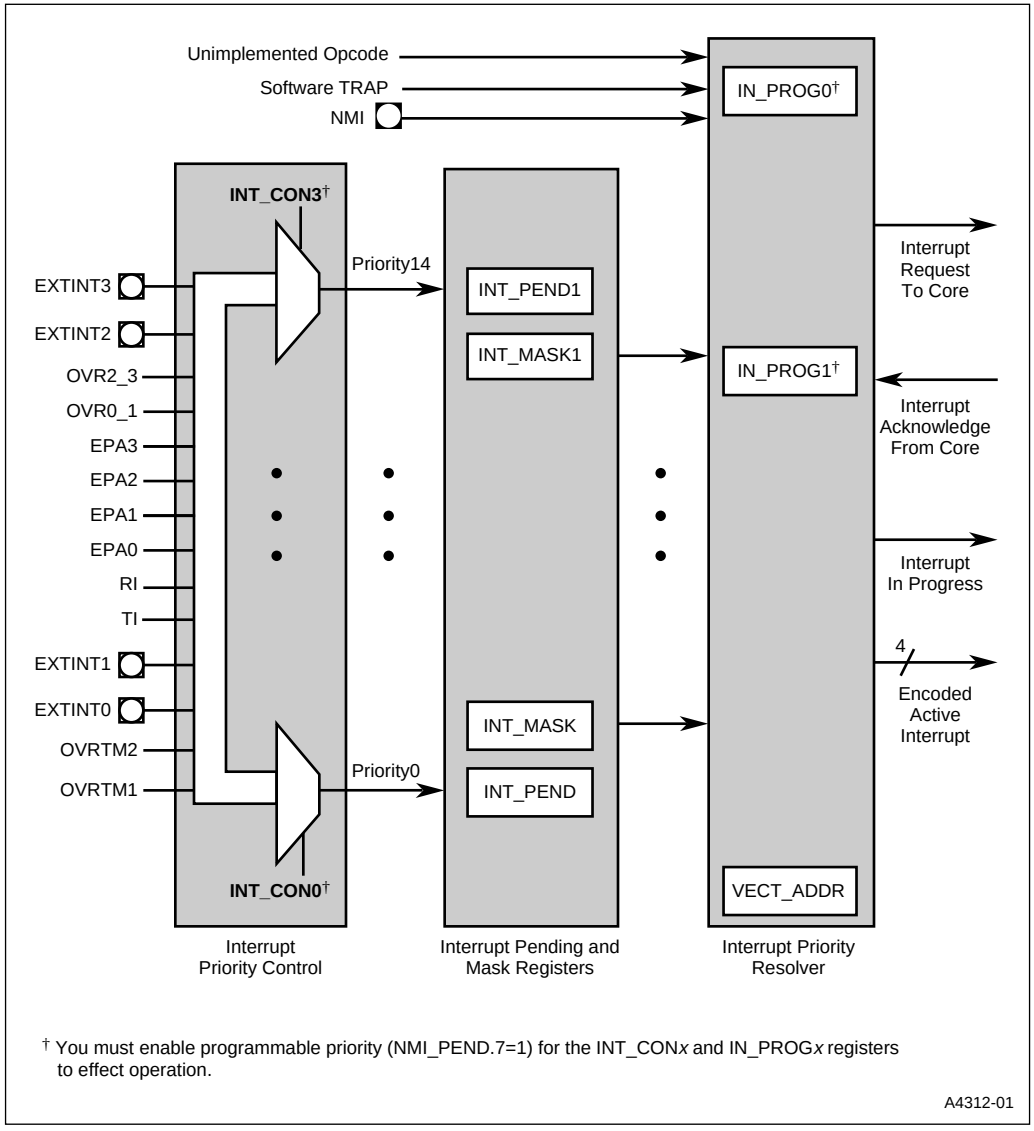
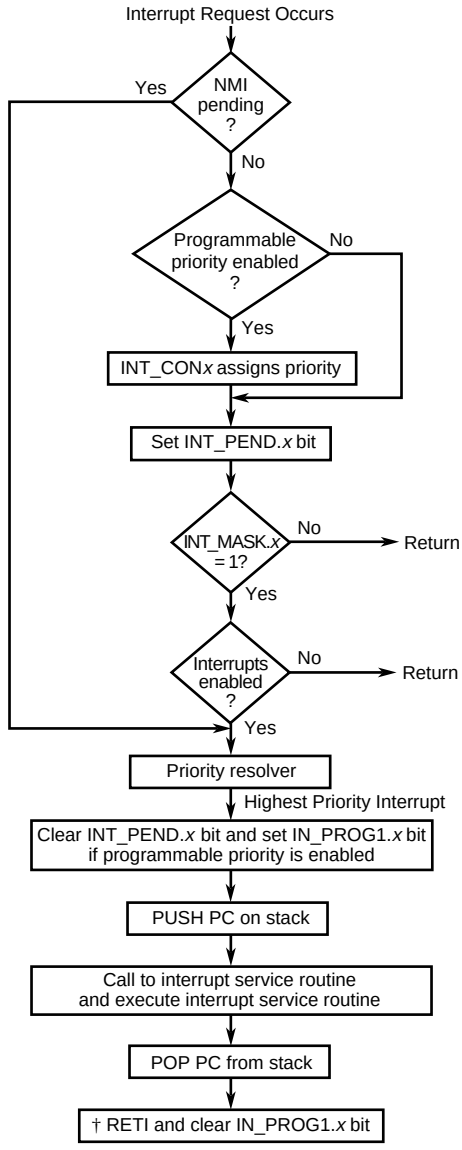


Figure 6-1. Interrupt Structure Block Diagram



† The RETI instruction must be used when priority-programming is enabled.

A4313-01

Figure 6-2. Interrupt Service Flow Diagram

6.2 INTERRUPT SIGNALS AND REGISTERS

Table 6-1 describes the external interrupt signals and Table 6-2 describes the interrupt control and status registers.

Table 6-1. Interrupt Signals

Interrupt Signal	Type	Description
EXTINT0 EXTINT1 EXTINT2 EXTINT3	I	External Interrupts In normal operating mode, a rising edge on EXTINT*x* sets the EXTINT*x* interrupt pending bit. EXTINT*x* is sampled during phase 2 (CLKOUT high). The minimum edge time is one state time. The minimum level time is two state times. In standby and powerdown modes, asserting the EXTINT*x* signal for at least 50 ns causes the device to resume normal operation. The interrupt need not be enabled, but the pin must be configured as a special-function input. If the EXTINT*x* interrupt is enabled, the CPU executes the interrupt service routine. Otherwise, the CPU executes the instruction that immediately follows the command that invoked the power-saving mode. In idle mode, asserting any enabled interrupt causes the device to resume normal operation. EXTINT0 shares a package pin with P2.2, EXTINT1 shares a package pin with P2.4, EXTINT2 shares a package pin with P3.6, and EXTINT3 shares a package pin with P3.7.
NMI	I	Nonmaskable Interrupt In normal operating mode, a rising edge on NMI generates a nonmaskable interrupt. NMI has the highest priority of all interrupts except trap and unimplemented opcode. Assert NMI for greater than one state time to guarantee that it is recognized. If NMI is held high during and immediately following reset, the microcontroller will execute the NMI vector when code execution begins. To prevent an inadvertent NMI interrupt vector, the first instruction (at FF2080H) must clear the NMI pending interrupt bit. ANDB INT_PEND1, #7FH.

Table 6-2. Interrupt Registers

Mnemonic	Address	Description
EPA_MASK	1F9CH	EPA Interrupt Mask Register This register enables/disables the four capture overrun interrupts (OVR0-3).
EPA_PEND	1F9EH	EPA Interrupt Pending Register The bits in this register are set by hardware to indicate that a capture overrun has occurred.
EXTINT_CON	1FCCH	External Interrupt Control Register This register enables you to individually select the edge or level that causes an interrupt request on each external interrupt input.

Table 6-2. Interrupt Registers (Continued)

Mnemonic	Address	Description
IN_PROG0 IN_PROG1	1FC8H 1FCAH	In-progress Registers The bits in these registers are set to indicate that an interrupt is being serviced. The IN_PROG0 register tracks the unimplemented opcode interrupt (UOP) and the software trap interrupt. The IN_PROG1 register tracks the NMI and maskable interrupts in terms of the priority that was assigned to them in the INT_CON*x* registers.
INT_CON0 INT_CON1 INT_CON2 INT_CON3	1FE8H 1FEAH 1FECH 1FEEH	Interrupt Control Registers These registers allow you to program the priority of the maskable interrupts.
INT_MASK INT_MASK1	0008H 0013H	Interrupt Mask Registers The bits in these registers enable or disable each maskable interrupt (that is, each interrupt except unimplemented opcode, software trap, and NMI).
INT_PEND INT_PEND1	0009H 0012H	Interrupt Pending Registers The bits in these registers are set by hardware to indicate that an interrupt is pending. Software can also set these bits.
NMI_PEND	1FC9H	Nonmaskable Interrupt Pending Register The bits in these registers are set by hardware to indicate that an unimplemented opcode or trap interrupt is pending. NMI_PEND also contains a programmable-priority-enable bit (PEN), which when set, causes the interrupt controller to reassign the interrupt priorities as defined by the INT_CON*x* register.
PSW	No direct access	Processor Status Word This register contains one bit that globally enables or disables servicing of all maskable interrupts.The bit is set by executing the enable interrupts (EI) instruction and cleared by executing the disable interrupts (DI) instruction.
VECT_ADDR	1FF0H	Interrupt Vector Base-address Register This register contains the upper sixteen address bits of the interrupt-vector table. When the CPU acknowledges an interrupt request, the vector-generation unit in the interrupt controller generates a jump address and then adds it to the contents of the base-address register to generate the complete vector address.

6.3 INTERRUPT SOURCES, PRIORITIES, AND VECTOR ADDRESSES

Table 6-3 lists the interrupts sources, their default priorities (17 is highest and 0 is lowest), and their default vector addresses. Higher priority interrupts are serviced before lower priority interrupts. A low-priority interrupt is always interrupted by a higher priority interrupt but not by another interrupt of equal or lower priority. The absolute highest priority interrupt is not interrupted by any other interrupt source.

The unimplemented opcode and software trap interrupts are not prioritized; they go directly to the interrupt resolver for servicing. These two interrupts are of higher priority than NMI and the other interrupts.

The priority of all maskable interrupts is programmable. In order to enable programmable priorities, you must first set the programmable-priority-enable bit in the NMI_PEND register (Figure 6-3 on page 6-7). Also, you must use the RETI instruction when priority programming is enabled. The four interrupt control registers (INT_CON*x*) define the interrupt priority when programmable priority is enabled. Each register has four, 4-bit fields that map a particular interrupt source to a specific priority and corresponding vector address. You assign the priorities by writing the hex value for each interrupt source to the appropriate 4-bit field (Figure 6-4 on page 6-8). If a priority is unused, write FH to the corresponding 4-bit field.

Table 6-3. Interrupt Sources, Vectors, and Priorities

Interrupt Source	Mnemonic	Name	Default Priority†	Default Vector Location†
Unimplemented Opcode	—	—	17††	FF2012H
Software TRAP Instruction	—	—	16††	FF2010H
Nonmaskable Interrupt	NMI	INT15	15††	FF203EH
EXTINT3 Pin	EXTINT3	INT14	14	FF203CH
EXTINT2 Pin	EXTINT2	INT13	13	FF203AH
EPA2 & 3 Overruns	OVR2_3	INT12	12	FF2038H
EPA0 & 1 Overruns	OVR0_1	INT11	11	FF2036H
EPA Capture/Compare 3	EPA3	INT10	10	FF2034H
EPA Capture/Compare 2	EPA2	INT09	9	FF2032H
EPA Capture/Compare 1	EPA1	INT08	8	FF2030H
EPA Capture/Compare 0	EPA0	INT07	7	FF200EH
SIO Receive	RI	INT06	6	FF200CH
SIO Transmit	TI	INT05	5	FF200AH
EXTINT1 Pin	EXTINT1	INT04	4	FF2008H
EXTINT0 Pin	EXTINT0	INT03	3	FF2006H
Reserved	Reserved	INT02	2	FF2004H
Timer 2 Overflow	OVRTM2	INT01	1	FF2002H
Timer 1 Overflow	OVRTM1	INT00	0	FF2000H

† Upon reset, the 80296SA defaults to the 80C196NU-compatible priority scheme. (The higher the number, the higher the priority.)

†† Fixed priority

NMI_PEND Address: 1FC9H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending registers (NMI_PEND, INT_PEND, or INT_PEND1). When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit. NMI_PEND also contains a programmable-priority-enable bit (PEN), which when set, causes the interrupt controller to reassign the interrupt priorities as defined by the INT_CON*x* register.

7							0
PEN	—	—	—	—	—	UOP	TRAP

Bit Number	Bit Mnemonic	Function
7	PEN	Programmable-priority Enable When PEN is set, the interrupt controller uses the interrupt priority scheme defined in the INT_CON*x* register. When PEN is cleared, the interrupt controller uses the default interrupt priorities.
6:2	—	Reserved; for compatibility with future devices, write zeros to these bits.
1:0	UOP TRAP	Any set bit indicates that the corresponding interrupt is pending. The pending bit is cleared when processing transfers to the corresponding interrupt vector. **Bit Mnemonic** **Interrupt Description** UOP Unimplemented Opcode TRAP Software Trap

Figure 6-3. NMI Pending (NMI_PEND) Register

INT_CON*x*
***x* = 0–3**

Address: See Table 6-4
Reset State: See Table 6-4

The interrupt control registers (INT_CON*x*) allow you to program the priority of the maskable interrupts. To assign a priority to an interrupt, write the interrupt's default priority hex value to the desired priority field. Before you can use this register, you must enable the programmable priority mode by setting bit 7 in NMI_PEND.

	15 8	7 0		
INT_CON3	—	PR14	PR13	PR12
INT_CON2	PR11	PR10	PR9	PR8
INT_CON1	PR7	PR6	PR5	PR4
INT_CON0	PR3	—	PR1	PR0

Bit Number	Bit Mnemonic	Function
INT_CON3.15:12	—	Priority Fields Write to these priority fields to program the interrupt priority and vector location. To assign an interrupt to a specific priority, write its interrupt default priority hex value to the desired priority field. Write FH to any unused priority field, including reserved priority fields, 2 and 15. For example, if you were to assign interrupt source EPA3 (default priority value 10) to priority twelve (PR12), the branching scheme for the EPA3 service routine would change from vector location FF2034H to FF2038H. This is possible by simply writing AH to bit field INT_CON3.3:0.
INT_CON3.11:8	PR14	
INT_CON3.7:4	PR13	
INT_CON3.3:0	PR12	
INT_CON2.15:12	PR11	
INT_CON2.11:8	PR10	
INT_CON2.7:4	PR9	
INT_CON2.3:0	PR8	
INT_CON1.15:12	PR7	
INT_CON1.11:8	PR6	
INT_CON1.7:4	PR5	
INT_CON1.3:0	PR4	
INT_CON0.15:12	PR3	
INT_CON0.11:8	—	
INT_CON0.7:4	PR1	
INT_CON0.3:0	PR0	

Figure 6-4. Interrupt Control (INT_CON*x*) Registers

Table 6-4. INT_CON*x* Address and Reset States

Register	Address	Reset State
INT_CON0	1FE8H	3210H
INT_CON1	1FEAH	7654H
INT_CON2	1FECH	BA98H
INT_CON3	1FEEH	FEDCH

For example, the following code assigns priorities to the EPA0, EXTINT1, EXTINT0, RI, TI, and OVRTM1 interrupts, with EPA0 having the highest priority and OVRTM1 the lowest. All other interrupts are unused.

```
;Enable priority scheme
LDB TEMP, #80H         ;
STB TEMP, NMI_PEND[0]  ;enables programmable priority scheme

;Add code to set up windows for direct access of INT_CONx registers.
;Assign priorities

LD INT_CON3, #0FFF7H   ;assigns EPA0 (interrupt 7) to priority and vector 12
LD INT_CON2, #0F4FFH   ;assigns EXTINT1 (interrupt 4) to priority and vector 10
LD INT_CON1, #0F365H   ;assigns EXTINT0 (interrupt 3) to priority and vector 6,
                       ;RI (interrupt 6) to priority and vector 5, and
                       ;TI (interrupt 5) to priority and vector 4
LD INT_CON0, #0FF0FH   ;assigns OVRTM1 (interrupt 0) to priority and vector 1

;Enable interrupts
ORB INT_MASK, #72H     ;enables interrupts assigned to vectors 1, 4, 5, and 6
ORB INT_MASK1, #14H    ;enables interrupts assigned to vectors 10 and 12
EI
```

6.3.1 Reassigning Vector Addresses

Interrupt vectors can be located anywhere in the user-accessible region of the 16-Mbyte address space on a 256-byte boundary. For faster execution of interrupt service routines, store the interrupt vector table in internal code RAM. To reassign the vectors, write the upper 16 bits of the interrupt vector table's base address to the VECT_ADDR register (Figure 6-5). When the CPU acknowledges an interrupt request, the interrupt controller generates an 8-bit jump address and adds it to the base address to generate a complete vector address. The 8-bit jump address represents the default vector location. The complete 24-bit vector address will be of the form, VECT_ADDR (upper word) plus the default vector location (lower byte).

VECT_ADDR

Address: 1FF0H
Reset State: FF20H

The base-address register (VECT_ADDR) contains the upper sixteen address bits of the interrupt-vector table. When the CPU acknowledges an interrupt request, the vector-generation unit in the interrupt controller generates a lower byte default vector location and then adds it to the contents of the base-address register to generate the complete vector address.

15							8
VA23	VA22	VA21	VA20	VA19	VA18	VA17	VA16
7							**0**
VA15	VA14	VA13	VA12	VA11	VA10	VA9	VA8

Bit Number	Bit Mnemonic	Function
15:0	VA23:8	Interrupt Vector Address Bits 23 through 8 This register contains the upper address bits for the indirect interrupt-vector-address table.

Figure 6-5. Interrupt Vector Address (VECT_ADDR) Register

6.3.2 Special Interrupts

Three special interrupt sources are always enabled: unimplemented opcode, software trap, and NMI. These interrupts are not affected by the EI (enable interrupts) and DI (disable interrupts) instructions, and they cannot be masked. Be aware that these interrupts are often assigned to special functions in development tools.

6.3.2.1 Unimplemented Opcode

If the CPU attempts to execute an unimplemented opcode, an indirect vector occurs. This prevents random software execution during hardware and software failures. The interrupt vector should contain the starting address of an error routine that will not further corrupt an already erroneous situation. When an unimplemented opcode interrupt occurs, no other interrupt request can be acknowledged until after the next instruction executes.

6.3.2.2 Software Trap

The TRAP instruction (opcode F7H) causes an interrupt call that is vectored through location FF2010H (default). This interrupt is useful when debugging software or generating software interrupts. Only the unimplemented opcode interrupt can interrupt a software trap interrupt.

6.3.2.3 NMI

The external NMI pin generates a nonmaskable interrupt for implementation of critical interrupt routines. NMI has a higher priority than all the prioritized interrupts. (Only the unimplemented opcode and software trap interrupts have higher priority.) It is passed directly from the transition detector to the priority resolver, and it vectors indirectly through location FF203EH.

If your system does not use the NMI interrupt, connect the NMI pin to V_{SS} to prevent spurious interrupts.

6.3.3 External Interrupt Signals

The external interrupt control (EXTINT_CON) register (Figure 6-6) enables you to select the level or edge that causes an interrupt request on each external interrupt signal. You can program each external interrupt signal to generate an interrupt request when either a high level, low level, rising edge, or falling edge occurs. The minimum level time is two states, and the minimum edge time is one state.

The external interrupt signals share package pins with the following I/O port signals: EXTINT0/P2.2, EXTINT1/P2.4, EXTINT2/P3.6, and EXTINT3/P3.7. To prevent false interrupts, first configure the port pins and then clear the interrupt pending registers before globally enabling interrupts. If the interrupt pending registers are not cleared before globally enabling interrupts, then writing to the Px_MODE register will set the corresponding pending bits and produce a false interrupt. See “External Interrupt Signals (Ports 2 and 3)” on page 7-9.

EXTINT_CON Address: 1FCCH
Reset State: 00H

The external interrupt control (EXTINT_CON) register enables you to individually select the action that causes an interrupt request on each external interrupt input.

7							0
LEV3	LEV2	LEV1	LEV0	POL3	POL2	POL1	POL0

Bit Number	Bit Mnemonic	Function
7:4	LEV3:0	These bits control what action on the external interrupt pins generates an interrupt request. LEV3 and POL3 program the EXTINT3 pin, LEV2 and POL2 program EXTINT2, and so on. **LEV*x*** **POL*x*** 0 0 rising edge on EXTINT*x* generates an interrupt request 0 1 falling edge on EXTINT*x* generates an interrupt request 1 0 high level on EXTINT*x* generates an interrupt request 1 1 low level on EXTINT*x* generates an interrupt request
3:0	POL3:0	

Figure 6-6. External Interrupt Control (EXTINT_CON) Register

6.3.4 Shared Interrupt Requests

The four EPA capture/compare channel overrun error interrupts are multiplexed into two interrupt requests. Channels 0 and 1 share the OVR0_1 interrupt request and channels 2 and 3 share the OVR2_3 interrupt request. Each source can generate the interrupt only if your software enables both the actual source interrupt request and the shared interrupt request. Enable the source interrupt requests by setting the appropriate bits in the EPA_MASK register (Figure 10-13 on page 10-24). Then enable the shared interrupt by setting the appropriate bit in the interrupt mask register.

The interrupt service routine should read the EPA_PEND register (Figure 10-16 on page 10-26) to determine the source of the interrupt. Before executing the return from interrupt (RETI) instruction, the interrupt service routine should check whether any of the other interrupt sources are pending.

6.4 INTERRUPT LATENCY

Interrupt latency is the total delay between the time that the interrupt request is generated (not acknowledged) and the time that the microcontroller begins executing the interrupt service routine. A three-state delay occurs between the time that the interrupt request is detected and the time that it is acknowledged. An interrupt request is acknowledged when the current instruction or uninterruptable instruction sequence completes execution. An interrupt request will not be acknowledged until after the third instruction in the pipeline finishes executing. This additional delay occurs because instructions are prefetched from external memory and assembled a minimum of four state times before they are executed. Thus, the maximum delay between interrupt request and acknowledgment is three state times plus a four-state minimum instruction fetch time and the execution time of the next instruction.

When a standard interrupt request is acknowledged, the hardware clears the interrupt pending bit and forces a call to the address contained in the corresponding interrupt vector.

6.4.1 Situations that Increase Interrupt Latency

If an interrupt request occurs while any of the following instructions are executing, the interrupt will not be acknowledged until after the **next** instruction is executed:

- the signed prefix opcode (FE) for the two-byte, signed multiply and divide instructions (the signed prefix opcode is supported on the 80296SA, but not required)
- any of these eight *protected instructions*: DI, EI, POPA, POPF, PUSHA, PUSHF (see Appendix A for descriptions of these instructions)
- any of the read-modify-write instructions: AND, ANDB, OR, ORB, XOR, XORB
- all eight multiply-accumulate (MAC) instructions
- the non-interruptable repeat instructions (RPT, RPT*xxx*) and the instruction that is being repeated
- windowed accesses to external peripherals or external memory
- the unimplemented opcode interrupt and the software trap interrupt

6.4.2 Calculating Latency

The maximum latency occurs when the interrupt request occurs too late (four states prior to end of current instruction) for acknowledgment following the current instruction. The following worst-case calculation assumes that the current instruction is not a protected instruction and that the stack, interrupt vector, and interrupt service routine are all located in external memory. Also assumed are, zero wait states, 16-bit buswidth, and demultiplexed mode. To calculate latency, add the following terms:

- Time for the interrupt request to be detected (4 state times).
  - — One state each to clock edge, synchronize interrupt, prioritize interrupt, and request interrupt.
- Time for the current instruction to finish execution (4 state times).
  - — If this is a protected instruction, the instruction that follows it must also execute before the interrupt can be acknowledged. Add the execution time of the instruction that follows a protected instruction.
- Time for the next instruction to execute. (See Appendix A for instruction execution times.)
  - — The longest instruction, DIV, takes 25 state times. However, the BMOV or RPT instruction could actually take longer if it is transferring a large block of data or repeating a divide instruction. If your code contains routines that transfer large blocks of data or use the RPT instruction, you may get a more accurate worst-case value if you use the BMOV or RPT execution time in your calculation instead of DIV.
- The response time to get the vector and force the call, and fetch the first instruction of the service routine.
  - — in 64-Kbyte mode, 10 state times.
  - — in 1-Mbyte mode, 12 state times.

6.4.2.1 Worst-case Interrupt Latency

Figure 6-7 illustrates worst-case interrupt latency. In 64-Kbyte mode, the worst-case delay for an interrupt is 43 state times (4 + 4 + 25 + 10). In 1-Mbyte mode, the worst-case delay increases to 45 state times (4 + 4 + 25 + 12) with the stack in external memory. This delay time does not include the time needed to execute the first instruction in the interrupt service routine or to execute the instruction following a protected instruction.

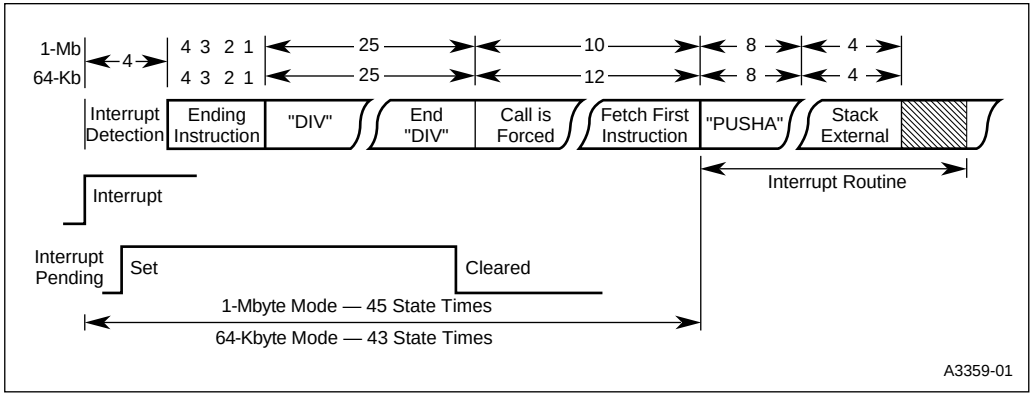


Figure 6-7. Worst-case Interrupt Response Time

6.5 PROGRAMMING THE INTERRUPTS

Table 6-5 describes how to program each maskable interrupt.

Table 6-5. Programming the Interrupts

To:	Your code must:
Operate with 80C196NU-compatible interrupt priorities	**Reset** the 80296SA microcontroller. Upon deassertion of RESET#, the 80296SA defaults to the 80C196NU-compatible interrupt controller structure.
Modify the priority of the maskable interrupts	**Set** the programmable-priority-enable bit in the NMI_PEND register (Figure 6-3 on page 6-7). Assign the interrupt priorities by writing the hex values for each interrupt source to the appropriate 4-bit field in the appropriate INT_CON*x* register (Figure 6-4 on page 6-8).
Reassign the default vector addresses	Write the upper 16 bits of the interrupt table's new base address to the VECT_ADDR register (Figure 6-5 on page 6-10).
Enable interrupt controller service for the maskable interrupts	Execute the EI instruction.
Disable interrupt controller service for the maskable interrupts	Execute the DI instruction.
Disable an individual maskable interrupt	**Clear** the interrupt's mask bit in the INT_MASK or INT_MASK1 register (Figure 6-8 or 6-9).
Enable a maskable interrupt	**Set** the interrupt's mask bit in the INT_MASK or INT_MASK1 register (Figure 6-8 or 6-9).
Disable an OVR0_1 or OVR2_3 interrupt source	**Clear** the interrupt's mask bit in the EPA_MASK register (Figure 10-13 on page 10-24).
Enable an OVR0_1 or OVR2_3 interrupt source	**Set** the interrupt's mask bit in the EPA_MASK register (Figure 10-13 on page 10-24).

INT_MASK

Address: 0008H
Reset State: 00H

The interrupt mask (INT_MASK) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK is the low byte of the processor status word (PSW). PUSHF or PUSHA saves the contents of this register onto the stack and then clears this register. Interrupt calls cannot occur immediately following this instruction. POPF or POPA restores it.

7 **0**

PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows:

Default Priority	Interrupt Source
7	EPA Capture/Compare Channel 0
6	SIO Receive
5	SIO Transmit
4	EXTINT1 pin
3	EXTINT0 pin
2	Reserved
1	Timer 2 Overflow/Underflow
0	Timer 1 Overflow/Underflow

Figure 6-8. Interrupt Mask (INT_MASK) Register

INT_MASK1 Address: 0013H
Reset State: 00H

The interrupt mask 1 (INT_MASK1) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK1 can be read from or written to as a byte register. PUSHA saves this register on the stack and POPA restores it.

7							0
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows: **Default Priority** — **Interrupt Source** 15 — Nonmaskable Interrupt† 14 — EXTINT3 pin 13 — EXTINT2 pin 12 — EPA Capture Channel 2 or 3 Overrun†† 11 — EPA Capture Channel 0 or 1 Overrun†† 10 — EPA Capture/Compare Channel 3 9 — EPA Capture/Compare Channel 2 8 — EPA Capture/Compare Channel 1 † NMI is always enabled and is always assigned to priority 15. This nonfunctional mask bit exists for design symmetry with the INT_PEND1 register. Always write zero to this bit. †† An overrun on the EPA capture/compare channels can generate the shared capture overrun interrupts. Write to EPA_MASK to enable the interrupt sources; read EPA_PEND to determine which source caused the interrupt.

Figure 6-9. Interrupt Mask 1 (INT_MASK1) Register

6.5.1 Determining the Source of an Interrupt

When hardware detects an interrupt, it sets the corresponding bit in the INT_PEND or INT_PEND1 register (Figures 6-11 or 6-12). It sets the bit even if the individual interrupt is disabled (masked). Software can read INT_PEND and INT_PEND1 to determine which interrupts are pending. If a shared overrun interrupt (OVR0_1 or OVR2_3) is pending, software can read the EPA_PEND register (Figure 10-16 on page 10-26) to determine the source of the interrupt request.

When priority-programming is enabled and the CPU acknowledges an interrupt request, hardware latches the interrupt pending bit into the corresponding IN_PROG0 or IN_PROG1 register bit (Figure 6-10) and clears the bit in the INT_PEND or INT_PEND1 register. After the interrupt service routine is finished, RETI is executed. Hardware clears the highest priority bit in the IN_PROG*x* registers. If a higher priority interrupt occurs while an interrupt service routine is ex-

ecuting, the higher priority interrupt is serviced and the IN_PROG*x* bit for the lower priority interrupt remains set until its interrupt service is executed.

NOTE

Reading the IN_PROG*x* registers outside the interrupt service routine is not recommended, as they will contain indeterminate data.

IN_PROG*x*
***x* = 0–1**

Address: 1FC8H, 1FCAH
Reset State: 00H, 0000H

The interrupt in-progress registers (IN_PROG*x*) track which interrupt is currently being serviced. The IN_PROG0 register tracks the unimplemented opcode interrupt (UOP) and the software trap interrupt. The IN_PROG1 register tracks the maskable interrupts in terms of the priority that was assigned to them in the INT_CON*x* registers. IN_PROG*x* registers should only be used when priority-programming is enabled.

	7							0
IN_PROG0	—	—	—	—	—	—	UOP	TRAP

	15							8
IN_PROG1	NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8
	7							0
	PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Bit Mnemonic	Function
IN_PROG0.7:2 IN_PROG1.2	—	Reserved; for compatibility with future devices, write zeros to these bits.
IN_PROG0.1	UOP	Any set bit indicates that the interrupt routine with the corresponding programmed priority level is executing. When processing transfers to an interrupt service routine, hardware sets the bit that corresponds to the interrupt's programmed priority level. When the return from interrupt (RETI) instruction is executed, at the end of an interrupt service routine, hardware clears the bit that corresponds to the interrupt's programmed priority level. The UOP, TRAP, and NMI are fixed priority interrupts.
IN_PROG0.0	TRAP	
IN_PROG1.15	NMI	
IN_PROG1.14:3 IN_PROG1.1:0	PR14:3 PR1:0	

Figure 6-10. Interrupt In-progress (IN_PROG*x*) Registers

Software can generate an interrupt by setting a bit in INT_PEND or INT_PEND1 register. We recommend the use of the read-modify-write instructions, such as AND and OR, to modify these registers.

```
ANDB INT_PEND, #11111110B; Clears the OVRTM1 pending bit
ORB  INT_PEND, #00000001B; Sets the OVRTM1 pending bit
```

Other methods could result in a partial interrupt cycle. For example, an interrupt could occur during an instruction sequence that loads the contents of the interrupt pending register into a temporary register, modifies the contents of the temporary register, and then writes the contents of the

temporary register back into the interrupt pending register. If the interrupt occurs during one of the last four states of the second instruction, it will not be acknowledged until after the completion of the third instruction. Because the third instruction overwrites the contents of the interrupt pending register, the jump to the interrupt vector will not occur.

INT_PEND Address: 0009H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending (NMI_PEND, INT_PEND, or INT_PEND1) registers. When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit.

7							0
PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Function
7:0	Any set bit indicates that the interrupt that is assigned to the corresponding priority is pending. The interrupt bit is cleared when processing transfers to the corresponding interrupt vector. The default interrupt priorities are as follows: **Default Priority — Interrupt Source** 7 — EPA Capture/Compare Channel 0 6 — SIO Receive 5 — SIO Transmit 4 — EXTINT1 pin 3 — EXTINT0 pin 2 — Reserved 1 — Timer 2 Overflow/Underflow 0 — Timer 1 Overflow/Underflow

Figure 6-11. Interrupt Pending (INT_PEND) Register

INT_PEND1 Address: 0012H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending (NMI_PEND, INT_PEND, or INT_PEND1) registers. When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit.

7							0
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8

Bit Number	Function
7:0	Any set bit indicates that the interrupt that is assigned to the corresponding priority is pending. The interrupt bit is cleared when processing transfers to the corresponding interrupt vector. The default interrupt priorities are as follows: **Default Priority** — **Interrupt Source** 15 — Nonmaskable Interrupt† 14 — EXTINT3 pin 13 — EXTINT2 pin 12 — EPA Capture Channel 2 or 3 Overrun†† 11 — EPA Capture Channel 0 or 1 Overrun†† 10 — EPA Capture/Compare Channel 3 9 — EPA Capture/Compare Channel 2 8 — EPA Capture/Compare Channel 1 † NMI is always assigned to priority 15. †† An overrun on the EPA capture/compare channels can generate the shared capture overrun interrupts. Write to EPA_MASK to enable the interrupt sources; read EPA_PEND to determine which source caused the interrupt.

Figure 6-12. Interrupt Pending 1 (INT_PEND1) Register

7

I/O Ports

CHAPTER 7
I/O PORTS

The microcontroller contains two 4-bit I/O ports and three 8-bit I/O ports. Each port pin can function as a general-purpose I/O signal or as a special-function signal. General-purpose I/O signals provide a mechanism to transfer information between the microcontroller and the surrounding system circuitry. They can read system status, monitor system operation, output microcontroller status, configure system options, generate control signals, provide serial communication, and so on. Special-function signals are associated with on-chip peripherals or system functions.

7.1 I/O PORTS OVERVIEW

Most port pins can serve as low-speed input/output signals (I/O mode) or as signals for peripheral and/or system functions (special-function mode). Each port pin can function as a complementary or open-drain signal. For complementary signals, the microcontroller drives a one or a zero on the pin. For open-drain signals, the microcontroller either floats the pin, making it available as a high impedance input, or pulls the pin low. Each port contains dedicated special-function registers (SFRs) that allow you to select a pin's mode, configuration, and output value, and read a pin's input value.

For each port, Table 7-1 lists the number of pins and associated peripheral or system function.

Table 7-1. Microcontroller I/O Ports

Port	Pins	Associated Peripheral(s) or System Function
Extended Port (EPORT)	4	Extended address lines
Port 1	8	EPA, SIO, timers
Port 2	8	SIO, interrupts, bus control, clock generation
Port 3	8	Chip-select unit, interrupts
Port 4	4	PWM

For each port pin, Table 7-2 lists the I/O and special-function signal names, the special-function signal type, and the special-function signal's associated peripheral or system function. For descriptions of a pin's special-function signal, see "Using the Special-function Signals" on page 7-6.

Table 7-2. Microcontroller Port Signals

Port	I/O Signal	Special-function Signal	Special-function Signal Type	Special-function Signal Peripheral or System Function
Extended Port	EPORT.0	A16	O	Extended address bus
	EPORT.1	A17	O	Extended address bus
	EPORT.2	A18	O	Extended address bus
	EPORT.3	A19	O	Extended address bus
Port 1	P1.0	EPA0	I/O	EPA
	P1.1	EPA1	I/O	EPA
	P1.2	EPA2	I/O	EPA
	P1.3	EPA3	I/O	EPA
	P1.4	T1CLK	I	Timer 1
	P1.5	T1DIR	I	Timer 1
	P1.6	T2CLK	I	Timer 2
	P1.7	T2DIR	I	Timer 2
Port 2	P2.0	TXD	O	Serial I/O unit
	P2.1	RXD	I/O	Serial I/O unit
	P2.2	EXTINT0	I	Interrupts
	P2.3	BREQ#	O	Bus controller
	P2.4	EXTINT1	I	Interrupts
	P2.5	HOLD#	I	Bus controller
	P2.6	HLDA#	O	Bus controller
	P2.7	CLKOUT	O	Clock generator
Port 3	P3.0	CS0#	O	Chip-select unit
	P3.1	CS1#	O	Chip-select unit
	P3.2	CS2#	O	Chip-select unit
	P3.3	CS3#	O	Chip-select unit
	P3.4	CS4#	O	Chip-select unit
	P3.5	CS5#	O	Chip-select unit
	P3.6	EXTINT2	I	Interrupts
	P3.7	EXTINT3	I	Interrupts
Port 4	P4.0	PWM0	O	PWM
	P4.1	PWM1	O	PWM
	P4.2	PWM2	O	PWM
	P4.3	—	—	—

Table 7-3 lists the registers associated with the ports.

Table 7-3. Port Control and Status Registers

Mnemonic	Address	Description
EP_DIR P1_DIR P2_DIR P3_DIR P4_DIR	1FE3H 1FD2H 1FD3H 1FDAH 1FDBH	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.
EP_MODE P1_MODE P2_MODE P3_MODE P4_MODE	1FE1H 1FD0H 1FD1H 1FD8H 1FD9H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
EP_PIN P1_PIN P2_PIN P3_PIN P4_PIN	1FE7H 1FD6H 1FD7H 1FDEH 1FDFH	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.
EP_REG P1_REG P2_REG P3_REG P4_REG	1FE5H 1FD4H 1FD5H 1FDCH 1FDDH	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.

The remainder of this chapter explains how to configure the ports, discusses using the port special-function signals, and describes the internal port structures.

7.2 CONFIGURING THE PORT PINS

Each port pin can be configured independently to operate as a special-function signal or an I/O signal. In addition, these signals can be independently configured to operate as complementary outputs, high-impedance inputs, or open-drain outputs.

7.2.1 Configuring Ports 1–4 and EPORT

Using the port mode register, you can individually configure each port 1–4 and EPORT pin to operate either as a general-purpose I/O signal (I/O mode) or as a special-function signal (special-function mode). In either mode, three configurations are possible: complementary output, high-impedance input, or open-drain output. The port direction and data output registers select the configuration for each pin. Complementary output means that the microcontroller drives the signal high or low. High-impedance input means that the microcontroller floats the signal. Open-drain output means the microcontroller drives the signal low or floats it. For I/O mode, the port data output register determines whether the microcontroller drives the signal high, drives it low, or floats it. For special-function mode, the on-chip peripheral or system function determines whether the microcontroller drives the signal high or low for complementary outputs.

The port 1–4 and EPORT pins are weakly pulled high during and after reset. Initializing the pins by writing to the port mode register turns off the weak pull-ups. To ensure that the ports are initialized correctly, follow this suggested initialization sequence:

1. Write to P*x*_DIR (or EP_DIR) to configure the individual pins. Clearing a bit configures a pin as a complementary output. Setting a bit configures a pin as a high-impedance input or open-drain output.
2. Write to P*x*_MODE (or EP_MODE) to select either I/O or special-function mode. Writing to P*x*_MODE (regardless of the value written) turns off the weak pull-ups. Even if the entire port is to be used as I/O (its default configuration after reset), **you must write to P*x*_MODE (or EP_MODE) to ensure that the weak pull-ups are turned off**.
3. Write to P*x*_REG (or EP_REG).

   For complementary output configurations:
   In I/O mode, write the data that is to be driven by the pins to the corresponding P*x*_REG (or EP_REG) bits. In special-function mode, the value is immaterial because the on-chip peripheral or system function controls the pin. However, you must still write to P*x*_REG (or EP_REG) to initialize the pin.

   For high-impedance input or open-drain output configurations:
   In I/O mode, write to P*x*_REG (or EP_REG) to either float the pin, making it available as a high impedance input, or pull it low. Setting the corresponding P*x*_REG (or EP_REG) bit floats the pin; clearing the corresponding P*x*_REG (or EP_REG) bit pulls the pin low. In special-function mode, if the on-chip peripheral uses the pin as an input signal, you must set the corresponding P*x*_REG (or EP_REG) bit so that the pin can be driven externally. If the on-chip peripheral uses the pin as an output signal, the value of the corresponding P*x*_REG (or EP_REG) bit is immaterial because the on-chip peripheral or system function controls the pin. However, you must still write to P*x*_REG (or EP_REG) to initialize the pin.

Table 7-4 lists the control register values for each possible configuration.

Table 7-4. Control Register Values for Each Configuration

Desired Pin Configuration	Configuration Register Settings		
General-purpose I/O Signal	**P*x*_DIR**	**P*x*_MODE**	**P*x*_REG**
Complementary, driving 0	0	0	0
Complementary, driving 1	0	0	1
Open drain, strongly driving 0	1	0	0
Input (high impedance)	1	0	1
Special-function Signal	**P*x*_DIR**	**P*x*_MODE**	**P*x*_REG**
Complementary, output value controlled by peripheral	0	1	X
Open drain, output value controlled by peripheral	1	1	X
Input (high impedance)	1	1	1

7.2.2 Port Configuration Example

Assume that you wish to configure the pins of a port as shown in Table 7-5.

Table 7-5. Port Configuration Example

Port Pin(s)	Configuration	Data
P*x*.0, P*x*.1	high-impedance input	high impedance
P*x*.2, P*x*.3	open-drain, driving 0	0
P*x*.4	open-drain, output with external pull-up	1 (because of external pull-up)
P*x*.5, P*x*.6	complementary, driving 0	0
P*x*.7	complementary, driving 1	1

To do so, you could use the following example code segment. Table 7-6 shows the state of each pin after reset and after execution of each line of the example code.

```
LDB  Px_DIR,#00011111B
LDB  Px_MODE,#00000000B
LDB  Px_REG,#10010011B
```

Table 7-6. Port Pin States After Reset and After Example Code Execution

Action or Code	Resulting Pin States†							
	P*x*.7	P*x*.6	P*x*.5	P*x*.4	P*x*.3	P*x*.2	P*x*.1	P*x*.0
Reset	WK	WK	WK	WK	WK	WK	WK	WK
LDB P*x*_DIR, #00011111B	1	1	1	WK	WK	WK	WK	WK
LDB P*x*_MODE, #00000000B	1	1	1	HZ	HZ	HZ	HZ	HZ
LDB P*x*_REG, #10010011B	1	0	0	1††	0	0	HZ	HZ

† WK = weakly pulled high, HZ = high impedance.

†† Pulled high by external pull-up.

7.3 USING THE SPECIAL-FUNCTION SIGNALS

Most port pins can function as either general-purpose I/O signals or as special-function signals. The following sections describe the special-function signals and outline special considerations for using these signals.

7.3.1 Address Signals (EPORT)

The extended port pins can function as address signals or general-purpose I/O signals (Table 7-7). To use an extended port pin as an address signal, set the corresponding EP_MODE bit, selecting special-functon mode. When an extended port pin is configured as an address signal, the microcontroller automatically configures the pin as a complementary output.

Table 7-7. Address Signals

Address Signal	I/O Signal	Address Signal Description
A19:16	EPORT.3:0	**Description**: Address Lines 16–19. These address lines provide address bits 16–19 during the entire external memory cycle, supporting extended addressing of the 1-Mbyte address space. **Considerations**: During the CCB fetch, all EPORT pins are strongly driven high. Designers should ensure that this does not conflict with external systems that are outputting signals to the EPORT. When EPORT pins are floated during idle, powerdown, or hold, the external system must provide circuitry to prevent CMOS inputs on external devices from floating. During powerdown, the EPORT input buffers on pins configured for their extended-address function are disconnected from the pins, so a floating pin will not cause increased power consumption. Open-drain outputs require an external pull-up resistor. Inputs must be driven or pulled high or low; they must not be allowed to float.

During reset, the EPORT pins are forced to their extended-address functions and are weakly pulled high. During the CCB fetch, FFH is strongly driven onto the pins. This value remains strongly driven until either the pin is configured for I/O or a different extended address is accessed. If the pins remain configured as extended-address functions, they are placed in a high-impedance state during idle, powerdown, standby, and hold. If they are configured as I/O, they retain their I/O function during those modes. See Figure 11-7 on page 11-8 and Table B-5 on page B-11 for additional information.

7.3.2 Bus-control Signals (Port 2)

Some port 2 pins function as either general-purpose I/O signals or as bus-control signals (Table 7-8). To use a port 2 pin as a bus-control signal, set the corresponding P2_MODE bit, selecting special-functon mode. To configure a port 2 pin as a complementary output signal, clear the corresponding P2_DIR bit. To configure a port 2 pin as an input signal, set the corresponding P2_DIR and P2_REG bits. To configure a port 2 pin as an open-drain output, set the corresponding P2_DIR bit.

Table 7-8. Bus-control Signals

Bus-control Signal	I/O Signal	Bus-control Signal Description and Considerations
BREQ#	P2.3	**Description**: Bus Request. This active-low output signal is asserted during a hold cycle when the bus controller has a pending external memory cycle. **Considerations**: When the bus-hold protocol is enabled (WSR.7 is set), the P2.3/BREQ# pin can function only as BREQ#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared).
CLKOUT	P2.7	**Description**: Clock Output. Output of the internal clock generator. The CLKOUT frequency is ½ the internal operating frequency (f). **Considerations**: Following reset, the microcontroller automatically configures P2.7 as CLKOUT. It is **not** held high. When P2.7 is configured as CLKOUT (P2_MODE.7 = 1), it is always a complementary output.

Table 7-8. Bus-control Signals (Continued)

Bus-control Signal	I/O Signal	Bus-control Signal Description and Considerations
HLDA#	P2.6	**Description**: Bus Hold Acknowledge. The HLDA# pin is used in systems with more than one processor using the system bus. The microcontroller asserts HLDA# to indicate that it has freed the bus in response to HOLD# and another processor can take control. (This signal is active low to avoid misinterpretation by external hardware immediately after reset.) **Considerations**: When the bus-hold protocol is enabled (WSR.7 is set), the P2.6/HLDA# pin can function only as HLDA#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared).
HOLD#	P2.5	**Description**: Bus Hold Request. An external device uses this active-low input signal to request control of the bus. **Considerations**: When the bus-hold protocol is enabled (WSR.7 is set), the P2.5/HOLD# pin can function only as HOLD#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared).

7.3.3 Chip-select Signals (Port 3)

Some port 3 pins function as chip-select signals or general-purpose I/O (Table 7-9). To use a port 3 pin as a chip-select signal, set the corresponding P3_MODE bit, selecting special-function mode, and clear the corresponding P3_DIR bit, selecting a complementary output configuration.

Table 7-9. Chip-select Signals

Chip-select Signal	I/O Signal	Chip-select Signal Descriptions and Considerations
CS5:0#	P3.5:0	**Description**: Chip-select Lines 0–5. The active-low output CS*x*# is asserted during an external memory cycle when the address to be accessed is in the range programmed for chip select *x*. **Considerations**: Pins P3.5:0 are weakly pulled high during reset. After reset, P3.0 defaults to the CS0# function. This chip-select signal detects address ranges that contain the CCBs and FF2080H (program start-up address).

7.3.4 EPA and Timer Signals (Port 1)

The port 1 pins can function as EPA and timer signals or general-purpose I/O signals (Table 7-10). To use the port 1 pins as EPA and timer signals, set the corresponding P1_MODE bits, selecting special-function mode. To configure an EPA or timer signal as a complementary output, clear the corresponding P1_DIR bit. To configure an EPA or timer signal as an input, set the corresponding P1_DIR and P1_REG bits. To configure an EPA or timer signal as an open-drain output, set the corresponding P1_DIR bit.

Table 7-10. EPA and Timer Signals

EPA or Timer Signal	I/O Signal	EPA or Timer Signal Descriptions and Considerations
EPA3:0	P1.3:0	**Description**: Event Processor Array (EPA) Capture/Compare Channels. High-speed input/output signals for the EPA capture/compare channels. **Considerations**: Following reset, these pins are weakly pulled high until your software writes configuration data into P*x*_MODE.
T1CLK T2CLK	P1.4 P1.6	**Description**: Timer *x* External Clock. External clock for timer *x*. Timer *x* increments (or decrements) on both rising and falling edges of T*x*CLK. **Considerations**: Following reset, pins P1.4 and P1.6 are weakly pulled high until your software writes configuration data into P1_MODE.
T1DIR T2DIR	P1.5 P1.7	**Description**: Timer *x* External Direction. External direction (up/down) for timer *x*. Timer *x* increments when T*x*DIR is high and decrements when it is low. **Considerations**: Following reset, pins P1.5 and P1.7 are weakly pulled high until your software writes configuration data into P1_MODE.

7.3.5 External Interrupt Signals (Ports 2 and 3)

Some port 2 and 3 pins can function as external interrupt signals or as general-purpose I/O signals (Table 7-11). To configure a port 2 or 3 pin as an external interrupt, set the corresponding P*x*_DIR, P*x*_MODE, and P*x*_REG bits. Setting the P*x*_MODE bit could cause the device to set the corresponding interrupt pending bit, indicating an interrupt request; therefore, we recommend the following sequence to prevent a false interrupt request:

1. Disable interrupts by executing the DI instruction.
2. Set the P*x*_DIR.*y*.
3. Set the P*x*_MODE.*y*.
4. Set the P*x*_REG.*y*.

5. Clear the external interrupt pending bit.
6. Enable interrupts (optional) by executing the EI instruction.

Table 7-11. External Interrupt Signals

External Interrupt Signal	I/O Signal	External Interrupt Signal Description and Considerations
EXTINT0 EXTINT1 EXTINT2 EXTINT3	P2.2 P2.4 P3.6 P3.7	**Description**: External Interrupts. In normal operating mode, a rising edge on EXTINT*x* sets the EXTINT*x* interrupt pending bit. EXTINT*x* is sampled during phase 2 (CLKOUT high). The minimum high time is one state time. In standby and powerdown modes, asserting the EXTINT*x* signal for at least 50 ns causes the device to resume normal operation. The interrupt need not be enabled, but the pin must be configured as a special-function input. If the EXTINT*x* interrupt is enabled, the CPU executes the interrupt service routine. Otherwise, the CPU executes the instruction that immediately follows the command that invoked the power-saving mode. In idle mode, asserting any enabled interrupt causes the device to resume normal operation. **Considerations**: Setting the P*x*_MODE bit for P2.2, P2.4, P3.6, or P3.7 could cause the microcontroller to set the corresponding external interrupt pending bit; therefore, to prevent a false interrupt request, clear the interrupt pending bits before globally enabling interrupts.

7.3.6 PWM Signals (Port 4)

The port 4 pins can function as PWM signals or general-purpose I/O signals (Table 7-12). To use a port 4 pin as a PWM signal, set the corresponding P4_MODE bit, selecting special-function mode, and clear the corresponding P4_DIR bit, configuring the pin as a complementary output.

Table 7-12. PWM Signals

PWM Signal	I/O Signal	PWM Signal Description and Considerations
PWM2:0	P4.2:0	**Description**: Pulse Width Modulator Outputs. These are PWM output pins with high-current drive capability. **Considerations**: Following reset, pins P4.2:0 are weakly pulled high until your software writes configuration data into P4_MODE.

7.3.7 Serial I/O Port Signals (Ports 1 and 2)

Some port 1 and 2 pins can function as SIO signals or general-purpose I/O signals (Table 7-13). To use a port 1 or 2 pin as an SIO signal, set the corresponding P*x*_MODE bit, selecting special-function mode. To configure an SIO signal as a complementary output, clear the corresponding P*x*_DIR bit. To configure an SIO signal as an input, set the corresponding P*x*_DIR and P*x*_REG bits. To configure an SIO signal as an open-drain output, set the corresponding P*x*_DIR bit.

Table 7-13. SIO Signals

SIO Signal	I/O Signal	SIO Signal Description and Considerations
RXD	P2.1	**Description**: Receive Serial Data. In modes 1, 2, and 3, RXD receives serial port input data. In mode 0, it functions as either an input or an open-drain output for data. **Considerations**: Following reset, pin P2.1 is weakly pulled high until your software writes configuration data into P2_MODE.
T1CLK	P1.4	**Description**: Timer 1 External Clock. External clock for the serial I/O baud-rate generator input (program selectable). **Considerations**: Following reset, pin P1.4 is weakly pulled high until your software writes configuration data into P1_MODE.
TXD	P2.0	**Description**: Transmit Serial Data. In serial I/O modes 1, 2, and 3, TXD transmits serial port output data. In mode 0, it is the serial clock output. **Considerations**: Following reset, pin P2.0 is weakly pulled high until your software writes configuration data into P2_MODE.

7.4 I/O PORT INTERNAL STRUCTURES

The following sections describe the internal structure of the ports.

7.4.1 Internal Structure for the Extended I/O Port (EPORT)

Figure 7-1 shows the internal structure for the EPORT. Consult the datasheet for specifications on the amount of current that the EPORT pins 0–4 can source and sink.

During reset, the falling edge of RESET# generates a short pulse that turns on the medium pull-up transistor Q3, which remains on for about 300 ns, causing the pin to change rapidly to its reset state. The active-low level of RESET# turns on transistor Q4, which weakly holds the pin high. When RESET# is inactive, both Q3 and Q4 are off; Q1 and Q2 determine output drive.

If RESET#, HOLD#, idle, or powerdown is asserted, the gates that control Q1 and Q2 are disabled and Q1 and Q2 remain off. Otherwise, the gates are enabled and complementary or open-drain operation is possible.

For complementary output mode, the gates that control Q1 and Q2 must be enabled. The Q2 gate is always enabled (except when RESET#, HOLD#, idle, or powerdown is asserted). Either clearing EP_DIR (selecting complementary mode) **or** setting EP_MODE (selecting address mode) enables the logic gate preceding Q1. The value of DATA determines which transistor is turned on. If DATA is equal to one, Q1 is turned on and the pin is pulled high. If DATA is equal to zero, Q2 is turned on and the pin is pulled low.

For open-drain output mode, the gate that controls Q1 must be disabled. Setting EP_DIR (selecting open-drain mode) **and** clearing EP_MODE (selecting I/O mode) disables the logic gate preceding Q1. The value of DATA determines whether Q2 is turned on. If DATA is equal to one, both Q1 and Q2 remain off and the pin is left in high-impedance state (floating). If DATA is equal to zero, Q2 is turned on and the pin is pulled low.

Input mode is obtained by configuring the pin as an open-drain output (EP_DIR set and EP_MODE clear) and writing a one to EP_REG.*x*. In this configuration, Q1 and Q2 are both off, allowing an external device to drive the pin. To determine the value of the I/O pin, read EP_PIN.*x*.

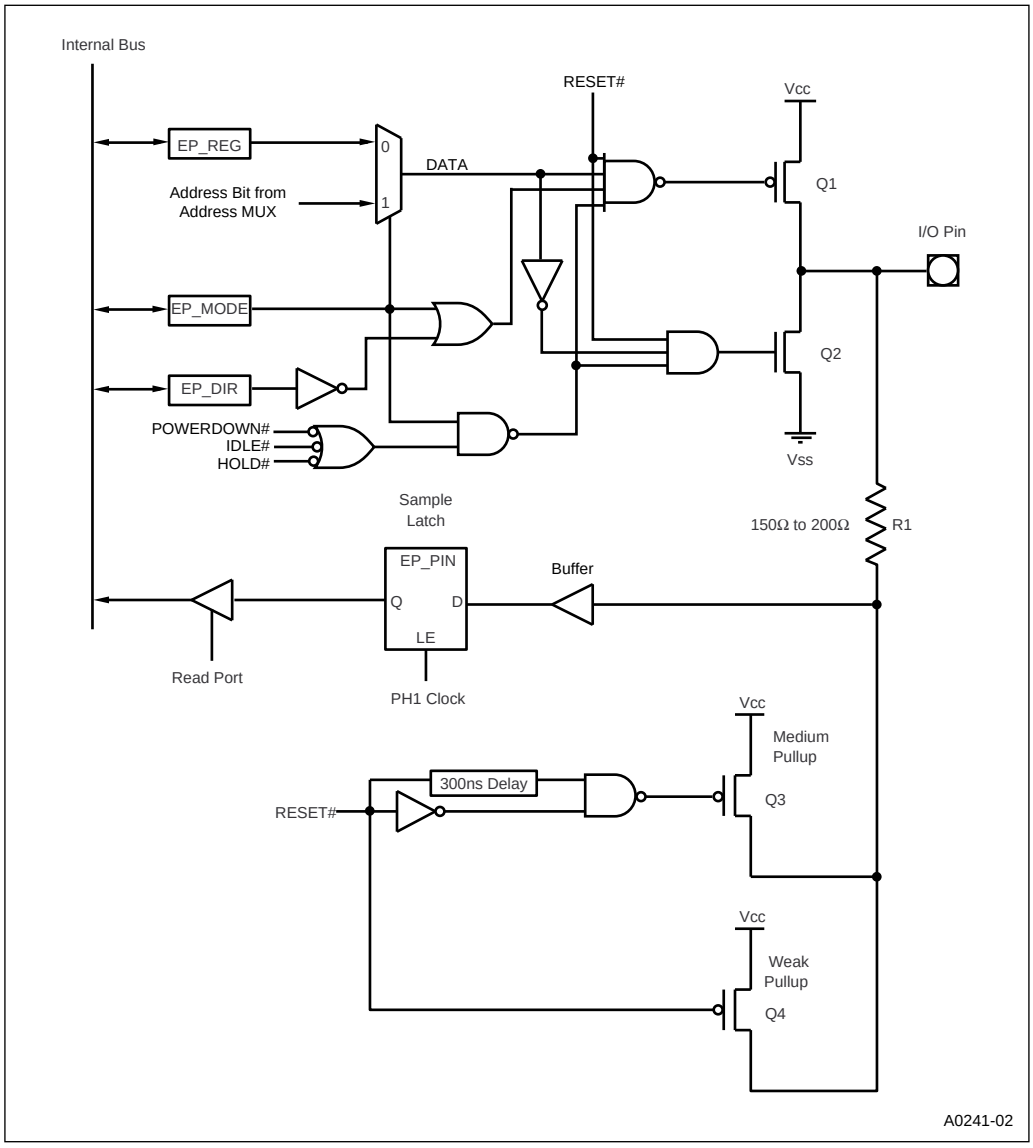


Figure 7-1. EPORT Internal Structure

7.4.2 Internal Structure for Ports 1–4

Figure 7-2 shows the logic for driving the output transistors, Q1 and Q2. Consult the datasheet for specifications on the amount of current that each port can source or sink.

In I/O mode (selected by clearing a port mode register bit), the port data output and the port direction registers are input to the multiplexers. These signals combine to drive the gates of Q1 and Q2 so that the output is high, low, or high impedance.

In special-function mode (selected by setting a port mode register bit), SFDIR and SFDATA are input to the multiplexers. These signals combine to drive the gates of Q1 and Q2 so that the output is high, low, or high impedance. Special-function output signals clear SFDIR; special-function input signals set SFDIR. Even if a pin is to be used in special-function mode, you must still initialize the pin as an input or output by writing to the port direction register.

Resistor R1 provides ESD protection for the pin. Input signals are buffered. The ports use Schmitt-triggered buffers for improved noise immunity. The signals are latched into the port pin register sample latch and output onto the internal bus when the port pin register is read.

The falling edge of RESET# turns on transistor Q3, which remains on for about 300 ns, causing the pin to change rapidly to its reset state. The active-low level of RESET# turns on transistor Q4, which weakly holds the pin high. Q4 remains on, weakly holding the pin high, until your software writes to the port mode register.

NOTE

P2.7 is an exception. After reset, P2.7 carries the CLKOUT signal rather than being held high. When CLKOUT is selected, it is always a complementary output.

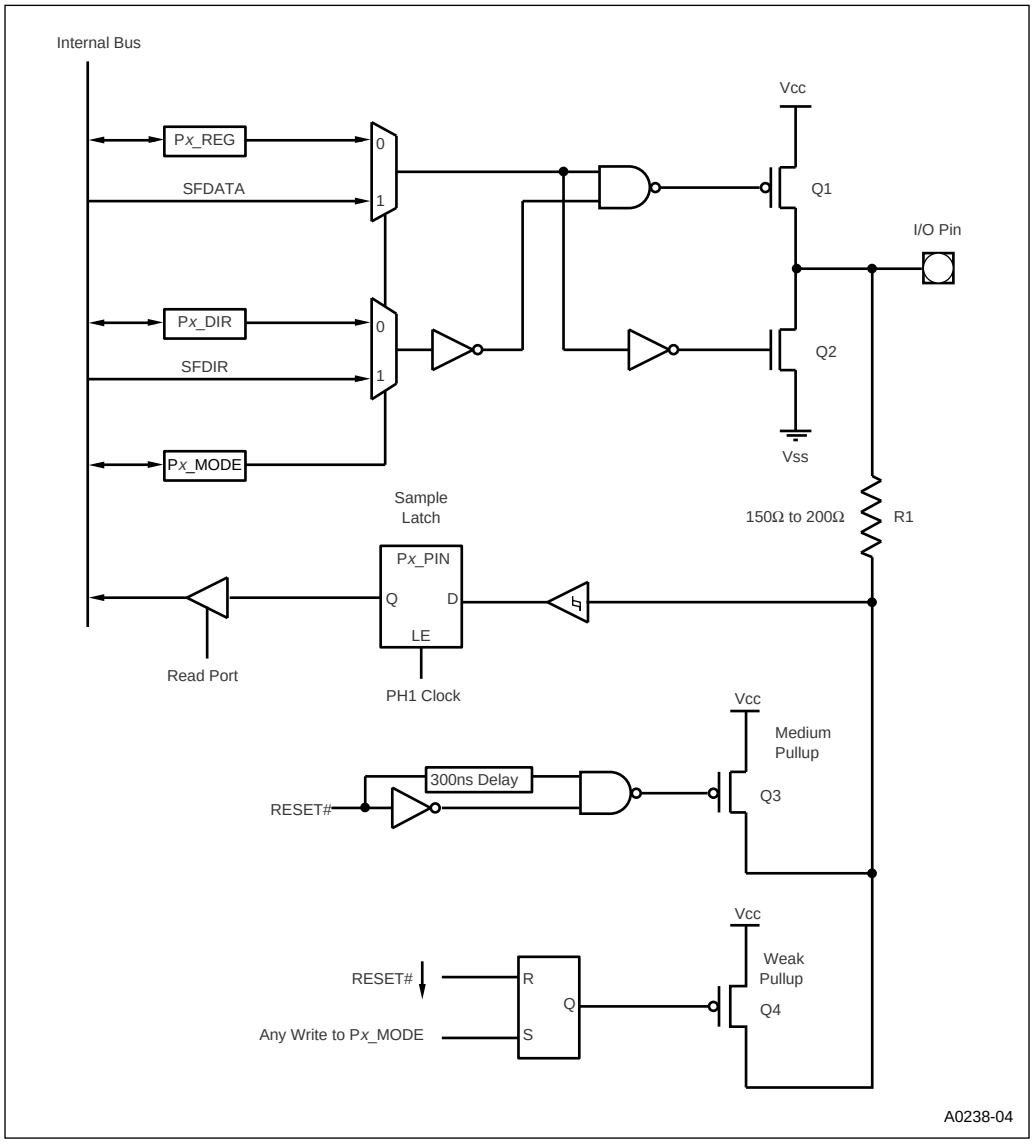


Figure 7-2. Ports 1–4 Internal Structure

8

Serial I/O (SIO) Port

CHAPTER 8
SERIAL I/O (SIO) PORT

A serial input/output (SIO) port provides a means for the system to communicate with external devices. This microcontroller has a serial I/O (SIO) port that shares pins with port 2. This chapter describes the SIO port and explains how to configure it.

8.1 SERIAL I/O (SIO) PORT FUNCTIONAL OVERVIEW

The serial I/O port is an asynchronous/synchronous port that has a universal asynchronous receiver and transmitter (UART) and four modes of operation; one synchronous mode (mode 0) and three asynchronous modes (modes 1, 2, and 3). It consists of a dedicated receiver, transmitter, control logic, two interrupt signals, and a baud-rate generator.

The transmitter and receiver contain buffers and shift registers. The buffers are accessible as special-function registers (SFRs). Write transmit data to the transmit buffer (SBUF_TX) and read received data from the receive buffer (SBUF_RX). Unlike the buffers, the shift registers are internal registers and are not accessible as SFRs. For receptions, data is shifted into the receive shift register, least-significant bit first, via the receive data pin (RXD). After the last bit (eighth bit for mode 0 or stop bit for modes 1, 2, and 3) is shifted in, the receiver transfers the data from the receive shift register to SBUF_RX where it can be accessed. For transmissions, data in SBUF_TX is transferred to the transmit shift register then shifted out through the serial transmit pin (RXD for mode 0 or TXD for modes 1, 2, and 3).

The serial I/O port contains a serial port control (SP_CON) register and a serial port status (SP_STATUS) register. SP_CON configures the SIO channel for one of the operating modes and for receptions or transmissions. SP_STATUS contains status and error flags. These registers are discussed in detail in “Programming the Control Register” on page 8-10 and “Determining Serial Port Status” on page 8-16.

The serial I/O port has two interrupt signals, allowing for interrupt-driven transmit and receive service routines. The receive interrupt (RI) indicates that the receive buffer (SBUF_RX) contains received data, available for reading. The transmit interrupt (TI) indicates that the transmit buffer (SBUF_TX) is empty, available for writing.

The serial I/O port contains a 15-bit baud-rate generator. Either the internal peripheral clock or a signal input on the T1CLK pin can provide the clock signal. The baud-rate register (SP_BAUD) selects the clock source and the baud rate. For synchronous mode 0, the baud-rate generator controls the baud rate output on the serial clock pin (TXD). For asynchronous modes 1, 2, and 3, the baud-rate generator controls the transmit and receive shift clocks.

The SIO channel signals, registers, and interrupts are shown in Figures 8-1 and 8-2. The signals and registers are described in the following section.

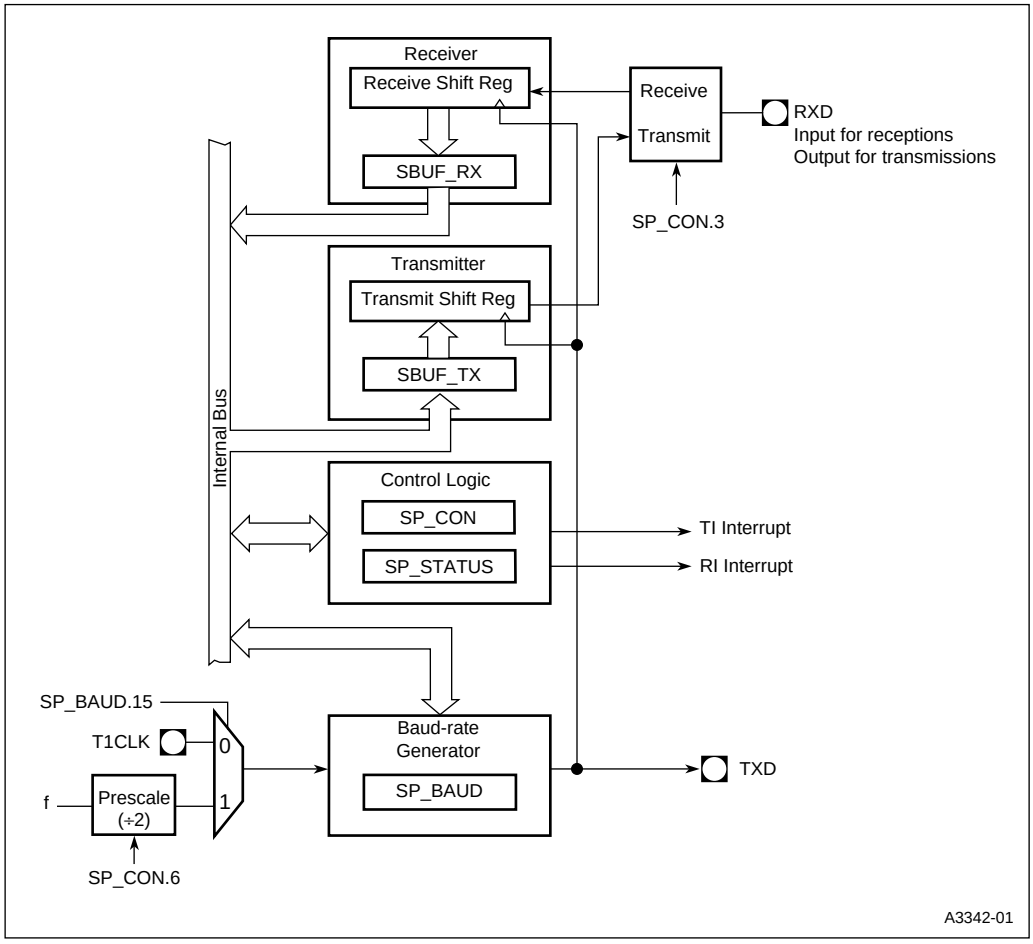


Figure 8-1. SIO Block Diagram (Mode 0)

As shown in Figure 8-1, the RXD pin is the data pin and the TXD pin is the clock pin for synchronous mode 0 operation. In this mode, the baud-rate generator drives eight pulses out the TXD pin and the UART shifts data, least-significant bit first, into or out of the microcontroller via the RXD pin. The UART samples data when the TXD pulse is low. "Synchronous Mode (Mode 0)" on page 8-6 describes mode 0 in detail.

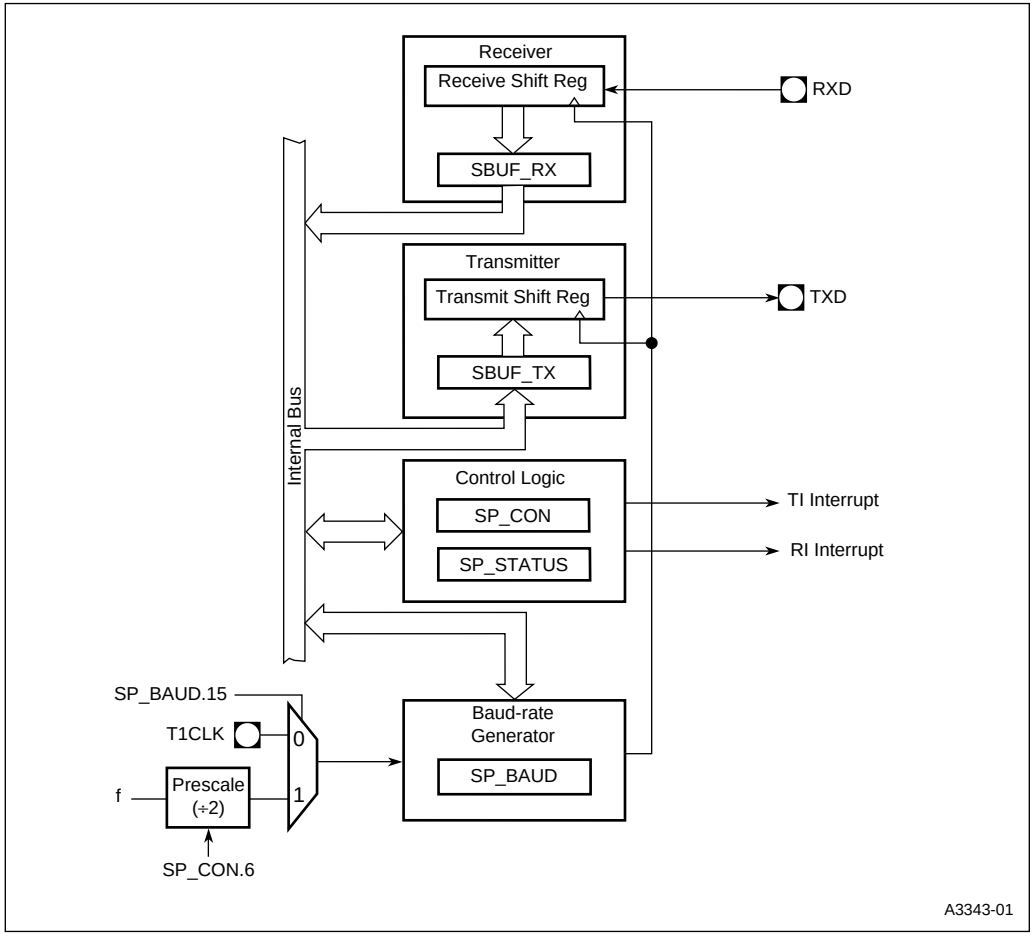


Figure 8-2. SIO Block Diagram (Mode 1, 2, and 3)

As shown in Figure 8-2, the RXD pin is the receive data pin and the TXD pin is the transmit data pin for asynchronous modes 1, 2, and 3. Either the internal operating frequency (f), which can be divided by two, or an input signal on the T1CLK pin provides the clock input to the baud-rate generator. “Asynchronous Modes (Modes 1, 2, and 3)” on page 8-7 describes modes 1, 2, and 3 in detail.

8.2 SERIAL I/O PORT SIGNALS AND REGISTERS

Table 8-1 describes the SIO signals and Table 8-2 describes the control and status registers.

Table 8-1. Serial Port Signals

Serial Port Signal	Serial Port Signal Type	Description
RXD	I/O	Receive Serial Data In modes 1, 2, and 3, RXD receives serial port input data. In mode 0, it functions as either an input or an open-drain output for data. RXD shares a package pin with P2.1.
T1CLK	I	Timer 1 Clock The internal operating freqency (f) or an input signal on T1CLK provides the clock source for the baud-rate generator. Clearing SP_BAUD.15 selects T1CLK as the clock source. T1CLK shares a package pin with P1.4.
TXD	O	Transmit Serial Data In serial I/O modes 1, 2, and 3, TXD transmits serial port output data. In mode 0, it is the serial clock output. TXD shares a package pin with P2.0.

Table 8-2. Serial Port Control and Status Registers

Mnemonic	Address	Description
INT_MASK	0008H	Interrupt Mask Setting the TI bit enables the transmit interrupt; clearing the bit disables (masks) the interrupt. Setting the RI bit enables the receive interrupt; clearing the bit disables (masks) the interrupt.
INT_PEND	0009H	Interrupt Pending When set, the TI bit indicates a pending transmit interrupt. When set, the RI bit indicates a pending receive interrupt.
P1_DIR P2_DIR	1FD2H 1FCBH	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures the corresponding pin as a complementary output; setting a bit configures the corresponding pin as an open-drain output or a high-impedance input. Write to P2_DIR.1, P1_DIR.4, and P2_DIR.0 to configure RXD, T1CLK, and TXD. (See "Configuring the Serial Port Pins" on page 8-10.)
P1_MODE P2_MODE	1FD0H 1FC9H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal. Set P2_DIR.1, P1_DIR.4, and P2_DIR.0 to configure pins P2.1, P1.4, and P2.0 as RXD, T1CLK, and TXD. (See "Configuring the Serial Port Pins" on page 8-10.)

Table 8-2. Serial Port Control and Status Registers (Continued)

Mnemonic	Address	Description
P1_PIN P2_PIN	1FD6H 1FCFH	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.
P1_REG P2_REG	1FD4H 1FDCH	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits. Write to P2_REG.1, P1_REG.4, and P2_REG.0 to configure RXD, T1CLK, and TXD. (See "Configuring the Serial Port Pins" on page
SBUF_RX	1FB8H	Serial Port Receive Buffer This register contains data received from the RXD pin.
SBUF_TX	1FBAH	Serial Port Transmit Buffer This register contains data that is ready for transmission. In modes 1, 2, and 3, writing to SBUF_TX starts a transmission. In mode 0, writing to SBUF_TX starts a transmission only if the receiver is disabled (SP_CON.3 = 0).
SP_BAUD	1FBCH, 1FBDH	Serial Port Baud Rate This register selects the serial port baud rate and clock source. The most-significant bit selects the clock source. The lower 15 bits represent the baud value, an unsigned integer that determines the baud rate.
SP_CON	1FBBH	Serial Port Control This register selects the serial mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables parity. For mode 2, and for mode 3 with parity disabled, it contains the ninth bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down-counter.

Table 8-2. Serial Port Control and Status Registers (Continued)

Mnemonic	Address	Description
SP_STATUS	1FB9H	Serial Port Status This register contains the serial port status bits. It has status bits for receive overrun error (OE), transmit buffer empty (TXE), framing error (FE), transmit interrupt (TI), receive interrupt (RI), and received parity error (RPE) or received bit 8 (RB8). Reading SP_STATUS clears all bits except TXE; writing a byte to SBUF_TX clears the TXE bit.

8.3 SERIAL PORT MODES

This section describes the serial port operating modes. Mode 0 is a synchronous mode. Mode 1 is an eight-bit asynchronous mode with optional parity. Modes 2 and 3 are nine-bit asynchronous modes. Like mode 1, mode 3 has optional parity. For mode 2, the SIO flags receptions (by setting the RI status bit and RI pending bit) only when the ninth data bit received is a one. This is useful for multiprocessor communication, which is described in detail in "Multiprocessor Communications" on page 8-9.

8.3.1 Synchronous Mode (Mode 0)

In mode 0, the TXD pin outputs a set of eight clock pulses, while the RXD pin either transmits or receives data. Data is transferred eight bits at a time, with the least-significant bit first. Figure 8-3 shows a diagram of the relative timing of these signals.

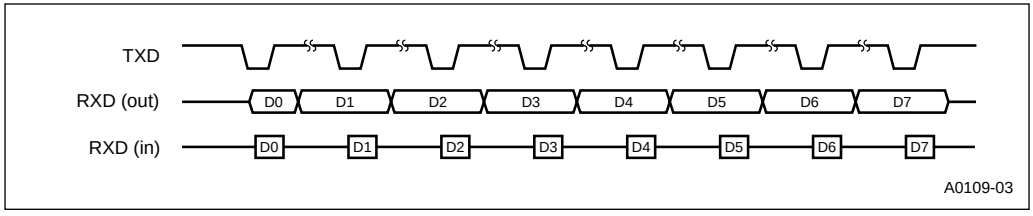


Figure 8-3. Mode 0 Timing

When using the internal clock source (f), the TXD clock signal remains low for 4t with the prescaler disabled (SP_CON.6 = 0) or 8t with the prescaler enabled (SP_CON.6 = 1). When using an external clock source on the T1CLK signal, the TXD clock signal remains low for 4t (the T1CLK signal bypasses the prescaler, as shown in Figure 8-1 on page 8-2).

The serial I/O port has a receive interrupt (RI) and a transmit interrupt (TI) that indicate when the receive buffer is full or the transmit buffer is empty. Additionally, the serial port status (SP_STATUS) register contains RI and TI flags. During a reception, the SIO sets the RI flag in SP_STATUS after it samples the eighth data bit. The RI pending bit in the interrupt pending register is set immediately before the RI flag is set. During a transmission, the SIO sets the TI flag immediately after it transmits the eighth data bit. The TI pending bit in the interrupt pending register is set when the TI flag in SP_STATUS is set.

In mode 0, the receiver must be enabled for receptions and disabled for transmissions. (The SP_CON register contains a bit that enables or disables the receiver. See “Programming the Control Register” on page 8-10.) When the receiver is enabled, clearing the receive interrupt (RI) flag in SP_STATUS starts a reception. When the receiver is disabled, writing to SBUF_TX starts a transmission.

Disabling the receiver stops a reception in progress and inhibits further receptions. When the receiver is enabled, clearing the RI flag in SP_STATUS starts a reception; therefore, to avoid a corrupted reception, disable the receiver before clearing the RI flag. This can be handled in an interrupt environment by using software flags or in straight-line code by polling the interrupt pending register to signal the completion of a reception.

8.3.2 Asynchronous Modes (Modes 1, 2, and 3)

Modes 1, 2, and 3 are full-duplex serial modes, meaning that they have dedicated receive and transmit data signals. Mode 1 is the standard eight-bit, asynchronous mode used for normal serial communications. With parity disabled, mode 1 transmits or receives eight data bits; with parity enabled, mode 1 transmits or receives seven data bits and a parity bit. Modes 2 and 3 are nine-bit asynchronous modes typically used for interprocessor communications (see “Multiprocessor Communications” on page 8-9). Like mode 1, mode 3 has optional parity. With parity disabled, mode 3 transmits or receives nine data bits; with parity enabled, mode 3 transmits or receives eight data bits and a parity bit.

When the serial port is configured for mode 1, 2, or 3, writing to SBUF_TX causes the serial port to start transmitting data. (The transmitter transfers the data to the transmit shift register and starts shifting the data out through TXD.) New data placed in SBUF_TX is transferred to the shift register only after the stop bit of the previous data has been sent. If the receiver is enabled, a falling edge on the RXD input causes the serial port to begin receiving data. Disabling the receiver stops a reception in progress and inhibits further receptions. (See “Programming the Control Register” on page 8-10.)

To minimize noise-related errors, the SIO samples the data line three times and uses majority logic to identify a valid start bit. That is, if two of the three samples are low, the bit is a valid start bit.

8.3.2.1 Mode 1

Mode 1 is the standard asynchronous communications mode with optional parity. If parity is enabled, the receiver checks for even or odd parity, and the transmitter sends data with even or odd parity. When parity is disabled, the data frame used in this mode (Figure 8-4) consists of ten bits: a start bit (0), eight data bits (LSB first), and a stop bit (1). When parity is enabled, the eighth data bit becomes the parity bit; therefore, the data frame consists of a start bit (0), seven data bits (LSB first), a parity bit, and a stop bit (1).

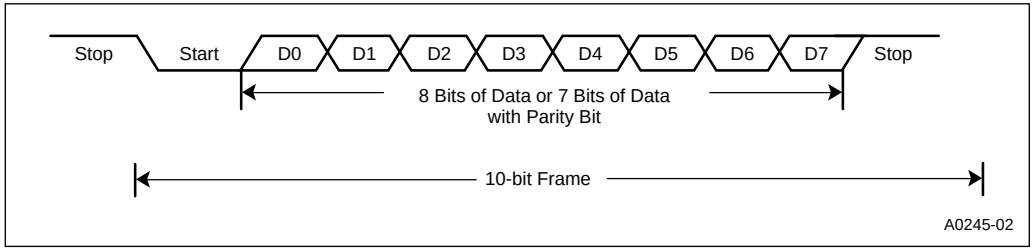


Figure 8-4. Serial Port Frames for Mode 1

The transmit and receive functions are controlled by separate shift clocks. The baud-rate generator controls both the transmit and receive shift clocks. The transmit shift clock starts when the baud-rate generator is initialized. The receive shift clock is reset when a start bit (falling edge) is received. Therefore, the transmit clock may not be synchronized with the receive clock, although both will be at the same frequency.

The SIO sets the transmit interrupt (TI) and receive interrupt (RI) flags in SP_STATUS to indicate completed operations. During a reception, the SIO sets both the RI flag and the RI interrupt pending bit just before it receives the end of the stop bit. During a transmission, the SIO sets the TI flag immediately after it starts to transmit the stop bit.

When connecting more than two microcontrollers with the serial port in half-duplex (that is, using a single data signal for both transmit and receive operations), it is important to wait for a reception to complete before starting to transmit. The receiving processor must wait for one bit time after the RI flag is set before starting to transmit. Otherwise, the transmission could corrupt the stop bit, causing a problem for other microcontrollers listening on the link.

8.3.2.2 Mode 2

Mode 2 is the asynchronous, ninth-bit recognition mode. Figure 8-5 shows the data frame used in this mode. It consists of a start bit (0), nine data bits (LSB first), and a stop bit (1). During transmissions, write data bits 0–7 to the transmit buffer (SBUF_TX) and write data bit 8 (the ninth data bit) to the transmit bit 8 (TB8) bit in the serial port control (SP_CON) register. The SIO clears the TB8 bit after every transmission, so you must set it (if desired) before each write to SBUF_TX. During receptions, the receive buffer (SBUF_RX) contains data bits 0–7, and bit 7 in the serial port status (SP_STATUS) register contains data bit 8 (the ninth data bit received).

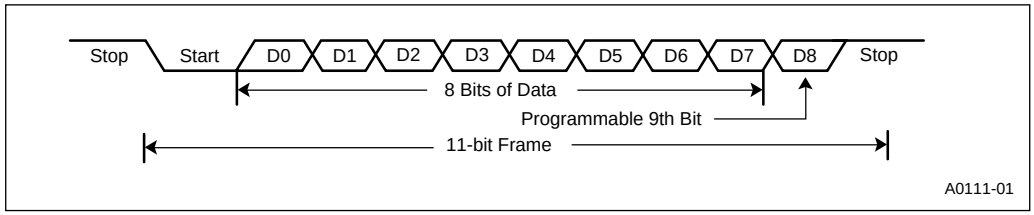


Figure 8-5. Serial Port Frames in Mode 2 and 3

As in mode 1, in mode 2, the SIO sets the transmit interrupt (TI) flag in SP_STATUS to indicate completed transmissions. During a transmission, the SIO sets the TI flag immediately after it starts to transmit the stop bit. Unlike mode 1, in mode 2, the SIO sets the receive interrupt (RI) flag in SP_STATUS only when the ninth data bit received is set. During a reception, when the ninth data bit is set, both the RI flag and the RI interrupt pending bit are set just before the end of the stop bit. This feature provides an easy way to have selective reception on a data link. (See “Multiprocessor Communications” on page 8-9.) Parity is not available in mode 2.

8.3.2.3 Mode 3

Mode 3 is the asynchronous, ninth-bit mode with optional parity. The data frame for this mode is identical to that of mode 2 (Figure 8-5 on page 8-9). Mode 3 differs from mode 2 during transmissions in that parity can be enabled, in which case the ninth bit becomes the parity bit. When parity is disabled, data bits 0–7 are written to the serial port transmit buffer (SBUF_TX), and the ninth data bit is written to SP_CON.4 (TB8). In mode 3, a reception always sets the RI interrupt pending bit, regardless of the state of the ninth bit. If parity is disabled, the SP_STATUS register bit 7 (RB8) contains the ninth data bit received. If parity is enabled, then the SP_STATUS register bit 7 becomes the received parity error (RPE) flag.

8.3.2.4 Multiprocessor Communications

Modes 2 and 3 are provided for multiprocessor communications. In mode 2, during receptions, the serial port sets the RI flag in SP_STATUS and the RI interrupt pending bit only when the ninth data bit received (SP_STATUS.7, the RB8 bit) is a one. In mode 3, the serial port sets the RI flag and the RI interrupt pending bit regardless of the value of the ninth data bit received.

One way to use these modes for multiprocessor communication is to set the master processor to mode 3 and the slave processors to mode 2. When the master processor wants to transmit a block of data to one of several slaves, it sends out an address frame that identifies the target slave. The ninth bit is always set in the address frame, so an address frame interrupts all slaves. Each slave examines the address byte to check whether it is being addressed. The addressed slave switches to mode 3 to receive the data frames, which are sent with the ninth bit cleared. The slaves that are not addressed continue to operate in mode 2, and therefore are not interrupted by the data frames, which are sent with the ninth data bit cleared.

8.4 PROGRAMMING THE SERIAL PORT

To use the SIO port, you must configure the port pins to serve as special-function signals and set up the SIO channel.

8.4.1 Configuring the Serial Port Pins

Before you can use the serial port, you must configure the associated port pins to serve as special-function signals. Table 8-1 on page 8-4 describes the pins associated with the serial port, Table 8-2 on page 8-4 describes the port configuration registers, and Table 8-3 explains how to configure the pins.

Table 8-3. Port Register Settings for the SIO Signals

Signal	Configuration	Port Register Settings
RXD (mode 0)	Input for receptions Open-drain output for transmissions	P2_DIR.1 = 1 P2_MODE.1 = 1 (external pull-up required)
RXD (modes 1, 2, and 3)	Input	P2_DIR.1 = 1 P2_MODE.1 = 1 P2_REG.1 = 1
T1CLK	Input	P1_DIR.4 = 1 P1_MODE.4 = 1 P1_REG.4 = 1
TXD	Complementary output	P2_DIR.0 = 0 P2_MODE.0 = 1

8.4.2 Programming the Control Register

The SP_CON register (Figure 8-6) selects the communication mode and enables or disables the receiver for all modes. For modes 1 and 3, SP_CON enables or disables even or odd parity. For modes 2 and 3, SP_CON contains the ninth data bit to be transmitted. Selecting a new mode stops any transmission or reception in progress on the channel.

SP_CON

Address: 1FBBH
Reset State: 80H

The serial port control (SP_CON) register selects the communications mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables or disables even or odd parity. For modes 2 and 3, it contains the ninth data bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down counter.

7							0
BGD	PRS	PAR	TB8	REN	PEN	M1	M0

Bit Number	Bit Mnemonic	Function
7	BGD	Baud-rate Generator Disable This bit allows power conservation when the SIO is not being used. The default disables the baud-rate counter at power-up or reset. You must clear this bit to enable the counter. 0 = enable the baud-rate counter 1 = disable the baud-rate counter (default at power-up or reset)
6	PRS	Prescale The internal operating frequency (f), which can be divided by two, or an input signal on the T1CLK pin provides the baud-rate generator clock source (SP_BAUD.15 determines the clock source). The PRS bit enables the divide-by-two prescaler for the internal operating frequency: 0 = disables the prescaler (baud-rate generator clock source equals f) 1 = enables the prescaler (baud-rate generator clock source equals f/2) When T1CLK is selected as the baud-rate generator clock source (SP_BAUD.15 = 0), this bit is ignored.
5	PAR	Parity Selection Bit In modes 1 and 3, this bit selects even or odd parity. 0 = even parity 1 = odd parity For modes 0 and 2, this bit is ignored.
4	TB8	Transmit Ninth Data Bit This is the ninth data bit that will be transmitted in mode 2 or 3. This bit is cleared after each transmission, so you must write to this bit before writing to SBUF_TX. For mode 3, when parity is enabled (SP_CON.2 = 1), the transmitter sets or clears this bit so that the byte being transmitted contains the correct parity.

Figure 8-6. Serial Port Control (SP_CON) Register

SP_CON (Continued)

Address: 1FBBH
Reset State: 80H

The serial port control (SP_CON) register selects the communications mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables or disables even or odd parity. For modes 2 and 3, it contains the ninth data bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down counter.

7							0
BGD	PRS	PAR	TB8	REN	PEN	M1	M0

Bit Number	Bit Mnemonic	Function
3	REN	Receive Enable In mode 1, 2, or 3, setting this bit enables receptions. When this bit is set, a falling edge on the RXD pin starts a reception. In these modes, this bit has no effect on transmissions. In mode 0, clearing this bit enables transmissions and setting it enables receptions. Clearing this bit stops a reception in progress and inhibits further receptions. In mode 0, clearing the RI flag in the SP_STATUS register starts a reception; therefore, to avoid corrupting your reception, clear this bit before clearing the RI bit.
2	PEN	Parity Enable In modes 1 and 3, setting this bit enables parity. For mode 1, when this bit is set, the seventh data bit takes the parity value on transmissions and SP_STATUS.7 becomes the receiver parity error bit. For mode 3, when this bit is set, SP_CON.4 (TB8) takes the parity value on transmissions and SP_STATUS.7 becomes the receive parity error bit. Clear this bit for mode 2. For mode 0, this bit is ignored.
1:0	M1:0	Mode Selection These bits select the communications mode. **M1 M0** 0 0 mode 0, synchronous 0 1 mode 1, 8-bit asynchronous with optional parity 1 0 mode 2, 9-bit asynchronous with optional receive interrupt 1 1 mode 3, 9-bit asynchronous with optional parity

Figure 8-6. Serial Port Control (SP_CON) Register (Continued)

8.4.3 Programming the Baud Rate and Clock Source

The SP_BAUD register (Figure 8-7) selects the clock input for the baud-rate generator and defines the baud rate for all serial I/O modes. For mode 0, this register determines the baud rate output on the serial clock pin (TXD). For modes 1, 2, and 3, this register controls the transmit and receive shift clocks.

SP_BAUD

Address: 1FBCH
Reset State: 0000H

The serial port baud rate (SP_BAUD) register selects the clock source and serial port baud rate. The most-significant bit selects the clock source. The lower 15 bits represent baud value, an unsigned integer that determines the baud rate.

The maximum baud value is 32,767 (7FFFH). In asynchronous modes 1, 2, and 3, the minimum baud value is 0001H. In synchronous mode 0, the minimum baud value is 0001H for transmissions and 0002H for receptions.

WARNING: Writing to the SP_BAUD register during a reception or transmission can corrupt the received or transmitted data. Before writing to SP_BAUD, check SP_STATUS or the interrupt pending register to ensure that the reception or transmission is complete.

15							**8**
CLKSRC	BV14	BV13	BV12	BV11	BV10	BV9	BV8
7							**0**
BV7	BV6	BV5	BV4	BV3	BV2	BV1	BV0

Bit Number	Bit Mnemonic	Function
15	CLKSRC	Serial Port Clock Source This bit determines whether the baud-rate generator is clocked from an internal or an external source. 0 = signal on the T1CLK pin (external source) 1 = internal operating frequency (f or f/2) When using T1CLK as the clock source (CLKSRC = 0), the maximum input frequency on the T1CLK pin is f/4. When using the internal operating frequency (CLKSRC = 1), the prescale bit in the serial port control register (SP_CON.6) determines whether the frequency of the baud-rate generator clock source is equal to the internal operating frequency (f) or half the internal operating frequency (f/2).
14:0	BV14:0	These bits constitute the baud value. Use the following equations to determine the baud value for a given baud rate. Synchronous mode 0:† $\text{Baud Value} = \frac{f}{\text{Baud Rate} \times 2} - 1$ or $\frac{\text{T1CLK}}{\text{Baud Rate}}$ Asynchronous modes 1, 2, and 3: $\text{Baud Value} = \frac{f}{\text{Baud Rate} \times 16} - 1$ or $\frac{\text{T1CLK}}{\text{Baud Rate} \times 8}$ † For mode 0 receptions, the baud value must be 0002H or greater. For mode 0 transmissions, the baud value must be 0001H or greater.

Figure 8-7. Serial Port Baud Rate (SP_BAUD) Register

Using the internal peripheral clock at 25 MHz, the maximum baud rate for mode 0 is 4.17 Mbaud for receptions and 6.25 Mbaud for transmissions. The maximum baud rate for modes 1, 2, and 3 is 1.56 Mbaud for both receptions and transmissions. Using the internal peripheral clock at 50 MHz, the maximum baud rates are doubled: 8.33 Mbaud for mode 0 receptions, 12.5 Mbaud for mode 0 transmissions, and 3.13 Mbaud for modes 1, 2, and 3.

Table 8-4 shows the SP_BAUD values for common baud rates when using a 25 MHz internal peripheral clock. These values also apply when using a 50 MHz internal peripheral clock with the prescaler enabled (SP_CON.6 = 1). Table 8-5 shows the SP_BAUD value for 9600 baud when using a 50 MHz clock input with the prescaler disabled. Because of rounding, the baud value formula is not exact and the resulting baud rate is slightly different than desired. The tables show the percentage of error when using the sample SP_BAUD values. In most cases, a serial link will work with up to a 5.0% difference in the receiving and transmitting baud rates.

Table 8-4. SP_BAUD Values When Using the Internal Clock at 25 MHz

Baud Rate	SP_BAUD Register Value†		% Error	
	Mode 0	Mode 1, 2, 3	Mode 0	Mode 1, 2, 3
9600	8515H	80A2H	0	–0.15
4800	8A2BH	8145H	0	–0.15
2400	9457H	828AH	0	0
1200	A8B0H	8515H	0	0
300	††	9457H	††	0

† Bit 15 is always set when the internal peripheral clock is selected as the clock source for the baud-rate generator.

†† For mode 0 operation at 25 MHz, the minimum baud rate is 381.47 (baud value = 7FFFH).
For mode 0 operation at 300 baud, the maximum internal clock frequency is 19.6608 MHz (baud value = 7FFFH).

Table 8-5. SP_BAUD Values When Using the Internal Clock at 50 MHz

Baud Rate	SP_BAUD Register Value†		% Error	
	Mode 0	Mode 1, 2, 3	Mode 0	Mode 1, 2, 3
9600	8A2BH	8145H	0	–0.15

† Bit 15 is always set when the internal peripheral clock is selected as the clock source for the baud-rate generator.

8.4.4 Enabling the Serial Port Interrupts

The serial port has both a transmit interrupt (TI) and a receive interrupt (RI). These interrupts indicate completed operations. For mode 0 receptions, the SIO sets the RI interrupt pending bit after it samples the eighth data bit. For mode 1 and 3 receptions, the SIO sets the RI interrupt pending bit just before it receives the end of the stop bit. For mode 2 receptions, the SIO sets the RI interrupt pending bit just before it receives the end of the stop bit only if the ninth data bit received was set. For mode 0 transmissions, the SIO sets the TI interrupt pending bit immediately after it transmits the eighth data bit. For mode 1, 2, and 3 transmissions, the SIO sets the TI flag immediately after it starts to transmit the stop bit.

To enable an interrupt, set the corresponding mask bit in the interrupt mask register (see INT_MASK on page C-35) and execute the EI instruction to globally enable servicing of interrupts. See Chapter 6, "Interrupts," for more information about interrupts.

8.4.5 Determining Serial Port Status

The SP_STATUS register (Figure 8-8) contains several bits that reflect the status of the serial port. Reading SP_STATUS **clears all bits** except TXE. To check the status of the serial port, copy the contents of the SP_STATUS register into a shadow register and then execute bit-test instructions such as JBC and JBS on the shadow register. Otherwise, the first bit-test instruction will clear the SP_STATUS register, losing all status information. Since the shadow register is not cleared when read, this method allows you to execute more than one bit-test instruction on the serial port status information. You can also read the interrupt pending register (see INT_PEND on page C-37) to determine the status of the serial port interrupts.

SP_STATUS

Address: 1FB9H
Reset State: 0BH

The serial port status (SP_STATUS) register contains bits that indicate the status of the serial port.

7							0
RPE/RB8	RI	TI	FE	TXE	OE	—	—

Bit Number	Bit Mnemonic	Function
7	RPE/RB8	Received Parity Error/Received Bit 8 For modes 1 and 3, RPE is set if parity is enabled (SP_CON.2 = 1) and the data received does not contain the correct parity, as programmed in SP_CON. For mode 2, and for mode 3 with parity disabled, this bit is the ninth data bit received. (The serial port receive buffer contains the received data bits 0–7. The received data bit 8 is written to this bit.) Reading SP_STATUS clears this bit.
6	RI	Receive Interrupt This bit indicates whether an incoming data byte has been received. For modes 0, 1, and 3, this bit is set when the last bit (eighth bit for mode 0, or stop bit for modes 1 and 3) is sampled. For mode 2, this bit is set when the stop bit is detected only if the ninth bit received (SP_STATUS, RB8) is a one. Reading SP_STATUS clears this bit.
5	TI	Transmit Interrupt This bit indicates whether a data byte has finished transmitting. For mode 0 transmissions, the SIO sets this bit immediately after it transmits the eighth data bit. For mode 1, 2, and 3 transmissions, the SIO sets this bit immediately after it starts to transmit the stop bit. Reading SP_STATUS clears this bit.
4	FE	Framing Error For modes 1, 2, and 3, this bit is set if the receiver does not detect a valid stop bit within the appropriate period of time. Reading SP_STATUS clears this bit. For mode 0, this bit has no function.
3	TXE	SBUF_TX Empty The SIO sets this bit, along with the TI flag, if the transmit buffer and the transmit shift register are both empty. When set, this bit indicates that two bytes can be written to the transmit buffer. Writing to the transmit buffer clears this bit.
2	OE	Overrun Error The SIO sets this bit if data in the receive shift register is loaded into SBUF_RX before the previous byte in SBUF_RX is read. Reading SP_STATUS clears this bit.
1:0	—	Reserved; for compatibility with future devices, write zeros to these bits.

Figure 8-8. Serial Port Status (SP_STATUS) Register

9

Pulse-width Modulator

CHAPTER 9
PULSE-WIDTH MODULATOR

The pulse-width modulator (PWM) module has three output pins, each of which can output a PWM signal with a fixed frequency and a variable duty cycle. These outputs can be used to drive motors that require an unfiltered PWM waveform for optimal efficiency, or they can be filtered to produce a smooth analog signal.

In addition, the 80296SA allows you to disable the PWM duty-cycle generator to conserve power when the peripheral is not being used.

This chapter provides a functional overview of the pulse-width modulator module, describes how to program it, and provides sample circuitry for converting the PWM outputs to analog signals.

9.1 PWM FUNCTIONAL OVERVIEW

The PWM module has three channels, each of which consists of a control register (PWM*x*_CONTROL), a buffer, a comparator, an RS flip-flop, and an output pin. Two other components, an eight-bit counter and a clock prescaler, are shared across the PWM module's three channels, completing the circuitry (see Figure 9-1).

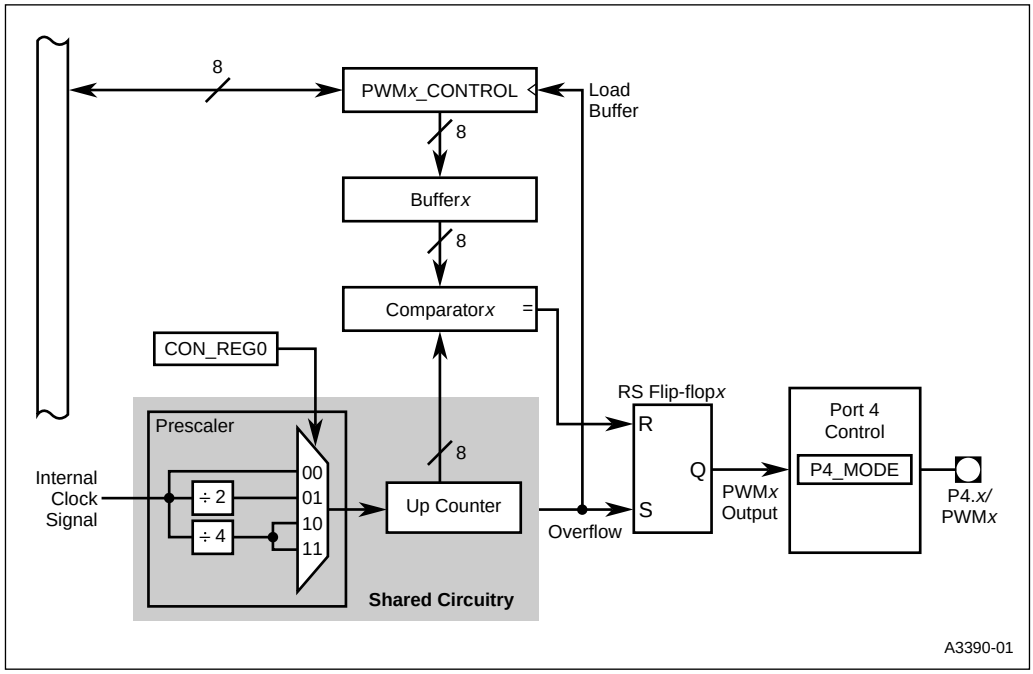


Figure 9-1. PWM Block Diagram

9.2 PWM SIGNALS AND REGISTERS

Table 9-1 describes the PWM's signals and Table 9-2 briefly describes the control and status registers.

Table 9-1. PWM Signals

Port Pin	PWM Signal	PWM Signal Type	Description
P4.0	PWM0	O	Pulse-width modulator 0 output with high-drive capability.
P4.1	PWM1	O	Pulse-width modulator 1 output with high-drive capability.
P4.2	PWM2	O	Pulse-width modulator 2 output with high-drive capability.

Table 9-2. PWM Control and Status Registers

Mnemonic	Address	Description
CON_REG0	1FB6H	PWM Control Register This register controls the clock prescaler and duty-cycle generator. Bits zero and one (CLK0, CLK1) control the output period of the PWM channels by enabling or disabling the divide-by-two or divide-by-four clock prescaler. Bit seven (DCD) controls the duty-cycle generator by enabling or disabling the PWM*x*_CON register.
PWM0_CONTROL PWM1_CONTROL PWM2_CONTROL	1FB0H 1FB2H 1FB4H	PWM Duty Cycle This register controls the PWM duty cycle. A zero loaded into this register causes the PWM to output a low continuously (0% duty cycle). An FFH in this register causes the PWM to have its maximum duty cycle (99.6% duty cycle).
P4_DIR	1FDBH	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.
P4_MODE	1FD9H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
P4_PIN	1FDFH	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.
P4_REG	1FDDH	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.

9.3 PWM OPERATION

Two bits, CON_REG0.0 (CLK0) and CON_REG0.1 (CLK1), control the PWM output frequency by enabling or disabling the divide-by-two and divide-by-four clock prescaler.

Each control register (PWM*x*_CONTROL) controls the duty cycle (the pulse width stated as a percentage of the period) of the corresponding PWM output. Each control register contains an eight-bit value that is loaded into a buffer when the eight-bit counter rolls over from FFH to 00H. The comparators compare the contents of the buffers to the counter value. Since the value written to the control register is buffered, you can write a new eight-bit value to PWM*x*_CONTROL register at any time. However, the comparators recognize the new value only after the current eight-bit count expires. The new value is used during the next PWM output period.

The counter continually increments until it rolls over to 00H, at which time the PWM output is driven high and the contents of the control registers are loaded into the buffers. The PWM output remains high until the counter value matches the value in the buffer, at which time the output is pulled low. When the counter resets again (i.e., when an overflow occurs) the output is switched high. (Loading PWM*x*_CONTROL with 00H forces the output to remain low.) Figure 9-2 shows typical PWM output waveforms.

The PWM can generate a duty cycle ranging in length from 0% to 99.6% of the pulse. To determine the desired duty cycle measurement, you must apply a multiplier (2, 4, or 8) to the PWM*x*_CONTROL value to compensate for the divided input frequency from the divide-by-two circuitry. (See Figure 2-5 on page 2-7 for additional information.)

Clearing CLK1 and CLK0 disables the prescaler, generating a pulse that is 512 state times in length. With the prescaler disabled, the correct PWM*x*_CONTROL multiplier is two.

Setting CLK0 enables the PWM's divide-by-two clock prescaler, generating a pulse that is 1,024 state times in length. With the divide-by-two clock prescaler enabled, the correct PWM*x*_CONTROL multiplier is four. For example, assume that CLK0 is set and the value you write to the PWM*x*_CON register is 19H (25 decimal). To arrive at the appropriate duty cycle, you must multiply the value stored in PWM*x*_CON by four, then divide that result by the total pulse length (1,024). This calculation results in a duty cycle value of approximately 10% (.0977).

Setting CLK1 enables the divide-by-four clock prescaler, generating a pulse that is 2,048 state times in length. With the divide-by-four prescaler enabled, the correct PWM*x*_CONTROL multiplier is eight. (When CLK1 is set, the divide-by-four clock prescaler is enabled and CLK0 is ignored.)

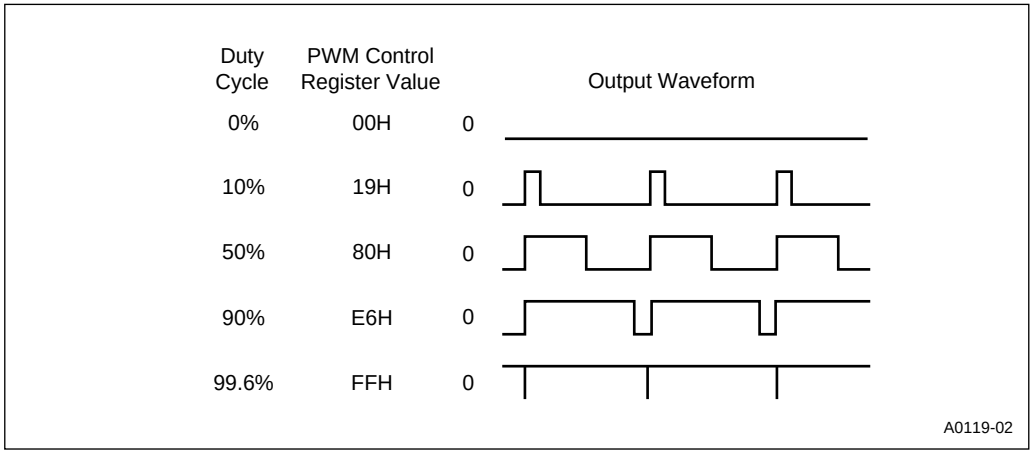


Figure 9-2. PWM Output Waveforms

9.4 PWM PERIPHERAL DISABLE CONTROL

The 80296SA implements an additional power conservation feature that is new to the MCS® 96 microcontroller family. This feature allows you to individually disable the PWM duty-cycle generator when your system is not using the PWM peripheral.

The DCD bit in the PWM clock control register (CON_REG0 on page 9-7) enables and disables the duty-cycle generator. Setting DCD enables the duty-cycle generator; clearing DCD disables it. The DCD bit is cleared at reset (duty-cycle generator enabled). If your system uses the PWM, ensure that your code leaves the DCD bit cleared. If your system is not using the PWM, you can set the DCD bit to conserve power.

Bit seven that implements this new feature (DCD in CON_REG0) is reserved in previous MCS 96 microcontrollers; it is documented as “Reserved; for compatibility with future devices, write zero to this bit.” Therefore, code written for a previous MCS 96 microcontroller system that uses this peripheral will enable the duty-cycle generator as part of the initialization.

9.5 PROGRAMMING THE FREQUENCY AND PERIOD

CLK0 and CLK1 determine the output frequency by enabling or disabling the clock prescaler. Use the following formulas to calculate the output frequency (F_{PWM}) and output period (T_{PWM}).

	Clock Prescaler Disabled	÷2 Clock Prescaler Enabled	÷4 Clock Prescaler Enabled
F_{PWM} (in MHz) =	$\frac{f}{512}$	$\frac{f}{1024}$	$\frac{f}{2048}$
T_{PWM} (in µs) =	$\frac{512}{f}$	$\frac{1024}{f}$	$\frac{2048}{f}$

The PWM module provides three selectable, fixed PWM output frequencies for a specified internal operating frequency (f). Table 9-3 shows the PWM output frequencies for common operating frequencies. The values of CLK0 and CLK1 in the CON_REG0 register determine the output frequency by enabling or disabling the divide-by-two and divide-by-four clock prescalers.

NOTE

Use the EPA module to produce variable PWM output frequencies (see "Operating in Compare Mode" on page 10-12).

Table 9-3. PWM Output Frequencies

CLK1	CLK0	f		
		12.5 MHz	25 MHz	50 MHz
0	0	24.41 kHz	48.83 kHz	97.66 kHz
0	1	12.21 kHz	24.41 kHz	48.83 kHz
1	X	6.10 kHz	12.21 kHz	24.41 kHz

CON_REG0

Address: 1FB6H
Reset State: 7CH

The control (CON_REG0) register controls the clock prescaler for the three pulse-width modulators (PWM0–PWM2) and enables or disables the duty-cycle generator.

7							0
DCD†	—	—	—	—	—	CLK1	CLK0

Bit Number	Bit Mnemonic	Function
7	DCD	Duty Cycle Disable Control This bit controls the duty-cycle generator for power conservation. Upon reset, the generator is enabled. 0 = enabled; PWM duty cycle generator is turned on 1 = disabled; PWM duty cycle generator is turned off
6:2	—	Reserved; for compatibility with future devices, write zeros to these bits.
1:0	CLK1:0	Enable PWM Clock Prescaler These bits control the PWM output period on the three pulse-width modulators (PWM2:0). **CLK1 CLK0** 0 0 disable clock prescaler 0 1 enable divide-by-two prescaler; PWM output period is 1024 state times 1 X enable divide-by-four prescaler; PWM output period is 2048 state times

† This bit was called PWM_HALT in earlier documentation for the 80296SA.

Figure 9-3. Control (CON_REG0) Register

9.6 PROGRAMMING THE DUTY CYCLE

The value written to the PWM*x*_CONTROL register controls the width of the high pulse, effectively controlling the duty cycle. The eight-bit value written to the control register is loaded into a buffer, and this value is used during the next period. Use the following formula to calculate a desired pulse width by extrapolating an appropriate value for PWM*x*_CONTROL from the range 00–FFH, and then write the value to the PWM*x*_CONTROL register.

		Clock Prescaler Disabled	÷2 Clock Prescaler Enabled	÷4 Clock Prescaler Enabled
Pulse width (in µs)	=	$\frac{PWMx\_CON \times 2}{f}$	$\frac{PWMx\_CON \times 4}{f}$	$\frac{PWMx\_CON \times 8}{f}$
Duty Cycle (in %)	=	$\frac{Pulsewidth}{T_{PWM}} \times 100$		

where:

PWM*x*_CON	=	eight-bit decimal value to load into the PWM*x*_CONTROL register
Pulse width	=	width of each high pulse
f	=	operating frequency, in MHz
T_{PWM}	=	output period on the PWM pin, in µs

PWM*x*_CONTROL
***x* = 0–2**

Address: See Table 9-2 on page 9-3
Reset: 00H

The PWM control (PWM*x*_CONTROL) register determines the duty cycle of the PWM *x* channel. A zero loaded into this register causes the PWM to output a low continuously (0% duty cycle). An FFH in this register causes the PWM to have its maximum duty cycle (99.6% duty cycle).

7							0
PWM Duty Cycle							

Bit Number	Function
7:0	PWM Duty Cycle This register controls the PWM duty cycle. A zero loaded into this register causes the PWM to output a low continuously (0% duty cycle). An FFH in this register causes the PWM to have its maximum duty cycle (99.6% duty cycle).

Figure 9-4. PWM Control (PWM*x*_CONTROL) Registers

9.6.1 Sample Calculations

For example, assume that the operating frequency is 25 MHz, the desired period of the PWM output waveform is either 20.48 µs (512 state times) if the prescaler is disabled or 40.96 µs (1,024 state times) if the divide-by-two prescaler is enabled. If PWM*x*_CONTROL equals 8AH (138 decimal), the pulse is held high for 11.04 µs (and low for 9.44 µs) of the total 20.48 µs period, resulting in a duty cycle of approximately 54% with the prescaler disabled. If the divide-by-two prescaler is enabled, the same values would produce a period of 40.96 µs with the pulse being held high for 22.08 µs (and low for 18.88 µs), for the same duty cycle, approximately 54%.

9.6.2 Enabling the PWM Outputs

Each PWM output shares a pin with a port, so you must configure it as a special-function output signal before using the PWM function. To do so, follow this sequence:

1. Clear the corresponding bit of P4_DIR (see Table 9-4).
2. Set the corresponding bit of P4_MODE (see Table 9-4).
3. Set or clear the corresponding bit of P4_REG (see Table 9-4).

Table 9-4 shows the alternate port function along with the register setting that selects the PWM output instead of the port function.

Table 9-4. PWM Output Alternate Functions

PWM Output	Alternate Port Function	PWM Output Enabled When
PWM0	P4.0	P4_DIR.0 = 0, P4_MODE.0 = 1, P4_REG = X
PWM1	P4.1	P4_DIR.1 = 0, P4_MODE.1 = 1, P4_REG = X
PWM2	P4.2	P4_DIR.2 = 0, P4_MODE.2 = 1, P4_REG = X

9.6.3 Generating Analog Outputs

The PWM modules can generate a rectangular pulse train that varies in duty cycle and period. Filtering this output will create a smooth analog signal. To make a signal swing over the desired analog range, first buffer the signal and then filter it with either a simple RC network or an active filter. Figure 9-5 is a block diagram of the type of circuit needed to create the smooth analog signal.

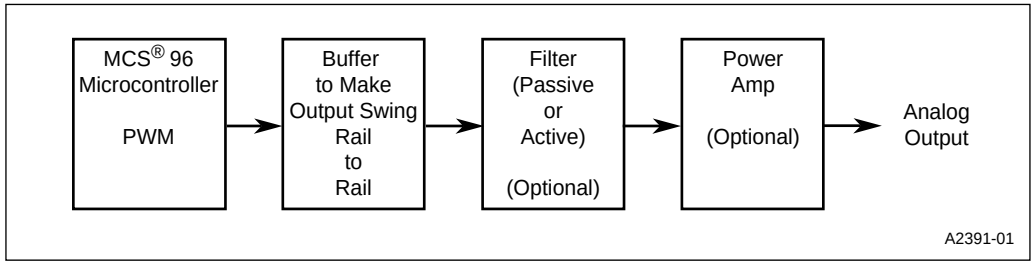


Figure 9-5. D/A Buffer Block Diagram

Figure 9-6 shows a sample circuit used for low output currents (less than 100 µA). Consider temperature and power-supply drift when selecting components for the external D/A circuitry. With proper components, a highly accurate 8-bit D/A converter can be made using the PWM.

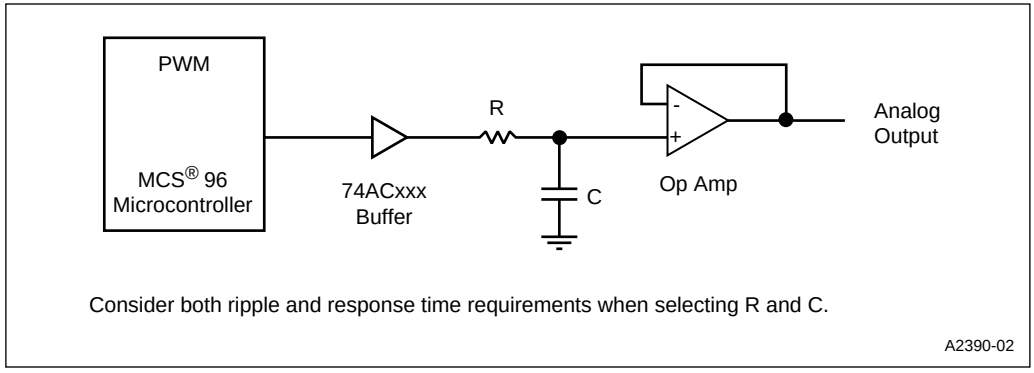


Figure 9-6. PWM to Analog Conversion Circuitry

10

Event Processor Array (EPA)

CHAPTER 10
EVENT PROCESSOR ARRAY (EPA)

Control applications often require high-speed event control. For example, the controller may need to periodically generate pulse-width modulated outputs or an interrupt. In another application, the controller may monitor an input signal to determine the status of an external device. The event processor array (EPA) was designed to reduce the CPU overhead associated with these types of event control. This chapter describes the EPA and its timers and explains how to configure and program them.

10.1 EPA FUNCTIONAL OVERVIEW

The EPA performs input and output functions associated with two timer/counters, timer 1 and timer 2 (Figure 10-1). In the input mode, the EPA monitors an input pin for an event: a rising edge, a falling edge, or an edge in either direction. When the event occurs, the EPA records the value of the timer/counter, so that the event is tagged with a time. This is called an *input capture*. Input captures are buffered to allow two captures before an overrun occurs.

In the output mode, the EPA monitors a timer/counter and compares its value with a value stored in a register. When the timer/counter value matches the stored value, the EPA can trigger an event: a timer reset or an output event (set a pin, clear a pin, toggle a pin, or take no action). This is called an *output compare*.

Each input capture or output compare sets an interrupt pending bit. This bit can optionally cause an interrupt. The EPA has four capture/compare channels, EPA3:0.

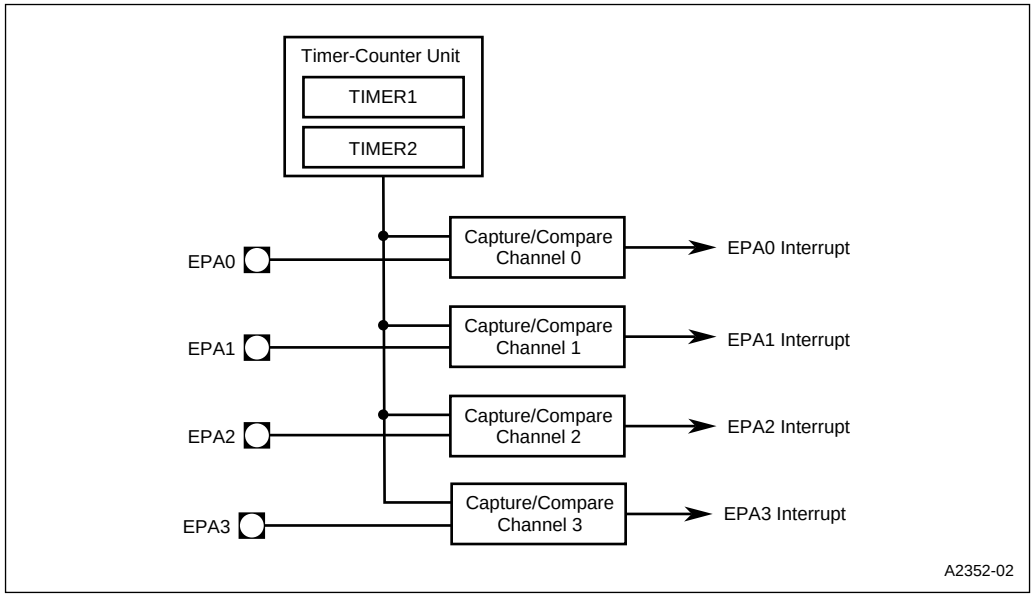


Figure 10-1. EPA Block Diagram

10.2 EPA AND TIMER/COUNTER SIGNALS AND REGISTERS

Table 10-1 describes the EPA and timer/counter input and output signals. Each signal shares a pin with a general-purpose I/O signal, as shown in the first column. Table 10-2 briefly describes the registers for the EPA capture/compare channels and timer/counters.

Table 10-1. EPA and Timer/Counter Signals

Port Pin	EPA Signals	EPA Signal Type	Description
P1.3:0	EPA3:0	I/O	High-speed input/output for capture/compare channels 0–3.
P1.4	T1CLK	I	External clock source for timer 1.
P1.5	T1DIR	I	External direction control for timer 1.
P1.6	T2CLK	I	External clock source for timer 2.
P1.7	T2DIR	I	External direction control for timer 2.

Table 10-2. EPA Control and Status Registers

Mnemonic	Address	Description
EPA_MASK	1F9CH	EPA Interrupt Mask Four bits (OVR0, OVR1, OVR2, and OVR3) in this 8-bit register enable and disable (mask) the individual capture overrun interrupt sources associated with capture/compare channels EPA3:0. OVR0 and OVR1 share one interrupt mask bit (OVR0_1) in INT_MASK1; OVR2 and OVR3 share another interrupt mask bit (OVR2_3) in INT_MASK1.
EPA_PEND	1F9EH	EPA Interrupt Pending Four bits (OVR0, OVR1, OVR2, and OVR3) in this 8-bit register indicate an overrun status for the associated capture/compare channels, EPA3:0. OVR0 and OVR1 share one interrupt pending bit (OVR0_1) in INT_PEND1; OVR2 and OVR3 share another interrupt pending bit (OVR2_3) in INT_PEND1.
EPA0_CON EPA1_CON EPA2_CON EPA3_CON	1F60H 1F64H, 1F65H 1F68H 1F6CH, 1F6DH	EPA*x* Capture/Compare Control These registers control the functions of the capture/compare channels. EPA1_CON and EPA3_CON require an extra byte because they contain an additional bit for PWM remap mode. These two registers must be addressed as words; the others can be addressed as bytes.
EPA0_TIME EPA1_TIME EPA2_TIME EPA3_TIME	1F62H 1F66H 1F6AH 1F6EH	EPA*x* Capture/Compare Time In capture mode, these registers contain the captured timer value. In compare mode, these registers contain the time at which an event is to occur. In capture mode, these registers are buffered to allow two captures before an overrun occurs. In compare mode, however, they are not buffered.
INT_MASK	0008H	Interrupt Mask Three bits in this 8-bit register (OVRTM1, OVRTM2, and EPA0) enable and disable (mask) the three interrupts associated with the corresponding bits in the INT_PEND register.
INT_MASK1	0013H	Interrupt Mask 1 Five bits in this 8-bit register (EPA1, EPA2, EPA3, OVR0_1, and OVR2_3) enable and disable (mask) the five interrupts associated with the corresponding bits in the INT_PEND1 register.
INT_PEND	0009H	Interrupt Pending Any set bit in this 8-bit register indicates a pending interrupt. The three bits associated with EPA interrupts are OVRTM1, OVRTM2, and EPA0.
INT_PEND1	0012H	Interrupt Pending 1 Any set bit in this 8-bit register indicates a pending interrupt. The five bits associated with EPA interrupts are EPA1, EPA2, EPA3, OVR0_1, and OVR2_3.

Table 10-2. EPA Control and Status Registers (Continued)

Mnemonic	Address	Description
P1_DIR	1FD2H	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.
P1_MODE	1FD0H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
P1_PIN	1FD6H	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.
P1_REG	1FD4H	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.
T1CONTROL T2CONTROL	1F90H 1F94H	Timer *x* Control This register enables/disables timer *x*, controls whether it counts up or down, selects the clock source and direction, and determines the clock prescaler setting.
TIMER1 TIMER2	1F92H 1F96H	Timer *x* Value This register contains the current value of timer *x*.

10.3 TIMER/COUNTER FUNCTIONAL OVERVIEW

The EPA has two up/down timer/counters, timer 1 and timer 2, which can be clocked internally or externally. Each is called a *timer* if it is clocked internally and a *counter* if it is clocked externally. Figure 10-2 illustrates the timer/counter structure for timers 1 and 2.

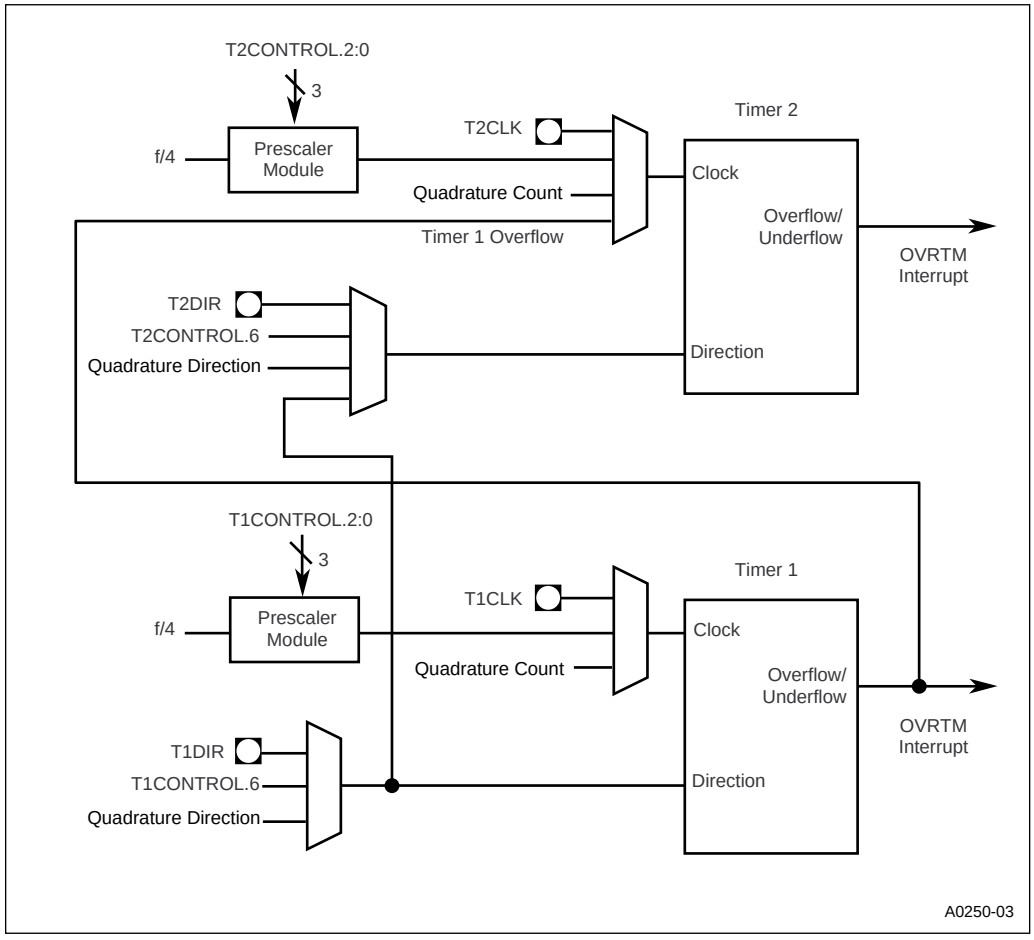


Figure 10-2. EPA Timer/Counters

The timer/counters can be used as time bases for input captures, output compares, and programmed interrupts (software timers). When a counter increments from FFFFH to 0000H or decrements from 0001H to 0000H, the counter-overflow/underflow interrupt pending bit is set. This bit can optionally cause an interrupt. The clock source, direction-control source, count direction, and resolution of the input capture or output compare are all programmable (see “Programming the Timers” on page 10-14). The maximum count rate is one-half the internal clock rate, or f/4 (see “Internal Timing” on page 2-8). This provides a minimum resolution for an input capture or output compare of 80 ns (at f = 50 MHz).

$$\text{resolution} = \frac{4 \times \text{prescaler\_divisor}}{f}$$

where:

prescaler_divisor — is the clock prescaler divisor from the T*x*CONTROL registers (see "Timer 1 Control (T1CONTROL) Register" on page 10-15 and "Timer 2 Control (T2CONTROL) Register" on page 10-16).

f — is the internal operating frequency. See "Internal Timing" on page 2-8 for details.

NOTE

The prescaler_divisor equals one when you use T*x*CLK as the clock source.

10.3.1 Cascade Mode (Timer 2 Only)

Timer 2 can be used in cascade mode. In this mode, the timer 1 overflow output is used as the timer 2 clock input. Either the direction control bit of the timer 2 control register or the direction control assigned to timer 1 controls the count direction. This method, called *cascading*, can provide a slow clock for idle mode timeout control or for slow pulse-width modulation (PWM) applications (see "Generating a Low-speed PWM Output" on page 10-12).

10.3.2 Quadrature Clocking Modes

Both timer 1 and timer 2 can be used in quadrature clocking mode. This mode uses the T*x*CLK and T*x*DIR pins as quadrature inputs, as shown in Figure 10-3. External quadrature-encoded signals (two signals at the same frequency that differ in phase by 90°) are input, and the timer increments or decrements by one count on each rising edge and each falling edge. Because the T*x*CLK and T*x*DIR inputs are sampled by the internal phase clocks, transitions must be separated by at least two state times for proper operation. The count is clocked by PH2, which is PH1 delayed by one-half period. The sequence of the signal edges and levels controls the count direction. Refer to Table 10-3 and Figure 10-4 for sequencing information.

A typical source of quadrature-encoded signals is a shaft-angle decoder, shown in Figure 10-3. Its output signals X and Y are input to T*x*CLK and T*x*DIR, which in turn output signals X_internal and Y_internal. These signals are used in Table 10-3 and Figure 10-4 to describe the direction of the shaft.

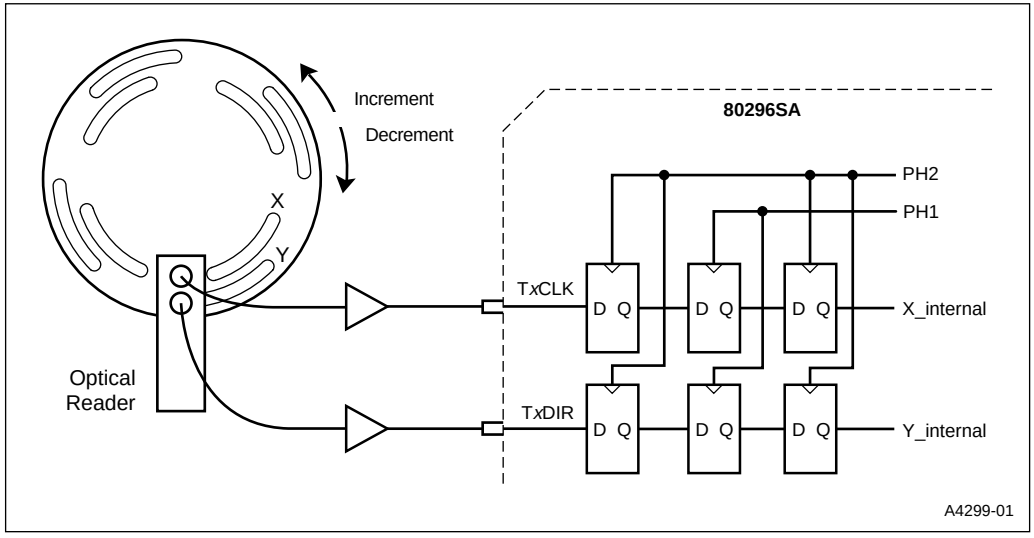


Figure 10-3. Quadrature Mode Interface

Table 10-3. Quadrature Mode Truth Table

State of X_internal (T*x*CLK)	State of Y_internal (T*x*DIR)	Count Direction
↑	0	Increment
↓	1	Increment
0	↓	Increment
1	↑	Increment
↓	0	Decrement
↑	1	Decrement
0	↑	Decrement
1	↓	Decrement

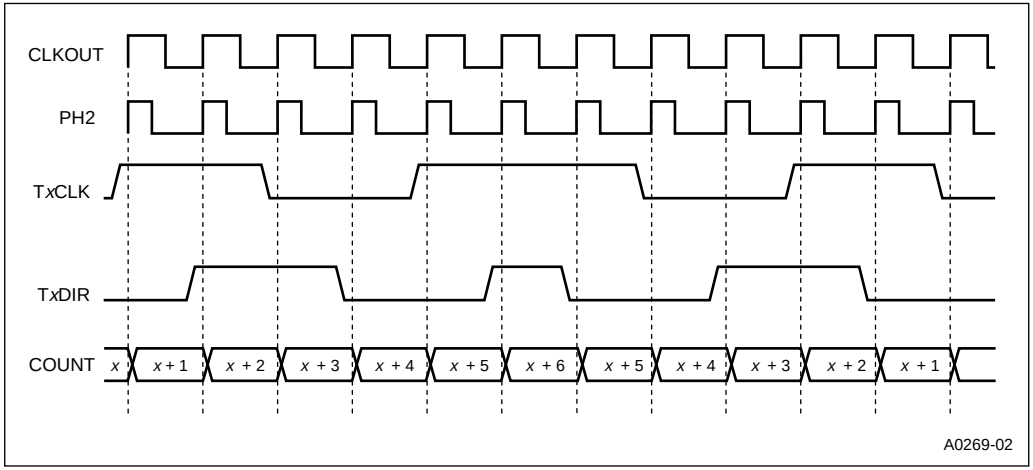


Figure 10-4. Quadrature Mode Timing and Count

10.4 EPA CHANNEL FUNCTIONAL OVERVIEW

Each capture/compare channel can perform the following tasks.

- capture the current timer value when a specified transition occurs on the EPA pin
- clear, set, or toggle the EPA pin when the timer value matches the programmed value in the event-time register
- generate an interrupt when a capture or compare event occurs
- generate an interrupt when a capture overrun occurs

Each EPA channel has a control register, EPA*x*_CON; an event-time register, EPA*x*_TIME; and a timer input (Figure 10-5). The control register selects the timer, the mode, and either the event that causes a timer/counter value to be captured or the event that is to occur at a given timer/counter value. The event-time register holds the captured timer value in capture mode or the event time in compare mode. See "Programming the Timers" on page 10-14 for configuration information.

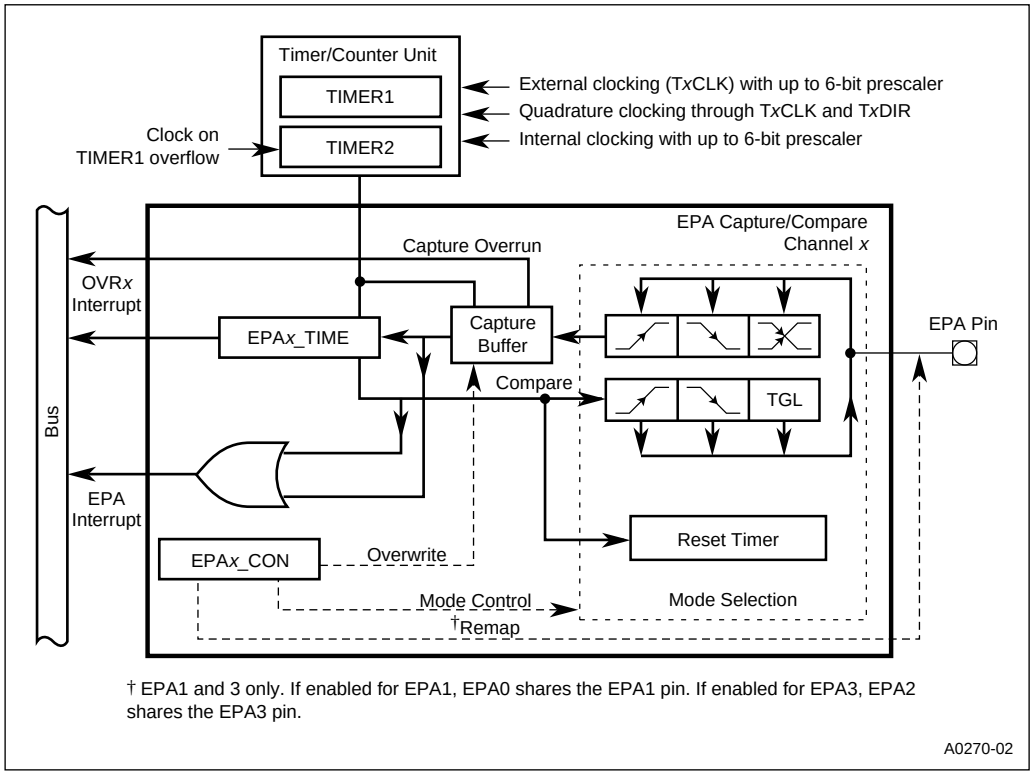


Figure 10-5. A Single EPA Capture/Compare Channel

10.4.1 Operating in Capture Mode

In capture mode, when a valid event occurs on the pin, the value of the selected timer is captured into a buffer. The timer value is then transferred from the buffer to the EPA*x*_TIME register, which sets the EPA interrupt pending bit as shown in Figure 10-6. If enabled, an interrupt is generated. If a second event occurs before the CPU reads the first timer value in EPA*x*_TIME, the current timer value is loaded into the buffer and held there. After the CPU reads the EPA*x*_TIME register, the contents of the capture buffer are automatically transferred into EPA*x*_TIME and the EPA interrupt pending bit is set again.

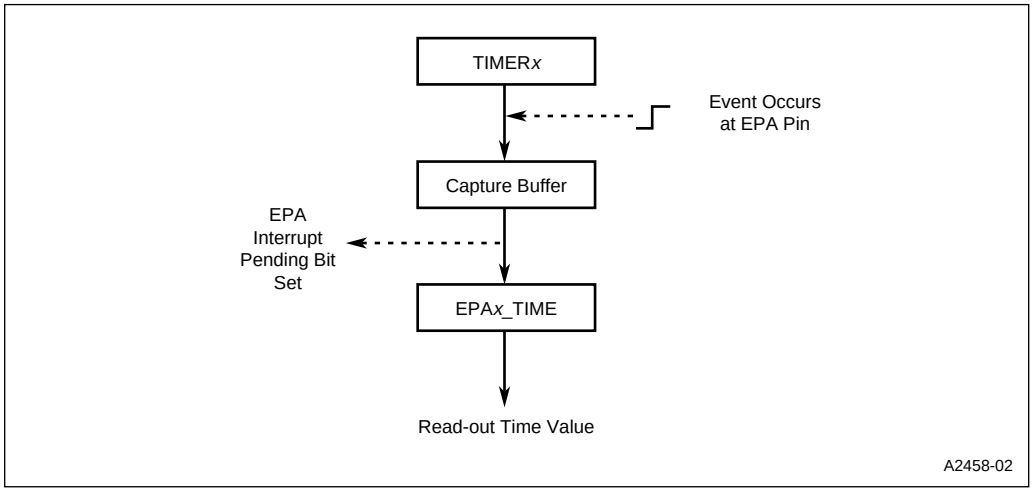


Figure 10-6. EPA Simplified Input-capture Structure

If a third event occurs before the CPU reads the event-time register, the overwrite bit (EPA*x*_CON.0) determines how the EPA will handle the event. If the bit is clear, the EPA ignores the third event. If the bit is set, the third event time overwrites the second event time in the capture buffer. Both situations set the overrun interrupt pending bit, and if the interrupt is enabled, they generate an overrun interrupt. Table 10-4 summarizes the possible actions when a valid event occurs.

NOTE

In order for an event to be captured, the signal must be stable for at least two state times both before and after the transition occurs (Figure 10-7).

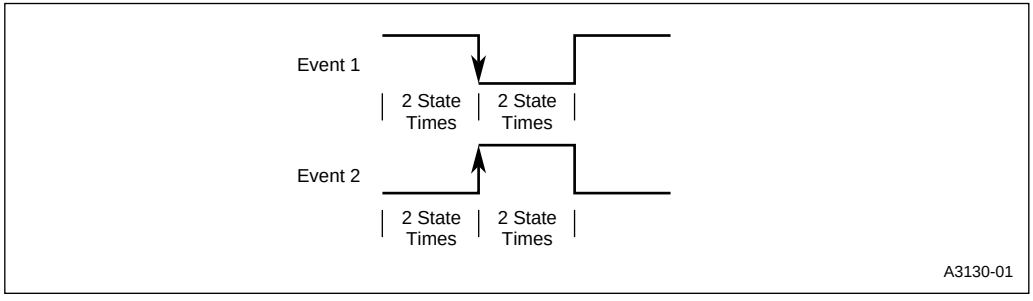


Figure 10-7. Valid EPA Input Events

Table 10-4. Action Taken When a Valid Edge Occurs

Overwrite Bit (EPA*x*_CON.0)	Status of Capture Buffer & EPA*x*_TIME	Action Taken When a Valid Edge Occurs
0	empty	Edge is captured and event time is loaded into the capture buffer and EPA*x*_TIME register.
0	full	New data is ignored — no capture, EPA interrupt, or transfer occurs; OVR*x* interrupt pending bit is set.
1	empty	Edge is captured and event time is loaded into the capture buffer and EPA*x*_TIME register.
1	full	Old data is overwritten in the capture buffer; OVR*x* interrupt pending bit is set.

An input capture event does not set the interrupt pending bit until the captured time value actually moves from the capture buffer into the EPA*x*_TIME register.

10.4.1.1 EPA Overruns

Overruns occur when an EPA input transitions at a rate that cannot be handled by the EPA interrupt service routine. If no overrun handling strategy is in place, and if the following three conditions exist, a situation may occur where both the capture buffer and the EPA*x*_TIME register contain data, and no EPA interrupt pending bit is set:

- an input signal with a frequency high enough to cause overruns is present on an enabled EPA pin, and
- the overwrite bit is set (EPA*x*_CON.0 = 1; old data is overwritten on overrun), and
- the EPA*x*_TIME register is read at the exact instant that the EPA recognizes the captured edge as valid.

The input frequency at which this occurs depends on the length of the interrupt service routine as well as other factors. Unless the interrupt service routine includes a check for overruns, this situation will remain the same until the device is reset or the EPA*x*_TIME register is read. The act of reading EPA*x*_TIME allows the buffered time value to be moved into EPA*x*_TIME. This clears the buffer and allows another event to be captured. Remember that the act of transferring the buffer contents to the EPA*x*_TIME register is what actually sets the EPA*x* interrupt pending bit and generates the interrupt.

10.4.1.2 Preventing EPA Overruns

Either of the following methods can be used to prevent or recover from an EPA overrun situation.

- Clear EPA*x*_CON.0

  When the overwrite bit (EPA*x*_CON.0) is zero and both the EPA*x*_TIME register and the buffer contain data, the EPA does not consider a captured edge until the EPA*x*_TIME register is read and the data in the capture buffer is transferred to EPA*x*_TIME. This prevents overruns by ignoring new input capture events when both the capture buffer and EPA*x*_TIME contain valid capture times. The OVR*x* pending bit in EPA_PEND is set to indicate that an overrun occurred.

- Enable the OVR*x* interrupt and read the EPA*x*_TIME register within the ISR

  If an overrun occurs, the overrun (OVR*x*) interrupt will be generated. The OVR*x* interrupt will then be acknowledged and its interrupt service routine will read the EPA*x*_TIME register. After the CPU reads the EPA*x*_TIME register, the buffered data moves from the buffer to the EPA*x*_TIME register. This sets the EPA interrupt pending bit.

10.4.2 Operating in Compare Mode

When the selected timer value matches the event-time value, the action specified in the control register occurs (i.e., no output occurs or the pin is set, cleared, or toggled). If the re-enable bit (EPA*x*_CON.3) is set, the action reoccurs on every timer match. If the re-enable bit is cleared, the action does not reoccur until a new value is written to the event-time register. See "Programming the Capture/Compare Channels" on page 10-18 for configuration information.

In compare mode, you can use the EPA to produce a pulse-width modulated (PWM) output. The following sections describe two possible methods.

10.4.2.1 Generating a Low-speed PWM Output

You can generate a low-speed, pulse-width modulated output with a single EPA channel and a standard interrupt service routine. Configure the EPA channel as follows: compare mode, toggle output, and the compare function re-enabled. Select standard interrupt service, enable the EPA interrupt, and globally enable interrupts with the EI instruction. When the assigned timer/counter value matches the value in the EPA*x*_TIME register, the EPA toggles the output pin and generates an interrupt. The interrupt service routine loads a new value into EPA*x*_TIME.

The maximum output frequency depends upon the total interrupt latency and the interrupt-service execution times used by your system. As additional EPA channels and the other functions of the microcontroller are used, the maximum PWM frequency decreases because the total interrupt latency and interrupt-service execution time increases. To determine the maximum, low-speed PWM frequency in your system, calculate your system's worst-case interrupt latency and worst-case interrupt-service execution time, and then add them together. The worst-case interrupt latency is the total latency of all the interrupts used in your system. The worst-case interrupt-service execution time is the total execution time of all interrupt service routines.

Assume a system with a single EPA channel, a single enabled interrupt, and the following interrupt service routine.

```
;If EPA0-3 interrupt is generated
;Add code to set-up windows for direct access of registers.
EPA0-3_ISR:
     PUSHA
     LD EPAx_CON, #toggle_command
     ADD EPAx_TIME, TIMERx, [next_duty_ptr]; Load next event time
     POPA
     RETI
```

The worst-case interrupt latency for a single-interrupt system is 45 state times for external stack usage (see "Worst-case Interrupt Latency" on page 6-13). To determine the execution time for an interrupt service routine, add up the execution time of the instructions (Table A-9).

The total execution time for the ISR that services the EPA interrupts is 18 state times. Therefore, a single capture/compare channel can be updated every 63 state times assuming external stack usage (45 + 18). Each PWM period requires two updates (one setting and one clearing), so the execution time for a PWM period equals 126 state times. When the input frequency on XTAL1 is 25 MHz and the phase-locked loop is disabled, the PWM period is 20 µs and the maximum PWM frequency is 50 kHz.

10.4.2.2 Generating the High-speed PWM Output

You can generate a high-speed, pulse-width modulated output with a pair of remapped EPA channels and a dedicated timer/counter. When configuring the channels, set the re-enable bit in the control register. The first channel toggles the output when the timer value matches EPA*x*_TIME, and at some later time, the second channel toggles the output again **and** resets the timer/counter. This restarts the cycle. No interrupts are required, resulting in the highest possible speed. Your code must calculate the appropriate EPA*x*_TIME values and load them at the correct time in the cycle in order to change the frequency or duty cycle.

With this method, the resolution of the EPA (selected by the T*x*CONTROL registers; see Figure 10-8 on page 10-15 and Figure 10-9 on page 10-16) determines the maximum PWM output frequency. (Resolution is the minimum time required between consecutive captures or compares.) When the input frequency on XTAL1 is 25 MHz and the phase-locked loop is disabled, a 160 ns resolution results in a maximum PWM of 6.25 MHz.

10.5 PROGRAMMING THE EPA AND TIMER/COUNTERS

This section discusses configuring the port pins for the EPA and the timer/counters, describes how to program the timers and the capture/compare channels, and explains how to enable the EPA interrupts.

10.5.1 Configuring the EPA and Timer/Counter Signals

Before you can use the EPA, you must configure the appropriate port signals to serve as the special-function signals for the EPA and, optionally, for the timer/counter clock source and direction control signals. See "Configuring the Port Pins" on page 7-3 for information about configuring the ports.

Table 10-1 on page 10-2 lists the signals associated with the EPA and the timer/counters. Signals that are not being used for an EPA channel or timer/counter can be configured as general-purpose I/O signals.

10.5.2 Programming the Timers

The control registers for the timers are T1CONTROL (Figure 10-8) and T2CONTROL (Figure 10-9). Write to these registers to configure the timers. Write to the TIMER1 and TIMER2 registers (see Table 10-2 on page 10-3 for addresses) to load a specific timer value.

T1CONTROL

Address: 1F90H
Reset State: 00H

The timer 1 control (T1CONTROL) register determines the clock source, counting direction, and count rate for timer 1.

7							0
CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
7	CE	Counter Enable This bit enables or disables the timer. From reset, the timers are disabled and not free running. 0 = disables timer 1 = enables timer
6	UD	Up/Down This bit determines the timer counting direction, in selected modes (see mode bits, M2:0). 0 = count down 1 = count up
5:3	M2:0	EPA Clock Direction Mode Bits These bits determine the timer clocking source and direction control source. **M2 M1 M0 Clock Source Direction Source** 0 0 0 f/4 UD bit (T1CONTROL.6) X 0 1 T1CLK pin† UD bit (T1CONTROL.6) 0 1 0 f/4 T1DIR pin 0 1 1 T1CLK pin† T1DIR pin 1 1 1 T1CLK and T1DIR quadrature clocking † If an external clock is selected, the timer counts on both the rising **and** falling edges of the clock.
2:0	P2:0	EPA Clock Prescaler Bits These bits determine the clock prescaler value. The prescaler can be used only if the clock source is f/4. It has no effect on the T1CLK or quadrature clock inputs. **P2 P1 P0 Prescaler Divisor Resolution†** 0 0 0 divide by 1 (disabled) 160 ns 0 0 1 divide by 2 320 ns 0 1 0 divide by 4 640 ns 0 1 1 divide by 8 1.28 µs 1 0 0 divide by 16 2.56 µs 1 0 1 divide by 32 5.12 µs 1 1 0 divide by 64 10.24 µs 1 1 1 divide by 128 20.48 µs † At f = 25 MHz. Use the formula on page 10-6 to calculate the resolution at other frequencies.

Figure 10-8. Timer 1 Control (T1CONTROL) Register

T2CONTROL

Address: 1F94H
Reset State: 00H

The timer 2 control (T2CONTROL) register determines the clock source, counting direction, and count rate for timer 2.

7 **0**

CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
7	CE	Counter Enable This bit enables or disables the timer. From reset, the timers are disabled and not free running. 0 = disables timer 1 = enables timer
6	UD	Up/Down This bit determines the timer counting direction, in selected modes (see mode bits, M2:0). 0 = count down 1 = count up

Figure 10-9. Timer 2 Control (T2CONTROL) Register

T2CONTROL (Continued)

Address: 1F94H
Reset State: 00H

The timer 2 control (T2CONTROL) register determines the clock source, counting direction, and count rate for timer 2.

7							0
CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
5:3	M2:0	EPA Clock Direction Mode Bits These bits determine the timer clocking source and direction source. **M2 M1 M0 Clock Source Direction Source** 0 0 0 f/4 UD bit (T2CONTROL.6) X 0 1 T2CLK pin† UD bit (T2CONTROL.6) 0 1 0 f/4 T2DIR pin 0 1 1 T2CLK pin† T2DIR pin 1 0 0 timer 1 overflow UD bit (T2CONTROL.6) 1 1 0 timer 1 overflow same as timer 1 1 1 1 T2CLK and T2DIR quadrature clocking † If an external clock is selected, the timer counts on both the rising **and** falling edges of the clock.
2:0	P2:0	EPA Clock Prescaler Bits These bits determine the clock prescaler value. The prescaler can be used only if the clock source is f/4. It has no effect on the T2CLK or quadrature clock inputs. **P2 P1 P0 Prescaler Resolution†** 0 0 0 divide by 1 (disabled) 160 ns 0 0 1 divide by 2 320 ns 0 1 0 divide by 4 640 ns 0 1 1 divide by 8 1.28 µs 1 0 0 divide by 16 2.56 µs 1 0 1 divide by 32 5.12 µs 1 1 0 divide by 64 10.24 µs 1 1 1 divide by 128 20.48 µs † Resolution at f = 25 MHz.Use the formula on to calculate the resolution at other frequencies.

Figure 10-9. Timer 2 Control (T2CONTROL) Register (Continued)

TIMER*x*
***x* = 1–2**

Address: 1F92H, 1F96H
Reset State: 0000H

This register contains the value of timer *x*. This register can be written, allowing timer *x* to be initialized to a value other than zero.

15															0
Timer Value															

Bit Number	Function
15:0	Timer Value Read the current timer *x* value from this register or write a new timer *x* value to this register.

Figure 10-10. Timer *x* Time (TIMER*x*) Registers

10.5.3 Programming the Capture/Compare Channels

The EPA*x*_CON register controls the function of its assigned capture/compare channel. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit (RM), which is used to enable and disable remapping for high-speed PWM generation. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON **must** be addressed as **words**, while the others can be addressed as bytes.

To program a compare event, always write to EPA*x*_CON (Figure 10-11) first to configure the EPA capture/compare channel, and then load the event time into EPA*x*_TIME. To program a capture event, you need only write to EPA*x*_CON. Table 10-5 shows the effects of various combinations of EPA*x*_CON bit settings for channels 0 and 2.

Table 10-5. Example EPA Control Register Settings

Capture Mode								
TB	**CE**	**MODE**		**RE**	**—**	**ROT**	**ON/RT**	**Operation**
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
X	0	0	0	—	0	—	0	None
X	0	0	1	—	0	X	X	Capture on falling edges
X	0	1	0	—	0	X	X	Capture on rising edges
X	0	1	1	—	0	X	X	Capture on both edges
X	0	X	1	—	0	1	X	Reset opposite timer
X	0	1	X	—	0	1	X	Reset opposite timer
Compare Mode								
TB	**CE**	**MODE**		**RE**	**—**	**ROT**	**ON/RT**	**Operation**
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
X	1	0	0	X	0	—	0	None
X	1	0	0	X	0	X	0	Generate interrupt only (software timer)
X	1	0	1	X	0	X	X	Clear output pin
X	1	1	0	X	0	X	X	Set output pin
X	1	1	1	X	0	X	X	Toggle output pin
X	1	X	X	X	0	0	1	Reset same timer
X	1	X	X	X	0	1	1	Reset opposite timer

NOTES:
1. — = bit is not used
2. X = bit may be used, but has no effect on the described operation. These bits cause other operations to occur.

EPA*x*_CON
***x* = 0–3**

Address: See Table 10-2 on page 10-3
Reset: 0000H

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.

***x* = 1, 3**

15							8
—	—	—	—	—	—	—	RM
7							**0**
TB	CE	M1	M0	RE	—	ROT	ON/RT

***x* = 0, 2**

7							0
TB	CE	M1	M0	RE	—	ROT	ON/RT

Bit Number	Bit Mnemonic	Function
15:9†	—	Reserved; always write as zeros.
8†	RM	Remap Feature The remap feature applies to the compare mode of the EPA1 and EPA3 only. When the remap feature of EPA1 is enabled, EPA capture/compare channel 0 shares output pin EPA1 with EPA capture/compare channel 1. When the remap feature of EPA3 is enabled, EPA capture/compare channel 2 shares output pin EPA3 with EPA capture/compare channel 3. 0 = remap feature disabled 1 = remap feature enabled
7	TB	Time Base Select Specifies the reference timer. 0 = timer 1 is the reference timer and timer 2 is the opposite timer 1 = timer 2 is the reference timer and timer 1 is the opposite timer A compare event (clearing, setting, or toggling an output pin; and/or resetting either timer) occurs when the reference timer matches the time programmed in the event-time register. When a capture event (falling edge, rising edge, or an edge change on the EPA*x* pin) occurs, the reference timer value is saved in the EPA event-time register (EPA*x*_TIME).
6	CE	Compare Enable Determines whether the EPA channel operates in capture or compare mode. 0 = capture mode 1 = compare mode

† These bits apply to the EPA1_CON and EPA3_CON registers only.

Figure 10-11. EPA Control (EPA*x*_CON) Registers

EPA*x*_CON (Continued) Address: See Table 10-2 on page 10-3
***x* = 0–3** Reset: 0000H

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.

***x* = 1, 3**

15							8
—	—	—	—	—	—	—	RM
7							**0**
TB	CE	M1	M0	RE	—	ROT	ON/RT

***x* = 0, 2**

7							0
TB	CE	M1	M0	RE	—	ROT	ON/RT

Bit Number	Bit Mnemonic	Function
5:4	M1:0	EPA Mode Select In capture mode, specifies the type of event that triggers an input capture. In compare mode, specifies the action that the EPA executes when the reference timer matches the event time. **M1 M0 Capture Mode Event** 0 0 no capture 0 1 capture on falling edge 1 0 capture on rising edge 1 1 capture on either edge **M1 M0 Compare Mode Action** 0 0 no output 0 1 clear output pin 1 0 set output pin 1 1 toggle output pin
3	RE	Re-enable Re-enable applies to the compare mode only. It allows a compare event to continue to execute each time the event-time register (EPA*x*_TIME) matches the reference timer rather than only upon the first time match. 0 = compare function is disabled after a single event 1 = compare function always enabled
2	—	Reserved; always write as zero.

† These bits apply to the EPA1_CON and EPA3_CON registers only.

Figure 10-11. EPA Control (EPA*x*_CON) Registers (Continued)

EPA*x*_CON (Continued) Address: See Table 10-2 on page 10-3
***x* = 0–3** Reset: 0000H

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.

***x* = 1, 3**

15							8
—	—	—	—	—	—	—	RM
7							**0**
TB	CE	M1	M0	RE	—	ROT	ON/RT

***x* = 0, 2**

7							0
TB	CE	M1	M0	RE	—	ROT	ON/RT

Bit Number	Bit Mnemonic	Function
1	ROT	Reset Opposite Timer Controls different functions for capture and compare modes. **In Capture Mode:** 0 = causes no action 1 = resets the opposite timer **In Compare Mode:** Selects the timer that is to be reset if the RT bit is set. 0 = selects the reference timer for possible reset 1 = selects the opposite timer for possible reset
0	ON/RT	Overwrite New/Reset Timer The ON/RT bit functions as overwrite new in capture mode and reset timer in compare mode. **In Capture Mode (ON):** An overrun error is generated when an input capture occurs while the event-time register (EPA*x*_TIME) and its buffer are both full. When an overrun occurs, the ON bit determines whether old data is overwritten or new data is ignored: 0 = ignores new data 1 = overwrites old data in the buffer **In Compare Mode (RT):** 0 = disables the reset function 1 = resets the ROT-selected timer

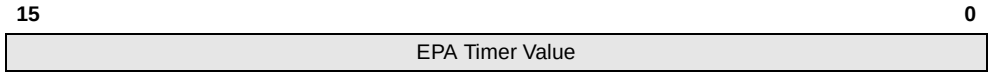
† These bits apply to the EPA1_CON and EPA3_CON registers only.

Figure 10-11. EPA Control (EPA*x*_CON) Registers (Continued)

EPA*x*_TIME
***x* = 0–3**

Address: Table 10-2
Reset: XXXXH

The EPA time (EPA*x*_TIME) registers are the event-time registers for the EPA channels. In capture mode, the value of the reference timer is captured in EPA*x*_TIME when an input transition occurs. Each event-time register is buffered, allowing the storage of two capture events at once. In compare mode, the EPA triggers a compare event when the reference timer matches the value in EPA*x*_TIME. EPA*x*_TIME is not buffered for compare mode.



Bit Number	Function
15:0	EPA Timer Value When an EPA channel is configured for capture mode, this register contains the value of the reference timer when the specified event occurred. When an EPA channel is configured for compare mode, write the compare event time to this register.

Figure 10-12. EPA Time (EPA*x*_TIME) Registers

10.6 ENABLING THE EPA INTERRUPTS

The EPA generates four individual event interrupts, EPA3:0, from the four capture/compare channels and two timer interrupts, OVRTM1 and OVRTM2, from timer 1 and timer 2. These interrupts are directly mapped into the interrupt pending registers (INT_PEND and INT_PEND1). The capture overrun interrupts from EPA0 and EPA1 share the OVRTM1 interrupt which maps into OVR0_1 (bit 4) of INT_PEND1; the capture overrun interrupts from EPA2 and EPA3 share the OVRTM2 interrupt which maps into OVR2_3 (bit 5) of INT_PEND1. To enable the interrupts, set the corresponding bits in the two 8-bit interrupt mask registers (INT_MASK and INT_MASK1). To enable the individual sources of the capture overrun interrupts OVR0_1 and OVR2_3, set the corresponding bits in the EPA mask register (EPA_MASK). Chapter 6, “Interrupts,” discusses the interrupts in greater detail.

EPA_MASK Address: 1F9CH
Reset State: AAH

The EPA interrupt mask (EPA_MASK) register enables or disables (masks) the shared EPA3:0 overrun interrupts (OVR3:0).

7							0
—	OVR3	—	OVR2	—	OVR1	—	OVR0

Bit Number	Bit Mnemonic	Function
7, 5, 3, 1	—	Reserved; for compatibility with future devices, write zeros to these bits.
6, 4, 2, 0	OVR3 OVR2 OVR1 OVR0	Setting this bit enables the corresponding source as a shared overrun interrupt source. The shared overrun interrupts (OVR0_1 and OVR2_3) are enabled by setting their interrupt enable bits in the interrupt mask 1 (INT_MASK1) register.

Figure 10-13. EPA Interrupt Mask (EPA_MASK) Register

INT_MASK Address: 0008H
Reset State: 00H

The interrupt mask (INT_MASK) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK is the low byte of the processor status word (PSW). PUSHF or PUSHA saves the contents of this register onto the stack and then clears this register. Interrupt calls cannot occur immediately following this instruction. POPF or POPA restores it.

7							0
PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows: **Default Priority — Interrupt Source** 7 — EPA Capture/Compare Channel 0 6 — SIO Receive 5 — SIO Transmit 4 — EXTINT1 pin 3 — EXTINT0 pin 2 — Reserved 1 — Timer 2 Overflow/Underflow 0 — Timer 1 Overflow/Underflow

Figure 10-14. Interrupt Mask (INT_MASK) Register

INT_MASK1 Address: 0013H
Reset State: 00H

The interrupt mask 1 (INT_MASK1) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK1 can be read from or written to as a byte register. PUSHA saves this register on the stack and POPA restores it.

7							0
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows: **Default Priority** — **Interrupt Source** 15 — Nonmaskable Interrupt† 14 — EXTINT3 pin 13 — EXTINT2 pin 12 — EPA Capture Channel 2 or 3 Overrun†† 11 — EPA Capture Channel 0 or 1 Overrun†† 10 — EPA Capture/Compare Channel 3 9 — EPA Capture/Compare Channel 2 8 — EPA Capture/Compare Channel 1 † NMI is always enabled and is always assigned to priority 15. This nonfunctional mask bit exists for design symmetry with the INT_PEND1 register. Always write zero to this bit. †† An overrun on the EPA capture/compare channels can generate the shared capture overrun interrupts. Write to EPA_MASK to enable the interrupt sources; read EPA_PEND to determine which source caused the interrupt.

Figure 10-15. Interrupt Mask 1 (INT_MASK1) Register

10.7 DETERMINING EVENT STATUS

In compare mode, an interrupt pending bit is set each time a match occurs on an enabled event (even if the interrupt is specifically masked in the mask register). In capture mode, an interrupt pending bit is set each time a programmed event is captured and the event time moves from the capture buffer to the EPA*x*_TIME register. If the capture buffer is full when an event occurs, an overrun interrupt pending bit is set.

Timer overflows/underflows and capture overruns also set interrupt pending bits. Even if an interrupt is masked, software can poll the interrupt pending registers to determine whether an event has occurred.

EPA_PEND Address: 1F9EH
Reset State: AAH

When hardware detects a pending EPA0–3 overrun interrupt request (OVR3:0), it sets the corresponding bit in the EPA interrupt pending register (EPA_PEND).

Reading EPA_PEND clears all bits.

7							0
—	OVR3	—	OVR2	—	OVR1	—	OVR0

Bit Number	Function
7, 5, 3, 1	Reserved. These bits are undefined.
6, 4, 2, 0	Any set bit indicates that the corresponding overrun interrupt source is pending.

Figure 10-16. EPA Interrupt Pending (EPA_PEND) Register

The EPA interrupt pending register, EPA_PEND, has the same bit structure as the EPA_MASK register. EPA_PEND is similar to an interrupt pending register in that it shows the status of the individual capture/compare overrun interrupts. The bits in EPA_PEND can be polled to determine the exact source of an OVR0_1 or OVR2_3 interrupt. However, hardware does not clear status bits in this register when it vectors to the interrupt service routine for an interrupt pair (OVR0_1, OVR2_3). Instead it clears the OVR0_1 or OVR2_3 bit in the EPA_MASK register. Also, software cannot generate an interrupt by setting a bit in EPA_PEND.

Reading EPA_PEND **clears all bits**. To check the status of the overrun interrupts, copy the contents of the EPA_PEND register into a shadow register and then execute bit-test instructions such as JBC and JBS on the shadow register. Otherwise, the first bit-test instruction will clear the register, losing all status information. Since the shadow register is not cleared when read, this method allows you to execute more than one bit-test instruction.

11

Minimum Hardware Considerations

CHAPTER 11
MINIMUM HARDWARE CONSIDERATIONS

The 80296SA has several basic requirements for operation within a system. This chapter describes options for providing the basic requirements and discusses other hardware considerations.

11.1 MINIMUM CONNECTIONS

Table 11-1 lists the signals that are required for the device to function and Figure 11-1 shows the connections for a minimum configuration.

Table 11-1. Minimum Required Signals

Signal Name	Type	Description
RESET#	I/O	Reset A level-sensitive reset input to, and an open-drain system reset output from, the microcontroller. Either a falling edge on RESET# or an internal reset turns on a pull-down transistor connected to the RESET# pin for 16 state times. In the powerdown, standby, and idle modes, asserting RESET# causes the chip to reset and return to normal operating mode. After a device reset, the first instruction fetch is from F2080H in external memory. The program and special-purpose memory locations (F2000–F2FFFH) reside in external memory.
RPD	I	Return from Powerdown Timing pin for the return-from-powerdown circuit. If your application uses powerdown mode, connect a capacitor† between RPD and V_{SS} if **either** of the following conditions is true. • the internal oscillator is the clock source • the phase-locked loop (PLL) circuitry is enabled The capacitor causes a delay that enables the oscillator and PLL circuitry to stabilize before the internal CPU and peripheral clocks are enabled. The capacitor is not required if your application uses powerdown mode and if **both** of the following conditions are true. • an external clock input is the clock source • the phase-locked loop circuitry is disabled If your application does not use powerdown mode, leave this pin unconnected. † Calculate the value of the capacitor using the formula found on page 12-12.
V_{CC}	PWR	Digital Supply Voltage Connect each V_{CC} pin to the digital supply voltage.
V_{SS}	GND	Digital Circuit Ground These pins supply ground for the digital circuitry. Connect each V_{SS} pin to ground through the lowest possible impedance path.

Table 11-1. Minimum Required Signals (Continued)

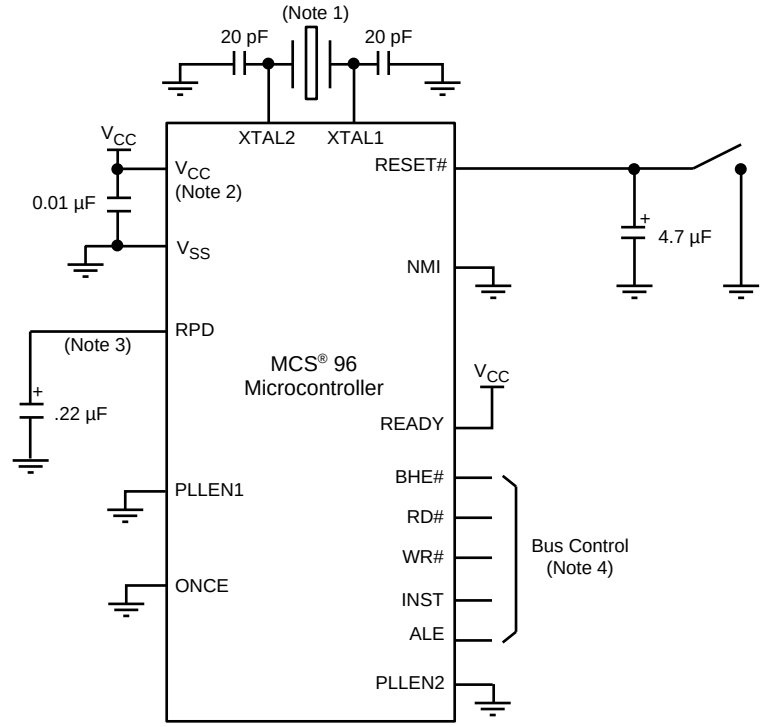
Signal Name	Type	Description
XTAL1	I	Input Crystal/Resonator or External Clock Input Input to the on-chip oscillator, internal phase-locked loop circuitry, and the internal clock generators. The internal clock generators provide the peripheral clocks, CPU clock, and CLKOUT signal. When using an external clock source instead of the on-chip oscillator, connect the clock input to XTAL1. The external clock signal must meet the V_{IH} specification for XTAL1.
XTAL2	O	Inverted Output for the Crystal/Resonator Output of the on-chip oscillator inverter. Leave XTAL2 floating when the design uses an external clock source instead of the on-chip oscillator.

11.1.1 Unused Inputs

For predictable performance, it is important to tie unused inputs to V_{CC} or V_{SS}. Otherwise, they can float to a mid-voltage level and draw excessive current. Unused interrupt inputs may generate spurious interrupts if left unconnected.

11.1.2 I/O Port Pin Connections

Chapter 7, "I/O Ports," contains information about initializing and configuring the ports. See "Configuring the Port Pins" on page 7-3.



Notes:
1. See the datasheet for the oscillator frequency range (F_{XTAL1}) and the crystal manufacturer's datasheet for recommended load capacitors.
2. The number of V_{CC} and V_{SS} pins varies with package type (see datasheet). Be sure to connect all V_{CC} pins to the supply voltage and all V_{SS} pins to ground.
3. Connect the capacitor to RPD when using powerdown mode and the internal oscillator or phase-locked loop circuitry. Otherwise, RPD may float.
4. No connection is required.

A3185-01

Figure 11-1. Minimum Hardware Connections

11.2 APPLYING AND REMOVING POWER

When power is first applied to the microcontroller, RESET# must remain continuously low for at least one state time after the power supply is within tolerance and the oscillator/clock has stabilized; otherwise, operation might be unpredictable. Similarly, when powering down a system, RESET# should be brought low before V_{CC} is removed; otherwise, an inadvertent write to an external location might occur. Carefully evaluate the possible effect of power-up and power-down sequences on a system.

11.3 NOISE PROTECTION TIPS

The fast rise and fall times of high-speed CMOS logic often produce noise spikes on the power supply lines and outputs. To minimize noise, it is important to follow good design and board layout techniques. We recommend liberal use of decoupling capacitors and transient absorbers. Add 0.01 µF bypass capacitors between V_{CC} and each V_{SS} pin to reduce noise (Figure 11-2). Place the capacitors as close to the device as possible. Use the shortest possible path to connect V_{SS} lines to ground and each other.

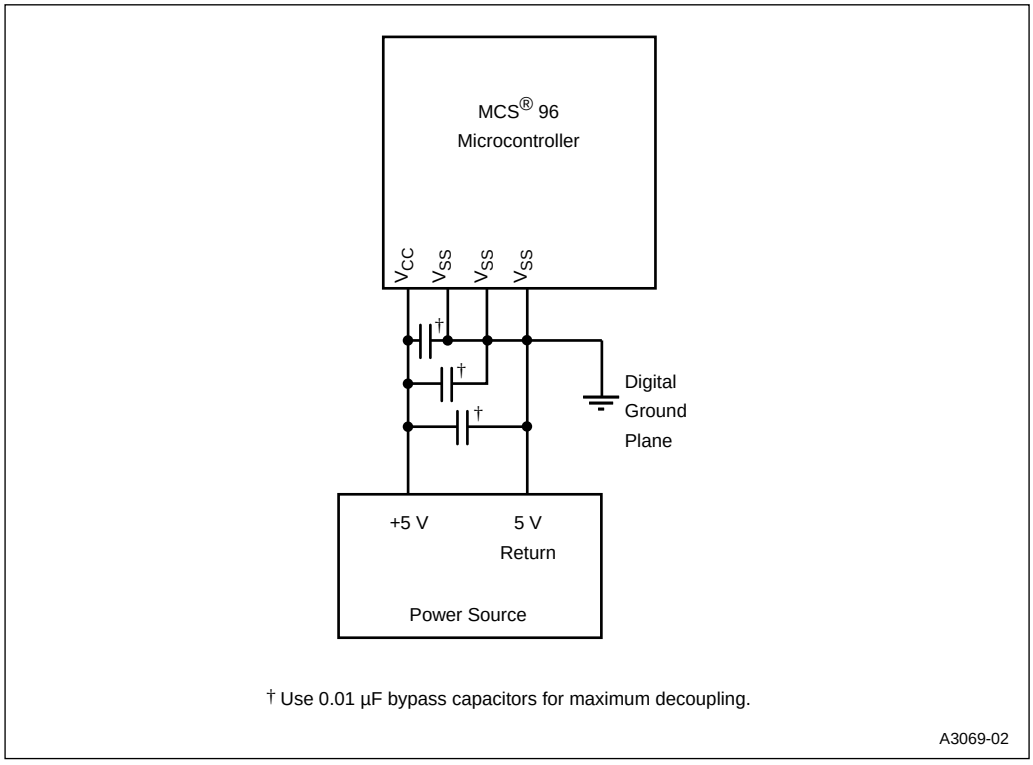


Figure 11-2. Power and Return Connections

Multilayer printed circuit boards with separate V_{CC} and ground planes also help to minimize noise. For more information on noise protection, refer to AP-125, *Designing Microcontroller Systems for Noisy Environments* (order number 210313) and AP-711, *EMI Design Techniques for Microcontrollers in Automotive Applications* (order number 272324).

11.4 THE ON-CHIP OSCILLATOR CIRCUITRY

The on-chip oscillator circuit (Figure 11-3) consists of a crystal-controlled, positive reactance oscillator. In this application, the crystal operates in a parallel resonance mode. The feedback resistor, Rf, consists of paralleled *n*-channel and *p*-channel FETs controlled by the internal powerdown signal. In powerdown mode, Rf acts as an open and the output drivers are disabled, which disables the oscillator. Both the XTAL1 and XTAL2 pins have built-in electrostatic discharge (ESD) protection.

NOTE

Although the maximum external clock input frequency is 50 MHz, the maximum oscillator input frequency is limited to 25 MHz.

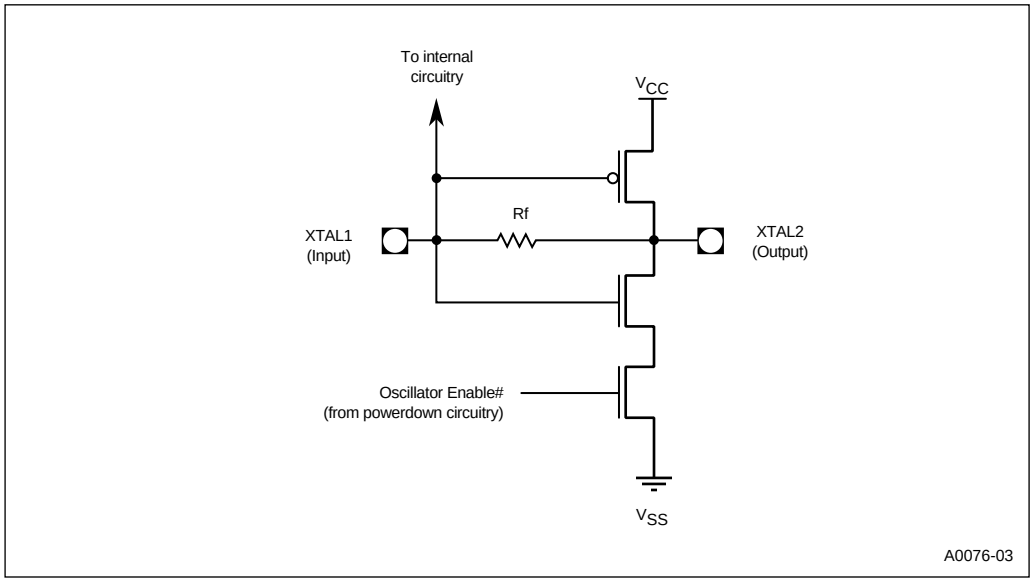
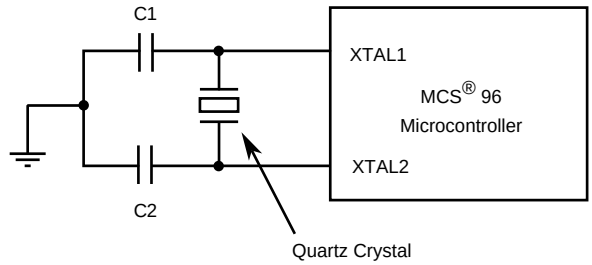


Figure 11-3. On-chip Oscillator Circuit

Figure 11-4 shows the connections between the external crystal and the device. When designing an external oscillator circuit, consider the effects of parasitic board capacitance, extended operating temperatures, and crystal specifications. Consult the manufacturer's datasheet for performance specifications and required capacitor values. With high-quality components, 20 pF load capacitors (C_L) are usually adequate for frequencies above 1 MHz.

Noise spikes on the XTAL1 or XTAL2 pin can cause a miscount in the internal clock-generating circuitry. Capacitive coupling between the crystal oscillator and traces carrying fast-rising digital signals can introduce noise spikes. To reduce this coupling, mount the crystal oscillator and capacitors near the device and use short, direct traces to connect to XTAL1, XTAL2, and V_{SS}. To further reduce the effects of noise, use grounded guard rings around the oscillator circuitry and ground the metallic crystal case.



Note:
Mount the crystal and capacitors close to the device using short, direct traces to XTAL1, XTAL2, and V_{SS}. When using a crystal, C1=C2≈20 pF. When using a ceramic resonator, consult the manufacturer for recommended oscillator circuitry.

A0273-03

Figure 11-4. External Crystal Connections

In cost-sensitive applications, you may choose to use a ceramic resonator instead of a crystal oscillator. Ceramic resonators may require slightly different load capacitor values and circuit configurations. Consult the manufacturer's datasheet for the requirements.

11.5 USING AN EXTERNAL CLOCK SOURCE

To use an external clock source, apply a clock signal to XTAL1 and let XTAL2 float (Figure 11-5). To ensure proper operation, the external clock source must meet the minimum high and low times (T_{XHXX} and T_{XLXX}) and the maximum rise and fall transition times (T_{XLXH} and T_{XHXL}) (Figure 11-6). The longer the rise and fall times, the higher the probability that external noise will affect the clock generator circuitry and cause unreliable operation. See the datasheet for required XTAL1 voltage drive levels and actual specifications.

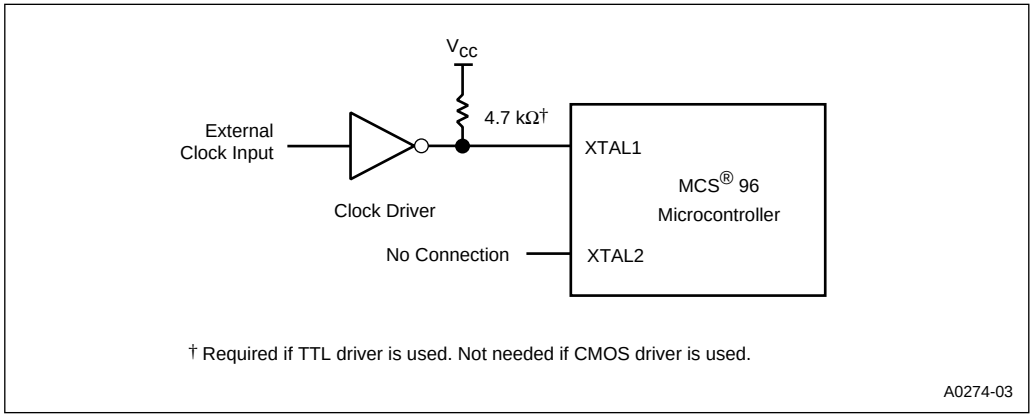


Figure 11-5. External Clock Connections

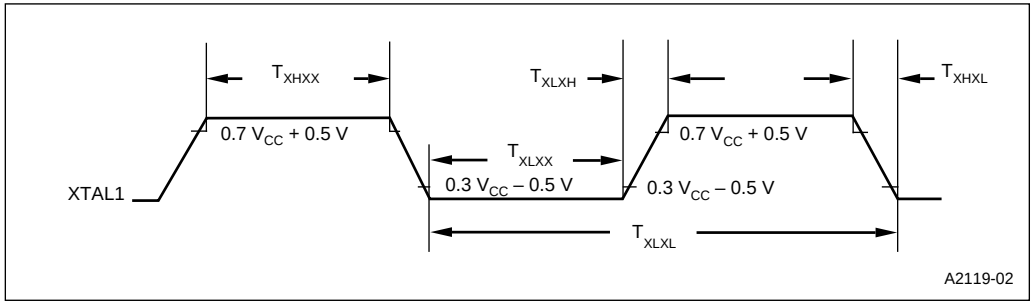


Figure 11-6. External Clock Drive Waveforms

At power-on, the interaction between the internal amplifier and its feedback capacitance (i.e., the Miller effect) may cause a load of up to 100 pF at the XTAL1 pin if the signal at XTAL1 is weak (such as might be the case during start-up of the external oscillator). This situation will go away when the XTAL1 input signal meets the V_{IL} and V_{IH} specifications (listed in the datasheet). If these specifications are met, the XTAL1 pin capacitance will not exceed 20 pF.

11.6 RESETTING THE DEVICE

Reset forces the device into a known state. As soon as RESET# is asserted, the I/O pins, the control pins, and the registers are driven to their reset states. Table B-5 on page B-11 lists the reset states of the pins. The device remains in its reset state until RESET# is deasserted. When RESET# is deasserted, the bus controller fetches the chip configuration bytes (CCBs), loads them into the chip configuration registers (CCRs), and then fetches the first instruction. Figure 11-7 shows the reset-sequence timing.

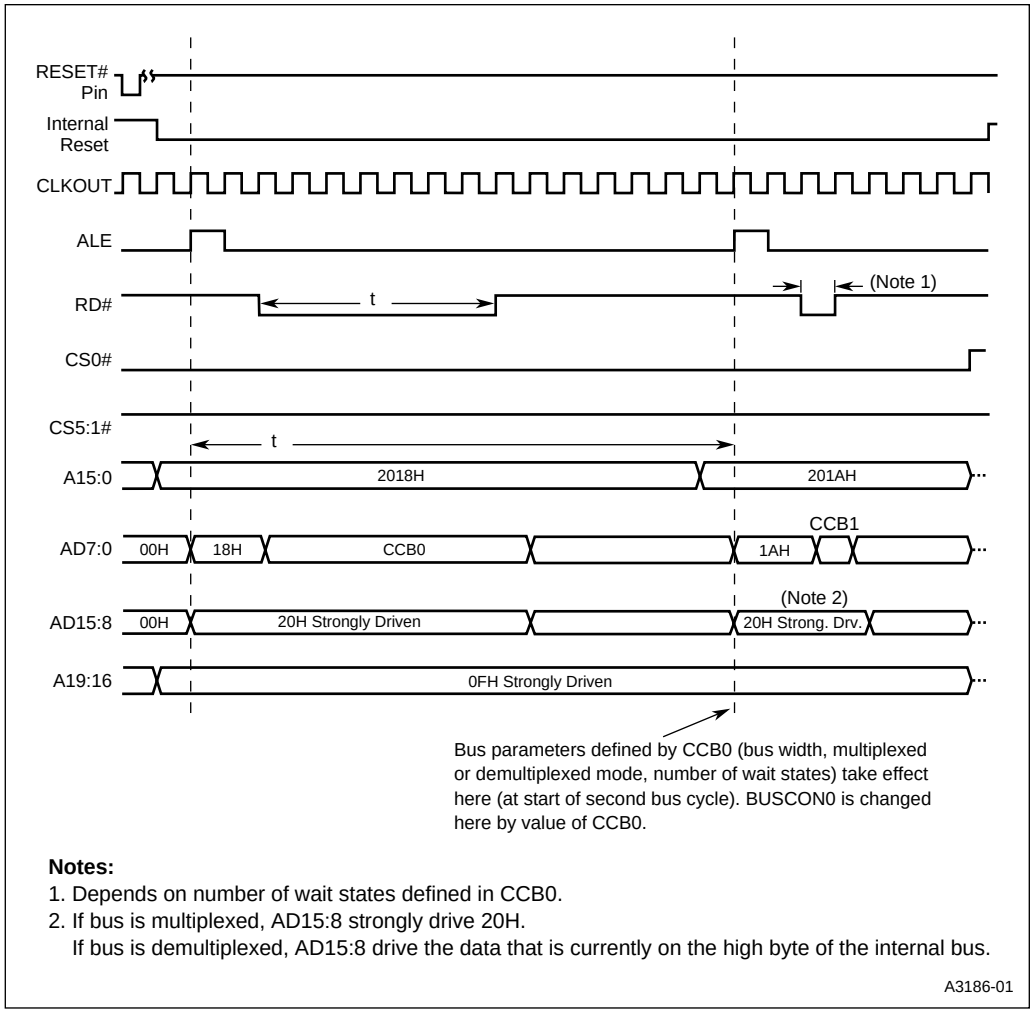


Figure 11-7. Reset Timing Sequence

The following events will reset the device (see Figure 11-8):

- an external device pulls the RESET# pin low
- the CPU issues the reset (RST) instruction
- the CPU issues an idle/powerdown/standby (IDLPD) instruction with an illegal key operand

The following paragraphs describe each of these reset methods in more detail.

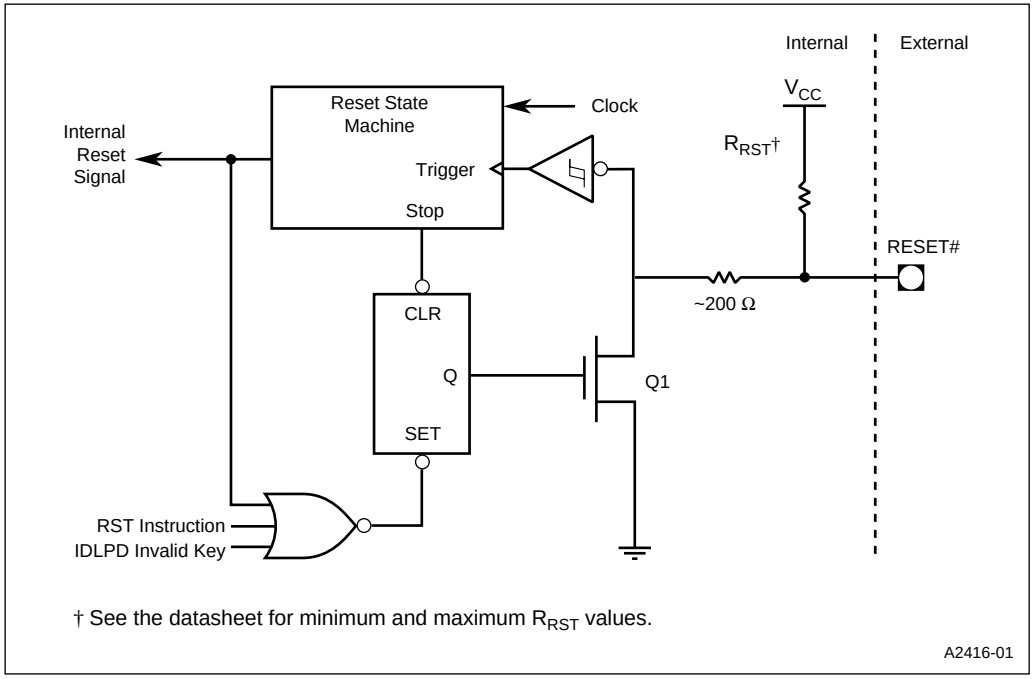


Figure 11-8. Internal Reset Circuitry

11.6.1 Generating an External Reset

To reset the device, hold the RESET# pin low for at least one state time after the power supply is within tolerance and the oscillator has stabilized. When RESET# is first asserted, the device turns on a pull-down transistor (Q1) in Figure 11-8 for 16 state times. This enables the RESET# signal to function as the system reset.

The simplest way to reset the microcontroller is to insert a capacitor between the RESET# pin and V_{SS}, as shown in Figure 11-9. The microcontroller has an internal pull-up resistor (R_{RST}), as shown in Figure 11-8. RESET# should remain asserted for at least one state time after V_{CC}, the on-chip oscillator, and the phase-locked loop circuitry have stabilized and met the operating conditions specified in the datasheet. A capacitor of 4.7 µF or greater should provide sufficient reset time, as long as V_{CC} rises quickly.

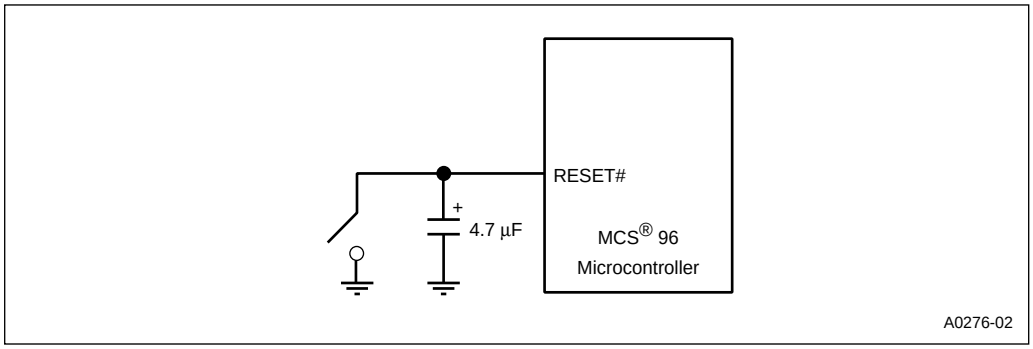


Figure 11-9. Minimum Reset Circuit

Other devices in the system may not be reset because the capacitor will keep the voltage above V_{IL}. Since RESET# is asserted for only 16 state times, it may be necessary to lengthen and buffer the system-reset pulse. Figure 11-10 shows an example of a system-reset circuit. In this example, D2 creates a wired-OR gate connection to the reset pin. An internal reset, system power-up, or SW1 closing will generate the system-reset signal.

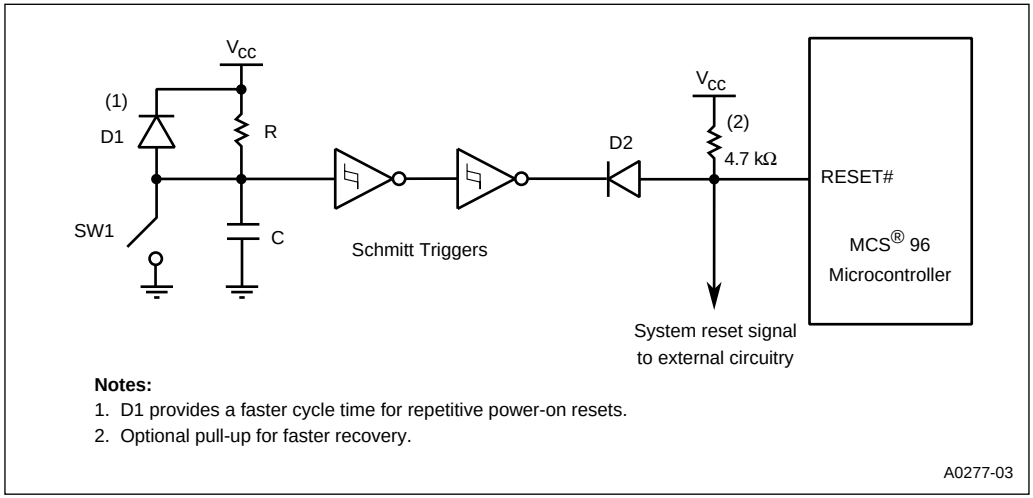


Figure 11-10. Example of a System Reset Circuit

11.6.2 Issuing the Reset (RST) Instruction

The RST instruction (opcode FFH) resets the device by pulling RESET# low for 16 state times. It also clears the processor status word (PSW), sets the master program counter (PC) to F2080H, and resets the special function registers (SFRs).

11.6.3 Issuing an Illegal IDLPD Key Operand

The device resets itself if an illegal key operand is used with the idle/powerdown/standby (IDLPD) command. The legal keys are “1” for idle mode, “2” for powerdown mode, and “3” for standby mode. If any other value is used, the device executes a reset sequence. (See Appendix A for a description of the IDLPD command.)

12

Special Operating Modes

CHAPTER 12
SPECIAL OPERATING MODES

The 80296SA provides three power saving modes: idle, standby, and powerdown. It also provides an on-circuit emulation (ONCE) mode that electrically isolates the microcontroller from the other system components. This chapter describes each mode and explains how to enter and exit each.

In addition, the 80296SA allows you to disable the PWM duty-cycle generator and the serial port baud-rate generator to conserve power when those peripherals are not being used.

12.1 SPECIAL OPERATING MODE SIGNALS AND REGISTERS

Table 12-1 lists the signals and Table 12-2 lists the registers that are mentioned in this chapter.

Table 12-1. Operating Mode Control Signals

Signal Name	Type	Description
CLKOUT	O	Clock Output Output of the internal clock generator. The CLKOUT frequency is ½ the internal operating frequency (f). CLKOUT has a 50% duty cycle. CLKOUT shares a package pin with P2.7.
EXTINT3 EXTINT2 EXTINT1 EXTINT0	I	External Interrupts In normal operating mode, a rising edge on EXTINT*x* sets the EXTINT*x* interrupt pending bit. EXTINT*x* is sampled during phase 2 (CLKOUT high). The minimum edge time is one state time. The minimum level time is two state times. In standby and powerdown modes, asserting the EXTINT*x* signal for at least 50 ns causes the device to resume normal operation. The interrupt need not be enabled, but the pin must be configured as a special-function input. If the EXTINT*x* interrupt is enabled, the CPU executes the interrupt service routine. Otherwise, the CPU executes the instruction that immediately follows the command that invoked the power-saving mode. In idle mode, asserting any enabled interrupt causes the device to resume normal operation. EXTINT0 shares a package pin with P2.2, EXTINT1 shares a package pin with P2.4, EXTINT2 shares a package pin with P3.6, and EXTINT3 shares a package pin with P3.7.
ONCE	I	On-circuit Emulation Holding ONCE high during the rising edge of RESET# places the device into on-circuit emulation (ONCE) mode. This mode puts all pins into a high-impedance state, thereby isolating the device from other components in the system. The value of ONCE is latched when the RESET# pin goes inactive. While the device is in ONCE mode, you can debug the system using a clip-on emulator. To exit ONCE mode, reset the device by pulling the RESET# signal low. To prevent inadvertent entry into ONCE mode, connect the ONCE pin to V_{SS}.

Table 12-1. Operating Mode Control Signals (Continued)

Signal Name	Type	Description
PLLEN2:1	I	Phase-locked Loop 1 and 2 Enable These input pins enable the on-chip clock multiplier feature and select either the doubled or the quadrupled clock speed: **PLLEN2** **PLLEN1** **Mode** 0 0 1x mode; PLL disabled; f = F_{XTAL1} 0 1 2x mode; PLL enabled; f = $2F_{XTAL1}$ 1 0 Reserved† 1 1 4x mode; PLL enabled; f = $4F_{XTAL1}$ † This reserved combination causes the device to enter an unsupported test mode.
RESET#	I/O	Reset A level-sensitive reset input to, and an open-drain system reset output from, the microcontroller. Either a falling edge on RESET# or an internal reset turns on a pull-down transistor connected to the RESET# pin for 16 state times. In the powerdown, standby, and idle modes, asserting RESET# causes the chip to reset and return to normal operating mode. After a device reset, the first instruction fetch is from F2080H in external memory. The program and special-purpose memory locations (F2000–F2FFFH) reside in external memory.
RPD	I	Return from Powerdown Timing pin for the return-from-powerdown circuit. If your application uses powerdown mode, connect a capacitor between RPD and V_{SS} if **either** of the following conditions are true. • the internal oscillator is the clock source • the phase-locked loop (PLL) circuitry is enabled (see PLLEN2:1 signal description) The capacitor causes a delay that enables the oscillator and PLL circuitry to stabilize before the internal CPU and peripheral clocks are enabled. The capacitor is not required if your application uses powerdown mode and if **both** of the following conditions are true. • an external clock input is the clock source • the phase-locked loop circuitry is disabled If your application does not use powerdown mode, leave this pin unconnected.

Table 12-2. Operating Mode Control and Status Registers

Mnemonic	Address	Description
CCR0	2018H	Chip Configuration 0 Enables or disables the IDLPD #2 and IDLPD #3 instructions. When enabled, the IDLPD #2 instruction causes the microcontroller to enter powerdown mode and the IDLPD #3 instruction causes the microcontroller to enter standby mode. This register also selects the write-control mode and contains the bus-control parameters for fetching chip configuration byte 1.
CON_REG0	1FB6H	PWM Control Register This register controls the clock prescaler and duty-cycle generator. Bits 0 and 1 (CLK0, CLK1) control the output period of the PWM channels by enabling or disabling the divide-by-two or divide-by-four clock prescaler. Bit 7 (DCD) controls the duty cycle generator by enabling or disabling the PWM*x*_CONTROL register.
INT_MASK	0008H	Interrupt Mask Bits 3 and 4 of this register enable and disable (mask) external interrupts EXTINT0 and EXTINT1.
INT_MASK1	0013H	Interrupt Mask 1 Bits 5 and 6 of this register enable and disable (mask) external interrupts EXTINT2 and EXTINT3.
INT_PEND	0009H	Interrupt Pending Bits 3 and 4 of this register are set to indicate pending external interrupts EXTINT0 and EXTINT1.
INT_PEND1	0012H	Interrupt Pending 1 Bits 5 and 6 of this register are set to indicate pending external interrupts EXTINT2 and EXTINT3.
P2_DIR P3_DIR	1FD3H 1FDAH	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.
P2_MODE P3_MODE	1FD1H 1FD8H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
P2_PIN P3_PIN	1FD7H 1F7EH	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.

Table 12-2. Operating Mode Control and Status Registers (Continued)

Mnemonic	Address	Description
P2_REG P3_REG	1FD5H 1FDCH	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.
SP_CON	1FBBH	Serial Port Control This register selects the serial mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables parity. For mode 2, and for mode 3 with parity disabled, it contains the ninth bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down-counter.

12.2 REDUCING POWER CONSUMPTION

Each power-saving mode conserves power by disabling portions of the internal clock circuitry (Figure 12-1). The following paragraphs describe each mode in detail.

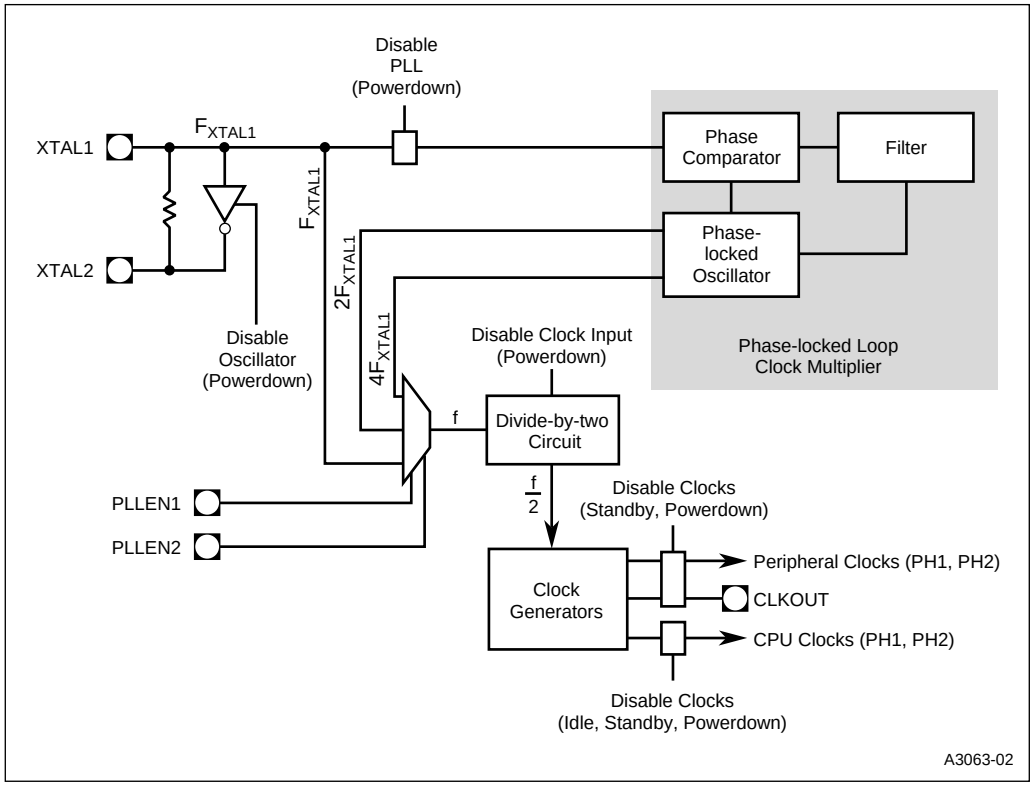


Figure 12-1. Clock Control During Power-saving Modes

12.3 IDLE MODE

In idle mode, the microcontroller's power consumption decreases to approximately 40% of normal consumption. Internal logic holds the CPU clocks at logic zero, causing the CPU to stop executing instructions. Neither the phase-locked loop circuitry, the peripheral clocks, nor CLKOUT are affected, so the special-function registers (SFRs) and register RAM retain their data, and the peripherals and interrupt system remain active. Table B-5 on page B-11 lists the values of the pins during idle mode.

The microcontroller enters idle mode after executing the IDLPD #1 instruction. Any enabled interrupt source, either internal or external, or a hardware reset can cause the device to exit idle mode. When an interrupt occurs, the CPU clocks restart and the CPU executes the corresponding interrupt service or PTS routine. When the routine is complete, the CPU fetches and then executes the instruction that follows the IDLPD #1 instruction.

NOTE

To prevent an accidental return to full power, hold the external interrupt pins (EXTINT*x*) low while the device is in idle mode.

12.4 STANDBY MODE

In standby mode, the microcontroller's power consumption decreases to approximately 10% of normal consumption. Internal logic holds the CPU and peripheral clocks at logic zero, which causes the CPU to stop executing instructions, the system bus control signals to become inactive, and the peripherals to turn off. The phase-locked loop (PLL) circuitry and the on-chip oscillator continue to operate. Table B-5 on page B-11 lists the values of the pins during standby mode.

12.4.1 Enabling and Disabling Standby Mode

The PD bit in the chip configuration register 0 (CCR0.0) either enables or disables both standby and powerdown modes. Because CCR0 cannot be accessed by code, the PD bit value is defined in chip configuration byte 0 (CCB0.0). Setting the PD bit enables both standby and powerdown modes and clearing it disables both modes. CCR0 is loaded from CCB0 when the microcontroller returns from reset. (See "Chip Configuration Registers and Chip Configuration Bytes" on page 13-17 for further clarification.)

12.4.2 Entering Standby Mode

Before entering standby mode, complete the following tasks:

- Complete all serial port transmissions or receptions. Otherwise, when the device exits standby, the serial port activity will continue where it left off and incorrect data may be transmitted or received.
- Disable the serial port baud-rate generator by setting SP_CON.7.
- Disable the PWM duty-cycle generator by setting CON_REG0.7.
- Put all other peripherals into an inactive state.

After completing these tasks, execute the IDLPD #3 instruction to enter standby mode.

NOTE

To prevent an accidental return to full power, hold the external interrupt pins (EXTINT*x*) low while the device is in standby mode.

12.4.3 Exiting Standby Mode

The device will exit standby mode when a transition on an **external** interrupt pin (EXTINT3:0) or a hardware reset occurs. An interrupt need not be enabled for it to bring the microcontroller out of standby, but the pin must be configured as a special-function input (see "Configuring the Port Pins" on page 7-3).

When an external interrupt brings the device out of standby mode, the corresponding pending bit is set in the interrupt pending register. If the interrupt is enabled, the microcontroller executes the interrupt service routine, then fetches and executes the instruction following the IDLPD #3 instruction. If the interrupt is disabled (masked), the microcontroller fetches and executes the instruction following the IDLPD #3, instruction and the pending bit remains set until the interrupt is serviced or software clears it.

12.5 POWERDOWN MODE

Powerdown mode places the microcontroller into a very low power state by disabling the internal oscillator, the phase-locked loop circuitry, and the clock generators. Internal logic holds the CPU and peripheral clocks at logic zero, which causes the CPU to stop executing instructions, the system bus-control signals to become inactive, the CLKOUT signal to become high, and the peripherals to turn off. Power consumption drops into the microwatt range (refer to the datasheet for exact specifications). I_{CC} is reduced to device leakage. Table B-5 on page B-11 lists the values of the pins during powerdown mode. If V_{CC} is maintained above the minimum specification, the special-function registers (SFRs) and register RAM retain their data.

12.5.1 Enabling and Disabling Powerdown Mode

The PD bit in the chip configuration register 0 (CCR0.0) either enables or disables both standby and powerdown modes. CCR0 cannot be accessed by code; the PD bit value is defined in chip configuration byte 0 (CCB0.0). If the PD bit is set, both standby and powerdown modes are enabled. If the PD bit is clear, both are disabled. CCR0 is loaded from CCB0 when the microcontroller returns from reset. (See "Chip Configuration Registers and Chip Configuration Bytes" on page 13-17 for further clarification.)

12.5.2 Entering Powerdown Mode

Before entering powerdown, complete the following tasks:

- Complete all serial port transmissions or receptions. Otherwise, when the device exits powerdown, the serial port activity will continue where it left off and incorrect data may be transmitted or received.
- Disable the serial port baud-rate generator by setting bit SP_CON.7.
- Disable the PWM duty cycle generator by setting CON_REG0.7.
- Put all other peripherals into an inactive state.

After completing these tasks, execute the IDLPD #2 instruction to enter powerdown mode.

NOTE

To prevent an accidental return to full power, hold the external interrupt pins (EXTINT*x*) low while the device is in powerdown mode.

12.5.3 Exiting Powerdown Mode

The microcontroller will exit powerdown mode when either of the following events occurs:

- a hardware reset is generated
- a transition occurs on an external interrupt pin

12.5.3.1 Generating a Hardware Reset

The microcontroller will exit powerdown if RESET# is asserted. Asserting RESET# causes the chip to reset and return to normal operating mode. If the phase-locked loop (PLL) clock circuitry is enabled or if the design uses an external clock input signal, you must hold RESET# low for at least 2 ms to allow the PLL to stabilize before the internal CPU and peripheral clocks are enabled. If the design uses the on-chip oscillator, then either a falling edge on RESET# or an internal reset turns on a pull-down transistor connected to the RESET# pin for 16 state times.

12.5.3.2 Asserting an External Interrupt Signal

The other way to exit powerdown mode is to assert an external interrupt signal (EXTINT3:0) for at least 50 ns. Although EXTINT3:0 are normally sampled inputs, the powerdown circuitry uses them as level-sensitive inputs. An interrupt need not be enabled to bring the microcontroller out of powerdown, but the pin must be configured as a special-function input (see "Configuring the Port Pins" on page 7-3). Figure 12-2 shows the power-up and power-down sequence when using an external interrupt to exit powerdown.

When the external interrupt brings the microcontroller out of powerdown mode, the corresponding pending bit is set in the interrupt pending register. If the interrupt is enabled, the device executes the interrupt service routine, then fetches and executes the instruction following the IDLPD #2 instruction. If the interrupt is disabled (masked), the device fetches and executes the instruction following the IDLPD #2, instruction and the pending bit remains set until the interrupt is serviced or software clears the pending bit.

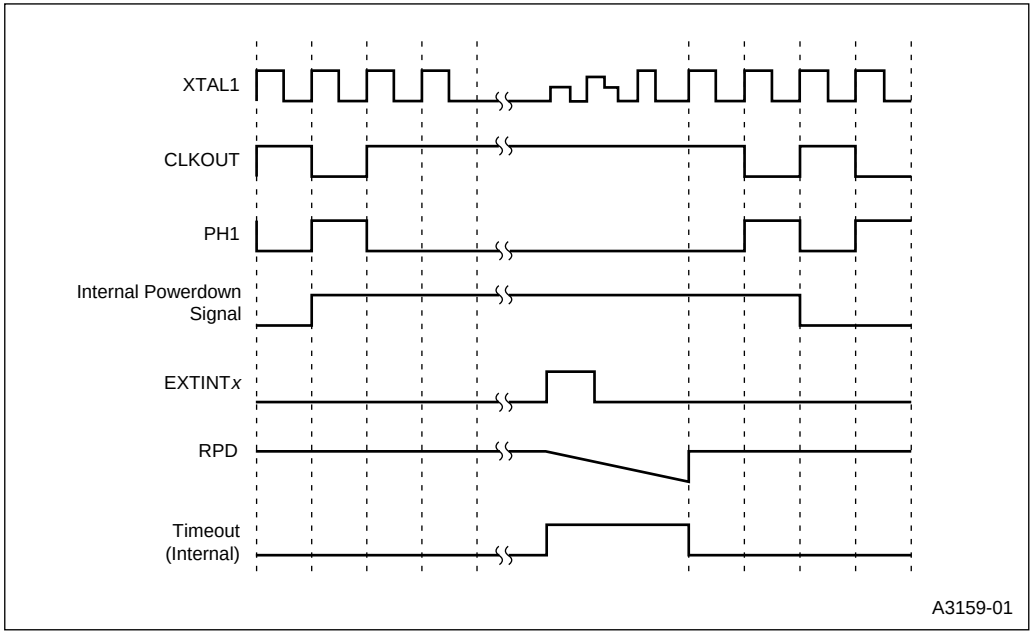


Figure 12-2. Power-up and Power-down Sequence When Using an External Interrupt

When using the external interrupt signal to exit powerdown mode, we recommend that you connect the external capacitor shown in Figure 12-3 to the RPD pin. The discharging of the capacitor causes a delay that allows the oscillator and phase-locked loop circuitry to stabilize before the internal CPU and peripheral clocks are enabled.

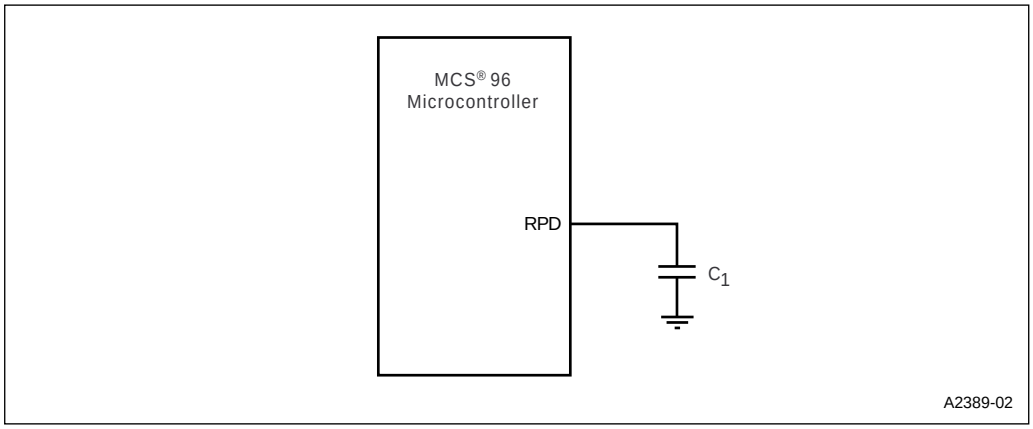


Figure 12-3. External RC Circuit

During normal operation (before entering powerdown mode), an internal pull-up holds the RPD pin at V_{CC}. When the external interrupt signal is asserted, the internal oscillator circuitry is enabled and turns on a weak internal pull-down (approximately 10 kΩ). This weak pull-down causes the external capacitor (C_1) to begin discharging at a typical rate of 200 µA. When the RPD pin voltage drops below the threshold voltage (about 2.5 V), the internal phase clocks are enabled and the device resumes code execution.

At this time, a Schmitt-triggered detection circuit prompted by the switching voltage levels strongly drives a logic one, quickly pulling the RPD pin back up to V_{CC} (see recovery time in Figure 12-4). The time constant (RC) follows an exponential charging curve. However, since there is no external resistor on the RPD pin, the time constant goes to zero and the recovery time is instantaneous.

$$V_c = V_{cc}[1 - e^{(t/\tau)}]; \quad (\tau = RC_1 = 0)$$

$$V_c = V_{cc}$$

where:

V_C = Charging capacitor voltage

12.5.3.3 Selecting C_1

With the resistance of the discharge path designed into the silicon with an internal pull-down resistor, the selection of an external capacitor (C_1) can be critical. Ideally, you want to select a component that will produce a sufficient discharge time to permit the internal oscillator circuitry to stabilize. Because many factors can influence the discharge time requirement, you should always fully characterize your design under worst-case conditions to verify proper operation.

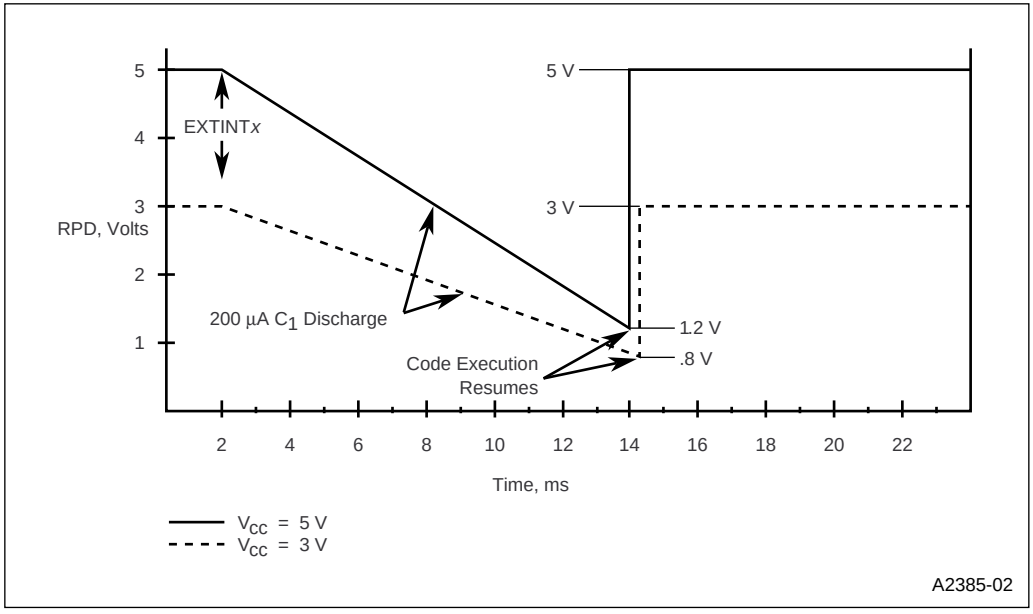


Figure 12-4. Typical Voltage on the RPD Pin While Exiting Powerdown

When selecting the capacitor, determine the worst-case discharge time needed for the oscillator to stabilize, then use this formula to calculate an appropriate value for C_1.

$$C_1 = \frac{T_{DIS} \times I}{V_t}$$

where:

C_1	is the capacitor value, in farads
T_{DIS}	is the worst-case discharge time, in seconds
I	is the discharge current, in amperes
V_t	is the threshold voltage

NOTE

If powerdown is re-entered and exited before C_1 charges to V_{CC}, it will take less time for the voltage to ramp down to the threshold. Therefore, the device will take less time to exit powerdown.

For example, assume that the oscillator needs at least 12.5 ms to discharge (T_{DIS} = 12.5 ms), V_t is 2.5 V, and the discharge current is 200 µA. The minimum C_1 capacitor size is 1 µF.

$$C_1 = \frac{(0.0125)(0.0002)}{2.5} = 1\ \mu F$$

When using an external oscillator, the value of C_1 can be very small, allowing rapid recovery from powerdown. For example, a 100 pF capacitor discharges in 1.25 µs.

$$T_{DIS} = \frac{C_1 \times V_t}{I} = \frac{(1.0 \times 10^{-10})(2.5)}{0.0002} = 1.25\ \mu s$$

12.6 ONCE MODE

On-circuit emulation (ONCE) mode isolates the microcontroller from other components in the system to allow printed-circuit-board testing or debugging with a clip-on emulator. During ONCE mode, all pins except XTAL1, XTAL2, V_{SS}, and V_{CC} are weakly pulled high or low. RESET# must be held high; otherwise, the microcontroller will exit ONCE mode and enter the reset state.

Holding the ONCE signal high during the rising edge of RESET# causes the microcontroller to enter ONCE mode. The ONCE signal is latched when RESET# goes inactive. Internally, the ONCE pin is tied to a medium-strength pull-down. To prevent accidental entry into ONCE mode, connect the ONCE pin to V_{SS}.

Exit ONCE mode by asserting the RESET# signal. Normal operations resume when RESET# goes high.

12.7 ADDITIONAL POWER CONSERVATION FEATURES

The 80296SA implements additional power conservation features that are new to the MCS® 96 microcontroller family. This feature allows you to individually disable the PWM duty-cycle generator and the serial I/O port's baud-rate generator when your system is not using these peripherals.

The DCD bit in the PWM clock control register (CON_REG0 on page C-7) enables and disables the duty-cycle generator. Setting DCD enables the duty-cycle generator; clearing DCD disables it. The DCD bit is cleared at reset (duty-cycle generator enabled). If your system uses the PWM, ensure that your code leaves the DCD bit cleared. If your system is not using the PWM, you can set the DCD bit to conserve power.

The BCD bit in the serial port control register (SP_CON on page C-11) enables and disables the baud-rate generator. Setting BCD enables the baud-rate generator; clearing BCD disables it. The BCD bit is set at reset (baud-rate generator disabled). If your system uses the SIO, ensure that your code clears the BCD bit. If your system is not using the serial I/O port, you need not write to SP_CON.

The bits that implement these new features (DCD in CON_REG0 and BCD in SP_CON) are reserved in previous MCS 96 microcontrollers; they are documented as "Reserved; for compatibility with future devices, write zero to this bit." Therefore, code written for a previous MCS 96 microcontroller system that uses these peripherals will enable the duty-cycle generator and baud-rate generator as part of the initialization.

12.8 RESERVED TEST MODES

Holding PLLEN1 low while PLLEN2 is held high causes the device to enter an unsupported test mode. Table 12.7 shows the proper PLLEN1 and PLLEN2 connections for valid clock modes.

Table 12-3. 80296SA Clock Modes

PLLEN2	PLLEN1	Mode
0	0	Clock-multiplier circuitry disabled.
0	1	Doubled; clock doubling circuitry enabled. Internal clock is twice the XTAL1 input.
1	0	Reserved. **CAUTION:** This combination causes the device to enter an unsupported test mode.
1	1	Quadrupled; clock quadrupling circuitry enabled. Internal clock is four times the XTAL1 input.

13

Interfacing with External Memory

CHAPTER 13
INTERFACING WITH EXTERNAL MEMORY

The microcontroller can interface with a variety of external memory devices. Six chip-selects can be individually programmed for bus width, the number of wait states, and a multiplexed or demultiplexed address/data bus. With the chip-select remap feature, the microcontroller can access a memory device using two different bus configurations. Other features of the external memory interface include ready control for inserting additional wait states, a bus-hold protocol that enables external devices to take control of the bus, and two write-control modes for writing words and bytes to memory. These features provide a great deal of flexibility when interfacing with external memory systems.

In addition to describing the signals and registers related to external memory, this chapter discusses the process of fetching the chip configuration bytes and configuring the external bus. It also provides examples of external memory configurations and chip-select setup.

13.1 INTERNAL AND EXTERNAL ADDRESSES

The address that external devices see is different from the address that the microcontroller generates internally. The microcontroller has 24 address bits internally, but only 20 address pins (A19:0) externally. The absence of the upper four address bits at the external pins causes different internal addresses to have the same external address. For example, the internal addresses FF2080H, 7F2080H, and 0F2080H all appear at the 20 external pins as F2080H. The upper four bits of the internal address have no effect on the external address.

The address seen by an external device also depends on the number of address lines that the external system uses. If the address on the external pins (A19:0) is F2080H, and only A17:0 are connected to the external device, the external device sees 32080H. The upper four address lines (A19:16) are implemented by the EPORT. Table 13-1 shows how the external address depends on the number of EPORT lines used to address the external device.

Table 13-1. Example of Internal and External Addresses

Internal Address	Address on the Microcontroller Pins	EPORT Pins Connected to the External Device	Address Seen by External Device
*x*F2080H	F2080H	A16	12080H
		A17:16	32080H
		A18:16	72080H
		A19:16	F2080H

13.2 EXTERNAL MEMORY INTERFACE SIGNALS AND REGISTERS

Table 13-2 lists the signals and Table 13-3 lists the registers that are mentioned in this chapter. Some of the microcontroller port pins can function as either bus-control signals or general purpose I/O signals. "Using the Special-function Signals" on page 7-6 describes how to configure a port pin as either a general purpose I/O signal or a bus-control signal.

Table 13-2. Bus-control Signals

Signal Name	Port Pin	Type	Description
A15:0	—	O	System Address Bus These address lines provide address bits 0–15 during the entire external memory cycle during both multiplexed and demultiplexed bus modes.
A19:16	EPORT.3:0	O	Address Lines 16–19 These address lines provide address bits 16–19 during the entire external memory cycle during both multiplexed and demultiplexed bus modes, supporting extended addressing of the 1-Mbyte address space. **NOTE:** Internally, there are 24 address bits; however, only 20 external address pins (A19:0) are implemented. The internal address space is 16 Mbytes (000000–FFFFFFH) and the external address space is 1 Mbyte (00000–FFFFFH). The device resets to F2080H in external memory. A19:16 share package pins with EPORT.3:0.
AD15:0	—	I/O	Address/Data Lines The function of these pins depends on the bus size and mode. **16-bit Multiplexed Bus Mode**: AD15:0 drive address bits 0–15 during the first half of the bus cycle and drive or receive data during the second half of the bus cycle. **8-bit Multiplexed Bus Mode**: AD15:8 drive address bits 8–15 during the entire bus cycle. AD7:0 drive address bits 0–7 during the first half of the bus cycle and drive or receive data during the second half of the bus cycle. **16-bit Demultiplexed Mode**: AD15:0 drive or receive data during the entire bus cycle. **8-bit Demultiplexed Mode**: AD7:0 drive or receive data during the entire bus cycle. AD15:8 drive the data that is currently on the high byte of the internal bus.
ALE	—	O	Address Latch Enable This active-high output signal is asserted only during external memory cycles. ALE signals the start of an external bus cycle and indicates that valid address information is available on the system address/data bus (A19:16 and AD15:0 for a multiplexed bus; A19:0 for a demultiplexed bus). An external latch can use this signal to demultiplex address bits 0–15 from the address/data bus in multiplexed mode.

Table 13-2. Bus-control Signals (Continued)

Signal Name	Port Pin	Type	Description
BHE#	—	O	Byte High Enable† During 16-bit bus cycles, this active-low output signal is asserted for word and high-byte reads and writes to external memory. BHE# indicates that valid data is being transferred over the upper half of the system data bus. Use BHE#, in conjunction with address bit 0 (A0 for a demultiplexed address bus, AD0 for a multiplexed address/data bus), to determine which memory byte is being transferred over the system bus: **BHE# AD0 or A0 Byte(s) Accessed** 0 0 both bytes 0 1 high byte only 1 0 low byte only BHE# shares a package pin with WRH#. † The chip configuration register 0 (CCR0) determines whether this pin functions as BHE# or WRH#. CCR0.2 = 1 selects BHE#; CCR0.2 = 0 selects WRH#.
BREQ#	P2.3	O	Bus Request This active-low output signal is asserted during a hold cycle when the bus controller has a pending external memory cycle. When the bus-hold protocol is enabled (WSR.7 is set), the P2.3/BREQ# pin can function only as BREQ#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). The device can assert BREQ# at the same time as or after it asserts HLDA#. Once it is asserted, BREQ# remains asserted until HOLD# is removed. BREQ# shares a package pin with P2.3.
CLKOUT	P2.7	O	Clock Output Output of the internal clock generator. The CLKOUT frequency is ½ the internal operating frequency (f). CLKOUT has a 50% duty cycle. CLKOUT shares a package pin with P2.7.
CS5:0#	P3.5:0	O	Chip-select Lines 0–5 The active-low output CS*x*# is asserted during an external memory cycle when the address to be accessed is in the range programmed for chip select *x* or chip select *x*+1 if remapping is enabled. If the external memory address is outside the range assigned to the six chip selects, no chip-select output is asserted and the bus configuration defaults to the CS5# values. Immediately following reset, CS0# is automatically assigned to the range F2000–F20FFH. CS5:0# share package pins with P3.5:0.

Table 13-2. Bus-control Signals (Continued)

Signal Name	Port Pin	Type	Description
HLDA#	P2.6	O	Bus Hold Acknowledge This active-low output indicates that the CPU has released the bus as the result of an external device asserting HOLD#. When the bus-hold protocol is enabled (WSR.7 is set), the P2.6/HLDA# pin can function only as HLDA#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). HLDA# shares a package pin with P2.6.
HOLD#	P2.5	I	Bus Hold Request An external device uses this active-low input signal to request control of the bus. When the bus-hold protocol is enabled (WSR.7 is set), the P2.5/HOLD# pin can function only as HOLD#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). HOLD# shares a package pin with P2.5.
INST	—	O	Instruction Fetch This active-high output signal is valid only during external memory bus cycles. When high, INST indicates that an instruction is being fetched from external memory. The signal remains high during the entire bus cycle of an external instruction fetch. INST is low for data accesses, including interrupt vector fetches and chip configuration byte reads. INST is low during internal memory fetches.
RD#	—	O	Read Read-signal output to external memory. RD# is asserted only during external memory reads.
READY	—	I	Ready Input This active-high input can be used to insert wait states in addition to those programmed in the chip configuration byte 0 (CCB0) and the bus control *x* register (BUSCON*x*). CCB0 is programmed with the minimum number of wait states (0, 5, 10, 15) for an external fetch of CCB1, and BUSCON*x* is programmed with the minimum number of wait states (0–15) for all external accesses to the address range assigned to the chip-select *x* channel. If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.

Table 13-2. Bus-control Signals (Continued)

Signal Name	Port Pin	Type	Description
WR#	—	O	Write† This active-low output indicates that an external write is occurring. This signal is asserted only during external memory writes. WR# shares a package pin with WRL#. † The chip configuration register 0 (CCR0) determines whether this pin functions as WR# or WRL#. CCR0.2 = 1 selects WR#; CCR0.2 = 0 selects WRL#.
WRH#	—	O	Write High† During 16-bit bus cycles, this active-low output signal is asserted for high-byte writes and word writes to external memory. During 8-bit bus cycles, WRH# is asserted for all write operations. WRH# shares a package pin with BHE#. † The chip configuration register 0 (CCR0) determines whether this pin functions as BHE# or WRH#. CCR0.2 = 1 selects BHE#; CCR0.2 = 0 selects WRH#.
WRL#	—	O	Write Low† During 16-bit bus cycles, this active-low output signal is asserted for low-byte writes and word writes to external memory. During 8-bit bus cycles, WRL# is asserted for all write operations. WRL# shares a package pin with WR#. † The chip configuration register 0 (CCR0) determines whether this pin functions as WR# or WRL#. CCR0.2 = 1 selects WR#; CCR0.2 = 0 selects WRL#.

Table 13-3. External Memory Interface Registers

Register Mnemonic	Address	Description
ADDRCOM0 ADDRCOM1 ADDRCOM2 ADDRCOM3 ADDRCOM4 ADDRCOM5	1F40H 1F48H 1F50H 1F58H 1F60H 1F68H	Address Compare Holds address bits 8–23 of the base address of the address range assigned to CS*x*#.
ADDRMSK0 ADDRMSK1 ADDRMSK2 ADDRMSK3 ADDRMSK4 ADDRMSK5	1F42H 1F4AH 1F52H 1F5AH 1F62H 1F6AH	Address Mask Determines the size of the address range (256 bytes–1 Mbyte) assigned to CS*x*#.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Table 13-3. External Memory Interface Registers (Continued)

Register Mnemonic	Address	Description
BUSCON0 BUSCON1 BUSCON2 BUSCON3 BUSCON4 BUSCON5	1F44H 1F4CH 1F54H 1F5CH 1F64H 1F6CH	Bus Control Determines the bus configuration for external accesses to the address range assigned to CS*x*# and enables or disables remapping. The bus parameters are 8- or 16-bit bus width, multiplexed or demultiplexed address/data lines, and the number of wait states inserted into each bus cycle.
CCR0	†	Chip Configuration 0 Enables or disables the IDLPD #2 and IDLPD #3 instructions. When enabled, the IDLPD #2 instruction causes the microcontroller to enter powerdown mode and the IDLPD #3 instruction causes the microcontroller to enter standby mode. This register also selects the write-control mode and contains the bus-control parameters for fetching chip configuration byte 1.
CCR1	†	Chip Configuration 1 Selects the 64-Kbyte or 1-Mbyte addressing mode.
EP_DIR	1FE3H	Extended Port Direction In I/O mode, each bit of the extended port I/O direction (EP_DIR) register controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary signal; setting a bit configures a pin as an open-drain signal. Any pin that is configured for its extended-address function is forced to the complementary output mode except during reset, hold, idle, powerdown, and standby.
EP_MODE	1FE1H	Extended Port Mode Each bit of the extended port mode (EP_MODE) register controls whether the corresponding pin functions as a general-purpose I/O signal or as a special-function (extended address or chip-select) signal. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
EP_PIN	1FE7H	Extended Port Input Each bit of the extended port input (EP_PIN) register reflects the current state of the corresponding pin, regardless of the pin configuration.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Table 13-3. External Memory Interface Registers (Continued)

Register Mnemonic	Address	Description
EP_REG	1FE5H	Extended Port Data Output **For I/O Mode (EP_MODE.*x* = 0)** When a port pin is configured as a complementary output (EP_DIR.*x* = 0), setting the corresponding EP_REG bit drives a one on the pin and clearing the corresponding EP_REG bit drives a zero on the pin. When a port pin is configured as a high impedance input or an open-drain output (EP_DIR.*x* = 1), clearing the corresponding EP_REG bit drives a zero on the pin and setting the corresponding EP_REG bit floats the pin, making it available as a high impedance input. **For Special-function Mode (EP_MODE.*x* = 1)** When an EPORT pin is configured as an extended-address signal, the EP_REG bit value is immaterial because the address bus controls the pin.
P2_DIR P3_DIR	1FD3H 1FDAH	Port Direction Register Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.
P2_MODE P3_MODE	1FD1H 1FD8H	Port Mode Register Each bit controls the mode of the corresponding pin. Setting a bit configures a pin as a special-function signal; clearing a bit configures a pin as a general-purpose I/O signal.
P2_PIN P3_PIN	1FD7H 1FDEH	Port Pin Register Each bit reflects the current state of the corresponding pin, regardless of the pin's mode and configuration.
P2_REG P3_REG	1FD5H 1FDCH	Port Data Output Register **For I/O Mode (P*x*_MODE.*x* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*x* = 0), setting the corresponding port data bit drives a one on the pin, and clearing the corresponding port data bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*x* = 1), clearing the corresponding port data bit drives a zero on the pin, and setting the corresponding port data bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*x* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

13.3 THE CHIP-SELECT UNIT

The chip-select unit provides six outputs, CS5:0#, for selecting an external device during an external bus cycle. During an external memory access, a chip-select output CS*x*# is asserted if the address falls within the address range assigned to that chip-select. The bus width, the number of wait states, and multiplexed or demultiplexed address/data lines are programmed independently for each of the six chip-selects. If the external address is outside the range of the six chip-selects, the chip-select 5 bus control register determines the wait states, bus width, and multiplexing for the current bus cycle, and no chip-select is asserted.

Figure 13-1 illustrates the microcontroller's calculation of a chip-select output CS*x*# for a given external memory address. Address bits 8–23 of the memory address are compared (XORed) bitwise with the 16 least-significant bits (BASE23:8) of the ADDRCOM*x* register. If all of the bits match, CS*x*# is asserted. Additionally, if some bits do not match, CS*x*# is still asserted if, for each nonmatching bit in ADDRCOM*x*, the corresponding bit in ADDRMSK*x* is cleared. The 16 least-significant bits are named MASK23:8 for their function in masking bits BASE23:8.

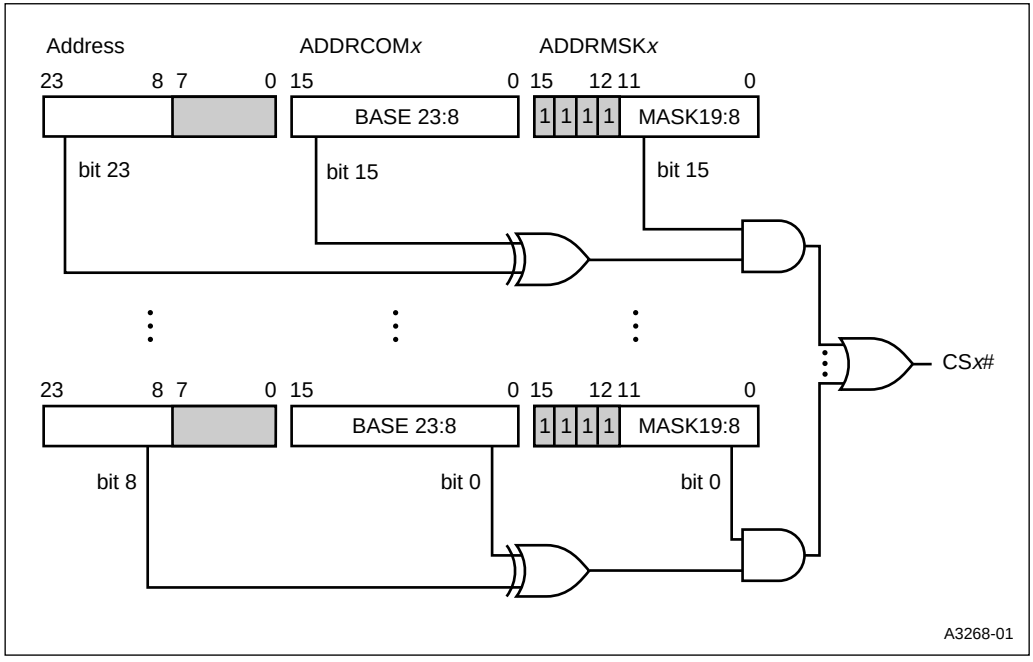


Figure 13-1. Calculation of a Chip-select Output

13.3.1 Defining Chip-select Address Ranges

This section describes the ADDRCOM*x* and ADDRMSK*x* registers and how to set them up for a desired address range. The ADDRCOM*x* register (Figure 13-2) and ADDRMSK*x* register (Figure 13-3) control the assertion of each chip-select output. The BASE23:8 bits in the ADDRCOM*x* register determine the base address of the address range. The MASK23:8 bits in the ADDRMSK*x* register determine the size of the address range.

ADDRCOM*x*
***x* = 0–5**

Address: Table 13-3 on page 13-5
Reset State: (*x* = 0) FF20H
(*x* = 1–5) 0000H

The address compare (ADDRCOM*x*) register specifies the base (lowest) address of the address range. The base address of a 2^n-byte address range must be on a 2^n-byte boundary.

15							8
BASE23	BASE22	BASE21	BASE20	BASE19	BASE18	BASE17	BASE16
7							**0**
BASE15	BASE14	BASE13	BASE12	BASE11	BASE10	BASE9	BASE8

Bit Number	Bit Mnemonic	Function
15:0	BASE23:8	Base Address Bits Write address bits 23–8 of the base address of the address range assigned to chip-select *x* to these bits.

Figure 13-2. Address Compare (ADDRCOM*x*) Registers

ADDRMSK*x*
***x* = 0–5**

Address: Table 13-3 on page 13-5
Reset State: FFFFH

The address mask (ADDRMSK*x*) register, together with the address compare register, defines the address range that is assigned to the chip-select *x* output, CS*x*#. The address mask register determines the size of the address range, which must be 2^n bytes, where $n = 8, 9, \ldots, 20$. For a 2^n-byte address range, calculate $n_1 = 24 - n$, and set the n_1 most-significant bits of MASK23:8 in the address mask register.

15							8
MASK23	MASK22	MASK21	MASK20	MASK19	MASK18	MASK17	MASK16
7							**0**
MASK15	MASK14	MASK13	MASK12	MASK11	MASK10	MASK9	MASK8

Bit Number	Bit Mnemonic	Function
15:0	MASK23:8	Address Mask Bits For a 2^n-byte address range, set the n_1 most-significant bits of MASK23:8, where $n_1 = 24 - n$. Since 20 external address lines are available, the maximum address range size is 1 Mbyte (2^{20}). Therefore, always write ones to the 4 most-significant mask bits (MASK23:20).

Figure 13-3. Address Mask (ADDRMSK*x*) Registers

Observe the following restrictions in choosing an address range for a chip-select output:

- The addresses in the address range must be contiguous.
- The size of the address range must be 2^n bytes, where $n = 8, 9, ..., 20$. This corresponds to block sizes of 256 bytes, 512 bytes, ..., 1 Mbyte.
- The base address of a 2^n-byte address range must be on a 2^n-byte boundary (that is, the base address must be evenly divisible by 2^n). For example, the base address of a 256-Kbyte range must be 00000H, 40000H, 80000H, or C0000H. Table 13-4 shows the base addresses for some address-range sizes.

Table 13-4. Base Addresses for Several Sizes of the Address Range

Address-Range Size	1 Mbyte (2^{20})	512 Kbyte (2^{19})	256 Kbyte (2^{18})		512 bytes (2^{9})	256 bytes (2^{8})
Base Addresses					FFD00H	FFF00H
					FFB00H	FFE00H
				• • •	• • •	• • •
			C0000H		00600H	00300H
			80000H		00400H	00200H
		80000H	40000H		00200H	00100H
	00000H	00000H	00000H		00000H	00000H

For an address range satisfying these restrictions, set up the ADDRCOM*x* and ADDRMSK*x* registers as follows:

- Place address bits 23–8 of the base address into bits BASE23:8 in the ADDRCOM*x* register (Figure 13-2).
- For an address range of 2^n bytes, set the n_1 most-significant bits of MASK23:8 in the ADDRMSK*x* register (Figure 13-3), where $n_1 = 24 - n$.

For example, assume that chip-select output *x* is to be assigned to a 32-Kbyte address range with base address EE0000H. The address range size is $32 \times 1024 = 2^{15}$, and $n_1 = 24 - 15 = 9$. To set up the registers, write address bits 23–8 of EE0000H to BASE23:8 in the ADDRCOM*x* register, and set the 9 most-significant bits of MASK23:8 in the ADDRMSK*x* register:

ADDRCOM*x* = EE00H
ADDRMSK*x* = FF80H

Note that the 32-Kbyte address range could not have 4000H as base address, for example, because 4000H is not on a 32-Kbyte boundary.

"Example of a Chip-select Setup" on page 13-15 shows another example of setting up the chip-select unit.

13.3.2 Controlling Bus Parameters

For each chip-select output address range, the bus control register BUSCON*x (*Figure 13-4*)* determines the wait states, the bus width, and the address/data multiplexing. Also, this register contains a bit for increasing data and address hold times for write operations and a bit for remapping chip-select output *x*+1 (CS*x*+1#) to chip-select output *x* (CS*x*#). This configuration enables you to access the same memory device using two different bus configurations. See "Example of a Chip-select Setup Using the Remap Feature" on page 13-16.

The chip-select output signals share package pins with port 3. Use the port registers to configure these pins as general-purpose I/O signals or as chip-select signals (see "Chip-select Signals (Port 3)" on page 7-8). The bus configuration programmed in BUSCON*x* applies to address range *x*, regardless of the port 3 pin configurations.

BUSCON*x*
***x* = 0–5**

Address: Table 13-3 on page 13-5
Reset State: (*x* = 0) 0FH
(*x* = 1–5) 00H

For the address range assigned to chip-select *x*, the bus control (BUSCON*x*) register specifies the number of wait states, the bus width, and the address/data multiplexing for all external bus cycles that access address range *x*. BUSCON*x* also determines whether chip-select output *x* will be activated when the address region for chip select *x*+1 is accessed. This option makes accessing a memory device using two different bus configurations possible.

The chip-select output signals share package pins with port 3. Use the port registers to configure these pins as general-purpose I/O signals or as chip-select signals (see "Chip-select Signals (Port 3)" on page 7-8). The bus configuration programmed in BUSCON*x* applies to address range *x*, regardless of the port 3 pin configurations.

7 **0**

DEMUX	BW16	REMAP	WRWS	WS3	WS2	WS1	WS0

Bit Number	Bit Mnemonic	Function
7	DEMUX	Address/Data Multiplexing This bit specifies the address/data multiplexing on AD15:0 for all external accesses to the address range assigned to chip-select *x* output. 0 = multiplexed 1 = demultiplexed
6	BW16	Bus Width This bit specifies the bus width for all external accesses to the address range assigned to chip-select *x* output. 0 = 8 bits 1 = 16 bits
5	REMAP	Remap Setting this bit remaps chip-select output *x*+1 (CS*x*+1#) to chip-select output x (CS*x*#). In other words, accessing chip select *x*'s address region activates CS*x*# and configures the bus as programmed in BUSCON*x*. Accessing chip select *x*+1's address region also activates CS*x*# but configures the bus as programmed in BUSCON*x*+1. See "Example of a Chip-select Setup Using the Remap Feature" on page 13-16. 0 = remapping disabled 1 = remapping enabled (CS*x*+1# is remapped to CS*x*#) **Note**: For chip-select channel 5, setting this bit remaps CS0# to CS5#. In this case, *x* = 5 and *x*+1 = 0.

Figure 13-4. Bus Control (BUSCON*x*) Registers

BUSCON*x* (Continued)
***x* = 0–5**

Address: Table 13-3 on page 13-5
Reset State: (*x* = 0) 0FH
(*x* = 1–5) 00H

For the address range assigned to chip-select *x*, the bus control (BUSCON*x*) register specifies the number of wait states, the bus width, and the address/data multiplexing for all external bus cycles that access address range *x*. BUSCON*x* also determines whether chip-select output *x* will be activated when the address region for chip select *x*+1 is accessed. This option makes accessing a memory device using two different bus configurations possible.

The chip-select output signals share package pins with port 3. Use the port registers to configure these pins as general-purpose I/O signals or as chip-select signals (see “Chip-select Signals (Port 3)” on page 7-8). The bus configuration programmed in BUSCON*x* applies to address range *x*, regardless of the port 3 pin configurations.

7							0
DEMUX	BW16	REMAP	WRWS	WS3	WS2	WS1	WS0

Bit Number	Bit Mnemonic	Function
4	WRWS	Write Operation Wait State When this bit is set, the bus controller adds one state time (2t) to write operations within the address region specified by chip select *x*. 0 = data and address hold time remains unchanged 1 = data and address hold time increases by one state time (2t) See the datasheet for the write operation data and address hold time specification (T_{WHAX}).
3:0	WS3:0	Wait States These bits, along with the READY pin, control the number of wait states for all external accesses to the address range assigned to the chip-select *x* channel. Write the desired minimum number of wait states (0–15) to WS3:0. If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.

Figure 13-4. Bus Control (BUSCON*x*) Registers (Continued)

13.3.3 Chip-select Unit Initial Conditions

A chip reset produces the following initial conditions for the chip-select unit:

- ADDRMSK*x* = FFFFH.
- ADDRCOM0 = FF20H. This asserts CS0# for the 256-byte address range FF2000–FF20FFH.
- ADDRCOM1 through ADDRCOM5 = 0000H.
- For the fetch of chip configuration byte 0 (CCB0), BUSCON0 is initialized for an 8-bit bus width, multiplexed mode, and 15 wait states (DEMUX = 0, BW16 = 0, WS0 = 1, WS1 = 1).
- Before the fetch of chip configuration byte 1 (CCB1), the values of DEMUX, BW16, WS0, and WS1 in BUSCON0 are loaded from CCB0. The external bus is configured according to the new values.

13.3.4 Programming the Chip-select Registers

The chip-select channels are prioritized; channel 0 has the lowest priority and channel 5 has the highest priority. By activating only the channel with the highest priority, the chip-select unit avoids bus contention that could occur if two chip-select channels were programmed with overlapping address ranges and different bus-parameters by activating only the channel with the highest priority. For example, if both channels 3 and 4 were configured for the address range 78000–7FFFFH, accessing address 79000H would assert chip-select output 4 and configure the bus as programmed in the bus control 4 register. Chip-select output 3 would remain unchanged.

Use the following sequence to program the chip-select registers after reset:

1. Program chip-select output 0:
    1.1. Clear ADDRMSK0.
    1.2. Write to ADDRCOM0 to establish the desired base address.
    1.3. Write to ADDRMSK0 to establish the desired address range.
    1.4. Write the desired bus-parameter values to BUSCON0.
2. While executing in the address range defined in step 1 for chip-select output 0, use the following sequence to program chip-select outputs 1–5. Begin with *x* = 1.
    2.1. Load ADDRMSK*x* with FFFFH.
    2.2. Write to ADDRCOM*x* to establish the desired base address.
    2.3. Write to ADDRMSK*x* to establish the desired address range.
    2.4. Write the desired bus-parameter values to BUSCON*x*.
    2.5. Repeat steps 2.1–2.4 for *x* = 2–5.

13.3.5 Example of a Chip-select Setup

This section shows an example of setting up the chip-select unit and provides details of the chip-select output calculation. This example shows how to set up the chip-select registers for the system shown in Figure 13-5. For each address range, the BUSCON*x* register (see Figure 13-4) specifies the address/data multiplexing (bit 7), the bus width (bit 6), and the number of wait states (bits 0–3). Table 13-5 lists the characteristics of the three chip-select outputs and the corresponding contents of BUSCON*x*.

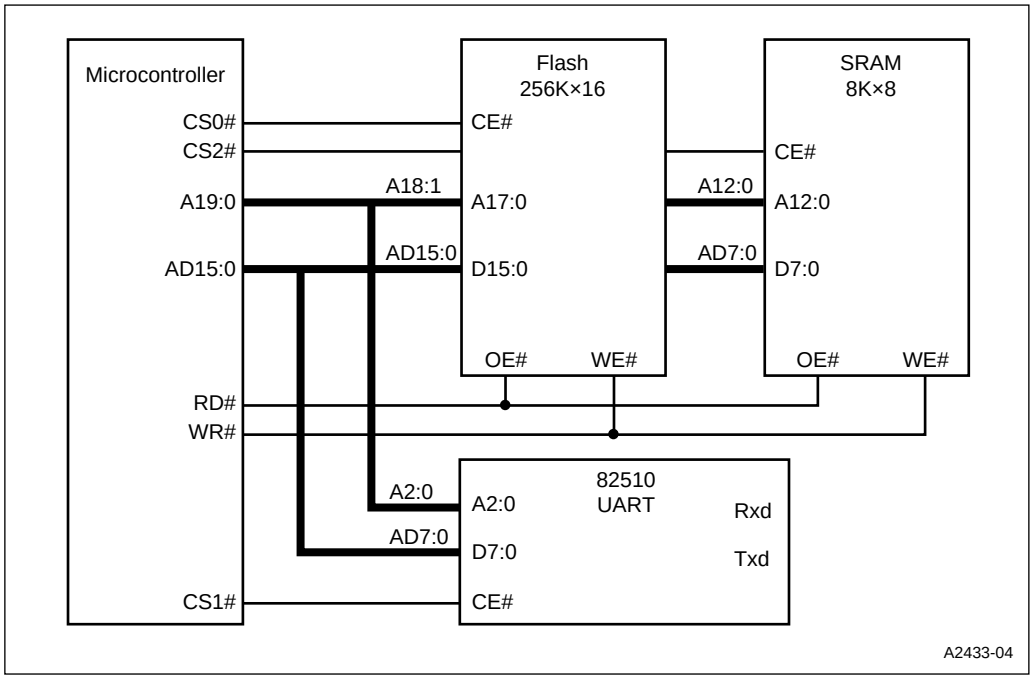


Figure 13-5. Example System for Setting Up Chip-select Outputs

Table 13-5. BUSCON*x* Registers for the Example System

Chip-select Output	Multiplexing	Bus Width	Wait States	Contents of BUSCON*x*
CS0#	Demultiplexed	16 bits	0	C0H
CS1#	Demultiplexed	8 bits	3	83H
CS2#	Demultiplexed	8 bits	0	80H

The location and size of an address range are specified by the ADDRCOM*x* register and the ADDRMSK*x* register (see Figure 13-2 on page 13-9 and Figure 13-3 on page 13-10). The 8-Kbyte SRAM is assigned to address range 37E000–37FFFFH and uses chip-select output 2. Address bits 23–8 of the base address (37E000H) are written to the BASE23:8 bits in the ADDRCOM2 register, which then contains 37E0H.

The address range for CS2# is 8 Kbytes or 2^{13} bytes (n = 13). The number of bits to be set in MASK23:8 of ADDRMSK2 is 24 – 13 = 11. After the 11 most-significant bits of MASK23:8 are set, ADDRMSK2 contains FFE0H. Results for CS0# and CS1# are found similarly (see Table 13-6).

Table 13-6. Results for the Chip-select Example

Chip-Select Output	Address Range	Size of Address Range	Number of Bits to Set in ADDRMSK*x*	Contents of ADDRCOM*x*	Contents of ADDRMSK*x*
CS0#	380000–3FFFFFH	512 Kbytes = 2^{19} bytes	n_1 = 24 – 19 = 5	3800H	F800H
CS1#	E01E00–E01EFFH	256 bytes = 2^8 bytes	n_1 = 24 – 8 = 16	E01EH	FFFFH
CS2#	37E000–37FFFFH	8 Kbytes = 2^{13} bytes	n_1 = 24 – 13 = 11	37E0H	FFE0H

13.3.6 Example of a Chip-select Setup Using the Remap Feature

The remap feature allows access to a memory device using two different bus configurations. With this feature, the microcontroller can easily access code and data, with different bus configurations, that reside in a single memory device. The following example illustrates how to configure chip-select channels 0 and 5 to access code and data from a single memory device.

Assume that boot code resides in a memory device starting at address FF2000H and data resides in the same memory device starting at address 2000H. The following code demonstrates how to use the remap feature so that an access to address region 2000–A000H configures the bus for two wait states and activates the chip-select channel 5 output (CS5#), while an access to address region FF2000–FFA000H configures the bus for one wait state and also activates CS5#.

```
;Set up correct window for addressing chip-select registers with direct
;addressing.

LDB  WSR,#3DH

;Configure chip-select channel 5 for an 8-Kbyte address region starting at 2000H
;with the following bus parameters: 2 wait states, demultiplexed address data
;bus, and 16-bit bus width. Also, enable remapping so that accesses to chip-
;select channel 0's address region will active CS5# rather than CS0#.

LDB  BUSCON5_3D,#0E2H    ;channel 5 set up for 2 wait, remap, demux, 16-bit bus
LD   ADDRCOM5_3D,#0020H  ;channel 5 base address 2000H
LD   ADDRMSK5_3D,#0FFE0H ;8-Kbyte region (n1=9)
```

```
;Configure chip-select channel 0 for an 8-Kbyte address region starting at
;FF2000H with the following bus parameters: 1 wait state, demultiplexed address
;data bus, and 16-bit data bus width.

LDB  BUSCON0_3D,#0C1H    ;channel 0 set up for 1 wait, demux, 16-bit bus
LD   ADDRCOM0_3D,#0FF20H ;channel 0 base address FF2000H
LD   ADDRMSK0_3D,#0FFE0H ;8-Kbyte region (n1=9)

;Nonextended instruction to chip-select channel 5's address region activates
;CS5# with bus parameters as programmed in BUSCON5.

LD   TEMP,3000H[0]

;Extended instruction to chip-select channel 0's address region activates CS5#
;with bus parameters as programmed in BUSCON0.

ELD  TEMP,0FF3000H[0]
```

13.4 CHIP CONFIGURATION REGISTERS AND CHIP CONFIGURATION BYTES

Two chip configuration registers (CCRs) have bits that set parameters for chip operation and external bus cycles. The CCRs cannot be accessed by code. They are loaded from the chip configuration bytes (CCBs), which reside at addresses FF2018H (CCB0) and FF201AH (CCB1). Since the CCBs are stored in external memory, their external addresses depend on the number of EPORT lines used in the external system (see "Internal and External Addresses" on page 13-1).

When the microcontroller returns from reset, the bus controller fetches the CCBs and loads them into the CCRs. From this point, these CCR bit values define the chip configuration until the microcontroller is reset again. The CCR bits are described in Figures 13-6 and 13-7. The remainder of this section describes the state of the chip following reset and the process of fetching the CCBs.

CCR0 no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7							0
1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5:4	WS1:0	Wait States These bits, along with the READY pin, control the number of wait states that are used for an external fetch of chip configuration byte 1 (CCB1). **WS1 WS0** 0 0 0 wait states 0 1 5 wait states 1 0 10 wait states 1 1 15 wait states If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.
3	DEMUX	Select Demultiplexed Bus Selects the demultiplexed bus mode for an external fetch of CCB1: 0 = multiplexed — address and data are multiplexed on AD15:0. 1 = demultiplexed — data only on AD15:0.
2	BHE#	Write-control Mode Selects the write-control mode, which determines the functions of the BHE#/WRH# and WR#/WRL# pins for external bus cycles: 0 = write strobe mode: the BHE#/WRH# pin operates as WRH#, and the WR#/WRL# pin operates as WRL#. 1 = standard write-control mode: the BHE#/WRH# pin operates as BHE#, and the WR#/WRL# pin operates as WR#.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 13-6. Chip Configuration 0 (CCR0) Register

CCR0 (Continued) no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7							0
1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
1	BW16	Buswidth Control Selects the bus width for an external fetch of CCB1: 0 = 8-bit bus 1 = 16-bit bus
0	PD	Powerdown Enable Enables or disables the IDLPD #2 and IDLPD #3 instructions. When enabled, the IDLPD #2 instruction causes the microcontroller to enter powerdown mode and the IDLPD #3 instruction causes the microcontroller to enter standby mode. 0 = disable powerdown and standby modes 1 = enable powerdown and standby modes If your design uses powerdown or standby mode, set this bit when you program the CCBs. If it does not, clearing this bit when you program the CCBs will prevent accidental entry into powerdown or standby mode. (Chapter 12, “Special Operating Modes,” discusses powerdown and standby modes.)

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 13-6. Chip Configuration 0 (CCR0) Register (Continued)

CCR1 no direct access†

The chip configuration 1 (CCR1) register selects the 64-Kbyte or 1-Mbyte addressing mode.

7							0
1	1	0	1	1	0	MODE64	0

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5	0	To guarantee proper operation, write zero to this bit.
4:3	1	To guarantee proper operation, write ones to these bits.
2	0	To guarantee proper operation, write zero to this bit.

The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 13-7. Chip Configuration 1 (CCR1) Register

CCR1 (Continued) no direct access†

The chip configuration 1 (CCR1) register selects the 64-Kbyte or 1-Mbyte addressing mode.

7							0
1	1	0	1	1	0	MODE64	0

Bit Number	Bit Mnemonic	Function
1	MODE64	Addressing Mode Selects 64-Kbyte or 1-Mbyte addressing. 0 = selects 1-Mbyte addressing 1 = selects 64-Kbyte addressing In 1-Mbyte mode, code can execute from almost anywhere in the address space. In 64-Kbyte mode, code can execute only from page FFH. (See "Fetching Code and Data in the 1-Mbyte and 64-Kbyte Modes" on page 5-22 for more information.)
0	0	Reserved; for compatibility with future devices, write zero to this bit.

The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

Figure 13-7. Chip Configuration 1 (CCR1) Register (Continued)

Upon leaving the reset state, the microcontroller is configured for normal operation. This section describes the state of the chip following reset and summarizes the steps in the configuration process. Following reset, the chip automatically fetches the two chip configuration bytes from external memory.

Since the CCBs are stored in external ROM, chip-select output 0 (CS0#) should be connected to that device. Chip-select output 0 is initialized for the address range FF2000–FF20FFH, which includes the CCB locations. Following the CCB fetches, the microcontroller fetches the instruction at FF2080H.

The microcontroller uses the following bus control parameters for the CCB0 fetch:

- Bus multiplexing (DEMUX): multiplexed
- Bus width (BW16): 8 bits
- Wait states (WS0, WS1): 15 wait states. The READY pin is active for the CCB0 and CCB1 fetches and can be used to insert additional wait states (see "Wait States (Ready Control)" on page 13-29).

CCB0 can be fetched over a 16-bit bus, even though BW16 defaults to 8 bits for the CCB0 fetch. The upper address pins, A19:8 and AD15:8, are strongly driven during the CCB0 fetch because an 8-bit bus is assumed. Therefore, if you have a 16-bit data bus, write the value 20H to FF2019H to avoid contention on AD15:8. Pins A19:0 are driven in the multiplexed mode. You can access the memory using A19:0 and use AD15:0 for data only.

CCB0 itself contains bits that specify DEMUX, BW16, WS0, and WS1. These values are used to control the CCB1 fetch, and following the fetch, they are stored in the chip-select output 0 bus control register, BUSCON0 (see “Chip-select Unit Initial Conditions” on page 13-14). The bits in CCB0 and CCB1 are described in “Chip Configuration Registers and Chip Configuration Bytes” on page 13-17.

After RESET# is deasserted, the following pins are initialized:

- The P2.7/CLKOUT pin operates as CLKOUT (as during reset). Be sure that the CLKOUT signal does not damage external hardware.
- The P3.0/CS0# pin operates as CS0#, which is asserted for the CCB fetches. If you plan to use the P3.0 pin as an input, you must reconfigure it from its post-reset operation as an output.
- The BHE#/WRH# pin operates as BHE#.
- The WR#/WRL# pin operates as WR#.
- The bus-hold function is disabled internally (WSR.7 = 0).
- The READY pin is active (that is, the chip responds to external requests for additional wait states).
- The INST pin is low (deasserted).
- The AD15:0 pins are active.
- The following port pins are weakly held high: P1.7:0, P2.6, P2.4:0, P3.7:1, and P4.7:0.
- The EPORT.3:0 pins are forced high.

Following reset, you should initialize the stack pointer and initialize the chip-select outputs using the procedure in “Example of a Chip-select Setup” on page 13-15.

13.5 BUS WIDTH AND MULTIPLEXING

The external bus can operate with a 16-bit or an 8-bit data bus and with a multiplexed or demultiplexed address/data bus. Figure 13-8 shows the external bus signals during operation in the four combinations of bus width and multiplexing.

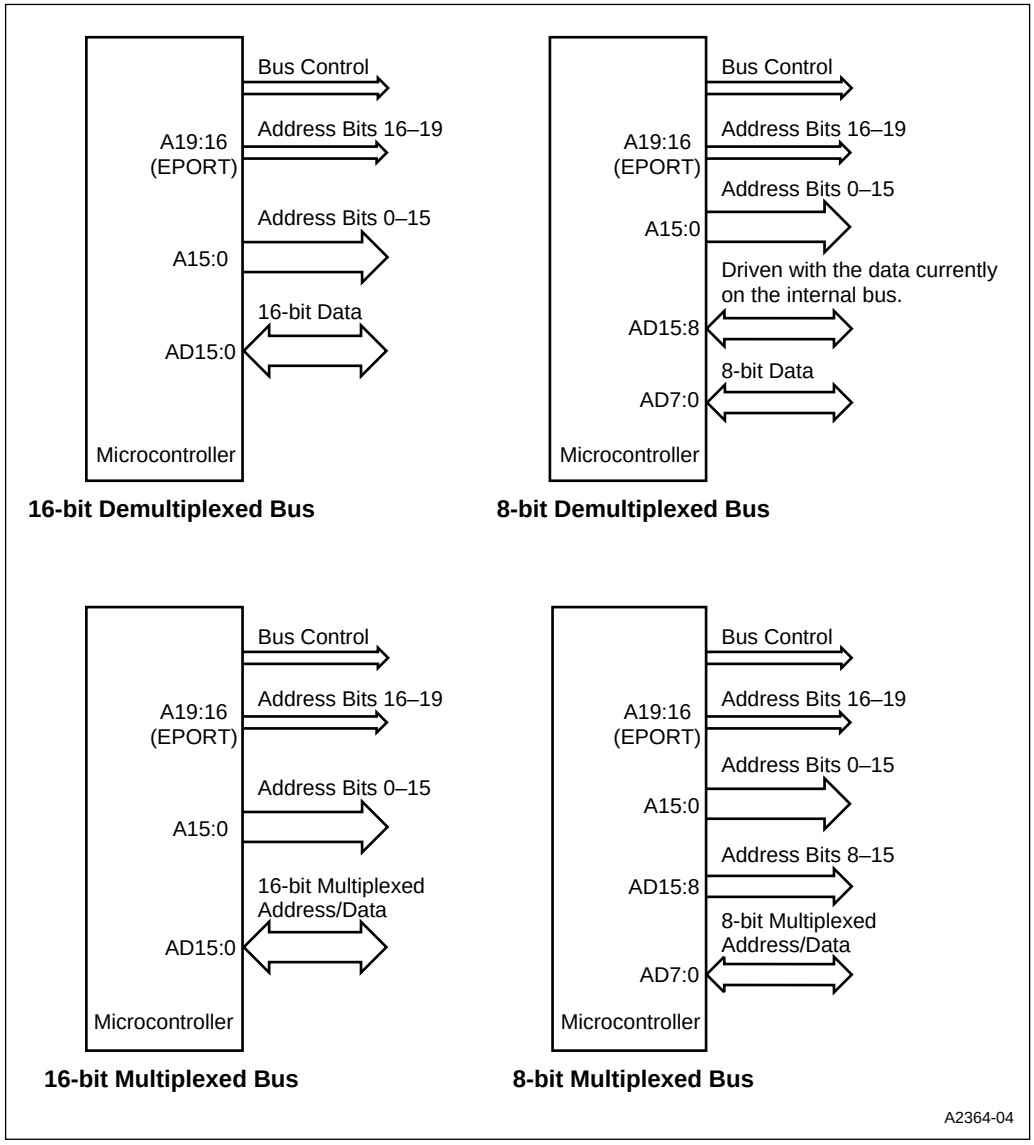


Figure 13-8. Multiplexing and Bus Width Options

A design can incorporate external devices that operate with different bus widths and multiplexing. The bus parameters used during a particular bus cycle are determined by the chip-select output that is assigned to the address being accessed. Figure 13-9 shows the address and data bus configurations for the four combinations of bus width and multiplexing. For detailed waveforms, see “16-bit Bus Timings” on page 13-25 and “System Bus AC Timing Specifications” on page 13-38.

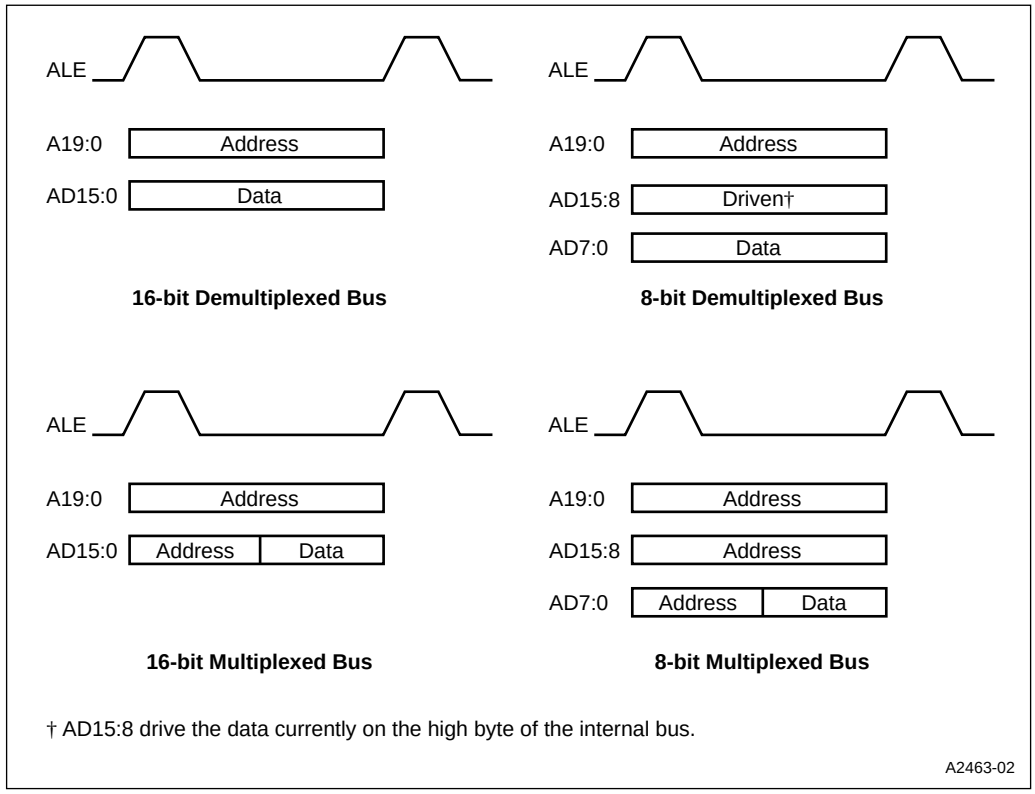


Figure 13-9. Bus Activity for Four Types of Buses

In an 8- or 16-bit demultiplexed mode (top of Figure 13-8 and Figure 13-9), the external device receives the address from A19:0. In a 16-bit system, the data is on AD15:0. In an 8-bit system, the data is on AD7:0, and AD15:8 drive the data currently on the high byte of the internal bus.

In multiplexed mode (bottom half of Figure 13-8 and Figure 13-9), both A19:0 and AD15:0 drive the address. A19:0 drive the address throughout the entire bus cycle. For a 16-bit bus width, AD15:0 drive the address for the first half of the bus cycle and drive or receive data during the second half. In the 8-bit case, AD15:8 drive the address during the entire bus cycle.

In multiplexed mode, with the full address on the bus for only half of the cycle, the external device has less time to receive it and to respond. As a result, for the same bus-cycle length (4t) a multiplexed system requires a faster external device (unless wait states are added to the bus cycle). Although the multiplexed mode has this disadvantage, it is useful for compatibility with devices designed for multiplexed operation.

In a 16-bit system (left side of Figure 13-8 and Figure 13-9) one data word can be transferred over AD15:0 in a single bus cycle. In an 8-bit system, one data word is transferred as two bytes over AD7:0 in successive bus cycles, and AD15:8 drive the upper eight address bits for the entire bus cycle.

The flexibility of the chip-select unit enables you to specify the bus width, the number of wait states, and a multiplexed or demultiplexed bus for each of the six chip-select outputs. The system in Figure 13-5 on page 13-15 illustrates a mixture of 8-bit and 16-bit devices with different numbers of wait states.

13.5.1 A 16-bit Example System

Figure 13-10 shows a 16-bit system in demultiplexed mode. The 256K×16 flash memory receives the address on A18:1; data is transferred on AD15:0. Using the WR# signal as shown, this system writes words, not single bytes, to the memory. (Using WRL# and WRH#, you can write single bytes on a 16-bit bus.)

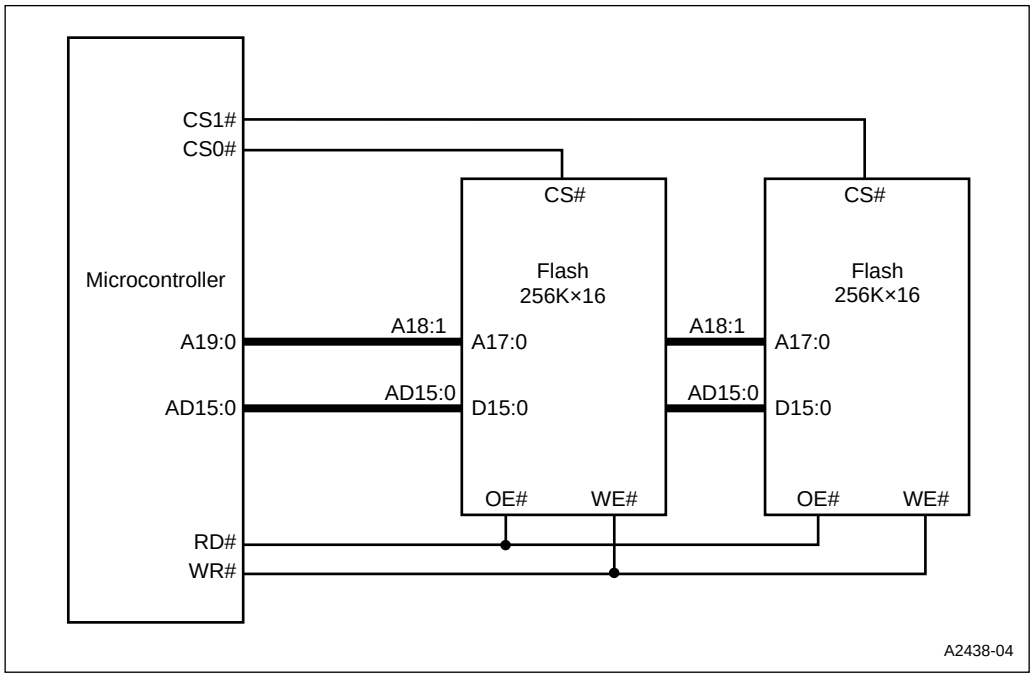


Figure 13-10. 16-bit External Devices in Demultiplexed Mode

13.5.2 16-bit Bus Timings

Figure 13-11 shows idealized 16-bit external-bus timings for the microcontroller. The signals are divided into two groups: signals for a demultiplexed bus (top) and signals for a multiplexed bus (bottom). Several bus signals are omitted from the figure to focus on a comparison of multiplexed and demultiplexed buses. The timing parameters are addressed in “Comparison of Multiplexed and Demultiplexed Buses” on page 13-29. Comprehensive timing specifications for the microcontroller are shown in Figures 13-19 and 13-20.

CLKOUT and ALE are the same in multiplexed and demultiplexed buses. The CLKOUT period is twice the internal oscillator period (2t). The bus cycles shown here, which have no wait states, require two CLKOUT periods (two state times, or 4t).

The rising edge of the address latch enable (ALE) signal indicates that the microcontroller is driving an address onto the bus (A19:16 and AD15:0 for a multiplexed bus, A19:0 for a demultiplexed bus). The microcontroller presents a valid address before ALE falls. In a multiplexed system, the ALE signal is used to strobe a transparent latch (such as a 74AC373), which captures the address from AD15:0 and holds it while the bus controller puts data onto AD15:0.

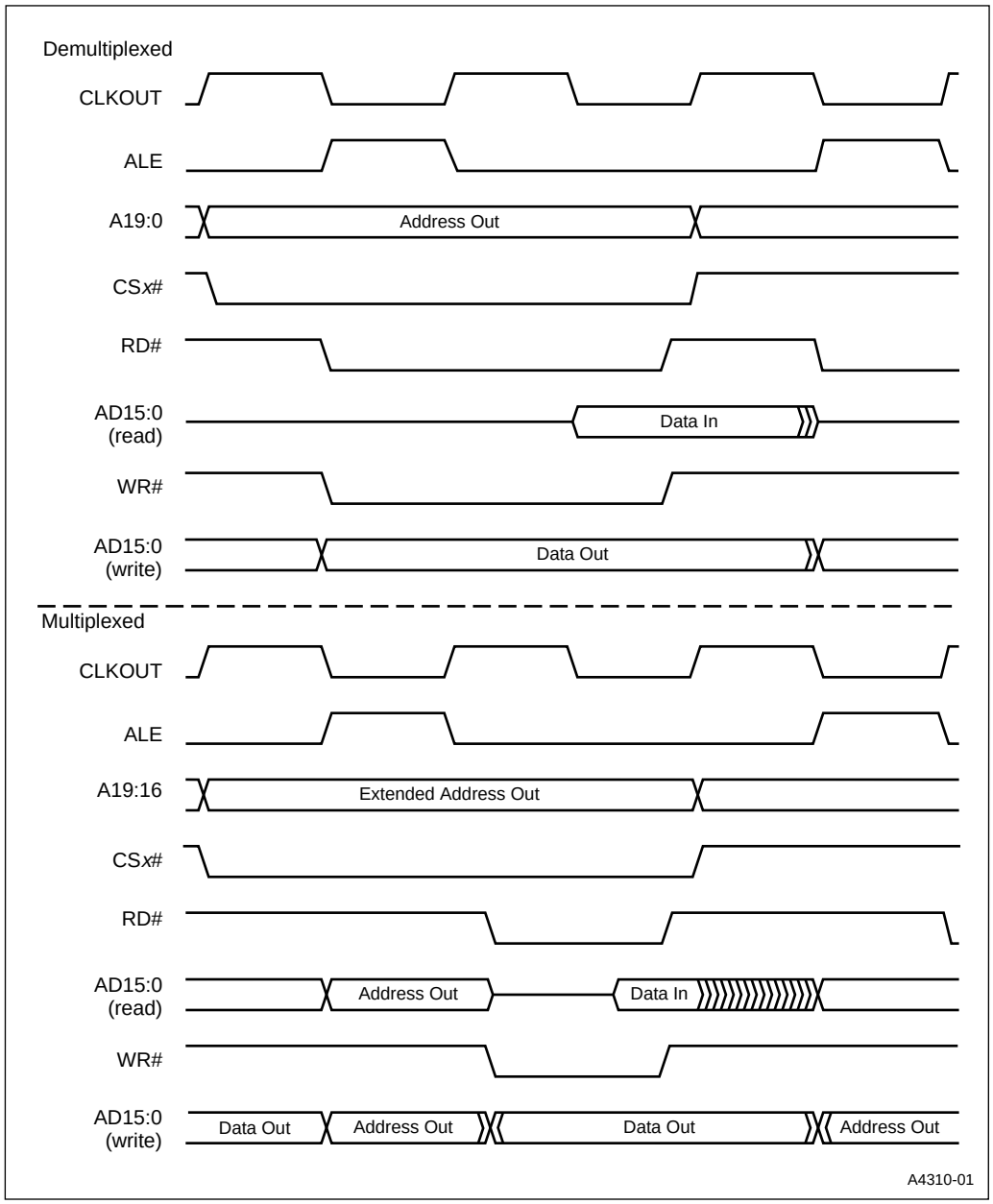


Figure 13-11. Timings for Multiplexed and Demultiplexed 16-bit Buses

13.5.3 8-bit Bus Timings

Figure 13-12 shows idealized 8-bit timings for the microcontroller. One cycle is required for an 8-bit read or write. A 16-bit access requires two cycles. The first cycle accesses the lower byte, and the second cycle accesses the upper byte. Except for requiring an extra cycle to write the bytes separately, the timings are the same as on the 16-bit bus, and the comparison between the multiplexed and demultiplexed cases is also the same. The demultiplexed bus can accommodate slower memory devices than the multiplexed bus can.

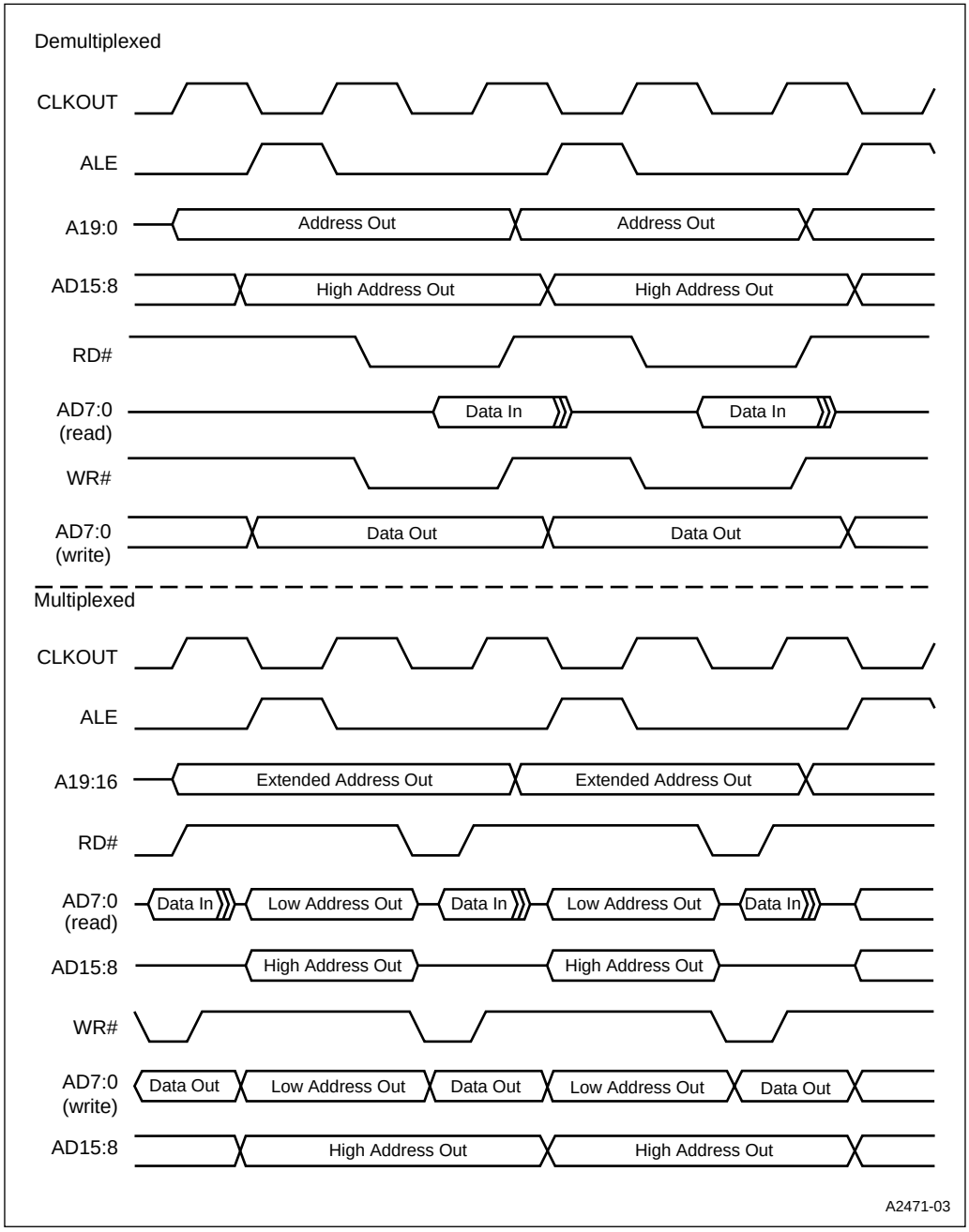


Figure 13-12. Timings for Multiplexed and Demultiplexed 8-bit Buses

13.5.4 Comparison of Multiplexed and Demultiplexed Buses

In a multiplexed system, where AD15:0 carry both address and data, bus activities are time-compressed in comparison with a demultiplexed system, where the address and data have separate pins (A19:0 and AD15:0). The compression is reflected in differences in specifications for the demultiplexed and multiplexed bus. The demultiplexed bus can accommodate slower memory devices. (Consult the microcontroller datasheet for the latest specifications.)

13.6 WAIT STATES (READY CONTROL)

An external device can use the READY input to lengthen an external bus cycle. When an external address is placed on the bus, the external device can pull the READY signal low to indicate it is not ready. In response, the microcontroller inserts wait states to lengthen the bus cycle until the external device asserts the READY signal. Each wait state adds one CLKOUT period to the bus cycle (2t).

The READY signal is effective for all bus cycles, including the CCB0 fetch (which has 15 internal wait states). Bits WS0 and WS1 in CCB0 specify the wait states for the CCB1 fetch. Thereafter, the WS3:0 bits in the BUSCON*x* registers control the wait states, and the READY signal can be used to insert additional wait states. (See “Controlling Bus Parameters” on page 13-11.)

The external device must meet setup and hold timings when using the READY signal to insert wait states into a bus cycle (see Figures 13-13 through 13-14 and Table 13-7). Because a decoded, valid address is used to generate the READY signal, the setup time is specified relative to the address being valid. This specification, T_{AVYV}, indicates how much time the external device has to decode the address and assert READY after the address is valid.

The external device must hold READY low until the minimum T_{CLYX} timing specification is met. Typically, this is a minimum of 0 ns from the time CLKOUT goes low. Do not exceed the maximum T_{CLYX} specification or additional (unwanted) wait states might be added. Refer to the datasheets for the current T_{AVYV} and T_{CLYX} specifications.

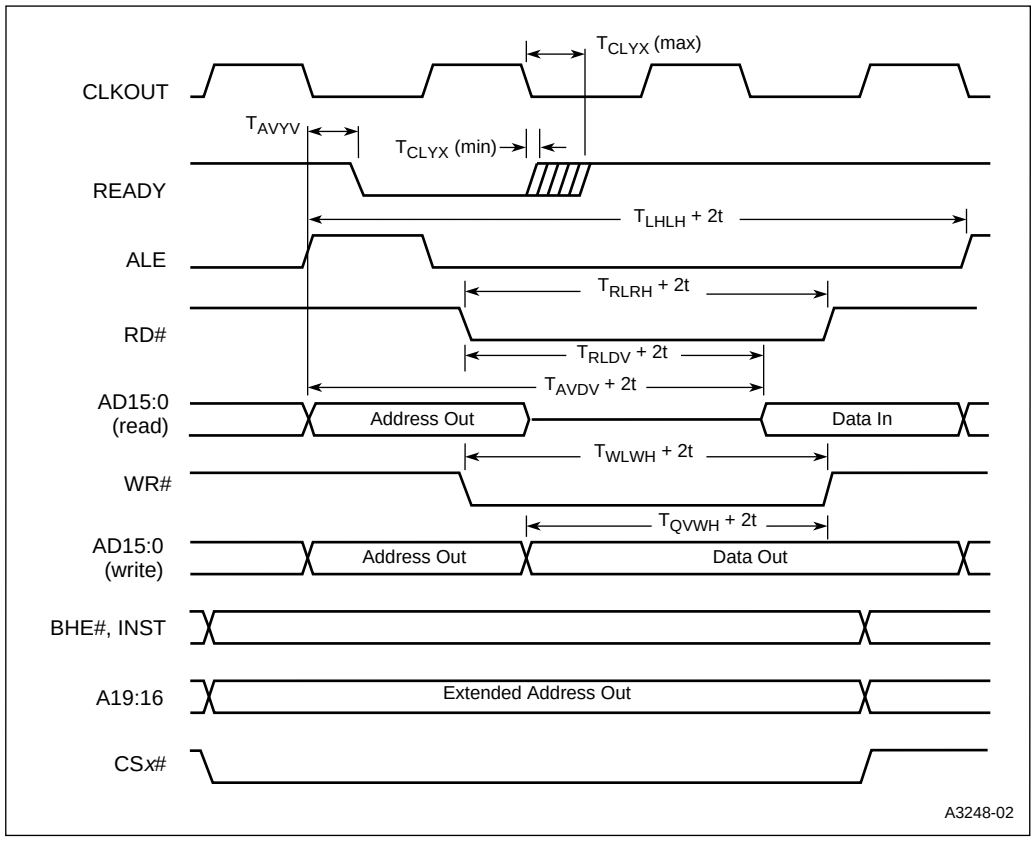


Figure 13-13. READY Timing Diagram — Multiplexed Mode

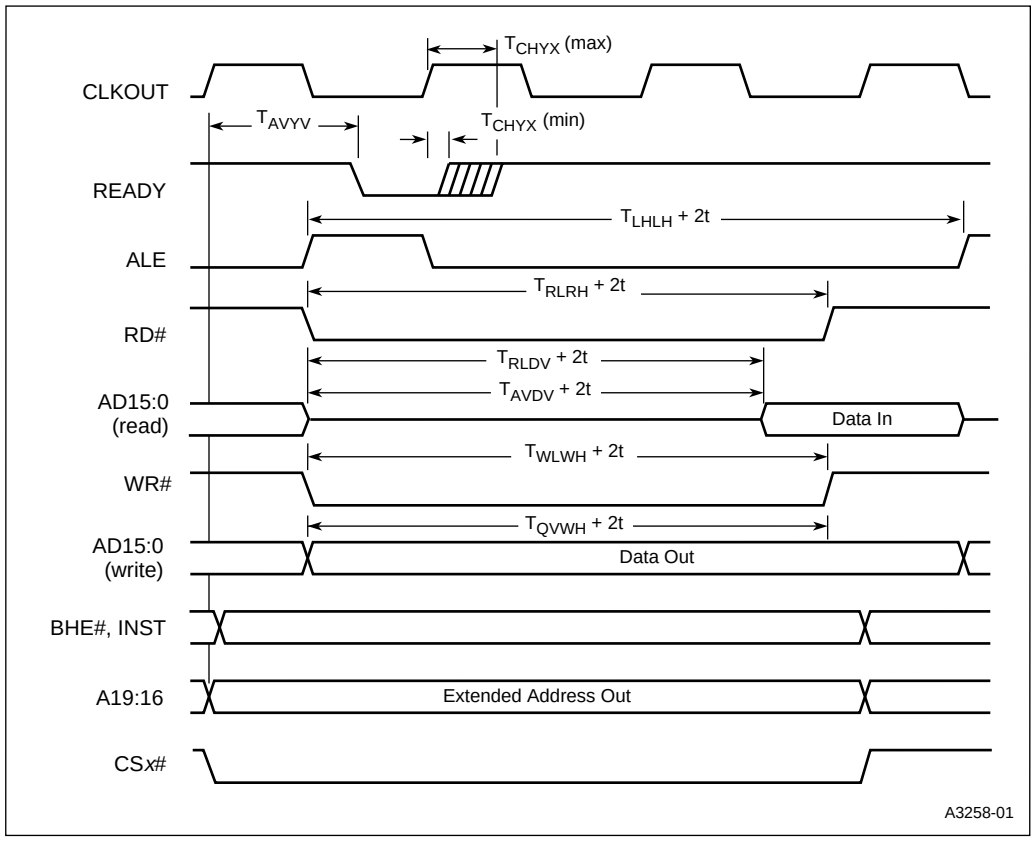


Figure 13-14. READY Timing Diagram — Demultiplexed Mode

Table 13-7. READY Signal Timing Definitions

Symbol	Definition
T_{AVDV}	Address Valid to Input Data Valid Maximum time the memory device has to output valid data after the microcontroller outputs a valid address.
T_{AVYV}	Address Valid to READY Setup Maximum time the external device has to pull READY low after the microcontroller outputs the address to guarantee that at least one wait state will occur.
T_{CHYX}	READY Hold after CLKOUT High If maximum specification is exceeded, additional wait states may occur.
T_{CLYX}	READY Hold after CLKOUT Low Minimum time the level of the READY signal must be valid after CLKOUT falls.

Table 13-7. READY Signal Timing Definitions (Continued)

Symbol	Definition
T_{LHLH}	ALE Cycle Time Minimum time between ALE pulses.
T_{QVWH}	Data Valid to WR# High Time between data being valid on the bus and the microcontroller deasserting WR#.
T_{RLDV}	RD# Low to Input Data Valid Maximum time the memory system has to output valid data after the microcontroller asserts RD#.
T_{RLRH}	RD# Low to RD# High RD# pulse width.
T_{WLWH}	WR# Low to WR# High WR# pulse width.

13.7 BUS-HOLD PROTOCOL

The microcontroller supports a bus-hold protocol that allows external devices to gain control of the address/data bus. The protocol uses three signals, all of which are port 2 special functions: HOLD#/P2.5 (bus-hold request), HLDA#/P2.6 (bus-hold acknowledge), and BREQ#/P2.3 (bus request). When an external device wants to use the microcontroller bus, it asserts the HOLD# signal. The microcontroller samples HOLD# while CLKOUT is low. If HOLD# is asserted, the microcontroller responds by releasing the bus and asserting HLDA#. During this hold time, the address/data bus floats, and signals CS*x*#, ALE, RD#, WR#/WRL#, BHE#/WRH#, and INST are weakly held in their inactive states. Figure 13-15 shows the timing for the bus-hold protocol, and Table 13-8 lists the timing parameters and their definitions. Refer to the datasheet for timing parameter values.

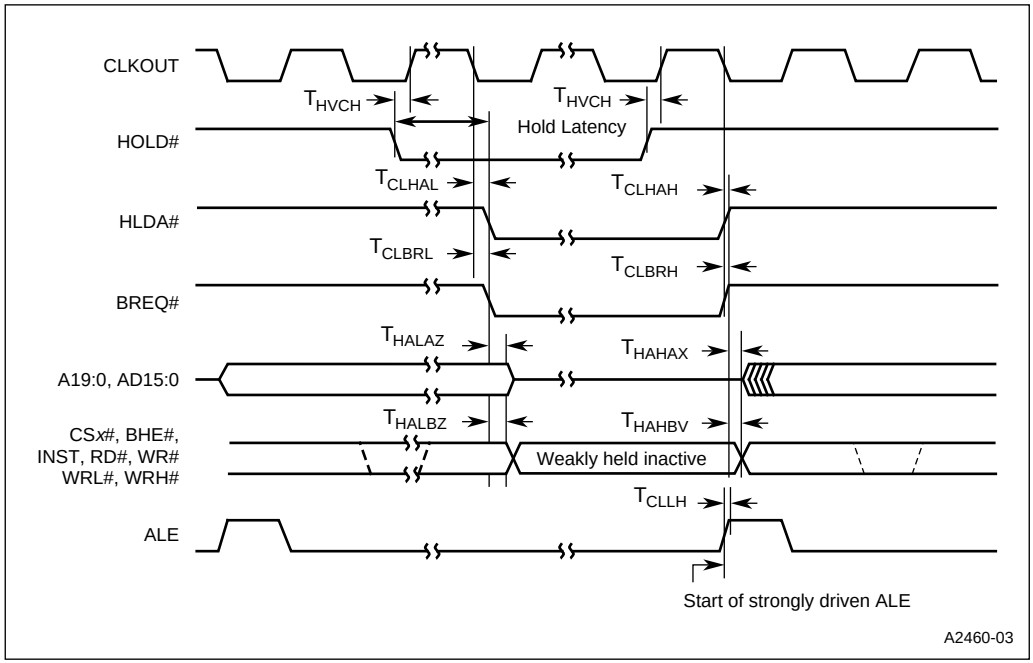


Figure 13-15. HOLD#, HLDA# Timing

Table 13-8. HOLD#, HLDA# Timing Definitions

Symbol	Parameter
T_{HVCH}	HOLD# Setup Time
T_{CLHAL}	CLKOUT Low to HLDA# Low
T_{CLHAH}	CLKOUT Low to HLDA# High
T_{CLBRL}	CLKOUT Low to BREQ# Low
T_{CLBRH}	CLKOUT Low to BREQ# High
T_{HALAZ}	HLDA# Low to Address Float
T_{HAHAX}	HLDA# High to Address No Longer Float
T_{HALBZ}	HLDA# Low to CS*x*#, BHE#, INST, RD#, WR#, WRL#, WRH# Weakly Driven
T_{HAHBV}	HLDA# High to CS*x*#, BHE#, INST, RD#, WR#, WRL#, WRH# valid
T_{CLLH}	Clock Falling to ALE Rising

† Assumes CLKOUT is equal to twice the internal operating period (2t).

When the external device is finished with the bus, it relinquishes control by driving HOLD# high. In response, the microcontroller deasserts HLDA# and resumes control of the bus.

If the microcontroller has a pending external bus cycle while another device has control of the bus, it asserts BREQ# to request control of the bus. After the external device responds by releasing HOLD#, the microcontroller exits hold and then deasserts BREQ# and HLDA#.

13.7.1 Enabling the Bus-hold Protocol

To use the bus-hold protocol, set the hold enable bit (HLDEN) in the window selection register (WSR.7). Setting HLDEN configures the P2.5/HOLD, #P2.3/BREQ#, and P2.6/HLDA# pins to function only as HOLD#, BREQ#, and HLDA#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change a pin's configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared).

13.7.2 Disabling the Bus-hold Protocol

To disable hold requests, clear WSR.7. The microcontroller does not take control of the bus immediately after HLDEN is cleared. Instead, it waits for the current hold request to finish and then disables the bus-hold feature and ignores any new requests until the bit is set again.

Sometimes it is important to prevent another device from taking control of the bus while a block of code is executing. One way to protect a code segment is to clear WSR.7 and then execute a JBC instruction to check the status of the HLDA# signal. The JBC instruction prevents the RALU from executing the protected block until current hold requests are serviced and the hold feature is disabled. This is illustrated in the following code:

```
          DI                          ;Disable interrupts to prevent
                                      ;code interruption
          PUSH WSR                    ;Disable hold requests and
          LDB  WSR,#1FH               ;window Port 2
WAIT:     JBC  P2_PIN,6, WAIT         ;Check the HLDA# signal. If set,
                                      ;add protected instruction here
          POP  WSR                    ;Enable hold requests
          EI                          ;Enable interrupts
```

13.7.3 Hold Latency

When an external device asserts HOLD#, the microcontroller finishes the current bus cycle and then asserts HLDA#. The time it takes the microcontroller to assert HLDA# after the external device asserts HOLD# is called *hold latency* (see Figure 13-15 on page 13-33). Table 13-9 lists the maximum hold latency for each type of bus cycle.

Table 13-9. Maximum Hold Latency

Bus Cycle Type	Maximum Hold Latency (state times)
Internal execution or idle mode	1.5
16-bit external execution	2.5 + 1 per wait state
8-bit external execution	2.5 + 2 per wait state

13.7.4 Regaining Bus Control

While HOLD# is asserted, the microcontroller continues executing code until it needs to access the external bus. If executing from internal memory, it continues until it needs to perform an external memory cycle. If executing from external memory, it continues executing until the queue is empty or until it needs to perform an external data cycle. As soon as it needs to access the external bus, the microcontroller asserts BREQ# and waits for the external device to deassert HOLD#. After asserting BREQ#, the microcontroller cannot respond to any interrupt requests, including NMI, until the external device deasserts HOLD#. One state time after HOLD# goes high, the microcontroller deasserts HLDA# and, with no delay, resumes control of the bus.

If the microcontroller is reset while in hold, bus contention can occur. For example, a device without internal ROM would try to fetch the chip configuration byte from external memory after RESET# was brought high. Bus contention would occur because both the external device and the microcontroller would attempt to access memory. One solution is to use the RESET# signal as the system reset; then all bus masters (including the microcontroller) are reset at once. Chapter 11, “Minimum Hardware Considerations,” shows system reset circuit examples.

13.8 WRITE-CONTROL MODES

The microcontroller has two write-control modes: the standard mode, which uses the WR# and BHE# signals; and the write strobe mode, which uses the WRL# and WRH# signals. Otherwise, the two modes are identical. The modes are selected by chip configuration register 0 (Figure 13-6 on page 13-18.)

Figure 13-16 shows the waveforms of the asserted write-control signals in the two modes. Note that only BHE# is valid throughout the bus cycle.

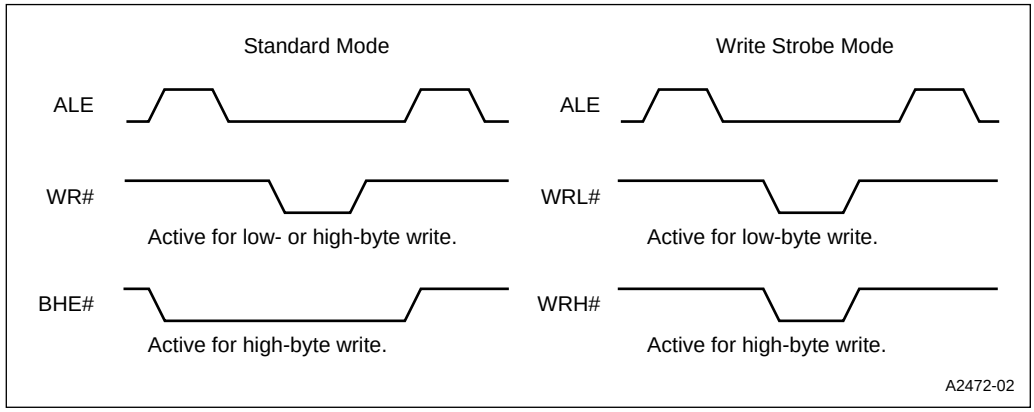


Figure 13-16. Write-control Signal Waveforms

Table 13-10 compares the values of the write-control signals for write operations in the standard mode and the write strobe mode. The table lists values of WR# and BHE# and values of WRL# and WRH# for byte and word writes on an 8-bit and a 16-bit bus.

Table 13-10. Write Signals for Standard and Write Strobe Modes

Bus Width	Word/Byte Written	A0 or AD0†	Standard (CCR0.2 = 1)		Write Strobe (CCR0.2 = 0)	
			WR#	BHE#	WRL#	WRH#
8	Low Byte	0	0	1	0	1
	High Byte	1	0	0	1	0
	Word	0	0	0	0	0
		1	Illegal		Illegal	
16	Low Byte	0	0	1	0	1
	High Byte	1	0	0	1	0
	Word	0	0	0	0	0
		1	Illegal		Illegal	

† A0 for a demultiplexed address bus; AD0 for a multiplexed address/data bus.

To select the standard write-control mode, set CCR0.2. In standard mode, the WR#/WRL# pin operates as WR#, and the BHE#/WRH# pin operates as BHE#. WR# is asserted for every external memory write. BHE# is asserted for word accesses (read and write) and for byte accesses to odd addresses. BHE# can be used to select the bank of memory that stores the high (odd) byte. Figure 13-10 on page 13-25 illustrates use of the standard mode in a 16-bit system. In this example, WR# writes words to the 16-bit flash memory. To write individual bytes, you can use the decoding logic in Figure 13-17 or use the write strobe mode.

To write single bytes on a 16-bit bus requires separate low-byte and high-byte write signals (WRL# and WRH#). Figure 13-17 shows a sample circuit that combines WR#, BHE#, and address bit 0 (A0 for a demultiplexed address bus, AD0 for a mulitplexed address/data bus) to produce these signals. This additional logic is unnecessary, however. In the write strobe mode, WRL# and WRH# are available at the microcontroller's external pins.

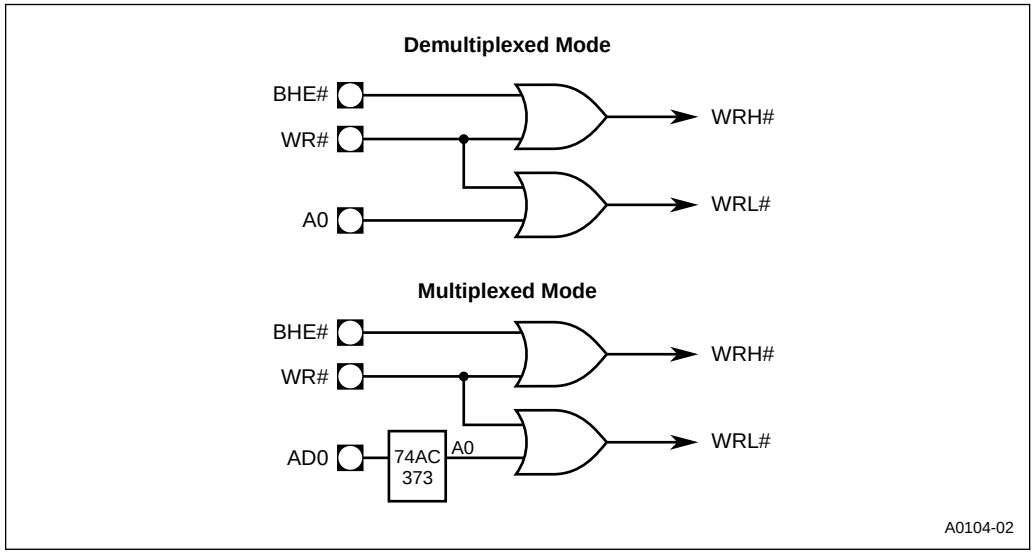


Figure 13-17. Decoding WRL# and WRH#

The write strobe mode eliminates the need to externally decode high-byte and low-byte write signals to external 16-bit memory on a 16-bit bus. When the write strobe mode is selected, the WR#/WRL# pin operates as WRL#, and the BHE#/WRH# pin operates as WRH#. In the 16-bit bus mode, WRL# is asserted for all low-byte writes (even addresses) and all word writes, and WRH# is asserted for all high-byte writes (odd addresses) and all word writes. In the 8-bit bus mode, WRH# and WRL# are asserted for both even and odd addresses (see Table 13-10).

Figure 13-18 illustrates the use of the write strobe mode in a mixed 8-bit and 16-bit system with two flash memories and one SRAM. The WRL# signal, which is generated for all 8-bit writes (Table 13-10), is used to write bytes to the SRAM. Note that the RD# signal is sufficient for single-byte reads on a 16-bit bus. Both bytes are put onto the data bus and the memory controller discards the unwanted byte.

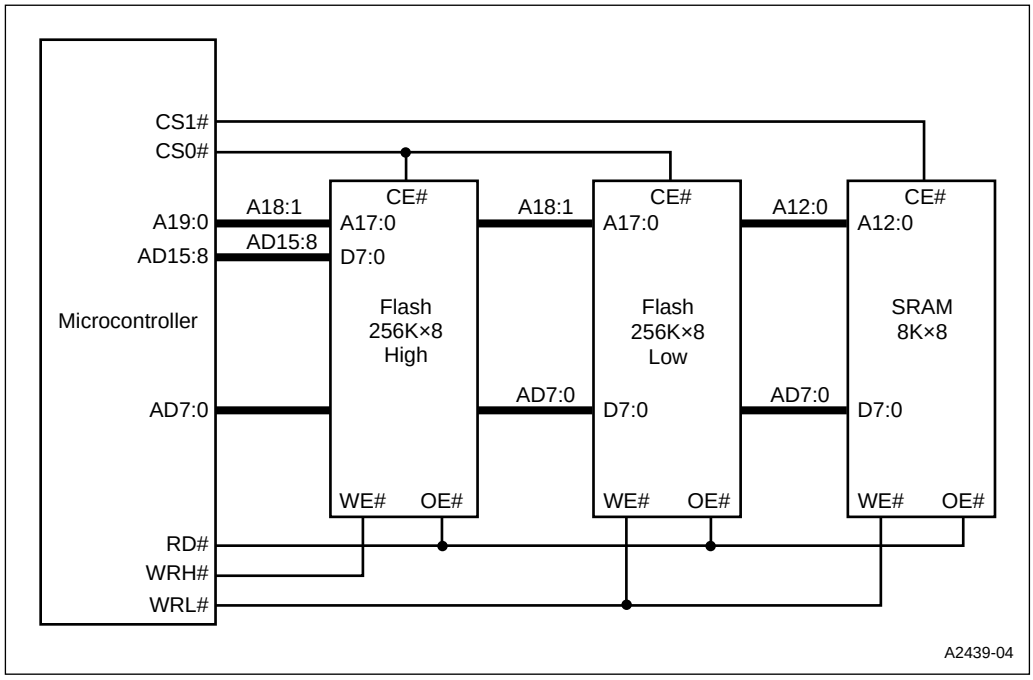


Figure 13-18. A System with 8-bit and 16-bit Buses

13.9 SYSTEM BUS AC TIMING SPECIFICATIONS

Refer to the latest datasheet for the AC timings to make sure your system meets specifications. The major external bus timing specifications are shown in Figures 13-19 and 13-20.

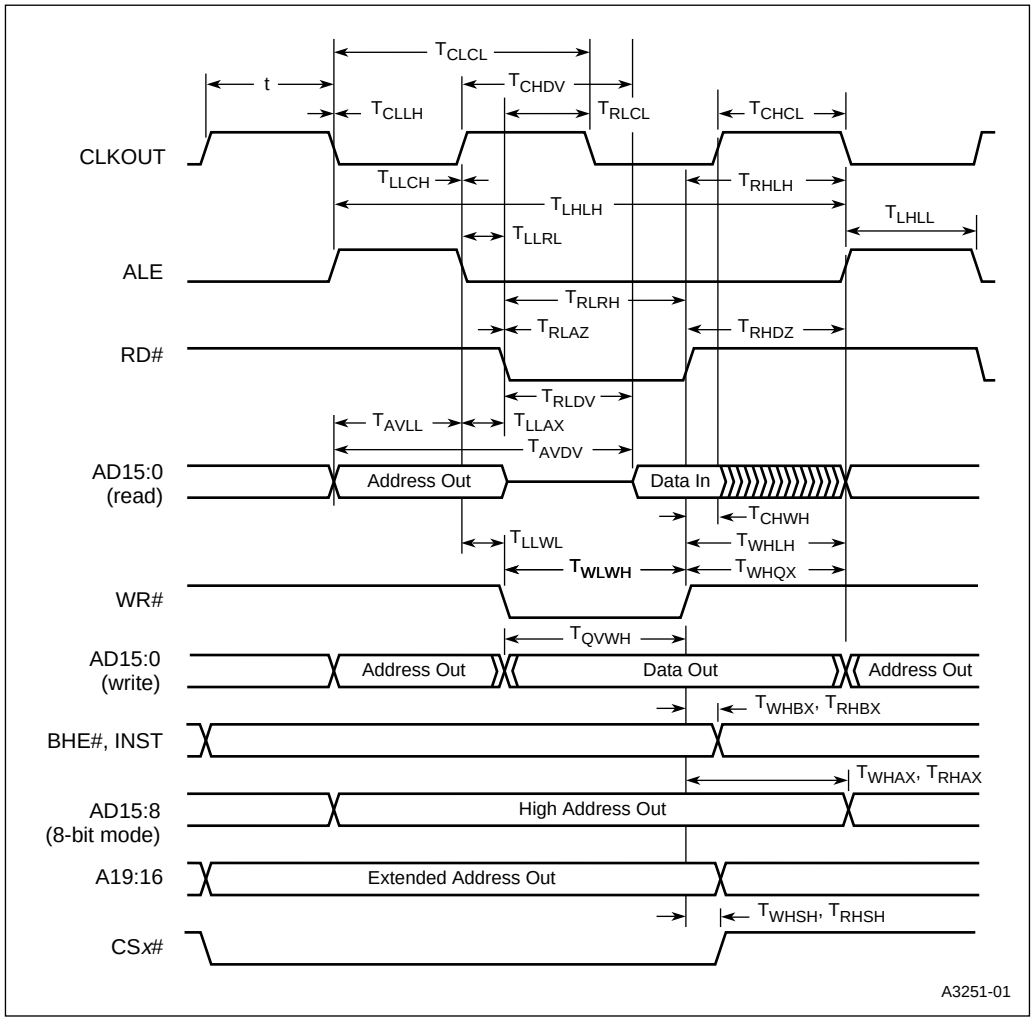


Figure 13-19. Multiplexed System Bus Timing

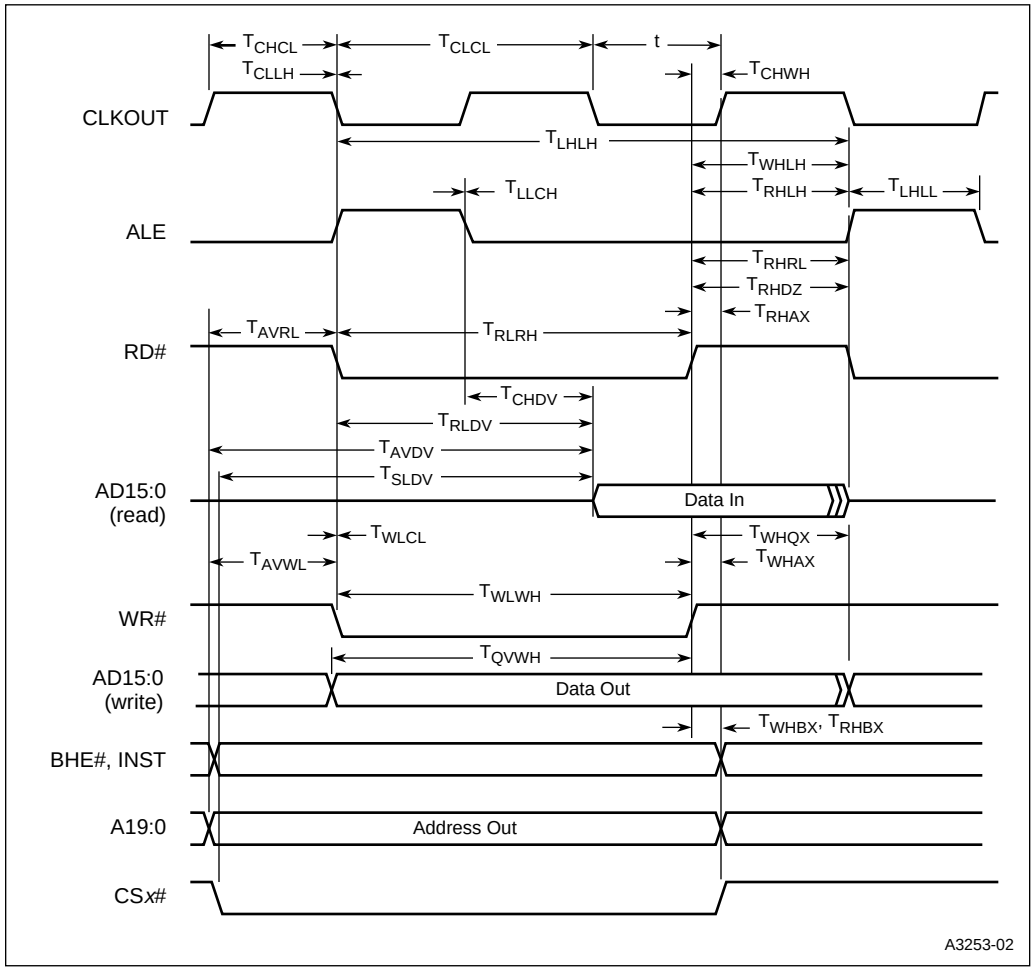


Figure 13-20. Demultiplexed System Bus Timing

13.9.1 Deferred Bus-cycle Mode

The microcontroller offers a deferred bus-cycle mode. This bus mode reduces bus contention when using the microcontroller in demultiplexed mode with slow memories. As shown in Figure 13-21, a delay of 2t occurs in the first bus cycle following a chip-select output change or the first write cycle following a read cycle.

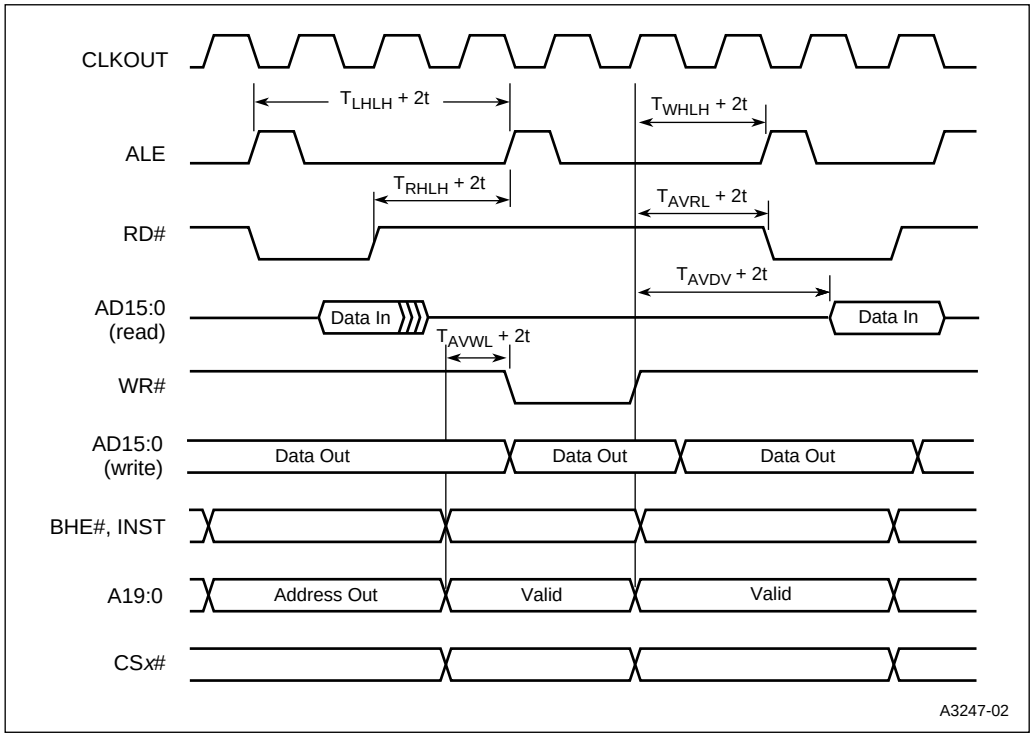


Figure 13-21. Deferred Bus-cycle Mode Timing Diagram

13.9.2 Explanation of AC Symbols

Each symbol consists of two pairs of letters prefixed by “T” (for time). The characters in a pair indicate a signal and its condition, respectively. Symbols represent the time between the two signal/condition points. For example, T_{LLRL} is the time between signal L (ALE) condition L (Low), and signal R (RD#) condition L (Low). Table 13-11 defines the signal and condition codes.

Table 13-11. AC Timing Symbol Definitions

Character	Signal(s)
A	AD15:0 or A:0
B	BHE#
C	CLKOUT
D	AD15:0 (Input Data)
H	HOLD#
HA	HLDA#
L	ALE
Q	AD15:0 (Output Data)
R	RD#
S	CS*x*#
W	WR#, WRL#

Character	Condition
H	High
L	Low
V	Valid
X	No Longer Valid
Z	Floating (low impedance)

13.9.3 AC Timing Definitions

Tables 13-12 and 13-13 define the AC timing specifications that the memory system must meet and those that the microcontroller will provide.

Table 13-12. External Memory Systems Must Meet These Specifications

Symbol	Definition
T_{AVDV}	Address Valid to Input Data Valid Maximum time the memory device has to output valid data after the microcontroller outputs a valid address.
T_{CHDV}	CLKOUT High to Input Data Valid Maximum time the memory system has to output valid data after CLKOUT rises.
T_{QVWH}	Data Valid to WR# High Time between data being valid on the bus and the microcontroller deasserting WR#.
T_{RHDZ}	RD# High to Input Data Float Time after RD# is inactive until the memory system must float the bus. If this timing is not met, bus contention will occur.

Table 13-12. External Memory Systems Must Meet These Specifications (Continued)

Symbol	Definition
T_{RLDV}	RD# Low to Input Data Valid Maximum time the memory system has to output valid data after the microcontroller asserts RD#.
T_{SLDV}	CS*x*# Valid to Input Data Valid Maximum time the memory device has to output valid data after the microcontroller outputs a valid chip-select output.

Table 13-13. The Microcontroller Meets These Specifications

Symbol	Definition
f	Operating frequency Frequency of the signal input on the XTAL1 pin times the clock multiplier (*x*); *x* is 1, 2, or 4, depending on the clock mode. The internal bus speed of the microcontroller is f/2.
t	Operating period (1/f) All AC Timings are referenced to t.
T_{AVRL}	Address Setup to RD# Low Length of time the address is valid before RD# falls.
T_{AVWL}	Address Setup to WR# Low Length of time the address is valid before WR# falls.
T_{CHCL}	CLKOUT High Period Needed in systems that use CLKOUT as clock for external devices.
T_{CHWH}	CLKOUT High to WR# High Time between CLKOUT going high and WR# going inactive.
T_{CHWL}	CLKOUT High to WR# Low Time between CLKOUT going high and WR# going active.
T_{CLCL}	CLKOUT Cycle Time Normally 2t.
T_{CLLH}	CLKOUT Falling to ALE Rising Use to derive other timings.
T_{LHLH}	ALE Cycle Time Minimum time between ALE pulses.
T_{LHLL}	ALE High Period Use this specification when designing the external latch.
T_{LLAX}	Address Hold after ALE Low Length of time the address is valid after ALE falls. Use this specification when designing the external latch.
T_{LLCH}	ALE Falling to CLKOUT Rising Use to derive other timings.

Table 13-13. The Microcontroller Meets These Specifications (Continued)

Symbol	Definition
T_{LLRL}	ALE Low to RD# Low Length of time after ALE falls before RD# is asserted. Could be needed to ensure proper memory decoding takes place before a device is enabled.
T_{LLWL}	ALE Low to WR# Low Length of time after ALE falls before WR# is asserted. Could be needed to ensure proper memory decoding takes place before a device is enabled.
T_{RHAX}	(Multiplexed Mode) AD15:8/CS*x*# Hold after RD# High Minimum time that the high byte of the address in 8-bit mode will be valid after RD# inactive. (Demultiplexed Mode) A19:0/CS*x*# Hold after RD# High Minimum time that the address will be valid after RD# inactive.
T_{RHBX}	BHE#, INST Hold after RD# High Minimum time that these signals will be valid after RD# inactive.
T_{RHLH}	RD# High to ALE Rising Time between the microcontroller deasserting RD# and the next ALE. Useful in calculating time between RD# inactive and next address valid.
T_{RHRL}	RD# High to RD# Low Minimum RD# inactive time.
T_{RHSH}	A19:0/CS*x*# Hold after RD# High Minimum time that the address and chip-select output are held after RD# inactive.
T_{RLAZ}	RD# Low to Address Float Used to calculate when the microcontroller stops driving the address on the bus.
T_{RLCL}	RD# Low to CLKOUT Low Length of time from RD# asserted to CLKOUT falling edge.
T_{RLRH}	RD# Low to RD# High RD# pulse width.
T_{WHAX}	(Multiplexed Mode) AD15:8/CS*x*# Hold after WR# High Minimum time that the high byte of the address in 8-bit mode will be valid after WR# inactive. (Demultiplexed Mode) A19:0/CS*x*# Hold after WR# High Minimum time that the address will be valid after WR# inactive.
T_{WHBX}	BHE#, INST Hold after WR# High Minimum time that these signals will be valid after WR# inactive.
T_{WHLH}	WR# High to ALE High Time between the microcontroller deasserting WR# and next ALE. Also used to calculate WR# inactive and next Address valid.
T_{WHQX}	Data Hold after WR# High Minimum time after WR# rises that the data stays valid on the bus.

Table 13-13. The Microcontroller Meets These Specifications (Continued)

Symbol	Definition
T_{WHSH}	A19:0/CS*x*# Hold after WR# High Minimum time that the address and chip-select output are held after WR# inactive.
T_{WLCL}	WR# Low to CLKOUT Low Minimum and maximum time between WR# being asserted and CLKOUT going low.
T_{WLWH}	WR# Low to WR# High WR# pulse width.

A

Instruction Set Reference

APPENDIX A
INSTRUCTION SET REFERENCE

This appendix provides reference information for the instruction set of the family of MCS® 96 microcontrollers. It defines the processor status word (PSW) flags, describes each instruction, shows the relationships between instructions and PSW flags, and shows hexadecimal opcodes, instruction lengths, and execution times. It includes the following tables.

- Table A-1 on page A-2 is a map of the opcodes.
- Table A-2 on page A-4 defines the processor status word (PSW) flags.
- Table A-3 on page A-5 shows the effect of the PSW flags or a specified register bit on conditional jump instructions.
- Table A-4 on page A-5 defines the symbols used in Table A-6.
- Table A-5 on page A-6 defines the variables used in Table A-6 to represent instruction operands.
- Table A-6 beginning on page A-7 lists the instructions alphabetically, describes each of them, and shows the effect of each instruction on the PSW flags.
- Table A-7 beginning on page A-57 lists the instruction opcodes, in hexadecimal order, along with the corresponding instruction mnemonics.
- Table A-8 on page A-64 lists instruction lengths and opcodes for each applicable addressing mode.
- Table A-9 on page A-72 lists instruction execution times, expressed in state times.

NOTE

The # symbol prefixes an immediate value in immediate addressing mode. Chapter 4, “Programming Considerations,” describes the operand types and addressing modes.

Table A-1. Opcode Map (Left Half)

Opcode	*x*0	*x*1	*x*2	*x*3	*x*4	*x*5	*x*6	*x*7
0*x*	SKIP	CLR	NOT	NEG	XCH di	DEC	EXT	INC
1*x*		CLRB	NOTB	NEGB	XCHB di	DECB	EXTB	INCB
2*x*	SJMP							
3*x*	JBC bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7
4*x*	AND 3op, RPT, RPT*xxx*, RPTI, & RPTI*xxx* (5) di	im	in	ix	ADD 3op di	im	in	ix
5*x*	ANDB 3op di	im	in	ix	ADDB 3op di	im	in	ix
6*x*	AND 2op di	im	in	ix	ADD 2op di	im	in	ix
7*x*	ANDB 2op di	im	in	ix	ADDB 2op di	im	in	ix
8*x*	OR di	im	in	ix	XOR di	im	in	ix
9*x*	ORB di	im	in	ix	XORB di	im	in	ix
A*x*	LD di	im	in	ix	ADDC di	im	in	ix
B*x*	LDB di	im	in	ix	ADDCB di	im	in	ix
C*x*	ST di	BMOV	ST in	ix	STB di	CMPL	STB in	ix
D*x*	JNST	JNH	JGT	JNC	JNVT	JNV	JGE	JNE
E*x*	DJNZ	DJNZW	TIJMP	BR/EBR in	EBMOVI	RETI	EJMP	LJMP
F*x*	RET	ECALL	PUSHF	POPF	PUSHA	POPA	IDLPD	TRAP

NOTE: The first digit of the opcode is listed vertically, and the second digit is listed horizontally. The related instruction mnemonic is shown at the intersection of the two digits. Shading indicates reserved opcodes. If the CPU attempts to execute an unimplemented opcode, an interrupt occurs. For more information, see "Unimplemented Opcode" on page 6-10.

Table A-1. Opcode Map (Right Half)

Opcode	*x*8	*x*9	*x*A	*x*B	*x*C	*x*D	*x*E	*x*F
0*x*	SHR	SHL	SHRA	XCH ix	SHRL	SHLL MVAC MSAC	SHRAL	NORML
1*x*	SHRB	SHLB	SHRAB	XCHB ix	EST in	EST ix	ESTB in	ESTB ix
2*x*	SCALL							
3*x*	JBS bit 0	JBS bit 1	JBS bit 2	JBS bit 3	JBS bit 4	JBS bit 5	JBS bit 6	JBS bit 7
4*x*	SUB 3op di	SUB 3op im	SUB 3op in	SUB 3op ix	MUL & MULU 3op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ di	MUL & MULU 3op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ im	MUL & MULU 3op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ in	MUL & MULU 3op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ ix
5*x*	SUBB 3op di	SUBB 3op im	SUBB 3op in	SUBB 3op ix	MULB & MULUB 3op (3) di	MULB & MULUB 3op (3) im	MULB & MULUB 3op (3) in	MULB & MULUB 3op (3) ix
6*x*	SUB 2op di	SUB 2op im	SUB 2op in	SUB 2op ix	MUL & MULU 2op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ di	MUL & MULU 2op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ im	MUL & MULU 2op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ in	MUL & MULU 2op (3)(4) MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ ix
7x	SUBB 2op di	SUBB 2op im	SUBB 2op in	SUBB 2op ix	MULB & MULUB 2op (3) di	MULB & MULUB 2op (3) im	MULB & MULUB 2op (3) in	MULB & MULUB 2op (3) ix
8*x*	CMP di	CMP im	CMP in	CMP ix	DIV & DIVU (3) di	DIV & DIVU (3) im	DIV & DIVU (3) in	DIV & DIVU (3) ix
9*x*	CMPB di	CMPB im	CMPB in	CMPB ix	DIVB & DIVUB (3) di	DIVB & DIVUB (3) im	DIVB & DIVUB (3) in	DIVB & DIVUB (3) ix
A*x*	SUBC di	SUBC im	SUBC in	SUBC ix	LDBZE di	LDBZE im	LDBZE in	LDBZE ix
B*x*	SUBCB di	SUBCB im	SUBCB in	SUBCB ix	LDBSE di	LDBSE im	LDBSE in	LDBSE ix
C*x*	PUSH di	PUSH im	PUSH in	PUSH ix	POP di	BMOVI	POP in	POP ix
D*x*	JST	JH	JLE	JC	JVT	JV	JLT	JE
E*x*	ELD in	ELD ix	ELDB in	ELDB ix			(1)	LCALL
F*x*	CLRC	SETC	DI	EI	CLRVT	NOP	(4)	RST

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.
3. Optional prefix opcode for signed multiplication and division instructions.
4. The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.
5. The RPT, RPT*xxx*, RPTI and RPTI*xxx* instructions do not support indexed addressing.

Table A-2. Processor Status Word (PSW) Flags

Mnemonic	Description
C	The carry flag is set to indicate an arithmetic carry from the MSB of the ALU or the state of the last bit shifted out of an operand. If a subtraction operation generates a borrow, the carry flag is cleared. **C** **Value of Bits Shifted Off** 0 < ½ LSB 1 ≥ ½ LSB Normally, the result is rounded up if the carry flag is set. The sticky bit flag allows a finer resolution in the rounding decision. **C ST** **Value of Bits Shifted Off** 0 0 = 0 0 1 > 0 and < ½ LSB 1 0 = ½ LSB 1 1 > ½ LSB and < 1 LSB
N	The negative flag is set to indicate that the result of an operation is negative. The flag is correct even if an overflow occurs. For all shift operations and the NORML instruction, the flag is set to equal the most-significant bit of the result, even if the shift count is zero.
ST	The sticky bit flag is set to indicate that, during a right shift, a "1" has been shifted into the carry flag and then shifted out. This bit is undefined after a multiply operation. The sticky bit flag can be used with the carry flag to allow finer resolution in rounding decisions. See the description of the carry (C) flag for details.
V	The overflow flag is set to indicate that the result of an operation is too large to be represented correctly in the available space. For shift operations, the flag is set if the most-significant bit of the operand changes during the shift. For divide operations, the quotient is stored in the low-order half of the destination operand and the remainder is stored in the high-order half. The overflow flag is set if the quotient is outside the range for the low-order half of the destination operand. (Chapter 4, "Programming Considerations," defines the operands and possible values for each.) **Instruction** **Quotient Stored in:** **V Flag Set if Quotient is:** DIVB Short-integer < –128 or > +127 (< 80H or > 7FH) DIV Integer < –32768 or > +32767 (< 8000H or > 7FFFH) DIVUB Byte > 255 (FFH) DIVU Word > 65535 (FFFFH)
VT	The overflow-trap flag is set when the overflow flag is set, but it is cleared only by the CLRVT, JVT, and JNVT instructions. This allows testing for a possible overflow at the end of a sequence of related arithmetic operations, which is generally more efficient than testing the overflow flag after each operation.
Z	The zero flag is set to indicate that the result of an operation was zero. For multiple-precision calculations, the zero flag cannot be set by the instructions that use the carry bit from the previous calculation (e.g., ADDC, SUBC). However, these instructions can clear the zero flag. This ensures that the zero flag will reflect the result of the entire operation, not just the last calculation. For example, if the result of adding together the lower words of two double words is zero, the zero flag would be set. When the upper words are added together using the ADDC instruction, the flag remains set if the result is zero and is cleared if the result is not zero.

Table A-3 shows the effect of the PSW flags or a specified condition on conditional jump instructions. Table A-4 defines the symbols used in Table A-6 to show the effect of each instruction on the PSW flags.

Table A-3. Effect of PSW Flags or Specified Conditions on Conditional Jump Instructions

Instruction	Jumps to Destination if	Continues if
DJNZ	decremented byte ≠ 0	decremented byte = 0
DJNZW	decremented word ≠ 0	decremented word = 0
JBC	specified register bit = 0	specified register bit = 1
JBS	specified register bit = 1	specified register bit = 0
JNC	C = 0	C = 1
JNH	C = 0 OR Z = 1	C = 1 AND Z = 0
JC	C = 1	C = 0
JH	C = 1 AND Z = 0	C = 0 OR Z = 1
JGE	N = 0	N = 1
JGT	N = 0 AND Z = 0	N = 1 OR Z = 1
JLT	N = 1	N = 0
JLE	N = 1 OR Z = 1	N = 0 AND Z = 0
JNST	ST = 0	ST = 1
JST	ST = 1	ST = 0
JNV	V = 0	V = 1
JV	V = 1	V = 0
JNVT	VT = 0	VT = 1 (clears VT)
JVT	VT = 1 (clears VT)	VT = 0
JNE	Z = 0	Z = 1
JE	Z = 1	Z = 0

Table A-4. PSW Flag Setting Symbols

Symbol	Description
✓	The instruction sets or clears the flag, as appropriate.
—	The instruction does not modify the flag.
↓	The instruction may clear the flag, if it is appropriate, but cannot set it.
↑	The instruction may set the flag, if it is appropriate, but cannot clear it.
1	The instruction sets the flag.
0	The instruction clears the flag.
?	The instruction leaves the flag in an indeterminate state.

Table A-5 defines the variables that are used in Table A-6 to represent the instruction operands.

Table A-5. Operand Variables

Variable	Description
aa	A 2-bit field within an opcode that selects the basic addressing mode used. This field is present only in those opcodes that allow addressing mode options. The field is encoded as follows: 00 register-direct 01 immediate 10 indirect 11 indexed
baop	A byte operand that is addressed by any addressing mode.
bbb	A 3-bit field within an opcode that selects a specific bit within a register.
bitno	A 3-bit field within an opcode that selects one of the eight bits in a byte.
breg	A byte register in the internal register file. When it could be unclear whether this variable refers to a source or a destination register, it is prefixed with an *S* or a *D*. The value must be in the range of 00–FFH.
cadd	An address in the program code.
Dbreg†	A byte register in the lower register file that serves as the destination of the instruction operation.
disp	Displacement. The distance between the end of an instruction and the target label.
Dlreg†	A 32-bit register in the lower register file that serves as the destination of the instruction operation. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH.
Dwreg†	A word register in the lower register file that serves as the destination of the instruction operation. Must be aligned on an address that is evenly divisible by 2. The value must be in the range of 00–FEH.
lreg	A 32-bit register in the lower register file. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH.
ptr2_reg	A double-pointer register, used with the EBMOVI instruction. Must be aligned on an address that is evenly divisible by 8. The value must be in the range of 00–F8H.
preg	A pointer register. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH.
Sbreg†	A byte register in the lower register file that serves as the source of the instruction operation.
Slreg†	A 32-bit register in the lower register file that serves as the source of the instruction operation. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH.
Swreg†	A word register in the lower register file that serves as the source of the instruction operation. Must be aligned on an address that is evenly divisible by 2. The value must be in the range of 00–FEH.
treg	A 24-bit register in the lower register file. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH.
waop	A word operand that is addressed by any addressing mode.
w2_reg	A double-word register in the lower register file. Must be aligned on an address that is evenly divisible by 4. The value must be in the range of 00–FCH. Although *w2_reg* is similar to *lreg*, there is a distinction: *w2_reg* consists of two halves, each containing a 16-bit address; *lreg* is indivisible and contains a 32-bit number.
wreg	A word register in the lower register file. When it could be unclear whether this variable refers to a source or a destination register, it is prefixed with an *S* or a *D*. Must be aligned on an address that is evenly divisible by 2. The value must be in the range of 00–FEH.
xxx	The three high-order bits of displacement.

† The *D* or *S* prefix is used only when it could be unclear whether a variable refers to a destination or a source register.

Table A-6. Instruction Set

Mnemonic	Operation	Instruction Format
ADD (2 operands)	ADD WORDS. Adds the source and destination word operands and stores the sum into the destination operand. (DEST) ← (DEST) + (SRC) **PSW Flag Settings** Z: ✓ N: ✓ C: ✓ V: ✓ VT: ↑ ST: —	DEST, SRC ADD wreg, waop (011001aa) (waop) (wreg)
ADD (3 operands)	ADD WORDS. Adds the two source word operands and stores the sum into the destination operand. (DEST) ← (SRC1) + (SRC2) **PSW Flag Settings** Z: ✓ N: ✓ C: ✓ V: ✓ VT: ↑ ST: —	DEST, SRC1, SRC2 ADD Dwreg, Swreg, waop (010001aa) (waop) (Swreg) (Dwreg)
ADDB (2 operands)	ADD BYTES. Adds the source and destination byte operands and stores the sum into the destination operand. (DEST) ← (DEST) + (SRC) **PSW Flag Settings** Z: ✓ N: ✓ C: ✓ V: ✓ VT: ↑ ST: —	DEST, SRC ADDB breg, baop (011101aa) (baop) (breg)
ADDB (3 operands)	ADD BYTES. Adds the two source byte operands and stores the sum into the destination operand. (DEST) ← (SRC1) + (SRC2) **PSW Flag Settings** Z: ✓ N: ✓ C: ✓ V: ✓ VT: ↑ ST: —	DEST, SRC1, SRC2 ADDB Dbreg, Sbreg, baop (010101aa) (baop) (Sbreg) (Dbreg)

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>ADDC</td><td>ADD WORDS WITH CARRY. Adds the source and destination word operands and the carry flag (0 or 1) and stores the sum into the destination operand. If the accumulator (ACC) is the destination, the addition will conform to the accumulator control and status (ACC_STAT) register requirements for saturation.
(DEST) ← (DEST) + (SRC) + C
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>↓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
ADDC wreg, waop
(101001aa) (waop) (wreg = ACC_02)</td></tr>
<tr><td>ADDCB</td><td>ADD BYTES WITH CARRY. Adds the source and destination byte operands and the carry flag (0 or 1) and stores the sum into the destination operand.
(DEST) ← (DEST) + (SRC) + C
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>↓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
ADDCB breg, baop
(101101aa) (baop) (breg)</td></tr>
<tr><td>AND
(2 operands)</td><td>LOGICAL AND WORDS. ANDs the source and destination word operands and stores the result into the destination operand. The result has ones in only the bit positions in which both operands had a “1” and zeros in all other bit positions.
(DEST) ← (DEST) AND (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
AND wreg, waop
(011000aa) (waop) (wreg)</td></tr>
<tr><td>AND
(3 operands)</td><td>LOGICAL AND WORDS. ANDs the two source word operands and stores the result into the destination operand. The result has ones in only the bit positions in which both operands had a “1” and zeros in all other bit positions.
(DEST) ← (SRC1) AND (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC1, SRC2
AND Dwreg, Swreg, waop
(010000aa) (waop) (Swreg) (Dwreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>ANDB
(2 operands)</td><td>LOGICAL AND BYTES. ANDs the source and destination byte operands and stores the result into the destination operand. The result has ones in only the bit positions in which both operands had a “1” and zeros in all other bit positions.
(DEST) ← (DEST) AND (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
ANDB breg, baop
(011100aa) (baop) (breg)</td></tr>
<tr><td>ANDB
(3 operands)</td><td>LOGICAL AND BYTES. ANDs the two source byte operands and stores the result into the destination operand. The result has ones in only the bit positions in which both operands had a “1” and zeros in all other bit positions.
(DEST) ← (SRC1) AND (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC1, SRC2
ANDB Dbreg, Sbreg, baop
(010100aa) (baop) (Sbreg) (Dbreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>BMOV</td><td>BLOCK MOVE. Moves a block of word data from one location in memory to another. The source and destination addresses are calculated using the indirect with autoincrement addressing mode. A long register (PTRS) addresses the source and destination pointers, which are stored in adjacent word registers. The source pointer (SRCPTR) is the low word and the destination pointer (DSTPTR) is the high word of PTRS. A word register (CNTREG) specifies the number of transfers. The blocks of word data can be located anywhere in page 00H, but should not overlap. Because the source (SRCPTR) and destination (DSTPTR) pointers are 16 bits wide, this instruction uses nonextended data moves. It cannot operate across page boundaries.

COUNT ← (CNTREG)
LOOP: SRCPTR ← (PTRS)
DSTPTR ← (PTRS + 2)
(DSTPTR) ← (SRCPTR)
(PTRS) ← SRCPTR + 2
(PTRS + 2) ← DSTPTR + 2
COUNT ← COUNT – 1
if COUNT ≠ 0 then
go to LOOP
end_if

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>PTRS, CNTREG
BMOV lreg, wreg
(11000001) (wreg) (lreg)

NOTE: The pointers are autoincremented during this instruction. However, CNTREG is not decremented. Therefore, it is easy to unintentionally create a long, uninterruptible operation with the BMOV instruction. Use the BMOVI instruction for an interruptible operation.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>BMOVI</td><td>INTERRUPTIBLE BLOCK MOVE. Moves a block of word data from one location in memory to another. The instruction is identical to BMOV, except that BMOVI is interruptible. The source and destination addresses are calculated using the indirect with autoincrement addressing mode. A long register (PTRS) addresses the source and destination pointers, which are stored in adjacent word registers. The source pointer (SRCPTR) is the low word and the destination pointer (DSTPTR) is the high word of PTRS. A word register (CNTREG) specifies the number of transfers. This register must reside in the lower register file; it cannot be windowed. The blocks of word data can be located anywhere in page 00H, but should not overlap. Because the source (SRCPTR) and destination (DSTPTR) pointers are 16 bits wide, this instruction uses nonexteneded data moves. It cannot operate across page boundaries. (If you need to cross page boundaries, use the EBMOVI instruction.)

COUNT ← (CNTREG)
LOOP: SRCPTR ← (PTRS)
DSTPTR ← (PTRS + 2)
(DSTPTR) ← (SRCPTR)
(PTRS) ← SRCPTR + 2
(PTRS + 2) ← DSTPTR + 2
COUNT ← COUNT – 1
if COUNT ≠ 0 then
go to LOOP
end_if

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>PTRS, CNTREG
BMOVI lreg, wreg
(11001101) (wreg) (lreg)

NOTE: The pointers are autoincremented during this instruction. However, CNTREG is decremented only when the instruction is interrupted. When BMOVI is interrupted, CNTREG is updated to store the interim word count at the time of the interrupt. For this reason, you should always reload CNTREG before starting a BMOVI.</td></tr>
<tr><td>BR</td><td>BRANCH INDIRECT. Continues execution at the address specified in the operand word register.

PC ← (DEST)

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST
BR [wreg]
(11100011) (wreg)

NOTE: In 1-Mbyte mode, the BR instruction always branches to page FFH. Use the EBR instruction to branch to an address on any other page.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>CLR</td><td>CLEAR WORD. Clears the value of the operand.
(DEST) ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>1</td><td>0</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST
CLR wreg
(00000001) (wreg)</td></tr>
<tr><td>CLRB</td><td>CLEAR BYTE. Clears the value of the operand.
(DEST) ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>1</td><td>0</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST
CLRB breg
(00010001) (breg)</td></tr>
<tr><td>CLRC</td><td>CLEAR CARRY FLAG. Clears the carry flag.
C ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>0</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>CLRC
(11111000)</td></tr>
<tr><td>CLRVT</td><td>CLEAR OVERFLOW-TRAP FLAG. Clears the overflow-trap flag.
VT ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>0</td><td>—</td></tr></table></td><td>CLRVT
(11111100)</td></tr>
<tr><td>CMP</td><td>COMPARE WORDS. Subtracts the source word operand from the destination word operand. The flags are altered, but the operands remain unaffected. If a borrow occurs, the carry flag is cleared; otherwise, it is set.
(DEST) – (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
CMP wreg, waop
(100010aa) (waop) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>CMPB</td><td>COMPARE BYTES. Subtracts the source byte operand from the destination byte operand. The flags are altered, but the operands remain unaffected. If a borrow occurs, the carry flag is cleared; otherwise, it is set.
(DEST) – (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
CMPB breg, baop
(100110aa) (baop) (breg)</td></tr>
<tr><td>CMPL</td><td>COMPARE LONG. Compares the magnitudes of two double-word (long) operands. The operands are specified using the direct addressing mode. The flags are altered, but the operands remain unaffected. If a borrow occurs, the carry flag is cleared; otherwise, it is set.
(DEST) – (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>—</td></tr></table></td><td>DEST, SRC
CMPL Dlreg, Slreg
(11000101) (Slreg) (Dlreg)</td></tr>
<tr><td>DEC</td><td>DECREMENT WORD. Decrements the value of the operand by one.
(DEST) ← (DEST) –1
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST
DEC wreg
(00000101) (wreg)</td></tr>
<tr><td>DECB</td><td>DECREMENT BYTE. Decrements the value of the operand by one.
(DEST) ← (DEST) –1
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST
DECB breg
(00010101) (breg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>DI</td><td>DISABLE INTERRUPTS. Disables maskable interrupts. Interrupt calls cannot occur after this instruction.
Interrupt Enable (PSW.1) ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DI
(11111010)</td></tr>
<tr><td>DIV</td><td>DIVIDE INTEGERS. Divides the contents of the destination long-integer operand by the contents of the source integer word operand, using signed arithmetic. It stores the quotient into the low-order word of the destination (i.e., the word with the lower address) and the remainder into the high-order word. The following two statements are performed concurrently.
(low word DEST) ← (DEST) / (SRC)
(high word DEST) ← (DEST) MOD (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
DIV lreg, waop
(11111110) (100011aa) (waop) (lreg)</td></tr>
<tr><td>DIVB</td><td>DIVIDE SHORT-INTEGERS. Divides the contents of the destination integer operand by the contents of the source short-integer operand, using signed arithmetic. It stores the quotient into the low-order byte of the destination (i.e., the word with the lower address) and the remainder into the high-order byte. The following two statements are performed concurrently.
(low byte DEST) ← (DEST) / (SRC)
(high byte DEST) ← (DEST) MOD (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
DIVB wreg, baop
(11111110) (100111aa) (baop) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>DIVU</td><td>DIVIDE WORDS, UNSIGNED. Divides the contents of the destination double-word operand by the contents of the source word operand, using unsigned arithmetic. It stores the quotient into the low-order word (i.e., the word with the lower address) of the destination operand and the remainder into the high-order word. The following two statements are performed concurrently.
(low word DEST) ← (DEST) / (SRC)
(high word DEST) ← (DEST) MOD (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
DIVU lreg, waop
(100011aa) (waop) (lreg)</td></tr>
<tr><td>DIVUB</td><td>DIVIDE BYTES, UNSIGNED. This instruction divides the contents of the destination word operand by the contents of the source byte operand, using unsigned arithmetic. It stores the quotient into the low-order byte (i.e., the byte with the lower address) of the destination operand and the remainder into the high-order byte. The following two statements are performed concurrently.
(low byte DEST) ← (DEST) / (SRC)
(high byte DEST) ← (DEST) MOD (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
DIVUB wreg, baop
(100111aa) (baop) (wreg)</td></tr>
<tr><td>DJNZ</td><td>DECREMENT AND JUMP IF NOT ZERO. Decrements the value of the byte operand by 1. If the result is 0, control passes to the next sequential instruction. If the result is not 0, the instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
(COUNT) ← (COUNT) –1
if (COUNT) ≠ 0 then
PC ← PC + 8-bit disp
end_if
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DJNZ breg, cadd
(11100000) (breg) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>DJNZW</td><td>DECREMENT AND JUMP IF NOT ZERO WORD. Decrements the value of the word operand by 1. If the result is 0, control passes to the next sequential instruction. If the result is not 0, the instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
(COUNT) ← (COUNT) –1
if (COUNT) ≠ 0 then
PC ← PC + 8-bit disp
end_if
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DJNZW wreg, cadd
(11100001) (wreg) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits</td></tr>
<tr><td>EBMOVI</td><td>EXTENDED INTERRUPTIBLE BLOCK MOVE. Moves a block of word data from one memory location to another. This instruction allows you to move blocks of up to 64K words between any two locations in the 16-Mbyte address space. This instruction is interruptible.
The source and destination addresses are calculated using the extended indirect with autoincrement addressing mode. A quad-word register (PTRS) addresses the 24-bit pointers, which are stored in adjacent double-word registers. The source pointer (SRCPTR) is the low double-word and the destination pointer is the high double-word of PTRS. A word register (CNTREG) specifies the number of transfers. This register must reside in the lower register file; it cannot be windowed. The blocks of data can reside anywhere in memory, but should not overlap.
COUNT ← (CNTREG)
LOOP: SRCPTR ← (PTRS)
DSTPTR ← (PTRS + 2)
(DSTPTR) ← (SRCPTR)
(PTRS) ← SRCPTR + 2
(PTRS + 2) ← DSTPTR + 2
COUNT ← COUNT 1
if COUNT ≠ 0 then
go to LOOP
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>PTRS, CNTREG
EBMOVI prt2_reg, wreg
(11100100) (wreg) (prt2_reg)

NOTES: The pointers are autoincremented during this instruction. However, CNTREG is decremented only when the instruction is interrupted. When EBMOVI is interrupted, CNTREG is updated to store the interim word count at the time of the interrupt. For this reason, you should always reload CNTREG before starting an EBMOVI.

For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>EBR</td><td>EXTENDED BRANCH INDIRECT. Continues execution at the address specified in the operand word register. This instruction is an unconditional indirect jump to anywhere in the 16-Mbyte address space.

EBR shares its opcode (E3) with the BR instruction. To differentiate between the two, the compiler sets the least-significant bit of treg for the EBR instruction. For example: EBR [50] becomes E351 when compiled.

PC ← (DEST)

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST
EBR cadd
or
EBR [treg]
(11100011) (treg)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>ECALL</td><td>EXTENDED CALL. Pushes the contents of the program counter (the return address) onto the stack, then adds to the program counter the offset between the end of this instruction and the target label, effecting the call. The operand may be any address in the address space.

This instruction is an unconditional relative call to anywhere in the 16-Mbyte address space. It functions only in extended addressing mode.

SP ← SP – 4
(SP) ← PC
PC ← PC + 24-bit disp

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>ECALL cadd
(1111 0001) (disp-low) (disp-high) (disp-ext)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>EI</td><td>ENABLE INTERRUPTS. Enables maskable interrupts following the execution of the next statement. Interrupt calls cannot occur immediately following this instruction.

Interrupt Enable (PSW.1) ← 1

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>EI
(11111011)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>EJMP</td><td>EXTENDED JUMP. Adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The operand may be any address in the entire address space. The offset must be in the range of +8,388,607 to –8,388,608 for 24-bit addresses.
This instruction is an unconditional, relative jump to anywhere in the 16-Mbyte address space. It functions only in extended addressing mode.
PC ←PC + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>EJMP cadd
(11100110) (disp-low) (disp-high) (disp-ext)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>ELD</td><td>EXTENDED LOAD WORD. Loads the value of the source word operand into the destination operand.
This instruction allows you to move data from anywhere in the 16-Mbyte address space into the lower register file.
ext. indirect: (DEST) ← (SRC)
ext indexed: (DEST)← (SRC) + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
ELD wreg, [treg]
ext. indirect: (11101000) (treg) (wreg)
ext. indexed: (11101001) (treg) (disp-low) (disp-high) (disp-ext) (wreg)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>ELDB</td><td>EXTENDED LOAD BYTE. Loads the value of the source byte operand into the destination operand.
This instruction allows you to move data from anywhere in the 16-Mbyte address space into the lower register file.
ext. indirect: (DEST) ← (SRC)
ext indexed: (DEST)← (SRC) + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
ELDB breg, [treg]
ext. indirect: (11101010) (treg) (breg)
ext. indexed: (11101011) (treg) (disp-low) (disp-high) (disp-ext) (breg)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>EST</td><td>EXTENDED STORE WORD. Stores the value of the source (leftmost) word operand into the destination (rightmost) operand.
This instruction allows you to move data from the lower register file to anywhere in the 16-Mbyte address space.
ext. indirect: (DEST) ← (SRC)
ext indexed: (DEST)← (SRC) + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC, DEST
EST wreg, [treg]
ext. indirect: (00011100) (treg) (wreg)
ext. indexed: (00011101) (treg) (disp-low) (disp-high) (disp-ext) (wreg)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>ESTB</td><td>EXTENDED STORE BYTE. Stores the value of the source (leftmost) byte operand into the destination (rightmost) operand.
This instruction allows you to move data from the lower register file to anywhere in the 16-Mbyte address space.
ext. indirect: (DEST) ← (SRC)
ext indexed: (DEST)← (SRC) + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC, DEST
ESTB breg, [treg]
ext. indirect: (00011110) (treg) (breg)
ext. indexed: (00011111) (treg) (disp-low) (disp-high) (disp-ext) (breg)

NOTE: For 20-bit addresses, the offset must be in the range of +524287 to –524288.</td></tr>
<tr><td>EXT</td><td>SIGN-EXTEND INTEGER INTO LONG-INTEGER. Sign-extends the low-order word of the operand throughout the high-order word of the operand.
if DEST.15 = 1 then
(high word DEST) ← 0FFFFH
else
(high word DEST) ← 0
end_if
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>EXT lreg
(00000110) (lreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>EXTB</td><td>SIGN-EXTEND SHORT-INTEGER INTO INTEGER. Sign-extends the low-order byte of the operand throughout the high-order byte of the operand.
if DEST.7 = 1 then
(high byte DEST) ← 0FFH
else
(high byte DEST) ← 0
end_if
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>EXTB wreg
(00010110) (wreg)</td></tr>
<tr><td>IDLPD</td><td>IDLE/POWERDOWN/STANDBY. Depending on the 8-bit value of the KEY operand, this instruction causes the device to:
• enter idle mode, if KEY=1,
• enter powerdown mode, if KEY=2,
• enter standby mode, if KEY=3,
• execute a reset sequence, if KEY = any value other than 1, 2, or 3.
The bus controller completes any prefetch cycle in progress before the CPU stops or resets.
if KEY = 1 then
enter idle
else if KEY = 2 then
enter powerdown
else if KEY = 3 then
enter standby
else
execute reset
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td colspan="6">KEY = 1, 2, or 3</td></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr><tr><td colspan="6">KEY = any value other than 1, 2, or 3</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>IDLPD #key
(11110110) (key)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>INC</td><td>INCREMENT WORD. Increments the value of the word operand by 1.
(DEST) ← (DEST) + 1
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>0</td></tr></table></td><td>INC wreg
(00000111) (wreg)</td></tr>
<tr><td>INCB</td><td>INCREMENT BYTE. Increments the value of the byte operand by 1.
(DEST) ← (DEST) + 1
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>INCB breg
(00010111) (breg)</td></tr>
<tr><td>JBC</td><td>JUMP IF BIT IS CLEAR. Tests the specified bit. If the bit is set, control passes to the next sequential instruction. If the bit is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if (specified bit) = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JBC breg, bitno, cadd
(00110bbb) (breg) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JBS</td><td>JUMP IF BIT IS SET. Tests the specified bit. If the bit is clear, control passes to the next sequential instruction. If the bit is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if (specified bit) = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JBS breg, bitno, cadd
(00111bbb) (breg) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JC</td><td>JUMP IF CARRY FLAG IS SET. Tests the carry flag. If the carry flag is clear, control passes to the next sequential instruction. If the carry flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if C = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JC cadd
(11011011) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JE</td><td>JUMP IF EQUAL. Tests the zero flag. If the flag is clear, control passes to the next sequential instruction. If the zero flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if Z = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JE cadd
(11011111) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JGE</td><td>JUMP IF SIGNED GREATER THAN OR EQUAL. Tests the negative flag. If the negative flag is set, control passes to the next sequential instruction. If the negative flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if N = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JGE cadd
(11010110) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JGT</td><td>JUMP IF SIGNED GREATER THAN. Tests both the zero flag and the negative flag. If either flag is set, control passes to the next sequential instruction. If both flags are clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if N = 0 AND Z = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JGT cadd
(11010010) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JH</td><td>JUMP IF HIGHER (UNSIGNED). Tests both the zero flag and the carry flag. If either the carry flag is clear or the zero flag is set, control passes to the next sequential instruction. If the carry flag is set and the zero flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if C = 1 AND Z = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JH cadd
(11011001) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JLE</td><td>JUMP IF SIGNED LESS THAN OR EQUAL. Tests both the negative flag and the zero flag. If both flags are clear, control passes to the next sequential instruction. If either flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if N = 1 OR Z = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JLE cadd
(11011010) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JLT</td><td>JUMP IF SIGNED LESS THAN. Tests the negative flag. If the flag is clear, control passes to the next sequential instruction. If the negative flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if N = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JLT cadd
(11011110) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JNC</td><td>JUMP IF CARRY FLAG IS CLEAR. Tests the carry flag. If the flag is set, control passes to the next sequential instruction. If the carry flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if C = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JNC cadd
(11010011) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JNE</td><td>JUMP IF NOT EQUAL. Tests the zero flag. If the flag is set, control passes to the next sequential instruction. If the zero flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –128 to +127.
if Z = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JNE cadd
(11010111) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JNH</td><td>JUMP IF NOT HIGHER (UNSIGNED). Tests both the zero flag and the carry flag. If the carry flag is set and the zero flag is clear, control passes to the next sequential instruction. If either the carry flag is clear or the zero flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if C = 0 OR Z = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JNH cadd
(11010001) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JNST</td><td>JUMP IF STICKY BIT FLAG IS CLEAR. Tests the sticky bit flag. If the flag is set, control passes to the next sequential instruction. If the sticky bit flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if ST = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JNST cadd
(11010000) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JNV</td><td>JUMP IF OVERFLOW FLAG IS CLEAR. Tests the overflow flag. If the flag is set, control passes to the next sequential instruction. If the overflow flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if V = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JNV cadd
(11010101) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JNVT</td><td>JUMP IF OVERFLOW-TRAP FLAG IS CLEAR. Tests the overflow-trap flag. If the flag is set, this instruction clears the flag and passes control to the next sequential instruction. If the overflow-trap flag is clear, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if VT = 0 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>0</td><td>—</td></tr></table></td><td>JNVT cadd
(11010100) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JST</td><td>JUMP IF STICKY BIT FLAG IS SET. Tests the sticky bit flag. If the flag is clear, control passes to the next sequential instruction. If the sticky bit flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if ST = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JST cadd
(11011000) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>JV</td><td>JUMP IF OVERFLOW FLAG IS SET. Tests the overflow flag. If the flag is clear, control passes to the next sequential instruction. If the overflow flag is set, this instruction adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if V = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>JV cadd
(11011101) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>JVT</td><td>JUMP IF OVERFLOW-TRAP FLAG IS SET. Tests the overflow-trap flag. If the flag is clear, control passes to the next sequential instruction. If the overflow-trap flag is set, this instruction clears the flag and adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in range of –128 to +127.
if VT = 1 then
PC ← PC + 8-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>0</td><td>—</td></tr></table></td><td>JVT cadd
(11011100) (disp)

NOTE: The displacement (disp) is sign-extended to 24 bits.</td></tr>
<tr><td>LCALL</td><td>LONG CALL. Pushes the contents of the program counter (the return address) onto the stack, then adds to the program counter the offset between the end of this instruction and the target label, effecting the call. The offset must be in the range of –32,768 to +32,767.
64-Kbyte mode:
SP ← SP – 2
(SP) ← PC
PC ← PC + 16-bit disp
1-Mbyte mode:
SP ← SP – 4
(SP) ← PC
PC ← PC + 24-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>LCALL cadd
(11101111) (disp-low) (disp-high)

NOTE: The displacement (disp) is sign-extended to 24 bits in the 1-Mbyte addressing mode. This displacement may cause the program counter to cross a page boundary.</td></tr>
<tr><td>LD</td><td>LOAD WORD. Loads the value of the source word operand into the destination operand.
(DEST) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
LD wreg, waop
(101000aa) (waop) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>LDB</td><td>LOAD BYTE. Loads the value of the source byte operand into the destination operand.
(DEST) ← (SRC)

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
LDB breg, baop
(101100aa) (baop) (breg)</td></tr>
<tr><td>LDBSE</td><td>LOAD BYTE SIGN-EXTENDED. Sign-extends the value of the source short-integer operand and loads it into the destination integer operand.
(low byte DEST) ← (SRC)
if DEST.15 = 1 then
(high word DEST) ← 0FFH
else
(high word DEST) ← 0
end_if

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
LDBSE wreg, baop
(101111aa) (baop) (wreg)</td></tr>
<tr><td>LDBZE</td><td>LOAD BYTE ZERO-EXTENDED. Zero-extends the value of the source byte operand and loads it into the destination word operand.
(low byte DEST) ← (SRC)
(high byte DEST) ← 0

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
LDBZE wreg, baop
(101011aa) (baop) (wreg)</td></tr>
<tr><td>LJMP</td><td>LONG JUMP. Adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –32,768 to +32,767.
64-Kbyte mode:
PC ← PC + 16-bit disp
1-Mbyte mode:
PC ← PC + 24-bit disp

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>LJMP cadd
(11100111) (disp-low) (disp-high)

NOTE: The displacement (disp) is sign-extended to 24 bits in the 1-Mbyte addressing mode. This displacement may cause the program counter to cross a page boundary.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MAC
(2 operands)</td><td>MULTIPLY UNSIGNED WORDS, ACCUMULATE. Multiplies the source and destination word operands, using unsigned arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator.
(ACC) ← (ACC) × (SRC) + ACC
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
MAC waop
(011011aa) (waop) (00)</td></tr>
<tr><td>MAC
(3 operands)</td><td>MULTIPLY UNSIGNED WORDS, ACCUMULATE. Multiplies the two source word operands, using unsigned arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator.
(ACC) ← (SRC1) × (SRC2) + ACC
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC1, SRC2
MAC wreg, waop
(010011aa) (waop) (wreg) (00)</td></tr>
<tr><td>MACR
(2 operands)</td><td>MULTIPLY UNSIGNED WORDS, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using unsigned arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator. The source (SRC) register contents are relocated in memory to SRC address + 2.
(ACC) ← (ACC) × (SRC) + ACC and
(SRC) ← (SRC) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
MACR waop†
(011011aa) (waop) (04)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MACR
(3 operands)</td><td>MULTIPLY UNSIGNED WORDS, ACCUMULATE, ROTATE. Multiplies the two source word operands, using unsigned arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator. The source 2 (SRC2) register contents are relocated in memory to SRC2 address + 2.
(ACC) ← (SRC1) × (SRC2) + ACC and (SRC2) ← (SRC2) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC1, SRC2
MACR wreg, waop†
(010011aa) (waop) (wreg) (04)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
<tr><td>MACRZ
(2 operands)</td><td>MULTIPLY UNSIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using unsigned arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The source (SRC) register contents are relocated in memory to SRC address + 2.
temp ← (ACC) × (SRC)
(ACC) ← 0
(ACC) ← temp and (SRC) ← (SRC) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
MACRZ waop†
(011011aa) (waop) (0C)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
<tr><td>MACRZ
(3 operands)</td><td>MULTIPLY UNSIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using unsigned arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The source 2 (SRC2) register contents are relocated in memory to SRC2 address + 2.
temp ← (SRC1) × (SRC2)
(ACC) ← 0
(ACC) ← temp and (SRC2) ← (SRC2) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC1, SRC2
MACRZ wreg, waop†
(010011aa) (waop) (wreg) (0C)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MACZ
(2 operands)</td><td>MULTIPLY UNSIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE. Multiplies the source and destination word operands, using unsigned arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
temp ← (ACC) × (SRC)
(ACC) ← 0
(ACC) ← temp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
MACZ waop
(011011aa) (waop) (08)</td></tr>
<tr><td>MACZ
(3 operands)</td><td>MULTIPLY UNSIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE. Multiplies the source and destination word operands, using unsigned arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
temp ← (SRC1) × (SRC2)
(ACC) ← 0
(ACC) ← temp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC1, SRC2
MACZ wreg, waop
(010011aa) (waop) (wreg) (08)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MSAC</td><td>MOVE SATURATED ACCUMULATOR.
Rotates a 32-bit signed value from the 40-bit accumulator to a register or memory location at a double-word boundary address using a 32-bit barrel shifter. The bit pointer (the SRC) is specified either as an immediate value in the range 0–31 (0–1FH) or as a register in the range 32–255 (20–FFH). The value in the register must be in the range 0–31. The bit pointer indicates the position of the bit that will assume the most-significant bit position of the low destination word (bit 15), the destination sign bit. If the value in the accumulator is greater (more positive) or less (more negative) than the low destination word (bits 0–15), then the low destination word will be replaced by the full-scale positive saturated value (7FFFH) or by the full-scale negative saturated value (8000H).
count ← (SRC) – 15
temp ← 31
do while temp ≠ –1
If (SRC) > 15, then
(DEST) ← ACC.temp ROTATE RIGHT BY count
If (SRC) < 15, then
(DEST) ← ACC.temp ROTATE LEFT BY count
If (SRC) = 15, then
(DEST) ← ACC.temp
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
MSAC lreg, breg
(00001101) (breg) (lreg)
or
MSAC lreg, #pointer
(00001101) (pointer) (lreg)

NOTE: The following table identifies the instructions executed by opcode 0DH and the necessary setups.
<table><tr><th>lreg.1</th><th>lreg.0</th><th>Execute</th></tr><tr><td>0</td><td>0</td><td>SHLL</td></tr><tr><td>0</td><td>1</td><td>MVAC</td></tr><tr><td>1</td><td>0</td><td>Reserved</td></tr><tr><td>1</td><td>1</td><td>MSAC</td></tr></table></td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MUL
(2 operands)</td><td>MULTIPLY INTEGERS. Multiplies the source and destination integer operands, using signed arithmetic, and stores the 32-bit result into the destination long-integer operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (DEST) × (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC
MUL lreg, waop
(11111110) (011011aa) (waop) (lreg)

NOTE: A destination address in the range 00–0FH enables the multiply-accumulate function. For example, if the destination address is 08H, the accumulator is cleared and then the results of the multiply are added. However, if the destination address is 00H, the results of the multiply are added to the current contents of the accumulator.</td></tr>
<tr><td>MUL
(3 operands)</td><td>MULTIPLY INTEGERS. Multiplies the two source integer operands, using signed arithmetic, and stores the 32-bit result into the destination long-integer operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (SRC1) × (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC1, SRC2
MUL lreg, wreg, waop
(11111110) (010011aa) (waop) (wreg) (lreg)

NOTE: A destination address in the range 00–0FH enables the multiply-accumulate function. For example, if the destination address is 08H, the accumulator is cleared and then the results of the multiply are added. However, if the destination address is 00H, the results of the multiply are added to the current contents of the accumulator.</td></tr>
<tr><td>MULB
(2 operands)</td><td>MULTIPLY SHORT-INTEGERS. Multiplies the source and destination short-integer operands, using signed arithmetic, and stores the 16-bit result into the destination integer operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (DEST) × (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC
MULB wreg, baop
(11111110) (011111aa) (baop) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MULB
(3 operands)</td><td>MULTIPLY SHORT-INTEGERS. Multiplies the two source short-integer operands, using signed arithmetic, and stores the 16-bit result into the destination integer operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (SRC1) × (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC1, SRC2
MULB wreg, breg, baop
(11111110) (010111aa) (baop) (breg) (wreg)</td></tr>
<tr><td>MULU
(2 operands)</td><td>MULTIPLY WORDS, UNSIGNED. Multiplies the source and destination word operands, using unsigned arithmetic, and stores the 32-bit result into the destination double-word operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (DEST) × (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC
MULU lreg, waop
(011011aa) (waop) (lreg)

NOTE: A destination address in the range 00–0FH enables the multiply-accumulate function. For example, if the destination address is 08H, the accumulator is cleared and then the results of the multiply are added. However, if the destination address is 00H, the results of the multiply are added to the current contents of the accumulator.</td></tr>
<tr><td>MULU
(3 operands)</td><td>MULTIPLY WORDS, UNSIGNED. Multiplies the two source word operands, using unsigned arithmetic, and stores the 32-bit result into the destination double-word operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (SRC1) × (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC1, SRC2
MULU lreg, wreg, waop
(010011aa) (waop) (wreg) (lreg)

NOTE: A destination address in the range 00–0FH enables the multiply-accumulate function. For example, if the destination address is 08H, the accumulator is cleared and then the results of the multiply are added. However, if the destination address is 00H, the results of the multiply are added to the current contents of the accumulator.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MULUB
(2 operands)</td><td>MULTIPLY BYTES, UNSIGNED. Multiplies the source and destination operands, using unsigned arithmetic, and stores the word result into the destination operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (DEST) × (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC
MULUB wreg, baop
(011111aa) (baop) (wreg)</td></tr>
<tr><td>MULUB
(3 operands)</td><td>MULTIPLY BYTES, UNSIGNED. Multiplies the two source byte operands, using unsigned arithmetic, and stores the word result into the destination operand. The sticky bit flag is undefined after the instruction is executed.
(DEST) ← (SRC1) × (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>DEST, SRC1, SRC2
MULUB wreg, breg, baop
(010111aa) (baop) (breg) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>MVAC</td><td>MOVE ACCUMULATOR. Allows a 32-bit signed value to be rotated from the 40-bit accumulator to a register or memory location at a double-word boundary address using a 32-bit barrel shifter. The bit pointer (the SRC) is specified either as an immediate value in the range 0–31 (0–1FH) or as a register in the range 32–255 (20–FFH). The value in the register must be in the range 0–31. The bit pointer indicates the position of the bit that will assume the most-significant bit position of the low destination word (bit 15), the destination sign bit.
count ⟵ (SRC) – 15
temp ⟵ 31
do while temp ≠ –1
If (SRC) > 15, then
(DEST) ⟵ ACC.temp ROTATE RIGHT BY count
If (SRC) < 15, then
(DEST) ⟵ ACC.temp ROTATE LEFT BY count
If (SRC) = 15, then
(DEST) ⟵ ACC.temp
temp ⟵ temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
MVAC lreg, breg
(00001101) (breg) (lreg)
or
MVAC lreg, #pointer
(00001101) (pointer) (lreg)

NOTE: The following table identifies the instructions executed by opcode 0DH and the necessary setups.
<table><tr><th>lreg.1</th><th>lreg.0</th><th>Execute</th></tr><tr><td>0</td><td>0</td><td>SHLL</td></tr><tr><td>0</td><td>1</td><td>MVAC</td></tr><tr><td>1</td><td>0</td><td>Reserved</td></tr><tr><td>1</td><td>1</td><td>MSAC</td></tr></table></td></tr>
<tr><td>NEG</td><td>NEGATE INTEGER. Negates the value of the integer operand.
(DEST) ⟵ – (DEST)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>NEG wreg
(00000011) (wreg)</td></tr>
<tr><td>NEGB</td><td>NEGATE SHORT-INTEGER. Negates the value of the short-integer operand.
(DEST) ⟵ – (DEST)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>NEGB breg
(00010011) (breg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>NOP</td><td>NO OPERATION. Does nothing. Control passes to the next sequential instruction.

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>NOP
(11111101)</td></tr>
<tr><td>NORML</td><td>NORMALIZE LONG-INTEGER. Normalizes the source (leftmost) long-integer operand. (That is, it shifts the operand to the left until its most significant bit is “1” or until it has performed 31 shifts). If the most significant bit is still “0” after 31 shifts, the instruction stops the process and sets the zero flag. The instruction stores the actual number of shifts performed in the destination (rightmost) operand.
(COUNT) ← 0
do while
(MSB (DEST) = 0) AND (COUNT) < 31)
(DEST) ← (DEST) × 2
(COUNT) ← (COUNT) + 1
end_while

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>?</td><td>0</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC, DEST
NORML lreg, breg
(00001111) (breg) (lreg)</td></tr>
<tr><td>NOT</td><td>COMPLEMENT WORD. Complements the value of the word operand (replaces each “1” with a “0” and each “0” with a “1”).
(DEST) ← NOT (DEST)

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>NOT wreg
(00000010) (wreg)</td></tr>
<tr><td>NOTB</td><td>COMPLEMENT BYTE. Complements the value of the byte operand (replaces each “1” with a “0” and each “0” with a “1”).
(DEST) ← NOT (DEST)

<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>NOTB breg
(00010010) (breg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>OR</td><td>LOGICAL OR WORDS. ORs the source word operand with the destination word operand and replaces the original destination operand with the result. The result has a “1” in each bit position in which either the source or destination operand had a “1”.
(DEST) ← (DEST) OR (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
OR wreg, waop
(100000aa) (waop) (wreg)</td></tr>
<tr><td>ORB</td><td>LOGICAL OR BYTES. ORs the source byte operand with the destination byte operand and replaces the original destination operand with the result. The result has a “1” in each bit position in which either the source or destination operand had a “1”.
(DEST) ← (DEST) OR (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
ORB breg, baop
(100100aa) (baop) (breg)</td></tr>
<tr><td>POP</td><td>POP WORD. Pops the word on top of the stack and places it at the destination operand.
(DEST) ← (SP)
SP ← SP + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>POP waop
(110011aa) (waop)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>POPA</td><td>POP ALL. This instruction is used instead of POPF, to support the eight additional interrupts. It pops two words off the stack and places the first word into the INT_MASK1/WSR register pair and the second word into the PSW/INT_MASK register-pair. This instruction increments the SP by 4. Interrupt calls cannot occur immediately following this instruction.
INT_MASK1/WSR ← (SP)
SP ← SP + 2
PSW/INT_MASK ← (SP)
SP ← SP + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr></table></td><td>POPA
(11110101)</td></tr>
<tr><td>POPF</td><td>POP FLAGS. Pops the word on top of the stack and places it into the PSW. Interrupt calls cannot occur immediately following this instruction.
(PSW)/INT_MASK ← (SP)
SP ← SP + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr></table></td><td>POPF
(11110011)</td></tr>
<tr><td>PUSH</td><td>PUSH WORD. Pushes the word operand onto the stack.
SP ← SP – 2
(SP) ← (DEST)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>PUSH waop
(110010aa) (waop)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>PUSHA</td><td>PUSH ALL. This instruction is used instead of PUSHF, to support the eight additional interrupts. It pushes two words — PSW/INT_MASK and INT_MASK1/WSR — onto the stack.
This instruction clears the PSW, INT_MASK, and INT_MASK1 registers and decrements the SP by 4. Interrupt calls cannot occur immediately following this instruction.
SP ← SP – 2
(SP) ← PSW/INT_MASK
PSW/INT_MASK ← 0
SP ← SP – 2
(SP) ← INT_MASK1/WSR
INT_MASK1 ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>PUSHA
(11110100)</td></tr>
<tr><td>PUSHF</td><td>PUSH FLAGS. Pushes the PSW onto the top of the stack, then clears it. Clearing the PSW disables interrupt servicing. Interrupt calls cannot occur immediately following this instruction.
SP ← SP – 2
(SP) ← PSW/INT_MASK
PSW/INT_MASK ← 0
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>PUSHF
(11110010)</td></tr>
<tr><td>RET</td><td>RETURN FROM SUBROUTINE. Pops the PC off the top of the stack.
64-Kbyte mode:
PC ← (SP)
SP ← SP + 2
1-Mbyte mode:
PC ← (SP)
SP ← SP + 4
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>RET
(11110000)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>RETI</td><td>RETURN FROM INTERRUPT. Pops the PC off the top of the stack. If in 1-Mbyte mode, it also pops the PSW off the stack. Resets highest priority bit set in the in-progress (IN_PROGx) register. The RETI instruction must be used when priority programming is enabled.
64-Kbyte mode: 1-Mbyte mode:
PC ← (SP) PC/PSW ← (SP)
SP ← SP + 2 SP ← SP + 4
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr></table></td><td>RETI
(11100101)</td></tr>
<tr><td>RPT</td><td>REPEAT NEXT INSTRUCTION. The instruction following is repeated x number of times based on the word count value in the repeat count (RPT_CNT) register, located at SFR address 04H. The RPT and repeated instruction will complete before interrupts are allowed. The maximum count possible is 65,536, achieved by initializing a count of 0000H to the RPT_CNT register.
(RPT_CNT) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
RPT waop†
(010000aa) (waop) (00) (04)

† The RPT, RPTxxx, RPTI and RPTIxxx instructions do not support indexed addressing.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>RPTxxx</td><td>REPEAT NEXT INSTRUCTION, CONDITIONAL. The instruction following is repeated x number of times based on the word count value in the repeat count (RPT_CNT) register, located at SFR address 04H, or until the specified condition (xxx) is satisfied. The RPTxxx and repeated instruction will complete before interrupts are allowed. The maximum count possible is 65,536, achieved by initializing a count of 0000H to the RPT_CNT register.
(RPT_CNT) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
RPTxxx waop†
(010000aa) (waop) (wreg) (04)

RPTxxx wreg(H)
RPTNST 10
RPTNH 11
RPTGT 12
RPTNC 13
RPTNVT 14
RPTNV 15
RPTGE 16
RPTNE 17
RPTST 18
RPTH 19
RPTLE 1A
RPTC 1B
RPTVT 1C
RPTV 1D
RPTLT 1E
RPTE 1F

† The RPT, RPTxxx, RPTI and RPTIxxx instructions do not support indexed addressing.</td></tr>
<tr><td>RPTI</td><td>REPEAT NEXT INSTRUCTION, INTERRUPTIBLE. The instruction following is repeated x number of times based on the word count value in the repeat count (RPT_CNT) register, located at SFR address 04H. The RPTI instruction may be interrupted between iterations of the repeated instruction. The maximum count possible is 65,536, achieved by initializing a count of 0000H to the RPT_CNT register.
(RPT_CNT) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
RPTI waop†
(010000aa) (waop) (20) (04)

† The RPT, RPTxxx, RPTI and RPTIxxx instructions do not support indexed addressing.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>RPTIxxx</td><td>REPEAT NEXT INSTRUCTION, CONDITIONAL and INTERRUPTIBLE. The instruction following is repeated x number of times based on the word count value in the repeat count (RPT_CNT) register, located at SFR address 04H, or until the specified condition (xxx) is satisfied. The RPTIxxx instruction may be interrupted between iterations of the repeated instruction. The maximum count possible is 65,536, achieved by initializing a count of 0000H to the RPT_CNT register.
(RPT_CNT) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC
RPTIxxx waop†
(010000aa) (waop) (wreg) (04)

RPTIxxx wreg(H)
RPTINST 30
RPTINH 31
RPTIGT 32
RPTINC 33
RPTINVT 34
RPTINV 35
RPTIGE 36
RPTINE 37
RPTIST 38
RPTIH 39
RPTILE 3A
RPTIC 3B
RPTIVT 3C
RPTIV 3D
RPTILT 3E
RPTIE 3F

† The RPT, RPTxxx, RPTI and RPTIxxx instructions do not support indexed addressing.</td></tr>
<tr><td>RST</td><td>RESET SYSTEM. Initializes the PSW to zero, the PC to FF2080H, and the pins and SFRs to their reset values. Executing this instruction causes the RESET# pin to be pulled low for 16 state times.
SFR ← Reset Status
Pin ← Reset Status
PSW ← 0
PC ← FF2080H
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>RST
(11111111)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SCALL</td><td>SHORT CALL. Pushes the contents of the program counter (the return address) onto the stack, then adds to the program counter the offset between the end of this instruction and the target label, effecting the call. The offset must be in the range of –1024 to +1023.
64-Kbyte mode:
SP ← SP – 2
(SP) ← PC
PC←PC +11-bit disp
1-Mbyte mode:
SP ← SP – 4
(SP) ← PC
PC←PC +11-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SCALL cadd
(00101xxx) (disp-low)

NOTE: The displacement (disp) is sign-extended to 16-bits in the 64-Kbyte addressing mode and to 24 bits in the 1-Mbyte addressing mode. This displacement may cause the program counter to cross a page boundary in 1-Mbyte mode.</td></tr>
<tr><td>SETC</td><td>SET CARRY FLAG. Sets the carry flag.
C ← 1
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>1</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SETC
(11111001)</td></tr>
<tr><td>SHL</td><td>SHIFT WORD LEFT. Shifts the destination word operand to the left as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The right bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← High order bit of (DEST)
(DEST) ← (DEST) × 2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>SHL wreg, #count
(00001001) (count) (wreg)
or
SHL wreg, breg
(00001001) (breg) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SHLB</td><td>SHIFT BYTE LEFT. Shifts the destination byte operand to the left as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The right bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← High order bit of (DEST)
(DEST) ← (DEST) × 2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>SHLB breg, #count
(00011001) (count) (breg)
or
SHLB breg, breg
(00011001) (breg) (breg)</td></tr>
<tr><td>SHLL</td><td>SHIFT DOUBLE-WORD LEFT. Shifts the destination double-word operand to the left as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The right bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← High order bit of (DEST)
(DEST) ← (DEST) × 2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>SHLL lreg, #count
(00001101) (count) (lreg)
or
SHLL lreg, breg
(00001101) (breg) (lreg)
NOTE: The following table identifies the instructions executed by opcode 0DH and the necessary setups.
<table><tr><th>lreg.1</th><th>lreg.0</th><th>Execute</th></tr><tr><td>0</td><td>0</td><td>SHLL</td></tr><tr><td>0</td><td>1</td><td>MVAC</td></tr><tr><td>1</td><td>0</td><td>Reserved</td></tr><tr><td>1</td><td>1</td><td>MSAC</td></tr></table></td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SHR</td><td>LOGICAL RIGHT SHIFT WORD. Shifts the destination word operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The left bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>0</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHR wreg, #count
(00001000) (count) (wreg)
or
SHR wreg, breg
(00001000) (breg) (wreg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents unsigned division.</td></tr>
<tr><td>SHRA</td><td>ARITHMETIC RIGHT SHIFT WORD. Shifts the destination word operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. If the original high order bit value was “0,” zeros are shifted in. If the value was “1,” ones are shifted in. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHRA wreg, #count
(00001010) (count) (wreg)
or
SHRA wreg, breg
(00001010) (breg) (wreg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents signed division.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SHRAB</td><td>ARITHMETIC RIGHT SHIFT BYTE. Shifts the destination byte operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. If the original high order bit value was “0,” zeros are shifted in. If the value was “1,” ones are shifted in. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHRAB breg, #count
(00011010) (count) (breg)
or
SHRAB breg, breg
(00011010) (breg) (breg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents signed division.</td></tr>
<tr><td>SHRAL</td><td>ARITHMETIC RIGHT SHIFT DOUBLE-WORD. Shifts the destination double-word operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. If the original high order bit value was “0,” zeros are shifted in. If the value was “1,” ones are shifted in.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHRAL lreg, #count
(00001110) (count) (lreg)
or
SHRAL lreg, breg
(00001110) (breg) (lreg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents signed division.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SHRB</td><td>LOGICAL RIGHT SHIFT BYTE. Shifts the destination byte operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The left bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2
temp ← temp–1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>0</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHRB breg, #count
(00011000) (count) (breg)
or
SHRB breg, breg
(00011000) (breg) (breg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents unsigned division.</td></tr>
<tr><td>SHRL</td><td>LOGICAL RIGHT SHIFT DOUBLE-WORD. Shifts the destination double-word operand to the right as many times as specified by the count operand. The count may be specified either as an immediate value in the range of 0 to 15 (0FH), inclusive, or as the content of any register (10–0FFH) with a value in the range of 0 to 31 (1FH), inclusive. The left bits of the result are filled with zeros. The last bit shifted out is saved in the carry flag.
temp ← (COUNT)
do while temp ≠ 0
C ← Low order bit of (DEST)
(DEST) ← (DEST)/2)
temp ← temp – 1
end_while
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>0</td><td>✓</td><td>0</td><td>—</td><td>✓</td></tr></table></td><td>SHRL lreg, #count
(00001100) (count) (lreg)
or
SHRL lreg, breg
(00001100) (breg) (lreg)

NOTES: This instruction clears the sticky bit flag at the beginning of the instruction. If at any time during the shift a “1” is shifted into the carry flag and another shift cycle occurs, the instruction sets the sticky bit flag.

In this operation, (DEST)/2 represents unsigned division.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SJMP</td><td>SHORT JUMP. Adds to the program counter the offset between the end of this instruction and the target label, effecting the jump. The offset must be in the range of –1024 to +1023, inclusive.
PC ← PC + 11-bit disp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SJMP cadd
(00100xxx) (disp-low)

NOTE: The displacement (disp) is sign-extended to 16 bits in the 64-Kbyte addressing mode and to 24 bits in the 1-Mbyte addressing mode. This displacement may cause the program counter to cross a page boundary in 1-Mbyte mode.</td></tr>
<tr><td>SKIP</td><td>TWO BYTE NO-OPERATION. Does nothing. Control passes to the next sequential instruction. This is actually a two-byte NOP in which the second byte can be any value and is simply ignored.
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SKIP breg
(00000000) (breg)</td></tr>
<tr><td>SMAC
(2 operands)</td><td>MULTIPLY SIGNED WORDS, ACCUMULATE. Multiplies the source and destination word operands, using signed arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator.
(ACC) ← (ACC) × (SRC) + ACC
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC
SMAC waop
(011011aa) (waop) (01)</td></tr>
<tr><td>SMAC
(3 operands)</td><td>MULTIPLY SIGNED WORDS, ACCUMULATE. Multiplies the two source word operands, using signed arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator.
(ACC) ← (SRC1) × (SRC2) + ACC
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC1, SRC2
SMAC wreg, waop
(010011aa) (waop) (wreg) (01)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SMACR
(2 operands)</td><td>MULTIPLY SIGNED WORDS, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using signed arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator. The source (SRC) register contents are relocated in memory to SRC address + 2.
(ACC) ← (ACC) × (SRC) + ACC and
(SRC) ← (SRC) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC
SMACR waop†
(011011aa) (waop) (05)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
<tr><td>SMACR
(3 operands)</td><td>MULTIPLY SIGNED WORDS, ACCUMULATE, ROTATE. Multiplies the two source word operands, using signed arithmetic, and adds the 32-bit result to the value currently stored in the 40-bit accumulator. The source 2 (SRC2) register contents are relocated in memory to SRC2 address + 2.
(ACC) ← (SRC1) × (SRC2) + ACC and
(SRC2) ← (SRC2) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC1, SRC2
SMACR wreg, waop†
(010011aa) (waop) (wreg) (05)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
<tr><td>SMACRZ
(2 operands)</td><td>MULTIPLY SIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using signed arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The source (SRC) register contents are relocated in memory to SRC address + 2.
temp ← (ACC) × (SRC)
(ACC) ← 0
(ACC) ← temp and (SRC) ← (SRC) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC
SMACRZ waop†
(011011aa) (waop) (0D)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SMACRZ
(3 operands)</td><td>MULTIPLY SIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE, ROTATE. Multiplies the source and destination word operands, using signed arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator. The source 2 (SRC2) register contents are relocated in memory to SRC2 address + 2.
temp ← (SRC1) × (SRC2)
(ACC) ← 0
(ACC) ← temp and (SRC2) ← (SRC2) + 2
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC1, SRC2
SMACRZ wreg, waop†
(010011aa) (waop) (wreg) (0D)

† The multiply-accumulate (MAC) instructions that use the relocate function do not support immediate addressing.</td></tr>
<tr><td>SMACZ
(2 operands)</td><td>MULTIPLY SIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE. Multiplies the source and destination word operands, using signed arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
temp ← (ACC) × (SRC)
(ACC) ← 0
(ACC) ← temp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC
SMACZ waop
(011011aa) (waop) (09)</td></tr>
<tr><td>SMACZ
(3 operands)</td><td>MULTIPLY SIGNED WORDS, ZERO ACCUMULATOR, ACCUMULATE. Multiplies the source and destination word operands, using signed arithmetic, clears the 40-bit accumulator, and stores the 32-bit result to the accumulator.
temp ← (SRC1) × (SRC2)
(ACC) ← 0
(ACC) ← temp
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>?</td></tr></table></td><td>SRC1, SRC2
SMACZ wreg, waop
(010011aa) (waop) (wreg) (09)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>ST</td><td>STORE WORD. Stores the value of the source (leftmost) word operand into the destination (rightmost) operand.
(DEST) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC, DEST
ST wreg, waop
(110000aa) (waop) (wreg)</td></tr>
<tr><td>STB</td><td>STORE BYTE. Stores the value of the source (leftmost) byte operand into the destination (rightmost) operand.
(DEST) ← (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>SRC, DEST
STB breg, baop
(110001aa) (baop) (breg)</td></tr>
<tr><td>SUB
(2 operands)</td><td>SUBTRACT WORDS. Subtracts the source word operand from the destination word operand, stores the result in the destination operand, and sets the carry flag as the complement of borrow.
(DEST) ← (DEST) – (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
SUB wreg, waop
(011010aa) (waop) (wreg)</td></tr>
<tr><td>SUB
(3 operands)</td><td>SUBTRACT WORDS. Subtracts the first source word operand from the second, stores the result in the destination operand, and sets the carry flag as the complement of borrow.
(DEST) ← (SRC1) – (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC1, SRC2
SUB Dwreg, Swreg, waop
(010010aa) (waop) (Swreg) (Dwreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SUBB
(2 operands)</td><td>SUBTRACT BYTES. Subtracts the source byte operand from the destination byte operand, stores the result in the destination operand, and sets the carry flag as the complement of borrow.
(DEST) ← (DEST) – (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
SUBB breg, baop
(011110aa) (baop) (breg)</td></tr>
<tr><td>SUBB
(3 operands)</td><td>SUBTRACT BYTES. Subtracts the first source byte operand from the second, stores the result in the destination operand, and sets the carry flag as the complement of borrow.
(DEST) ← (SRC1) – (SRC2)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC1, SRC2
SUBB Dbreg, Sbreg, baop
(010110aa) (baop) (Sbreg) (Dbreg)</td></tr>
<tr><td>SUBC</td><td>SUBTRACT WORDS WITH BORROW. Subtracts the source word operand from the destination word operand. If the carry flag was clear, SUBC subtracts 1 from the result. It stores the result in the destination operand and sets the carry flag as the complement of borrow. If the accumulator (ACC) is the destination, the subtraction will conform to the accumulator control and status (ACC_STAT) register requirements for saturation.
(DEST) ← (DEST) – (SRC) – (1–C)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>↓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
SUBC wreg, waop
(101010aa) (waop) (wreg = ACC_02)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>SUBCB</td><td>SUBTRACT BYTES WITH BORROW. Subtracts the source byte operand from the destination byte operand. If the carry flag was clear, SUBCB subtracts 1 from the result. It stores the result in the destination operand and sets the carry flag as the complement of borrow.
(DEST) ← (DEST) – (SRC) – (1–C)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>↓</td><td>✓</td><td>✓</td><td>✓</td><td>↑</td><td>—</td></tr></table></td><td>DEST, SRC
SUBCB breg, baop
(101110aa) (baop) (breg)</td></tr>
<tr><td>TIJMP</td><td>TABLE INDIRECT JUMP. Causes execution to continue at an address selected from a table of addresses.
The first word register, TBASE, contains the 16-bit address of the beginning of the jump table. TBASE can be located in RAM up to FEH without windowing or above FFH with windowing. The jump table itself can be placed at any nonreserved memory location on a word boundary in page FFH.
The second word register, INDEX, contains the 16-bit address that points to a register containing a 7-bit value. This value is used to calculate the offset into the jump table. Like TBASE, INDEX can be located in RAM up to FEH without windowing or above FFH with windowing. Note that the 16-bit address contained in INDEX is absolute; it disregards any windowing that may be in effect when the TIJMP instruction is executed.
The byte operand, #MASK, is 7-bit immediate data to mask INDEX. #MASK is ANDed with INDEX to determine the offset (OFFSET). OFFSET is multiplied by two, then added to the base address (TBASE) to determine the destination address (DEST X) in page FFH.
[INDEX] AND #MASK = OFFSET
(2 × OFFSET) + TBASE = DEST X
PC ← (DEST X)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>TIJMP TBASE, [INDEX], #MASK
(11100010) [INDEX] (#MASK) (TBASE)

NOTE: TIJMP multiplies OFFSET by two to provide for word alignment of the jump table.</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>TRAP</td><td>SOFTWARE TRAP. This instruction causes an interrupt call that is vectored through location FF2010H. The operation of this instruction is not affected by the state of the interrupt enable flag (I) in the PSW. Interrupt calls cannot occur immediately following this instruction.
64-Kbyte mode:
SP ← SP – 2
(SP) ← PC
PC ← (2010H)
1-Mbyte mode:
SP ← SP – 4
(SP) ← PC
PC ← (0FF2010H)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>TRAP
(11110111)</td></tr>
<tr><td>XCH</td><td>EXCHANGE WORD. Exchanges the value of the source word operand with that of the destination word operand.
(DEST) ↔ (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
XCH wreg, waop
(00000100) (waop) (wreg) direct
(00001011) (waop) (wreg) indexed</td></tr>
<tr><td>XCHB</td><td>EXCHANGE BYTE. Exchanges the value of the source byte operand with that of the destination byte operand.
(DEST) ↔ (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
XCHB breg, baop
(00010100) (baop) (breg) direct
(00011011) (baop) (breg) indexed</td></tr>
<tr><td>XOR</td><td>LOGICAL EXCLUSIVE-OR WORDS. XORs the source word operand with the destination word operand and stores the result in the destination operand. The result has ones in the bit positions in which either operand (but not both) had a “1” and zeros in all other bit positions.
(DEST) ← (DEST) XOR (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
XOR wreg, waop
(100001aa) (waop) (wreg)</td></tr>
</table>

Table A-6. Instruction Set (Continued)

<table>
<tr><th>Mnemonic</th><th>Operation</th><th>Instruction Format</th></tr>
<tr><td>XORB</td><td>LOGICAL EXCLUSIVE-OR BYTES. XORs the source byte operand with the destination byte operand and stores the result in the destination operand. The result has ones in the bit positions in which either operand (but not both) had a “1” and zeros in all other bit positions.
(DEST) ← (DEST) XOR (SRC)
<table><tr><th colspan="6">PSW Flag Settings</th></tr><tr><th>Z</th><th>N</th><th>C</th><th>V</th><th>VT</th><th>ST</th></tr><tr><td>✓</td><td>✓</td><td>0</td><td>0</td><td>—</td><td>—</td></tr></table></td><td>DEST, SRC
XORB breg, baop
(100101aa) (baop) (breg)</td></tr>
</table>

Table A-7 lists the instruction opcodes, in hexadecimal order, along with the corresponding instruction mnemonics.

Table A-7. Instruction Opcodes

Hex Code	Instruction Mnemonic
00	SKIP
01	CLR
02	NOT
03	NEG
04	XCH Direct
05	DEC
06	EXT
07	INC
08	SHR
09	SHL
0A	SHRA
0B	XCH Indexed
0C	SHRL
0D	SHLL, MVAC, & MSAC
0E	SHRAL
0F	NORML
10	Reserved
11	CLRB
12	NOTB
13	NEGB
14	XCHB Direct
15	DECB
16	EXTB
17	INCB
18	SHRB
19	SHLB
1A	SHRAB
1B	XCHB Indexed
1C	EST Indirect
1D	EST Indexed
1E	ESTB Indirect
1F	ESTB Indexed
20–27	SJMP

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
28–2F	SCALL
30–37	JBC
38–3F	JBS
40	AND, RPT, RPT*xxx*, RPTI, & RPTI*xxx* Direct (3 ops)
41	AND, RPT, RPT*xxx*, RPTI, & RPTI*xxx* Immediate (3 ops)
42	AND, RPT, RPT*xxx*, RPTI, & RPTI*xxx* Indirect (3 ops)
43	AND Indexed (3 ops)
44	ADD Direct (3 ops)
45	ADD Immediate (3 ops)
46	ADD Indirect (3 ops)
47	ADD Indexed (3 ops)
48	SUB Direct (3 ops)
49	SUB Immediate (3 ops)
4A	SUB Indirect (3 ops)
4B	SUB Indexed (3 ops)
4C	MUL (3 ops), MULU (3 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Direct (Note 2)
4D	MUL (3 ops), MULU (3 ops), MAC, MACZ, SMAC, SMACZ Immediate (Note 2)
4E	MUL (3 ops), MULU (3 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Indirect (Note 2)
4F	MUL (3 ops), MULU (3 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Indexed (Note 2)
50	ANDB Direct (3 ops)
51	ANDB Immediate (3 ops)
52	ANDB Indirect (3 ops)
53	ANDB Indexed (3 ops)
54	ADDB Direct (3 ops)
55	ADDB Immediate (3 ops)
56	ADDB Indirect (3 ops)
57	ADDB Indexed (3 ops)
58	SUBB Direct (3 ops)
59	SUBB Immediate (3 ops)
5A	SUBB Indirect (3 ops)
5B	SUBB Indexed (3 ops)
5C	MULUB Direct (3 ops) (Note 2)
5D	MULUB Immediate (3 ops) (Note 2)
5E	MULUB Indirect (3 ops) (Note 2)

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
5F	MULUB Indexed (3 ops) (Note 2)
60	AND Direct (2 ops)
61	AND Immediate (2 ops)
62	AND Indirect (2 ops)
63	AND Indexed (2 ops)
64	ADD Direct (2 ops)
65	ADD Immediate (2 ops)
66	ADD Indirect (2 ops)
67	ADD Indexed (2 ops)
68	SUB Direct (2 ops)
69	SUB Immediate (2 ops)
6A	SUB Indirect (2 ops)
6B	SUB Indexed (2 ops)
6C	MUL (2 ops), MULU (2 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Direct (Note 2)
6D	MUL (2 ops), MULU (2 ops), MAC, MACZ, SMAC, SMACZ Immediate (Note 2)
6E	MUL (2 ops), MULU (2 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Indirect (Note 2)
6F	MUL (2 ops), MULU (2 ops), MAC, MACR, MACRZ, MACZ, SMAC, SMACR, SMACRZ, SMACZ Indexed (Note 2)
70	ANDB Direct (2 ops)
71	ANDB Immediate (2 ops)
72	ANDB Indirect (2 ops)
73	ANDB Indexed (2 ops)
74	ADDB Direct (2 ops)
75	ADDB Immediate (2 ops)
76	ADDB Indirect (2 ops)
77	ADDB Indexed (2 ops)
78	SUBB Direct (2 ops)
79	SUBB Immediate (2 ops)
7A	SUBB Indirect (2 ops)
7B	SUBB Indexed (2 ops)
7C	MULUB Direct (2 ops) (Note 2)
7D	MULUB Immediate (2 ops) (Note 2)
7E	MULUB Indirect (2 ops) (Note 2)
7F	MULUB Indexed (2 ops) (Note 2)
80	OR Direct

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
81	OR Immediate
82	OR Indirect
83	OR Indexed
84	XOR Direct
85	XOR Immediate
86	XOR Indirect
87	XOR Indexed
88	CMP Direct
89	CMP Immediate
8A	CMP Indirect
8B	CMP Indexed
8C	DIVU Direct (Note 2)
8D	DIVU Immediate (Note 2)
8E	DIVU Indirect (Note 2)
8F	DIVU Indexed (Note 2)
90	ORB Direct
91	ORB Immediate
92	ORB Indirect
93	ORB Indexed
94	XORB Direct
95	XORB Immediate
96	XORB Indirect
97	XORB Indexed
98	CMPB Direct
99	CMPB Immediate
9A	CMPB Indirect
9B	CMPB Indexed
9C	DIVUB Direct (Note 2)
9D	DIVUB Immediate (Note 2)
9E	DIVUB Indirect (Note 2)
9F	DIVUB Indexed (Note 2)
A0	LD Direct
A1	LD Immediate
A2	LD Indirect
A3	LD Indexed
A4	ADDC Direct

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
A5	ADDC Immediate
A6	ADDC Indirect
A7	ADDC Indexed
A8	SUBC Direct
A9	SUBC Immediate
AA	SUBC Indirect
AB	SUBC Indexed
AC	LDBZE Direct
AD	LDBZE Immediate
AE	LDBZE Indirect
AF	LDBZE Indexed
B0	LDB Direct
B1	LDB Immediate
B2	LDB Indirect
B3	LDB Indexed
B4	ADDCB Direct
B5	ADDCB Immediate
B6	ADDCB Indirect
B7	ADDCB Indexed
B8	SUBCB Direct
B9	SUBCB Immediate
BA	SUBCB Indirect
BB	SUBCB Indexed
BC	LDBSE Direct
BD	LDBSE Immediate
BE	LDBSE Indirect
BF	LDBSE Indexed
C0	ST Direct
C1	BMOV
C2	ST Indirect
C3	ST Indexed
C4	STB Direct
C5	CMPL
C6	STB Indirect
C7	STB Indexed
C8	PUSH Direct

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
C9	PUSH Immediate
CA	PUSH Indirect
CB	PUSH Indexed
CC	POP Direct
CD	BMOVI
CE	POP Indirect
CF	POP Indexed
D0	JNST
D1	JNH
D2	JGT
D3	JNC
D4	JNVT
D5	JNV
D6	JGE
D7	JNE
D8	JST
D9	JH
DA	JLE
DB	JC
DC	JVT
DD	JV
DE	JLT
DF	JE
E0	DJNZ
E1	DJNZW
E2	TIJMP
E3	BR Indirect, 64-Kbyte mode
	EBR Indirect, 1-Mbyte mode
E4	EBMOVI
E5	RETI
E6	EJMP
E7	LJMP
E8	ELD Indirect
E9	ELD Indexed
EA	ELDB Indirect
EB	ELDB Indexed

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-7. Instruction Opcodes (Continued)

Hex Code	Instruction Mnemonic
EC–ED	Reserved
EE	Reserved (Note 1)
EF	LCALL
F0	RET
F1	ECALL
F2	PUSHF
F3	POPF
F4	PUSHA
F5	POPA
F6	IDLPD
F7	TRAP
F8	CLRC
F9	SETC
FA	DI
FB	EI
FC	CLRVT
FD	NOP
FE	Optional (Note 2)
FF	RST

NOTES:
1. This opcode is reserved, but it does not generate an unimplemented opcode interrupt.
2. Other MCS® 96 microcontrollers require a prefix (FE) to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8 lists instructions along with the number of bytes and opcodes for each applicable addressing mode. A dash (—) in any column indicates "not applicable."

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes

Arithmetic (Group I)								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
ADD (2 ops)	3	64	4	65	3	66	4/5	67
ADD (3 ops)	4	44	5	45	4	46	5/6	47
ADDB (2 ops)	3	74	3	75	3	76	4/5	77
ADDB (3 ops)	4	54	4	55	4	56	5/6	57
ADDC	3	A4	4	A5	3	A6	4/5	A7
ADDCB	3	B4	3	B5	3	B6	4/5	B7
CLR	2	01	—	—	—	—	—	—
CLRB	2	11	—	—	—	—	—	—
CMP	3	88	4	89	3	8A	4/5	8B
CMPB	3	98	3	99	3	9A	4/5	9B
CMPL	3	C5	—	—	—	—	—	—
DEC	2	05	—	—	—	—	—	—
DECB	2	15	—	—	—	—	—	—
EXT	2	06	—	—	—	—	—	—
EXTB	2	16	—	—	—	—	—	—
INC	2	07	—	—	—	—	—	—
INCB	2	17	—	—	—	—	—	—
SUB (2 ops)	3	68	4	69	3	6A	4/5	6B
SUB (3 ops)	4	48	5	49	4	4A	5/6	4B
SUBB (2 ops)	3	78	3	79	3	7A	4/5	7B
SUBB (3 ops)	4	58	4	59	4	5A	5/6	5B
SUBC	3	A8	4	A9	3	AA	4/5	AB
SUBCB	3	B8	3	B9	3	BA	4/5	BB

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Arithmetic (Group II)								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
DIV (3)	4	(FE) 8C	5	(FE) 8D	4	(FE) 8E	5/6	(FE) 8F
DIV	3	8C	4	8D	3	8E	4/5	8F
DIVB (3)	4	(FE) 9C	4	(FE) 9D	4	(FE) 9E	5/6	(FE) 9F
DIVB	3	9C	3	9D	3	9E	4/5	9F
DIVU	3	8C	4	8D	3	8E	4/5	8F
DIVUB	3	9C	3	9D	3	9E	4/5	9F
MUL (2 ops) (3)	4	(FE) 6C	5	(FE) 6D	4	(FE) 6E	5/6	(FE) 6F
MUL (2 ops)	3	6C	4	6D	3	6E	4/5	6F
MUL (3 ops) (3)	5	(FE) 4C	6	(FE) 4D	5	(FE) 4E	6/7	(FE) 4F
MUL (3 ops)	4	4C	5	4D	4	4E	5/6	4F
MULB (2 ops) (3)	4	(FE) 7C	4	(FE) 7D	4	(FE) 7E	5/6	(FE) 7F
MULB (2 ops)	3	7C	3	7D	3	7E	4/5	7F
MULB (3 ops) (3)	5	(FE) 5C	5	(FE) 5D	5	(FE) 5E	6/7	(FE) 5F
MULB (3 ops)	4	5C	4	5D	4	5E	5/6	5F
MULU (2 ops)	3	6C	4	6D	3	6E	4/5	6F
MULU (3 ops)	4	4C	5	4D	4	4E	5/6	4F
MULUB (2 ops)	3	7C	3	7D	3	7E	4/5	7F
MULUB (3 ops)	4	5C	4	5D	4	5E	5/6	5F

NOTES:

1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Arithmetic (Group III)								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
MAC (2 ops)	3	6C	4	6D	3	6E	4/5	6F
MAC (3 ops)	4	4C	5	4D	4	4E	5/6	4F
MACR (2 ops)	3	6C	—	—	3	6E	4/5	6F
MACR (3 ops)	4	4C	—	—	4	4E	5/6	4F
MACRZ (2 ops)	3	6C	—	—	3	6E	4/5	6F
MACRZ (3 ops)	4	4C	—	—	4	4E	5/6	4F
MACZ (2 ops)	3	6C	4	6D	3	6E	4/5	6F
MACZ (3 ops)	4	4C	5	4D	4	4E	5/6	4F
SMAC (2 ops)	3	6C	4	6D	3	6E	4/5	6F
SMAC (3 ops)	4	4C	5	4D	4	4E	5/6	4F
SMACR (2 ops)	3	6C	—	—	3	6E	4/5	6F
SMACR (3 ops)	4	4C	—	—	4	4E	5/6	4F
SMACRZ (2 ops)	3	6C	—	—	3	6E	4/5	6F
SMACRZ (3 ops)	4	4C	—	—	4	4E	5/6	4F
SMACZ (2 ops)	3	6C	4	6D	3	6E	4/5	6F
SMACZ (3 ops)	4	4C	5	4D	4	4E	5/6	4F

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Logical								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
AND (2 ops)	3	60	4	61	3	62	4/5	63
AND (3 ops)	4	40	5	41	4	42	5/6	43
ANDB (2 ops)	3	70	3	71	3	72	4/5	73
ANDB (3 ops)	4	50	4	51	4	52	5/6	53
NEG	2	03	—	—	—	—	—	—
NEGB	2	13	—	—	—	—	—	—
NOT	2	02	—	—	—	—	—	—
NOTB	2	12	—	—	—	—	—	—
OR	3	80	4	81	3	82	4/5	83
ORB	3	90	3	91	3	92	4/5	93
XOR	3	84	4	85	3	86	4/5	87
XORB	3	94	3	95	3	96	4/5	97
Stack								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
POP	2	CC	—	—	2	CE	3/4	CF
POPA	1	F5	—	—	—	—	—	—
POPF	1	F3	—	—	—	—	—	—
PUSH	2	C8	3	C9	2	CA	3/4	CB
PUSHA	1	F4	—	—	—	—	—	—
PUSHF	1	F2	—	—	—	—	—	—

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Data								
Mnemonic	**Direct**		**Immediate**		**Extended-indirect**		**Extended-indexed**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
EBMOVI	—	—	—	—	3	E4	—	—
ELD	—	—	—	—	3	E8	6	E9
ELDB	—	—	—	—	3	EA	6	EB
EST	—	—	—	—	3	1C	6	1D
ESTB	—	—	—	—	3	1E	6	1F
Mnemonic	**Direct**		**Immediate**		**Indirect**		**Indexed (1)**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes S/L**	**Opcode**
BMOV	—	—	—	—	3	C1	—	—
BMOVI	—	—	—	—	3	CD	—	—
LD	3	A0	4	A1	3	A2	4/5	A3
LDB	3	B0	3	B1	3	B2	4/5	B3
LDBSE	3	BC	3	BD	3	BE	4/5	BF
LDBZE	3	AC	3	AD	3	AE	4/5	AF
ST	3	C0	—	—	3	C2	4/5	C3
STB	3	C4	—	—	3	C6	4/5	C7
XCH	3	04	—	—	—	—	4/5	0B
XCHB	3	14	—	—	—	—	4/5	1B

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Jump								
Mnemonic	**Direct**		**Immediate**		**Extended-indirect**		**Extended-indexed**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
EBR	—	—	—	—	2	E3	—	—
EJMP	—	—	—	—	—	—	4	E6
Mnemonic	**Direct**		**Immediate**		**Indirect**		**Indexed (1)**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes S/L**	**Opcode**
BR	—	—	—	—	2	E3	—	—
LJMP	—	—	—	—	—	—	—/3	E7
SJMP (2)	—	—	—	—	—	—	2/—	20–27
TIJMP	—	—	—	—	—	—	—/4	E2
Call								
Mnemonic	**Direct**		**Immediate**		**Extended-indirect**		**Extended-indexed**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
ECALL	—	—	—	—	—	—	4	F1
Mnemonic	**Direct**		**Immediate**		**Indirect**		**Indexed (1)**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
LCALL	—	—	—	—	—	—	3	EF
RET	—	—	—	—	1	F0	—	—
RETI	—	—	—	—	1	E5	—	—
SCALL (2)	—	—	—	—	—	—	2	28–2F
TRAP	1	F7	—	—	—	—	—	—

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Conditional Jump								
Mnemonic	Direct		Immediate		Indirect		Indexed (1)	
	Bytes	Opcode	Bytes	Opcode	Bytes	Opcode	Bytes S/L	Opcode
DJNZ	—	—	—	—	—	—	3/—	E0
DJNZW	—	—	—	—	—	—	3/—	E1
JBC	—	—	—	—	—	—	3/—	30–37
JBS	—	—	—	—	—	—	3/—	38–3F
JC	—	—	—	—	—	—	2/—	DB
JE	—	—	—	—	—	—	2/—	DF
JGE	—	—	—	—	—	—	2/—	D6
JGT	—	—	—	—	—	—	2/—	D2
JH	—	—	—	—	—	—	2/—	D9
JLE	—	—	—	—	—	—	2/—	DA
JLT	—	—	—	—	—	—	2/—	DE
JNC	—	—	—	—	—	—	2/—	D3
JNE	—	—	—	—	—	—	2/—	D7
JNH	—	—	—	—	—	—	2/—	D1
JNST	—	—	—	—	—	—	2/—	D0
JNV	—	—	—	—	—	—	2/—	D5
JNVT	—	—	—	—	—	—	2/—	D4
JST	—	—	—	—	—	—	2/—	D8
JV	—	—	—	—	—	—	2/—	DD
JVT	—	—	—	—	—	—	2/—	DC

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-8. Number of Bytes for Each Instruction and Hexadecimal Opcodes (Continued)

Shift								
Mnemonic	**Direct**		**Immediate**		**Indirect**		**Indexed**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
MSAC	3	0D	3	0D	—	—	—	—
MVAC	3	0D	3	0D	—	—	—	—
NORML	3	0F	3	0F	—	—	—	—
SHL	3	09	3	09	—	—	—	—
SHLB	3	19	3	19	—	—	—	—
SHLL	3	0D	3	0D	—	—	—	—
SHR	3	08	3	08	—	—	—	—
SHRA	3	0A	3	0A	—	—	—	—
SHRAB	3	1A	3	1A	—	—	—	—
SHRAL	3	0E	3	0E	—	—	—	—
SHRB	3	18	3	18	—	—	—	—
SHRL	3	0C	3	0C	—	—	—	—
Special								
Mnemonic	**Direct**		**Immediate**		**Indirect**		**Indexed**	
	Bytes	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**	**Bytes**	**Opcode**
CLRC	1	F8	—	—	—	—	—	—
CLRVT	1	FC	—	—	—	—	—	—
DI	1	FA	—	—	—	—	—	—
EI	1	FB	—	—	—	—	—	—
IDLPD	—	—	1	F6	—	—	—	—
NOP	1	FD	—	—	—	—	—	—
RPT	4	40	5	41	4	42	—	—
RPT*xxx*	4	40	5	41	4	42	—	—
RPTI	4	40	5	41	4	42	—	—
RPTI*xxx*	4	40	5	41	4	42	—	—
RST	1	FF	—	—	—	—	—	—
SETC	1	F9	—	—	—	—	—	—
SKIP	2	00	—	—	—	—	—	—

NOTES:
1. For indexed instructions, the first column lists instruction bytes as *S*/*L*, where *S* is the number of bytes for the short-indexed instruction and *L* is the number of bytes for the long-indexed instruction.
2. For the SCALL and SJMP instructions, the three least-significant bits of the opcode are concatenated with the eight bits to form an 11-bit, two's complement offset.
3. Other MCS® 96 microcontroller products require a prefix opcode of FE to indicate signed multiplication and division. For the 80296SA, setting bit zero in the destination register indicates signed multiplication. The FE prefix opcode is not required and is supported only for compatibility. The preferred usage is to eliminate the prefix and set bit zero in the destination register.

Table A-9 lists instructions alphabetically within groups, along with their execution times, expressed in state times.

Table A-9. Instruction Execution Times (in State Times)

Arithmetic (Group I)										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
ADD (2 ops)	1	1	2	4	2	4	2	4	2	4
ADD (3 ops)	1	1	2	4	2	4	2	4	2	4
ADDB (2 ops)	1	1	2	4	2	4	2	4	2	4
ADDB (3 ops)	1	1	2	4	2	4	2	4	2	4
ADDC	1	1	2	4	2	4	2	4	2	4
ADDCB	1	1	2	4	2	4	2	4	2	4
CLR	1	—	—	—	—	—	—	—	—	—
CLRB	1	—	—	—	—	—	—	—	—	—
CMP	1	1	2	4	2	4	2	4	2	4
CMPB	1	1	2	4	2	4	2	4	2	4
CMPL	2	—	—	—	—	—	—	—	—	—
DEC	1	—	—	—	—	—	—	—	—	—
DECB	1	—	—	—	—	—	—	—	—	—
EXT	2	—	—	—	—	—	—	—	—	—
EXTB	1	—	—	—	—	—	—	—	—	—
INC	1	—	—	—	—	—	—	—	—	—
INCB	1	—	—	—	—	—	—	—	—	—
SUB (2 ops)	1	1	2	4	2	4	2	4	2	4
SUB (3 ops)	1	1	2	4	2	4	2	4	2	4
SUBB (2 ops)	1	1	2	4	2	4	2	4	2	4
SUBB (3 ops)	1	1	2	4	2	4	2	4	2	4
SUBC	1	1	2	4	2	4	2	4	2	4
SUBCB	1	1	2	4	2	4	2	4	2	4

NOTE: The column entitled "Reg." lists the instruction execution times for accesses to the register file or peripheral SFRs. The column entitled "Mem." lists the instruction execution times for accesses to all memory-mapped registers, I/O, or memory. See Table 5-2 on page 5-6 for address information.

Table A-9. Instruction Execution Times (in State Times) (Continued)

Arithmetic (Group II)										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
DIV	22	22	23	25	23	25	23	25	23	25
DIVB	14	14	15	17	15	17	15	17	15	17
DIVU	22	22	23	25	23	25	23	25	23	25
DIVUB	14	14	15	17	15	17	15	17	15	17
MUL (2 ops)	3	3	4	6	4	6	4	6	4	6
MUL (3 ops)	3	3	4	6	4	6	4	6	4	6
MULB (2 ops)	1	1	2	4	2	4	2	4	2	4
MULB (3 ops)	1	1	2	4	2	4	2	4	2	4
MULU (2 ops)	3	3	4	6	4	6	4	6	4	6
MULU (3 ops)	3	3	4	6	4	6	4	6	4	6
MULUB (2 ops)	1	1	2	4	2	4	2	4	2	4
MULUB (3 ops)	1	1	2	4	2	4	2	4	2	4
Arithmetic (Group III)										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
MAC	2	2	3	5	3	5	3	5	3	5
MACR	2	—	3	5	3	5	3	5	3	5
MACRZ	2	—	3	5	3	5	3	5	3	5
MACZ	2	2	3	5	3	5	3	5	3	5
SMAC	2	2	3	5	3	5	3	5	3	5
SMACR	2	—	3	5	3	5	3	5	3	5
SMACRZ	2	—	3	5	3	5	3	5	3	5
SMACZ	2	2	3	5	3	5	3	5	3	5

NOTE: The column entitled “Reg.” lists the instruction execution times for accesses to the register file or peripheral SFRs. The column entitled “Mem.” lists the instruction execution times for accesses to all memory-mapped registers, I/O, or memory. See Table 5-2 on page 5-6 for address information.

Table A-9. Instruction Execution Times (in State Times) (Continued)

Logical										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
AND (2 ops)	1	1	2	4	2	4	2	4	2	4
AND (3 ops)	1	1	2	4	2	4	2	4	2	4
ANDB (2 ops)	1	1	2	4	2	4	2	4	2	4
ANDB (3 ops)	1	1	2	4	2	4	2	4	2	4
NEG	1	—	—	—	—	—	—	—	—	—
NEGB	1	—	—	—	—	—	—	—	—	—
NOT	1	—	—	—	—	—	—	—	—	—
NOTB	1	—	—	—	—	—	—	—	—	—
OR	1	1	2	4	2	4	2	4	2	4
ORB	1	1	2	4	2	4	2	4	2	4
XOR	1	1	2	4	2	4	2	4	2	4
XORB	1	1	2	4	2	4	2	4	2	4
Stack (Register)										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
POP	1	—	2	2	2	2	2	2	2	2
POPA	3	—	—	—	—	—	—	—	—	—
POPF	2	—	—	—	—	—	—	—	—	—
PUSH	1	1	2	4	2	4	2	4	2	4
PUSHA	8	—	—	—	—	—	—	—	—	—
PUSHF	4	—	—	—	—	—	—	—	—	—

NOTE: The column entitled "Reg." lists the instruction execution times for accesses to the register file or peripheral SFRs. The column entitled "Mem." lists the instruction execution times for accesses to all memory-mapped registers, I/O, or memory. See Table 5-2 on page 5-6 for address information.

Table A-9. Instruction Execution Times (in State Times) (Continued)

Stack (Memory)										
Mnemonic	Direct	Immed.	Indirect				Indexed			
			Normal		Autoinc.		Short		Long	
			Reg.	Mem.	Reg.	Mem.	Reg.	Mem.	Reg.	Mem.
POP	3	—	4	4	4	4	4	4	4	4
POPA	7	—	—	—	—	—	—	—	—	—
POPF	3	—	—	—	—	—	—	—	—	—
PUSH	1	1	2	4	2	4	2	4	2	4
PUSHA	12	—	—	—	—	—	—	—	—	—
PUSHF	6	—	—	—	—	—	—	—	—	—

NOTE: The column entitled “Reg.” lists the instruction execution times for accesses to the register file or peripheral SFRs. The column entitled “Mem.” lists the instruction execution times for accesses to all memory-mapped registers, I/O, or memory. See Table 5-2 on page 5-6 for address information.

Table A-9. Instruction Execution Times (in State Times) (Continued)

Data										
Mnemonic	**Extended-indirect (Normal)**									
EBMOVI	register/register 9 + 1 per word + 10 per interrupt memory/register 9 + 3 per word + 10 per interrupt memory/memory 9 + 5 per word + 10 per interrupt									
Mnemonic	**Indirect**									
BMOV	register/register 5 + 1 per word memory/register 5 + 3 per word memory/memory 5 + 5 per word									
BMOVI	register/register 5 + 1 per word + 6 per interrupt memory/register 5 + 3 per word + 6 per interrupt memory/memory 5 + 5 per word + 6 per interrupt									
Mnemonic	**Direct**	**Immed.**	**Extended-indirect**				**Extended-indexed**			
			Normal		**Autoinc.**					
ELD	—	—	2	4	3	5	2		4	
ELDB	—	—	2	4	3	5	2		4	
EST	—	—	2	2	3	5	2		2	
ESTB	—	—	2	2	3	5	2		2	
Mnemonic	**Direct**	**Immed.**	**Indirect**				**Indexed**			
			Normal		**Autoinc.**		**Short**		**Long**	
			Reg.	**Mem.**	**Reg.**	**Mem.**	**Reg.**	**Mem.**	**Reg.**	**Mem.**
LD	1	1	2	4	2	4	2	4	2	4
LDB	1	1	2	4	2	4	2	4	2	4
LDBSE	1	1	2	4	2	4	2	4	2	4
LDBZE	1	1	2	4	2	4	2	4	2	4
RPT	1	1	2	4	2	4	—	—	—	—
RPT*xxx*	1	1	2	4	2	4	—	—	—	—
RPTI	1	1	2	4	2	4	—	—	—	—
RPTI*xxx*	1	1	2	4	2	4	—	—	—	—
ST	1	—	2	2	2	2	2	2	2	2
STB	1	—	2	2	2	2	2	2	2	2
XCH	2	—	—	—	—	—	3	5	3	5
XCHB	2	—	—	—	—	—	3	5	3	5

NOTE: The column entitled "Reg." lists the instruction execution times for accesses to the register file or peripheral SFRs. The column entitled "Mem." lists the instruction execution times for accesses to all memory-mapped registers, I/O, or memory. See Table 5-2 on page 5-6 for address information.

Table A-9. Instruction Execution Times (in State Times) (Continued)

Jump						
Mnemonic	**Direct**	**Immed.**	**Extended-indirect**		**Extended-indexed**	
			Normal	**Autoinc.**		
EBR	—	—	1	—	—	
EJMP	—	—	—	—	1	
Mnemonic	**Direct**	**Immed.**	**Indirect**		**Indexed**	
			Normal	**Autoinc.**	**Short**	**Long**
BR	—	—	1	1	—	—
LJMP	—	—	—	—	—	1
SJMP	—	—	—	—	1	—
TIJMP register/register memory/register memory/memory	—	—	—	—	 6 6 8	—
Call (Register)						
Mnemonic	**Direct**	**Immed.**	**Extended-indirect**		**Extended-indexed**	
			Normal	**Autoinc.**		
ECALL 1-Mbyte mode	—	—	—	—	2	
Mnemonic	**Direct**	**Immed.**	**Indirect**		**Indexed**	
			Normal	**Autoinc.**	**Short**	**Long**
LCALL 1-Mbyte mode 64-Kbyte mode	—	—	—	—	—	2 1
RET 1-Mbyte mode 64-Kbyte mode	—	—	2 1	—	—	—
RETI 1-Mbyte mode 64-Kbyte mode	—	—	2 1	—	—	—
SCALL 1-Mbyte mode 64-Kbyte mode	—	—	—	—	2 1	
TRAP 1-Mbyte mode 64-Kbyte mode	—	—	4 3	—	—	—

Table A-9. Instruction Execution Times (in State Times) (Continued)

Call (Memory)						
Mnemonic	**Direct**	**Immed.**	**Extended-indirect**		**Extended-indexed**	
			Normal	**Autoinc.**		
ECALL 1-Mbyte mode	—	—	—	—	4	
Mnemonic	**Direct**	**Immed.**	**Indirect**		**Indexed**	
			Normal	**Autoinc.**	**Short**	**Long**
LCALL 1-Mbyte mode 64-Kbyte mode	—	—	—	—	—	4 1
RET 1-Mbyte mode 64-Kbyte mode	—	—	6 3	—	—	—
RETI 1-Mbyte mode 64-Kbyte mode	—	—	6 3	—	—	—
SCALL 1-Mbyte mode 64-Kbyte mode	—	—	—	—	4 1	
TRAP 1-Mbyte mode 64-Kbyte mode	—	—	6 3	—	—	—

Table A-9. Instruction Execution Times (in State Times) (Continued)

Conditional Jump	
Mnemonic	**Short-Indexed**
DJNZ	2
DJNZW	2
JBC	1
JBS	1
JC	1
JE	1
JGE	1
JGT	1
JH	1
JLE	1
JLT	1
JNC	1
JNE	1
JNH	1
JNST	1
JNV	1
JNVT	1
JST	1
JV	1
JVT	1
Shift	
Mnemonic	**Direct**
MSAC	3
MVAC	3
NORML	3
SHL	1
SHLB	1
SHLL	2
SHR	1
SHRA	1
SHRAB	1
SHRAL	2
SHRB	1
SHRL	2

Table A-9. Instruction Execution Times (in State Times) (Continued)

Special						
Mnemonic	Direct	Immed.	Indirect		Indexed	
			Normal	Autoinc.	Short	Long
CLRC	1	—	—	—	—	—
CLRVT	1	—	—	—	—	—
DI	1	—	—	—	—	—
EI	1	—	—	—	—	—
IDLPD Valid key Invalid key	 — —	 3 3	 — —	 — —	 — —	 — —
NOP	1	—	—	—	—	—
RST	4	—	—	—	—	—
SETC	1	—	—	—	—	—
SKIP	2	—	—	—	—	—

B

Signal Descriptions

APPENDIX B
SIGNAL DESCRIPTIONS

This appendix provides reference information for the pin functions of the 80296SA.

B.1 FUNCTIONAL GROUPINGS OF SIGNALS

Table B-1 lists the signals for the 80296SA, grouped by function. A diagram of each package that is currently available shows the pin location of each signal.

NOTE

The datasheets are revised more frequently than this manual. As new packages are supported, the pin-out diagrams will be added to the datasheets first. If your package type is not shown in this appendix, refer to the latest datasheet to find the pin locations.

Table B-1. 80296SA Signals Arranged by Function

Address & Data
A19:0
AD15:0

Power & Ground
V_{CC}
V_{SS}

Processor Control
CLKOUT
EXTINT3:0
NMI
ONCE
PLLEN1
PLLEN2
RESET#
RPD
XTAL1
XTAL2

Input/Output
EPORT3:0
P1.3:0/EPA3:0
P1.4/T1CLK
P1.5/T1DIR
P1.6/T2CLK
P1.7/T2DIR
P2.0/TXD
P2.1/RXD
P2.7:2
P3.7:0
P4.2:0/PWM2:0
P4.3

Bus Control & Status
ALE
BHE#/WRH#
BREQ#
CS5:0#
HLDA#
HOLD#
INST
RD#
READY
WR#/WRL#

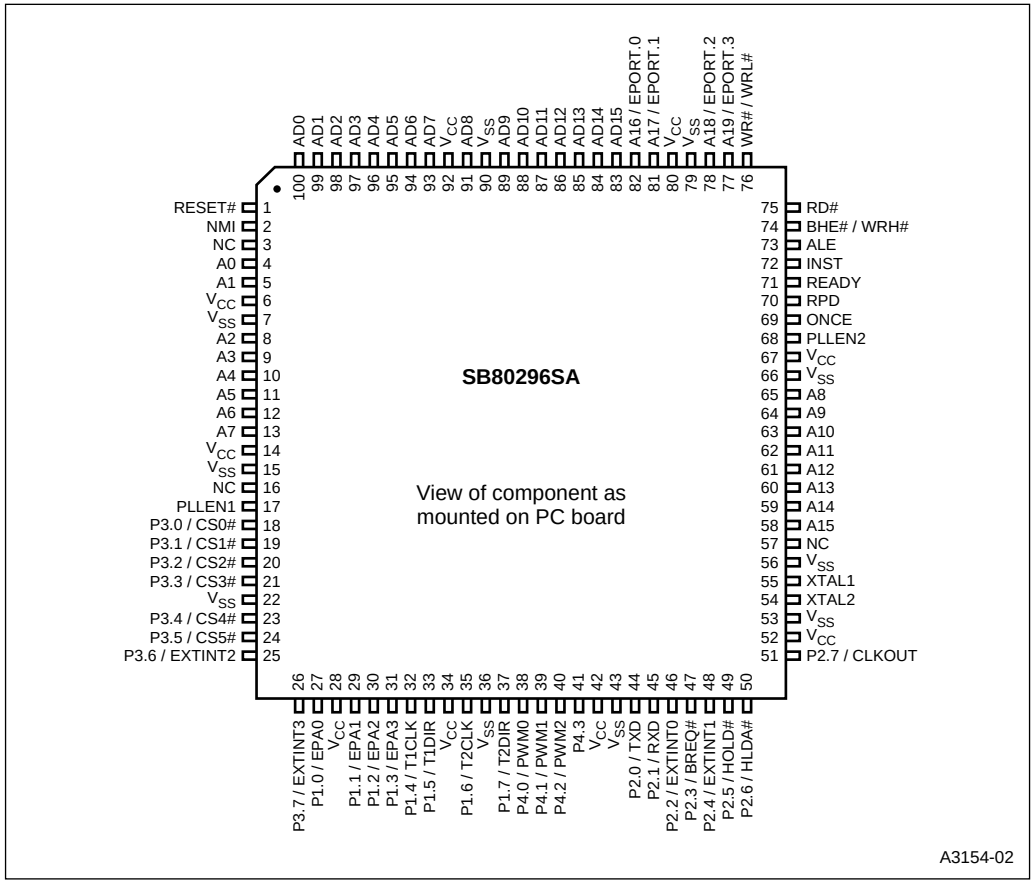


Figure B-1. 80296SA 100-pin SQFP Package

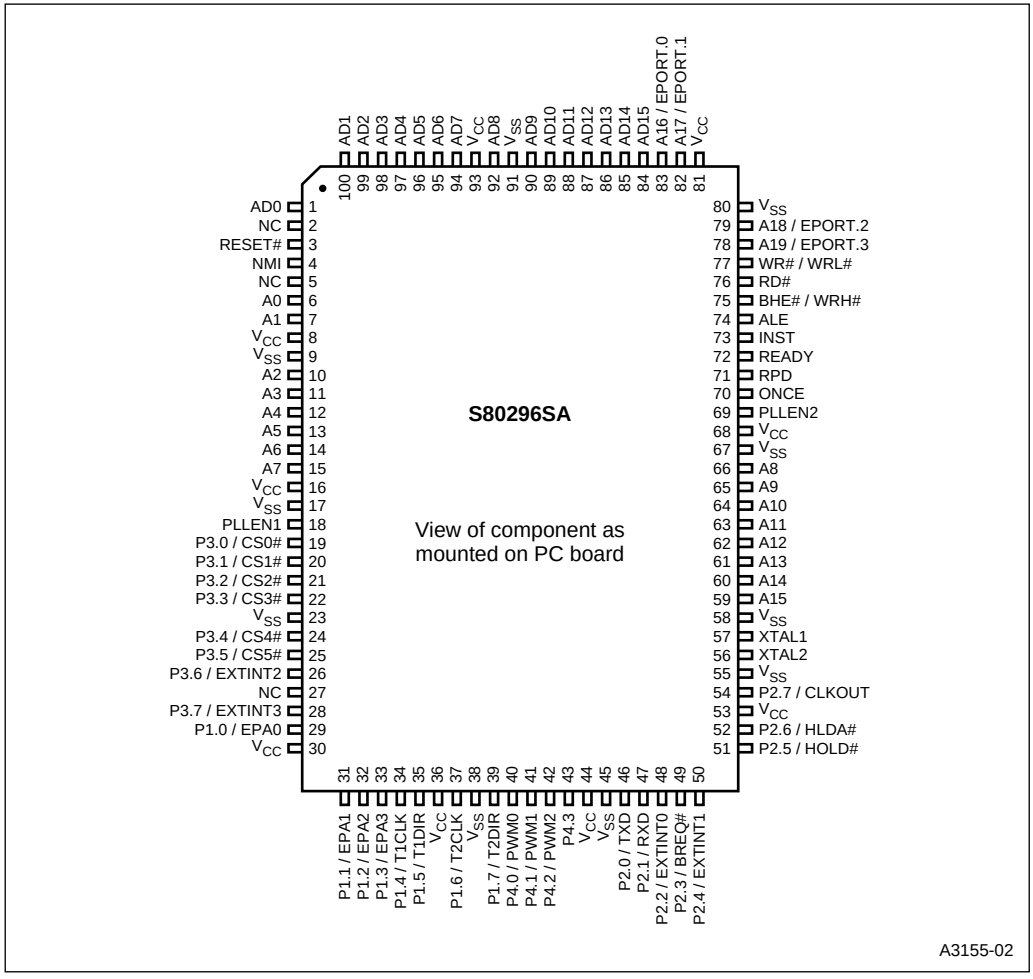


Figure B-2. 80296SA 100-pin QFP Package

B.2 SIGNAL DESCRIPTIONS

Table B-2 defines the columns used in Table B-3, which describes the signals.

Table B-2. Description of Columns of Table B-3

Column Heading	Description
Name	Lists the signals, arranged alphabetically. Many pins have two functions, so there are more entries in this column than there are pins. Every signal is listed in this column.
Type	Identifies the pin function listed in the *Name* column as an input (I), output (O), bidirectional (I/O), power (PWR), or ground (GND). Note that all inputs except RESET# are *sampled inputs*. RESET# is a level-sensitive input. During powerdown mode, the powerdown circuitry uses EXTINT as a level-sensitive input.
Description	Briefly describes the function of the pin for the specific signal listed in the *Name* column. Also lists any alternate fuctions that share package pins with the signal.

Table B-3. Signal Descriptions

Name	Type	Description
A15:0	O	System Address Bus These address lines provide address bits 0–15 during the entire external memory cycle during both multiplexed and demultiplexed bus modes.
A19:16	I/O	Address Lines 16–19 These address lines provide address bits 16–19 during the entire external memory cycle during both multiplexed and demultiplexed bus modes, supporting extended addressing of the 1-Mbyte address space. **NOTE:** Internally, there are 24 address bits; however, only 20 external address pins (A19:0) are implemented. The internal address space is 16 Mbytes (000000–FFFFFFH) and the external address space is 1 Mbyte (00000–FFFFFH). The device resets to F2080H in external memory. A19:16 share package pins with EPORT.3:0.
AD15:0	I/O	Address/Data Lines The function of these pins depends on the bus size and mode. **16-bit Multiplexed Bus Mode**: AD15:0 drive address bits 0–15 during the first half of the bus cycle and drive or receive data during the second half of the bus cycle. **8-bit Multiplexed Bus Mode**: AD15:8 drive address bits 8–15 during the entire bus cycle. AD7:0 drive address bits 0–7 during the first half of the bus cycle and drive or receive data during the second half of the bus cycle. **16-bit Demultiplexed Mode**: AD15:0 drive or receive data during the entire bus cycle. **8-bit Demultiplexed Mode**: AD7:0 drive or receive data during the entire bus cycle. AD15:8 drive the data that is currently on the high byte of the internal bus.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
ALE	O	Address Latch Enable This active-high output signal is asserted only during external memory cycles. ALE signals the start of an external bus cycle and indicates that valid address information is available on the system address/data bus (A19:16 and AD15:0 for a multiplexed bus; A19:0 for a demultiplexed bus). An external latch can use this signal to demultiplex address bits 0–15 from the address/data bus in multiplexed mode.
BHE#	O	Byte High Enable† During 16-bit bus cycles, this active-low output signal is asserted for word and high-byte reads and writes to external memory. BHE# indicates that valid data is being transferred over the upper half of the system data bus. Use BHE#, in conjunction with address bit 0 (A0 for a demultiplexed address bus, AD0 for a multiplexed address/data bus), to determine which memory byte is being transferred over the system bus: **BHE# AD0 or A0 Byte(s) Accessed** 0 0 both bytes 0 1 high byte only 1 0 low byte only BHE# shares a package pin with WRH#. † The chip configuration register 0 (CCR0) determines whether this pin functions as BHE# or WRH#. CCR0.2 = 1 selects BHE#; CCR0.2 = 0 selects WRH#.
BREQ#	O	Bus Request This active-low output signal is asserted during a hold cycle when the bus controller has a pending external memory cycle. When the bus-hold protocol is enabled (WSR.7 is set), the P2.3/BREQ# pin can function only as BREQ#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). The device can assert BREQ# at the same time as or after it asserts HLDA#. Once it is asserted, BREQ# remains asserted until HOLD# is removed. BREQ# shares a package pin with P2.3.
CLKOUT	O	Clock Output Output of the internal clock generator. The CLKOUT frequency is ½ the internal operating frequency (f). CLKOUT has a 50% duty cycle. CLKOUT shares a package pin with P2.7.
CS5:0#	O	Chip-select Lines 0–5 The active-low output CS*x*# is asserted during an external memory cycle when the address to be accessed is in the range programmed for chip select *x* or chip select *x*+1 if remapping is enabled. If the external memory address is outside the range assigned to the six chip selects, no chip-select output is asserted and the bus configuration defaults to the CS5# values. Immediately following reset, CS0# is automatically assigned to the range F2000–F20FFH. CS5:0# share package pins with P3.5:0.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
EPA3:0	I/O	Event Processor Array (EPA) Capture/Compare Channels High-speed input/output signals for the EPA capture/compare channels. EPA3:0 share package pins with P1.3:0.
EPORT.3:0	I/O	Extended Addressing Port This is a standard 4-bit, bidirectional port. EPORT.3:0 share package pins with A.19:16.
EXTINT3:0	I	External Interrupts In normal operating mode, a rising edge on EXTINT*x* sets the EXTINT*x* interrupt pending bit. EXTINT*x* is sampled during phase 2 (CLKOUT high). The minimum edge time is one state time. The minimum level time is two state times. In standby and powerdown modes, asserting the EXTINT*x* signal for at least 50 ns causes the device to resume normal operation. The interrupt need not be enabled, but the pin must be configured as a special-function input. If the EXTINT*x* interrupt is enabled, the CPU executes the interrupt service routine. Otherwise, the CPU executes the instruction that immediately follows the command that invoked the power-saving mode. In idle mode, asserting any enabled interrupt causes the device to resume normal operation. EXTINT0 shares a package pin with P2.2, EXTINT1 shares a package pin with P2.4, EXTINT2 shares a package pin with P3.6, and EXTINT3 shares a package pin with P3.7.
HLDA#	O	Bus Hold Acknowledge This active-low output indicates that the CPU has released the bus as the result of an external device asserting HOLD#. When the bus-hold protocol is enabled (WSR.7 is set), the P2.6/HLDA# pin can function only as HLDA#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). HLDA# shares a package pin with P2.6.
HOLD#	I	Bus Hold Request An external device uses this active-low input signal to request control of the bus. When the bus-hold protocol is enabled (WSR.7 is set), the P2.5/HOLD# pin can function only as HOLD#, regardless of the configuration selected through the port configuration registers (P2_MODE, P2_DIR, and P2_REG). An attempt to change the pin configuration is ignored until the bus-hold protocol is disabled (WSR.7 is cleared). HOLD# shares a package pin with P2.5.
INST	O	Instruction Fetch This active-high output signal is valid only during external memory bus cycles. When high, INST indicates that an instruction is being fetched from external memory. The signal remains high during the entire bus cycle of an external instruction fetch. INST is low for data accesses, including interrupt vector fetches and chip configuration byte reads. INST is low during internal memory fetches.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
NMI	I	Nonmaskable Interrupt In normal operating mode, a rising edge on NMI generates a nonmaskable interrupt. NMI has the highest priority of all interrupts except trap and unimplemented opcode. Assert NMI for greater than one state time to guarantee that it is recognized. If NMI is held high during and immediately following reset, the microcontroller will execute the NMI vector when code execution begins. To prevent an inadvertent NMI interrupt vector, the first instruction (at FF2080H) must clear the NMI pending interrupt bit. ANDB INT_PEND1, #7FH.
ONCE	I	On-circuit Emulation Holding ONCE high during the rising edge of RESET# places the device into on-circuit emulation (ONCE) mode. This mode puts all pins into a high-impedance state, thereby isolating the device from other components in the system. The value of ONCE is latched when the RESET# pin goes inactive. While the device is in ONCE mode, you can debug the system using a clip-on emulator. To exit ONCE mode, reset the device by pulling the RESET# signal low. To prevent inadvertent entry into ONCE mode, connect the ONCE pin to V_{SS}.
P1.7:0	I/O	Port 1 This is a standard, 8-bit, bidirectional port that shares package pins with individually selectable special-function signals. Port 1 shares package pins with the following signals: P1.0/EPA0, P1.1/EPA1, P1.2/EPA2, P1.3/EPA3, P1.4/T1CLK, P1.5/T1DIR, P1.6/T2CLK, and P1.7/T2DIR.
P2.7:0	I/O	Port 2 This is a standard, 8-bit, bidirectional port that shares package pins with individually selectable special-function signals. Port 2 shares package pins with the following signals: P2.0/TXD, P2.1/RXD, P2.2/EXTINT0, P2.3/BREQ#, P2.4/EXTINT1, P2.5/HOLD#, P2.6/HLDA#, and P2.7/CLKOUT.
P3.7:0	I/O	Port 3 This is a standard, 8-bit, bidirectional port that shares package pins with individually selectable special-function signals. Port 3 shares package pins with the following signals: P3.0/CS0#, P3.1/CS1#, P3.2/CS2#, P3.3/CS3#, P3.4/CS4#, P3.5/CS5#, P3.6/EXTINT2, and P3.7/EXTINT3.
P4.3:0	I/O	Port 4 This ia a 4-bit bidirectional, standard I/O port with high-current drive capability. Port 4 shares package pins with the following signals: P4.0/PWM0, P4.1/PWM1, and P4.2/PWM2. P4.3 has a dedicated package pin.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
PLLEN2:1	I	Phase-locked Loop 1 and 2 Enable These input pins enable the on-chip clock multiplier feature and select either the doubled or the quadrupled clock speed: **PLLEN2 PLLEN1 Mode** 0 0 1x mode; PLL disabled; f = F_{XTAL1} 0 1 2x mode; PLL enabled; f = $2F_{XTAL1}$ 1 0 Reserved† 1 1 4x mode; PLL enabled; f = $4F_{XTAL1}$ † This reserved combination causes the device to enter an unsupported test mode.
PWM2:0	O	Pulse Width Modulator Outputs These are PWM output pins with high-current drive capability. PWM2:0 share package pins with P4.2:0.
RD#	O	Read Read-signal output to external memory. RD# is asserted only during external memory reads.
READY	I	Ready Input This active-high input can be used to insert wait states in addition to those programmed in the chip configuration byte 0 (CCB0) and the bus control *x* register (BUSCON*x*). CCB0 is programmed with the minimum number of wait states (0, 5, 10, 15) for an external fetch of CCB1, and BUSCON*x* is programmed with the minimum number of wait states (0–15) for all external accesses to the address range assigned to the chip-select *x* channel. If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.
RESET#	I/O	Reset A level-sensitive reset input to, and an open-drain system reset output from, the microcontroller. Either a falling edge on RESET# or an internal reset turns on a pull-down transistor connected to the RESET# pin for 16 state times. In the powerdown, standby, and idle modes, asserting RESET# causes the chip to reset and return to normal operating mode. After a device reset, the first instruction fetch is from F2080H in external memory. The program and special-purpose memory locations (F2000–F2FFFH) reside in external memory.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
RPD	I	Return from Powerdown Timing pin for the return-from-powerdown circuit. If your application uses powerdown mode, connect a capacitor between RPD and V_{SS} if **either** of the following conditions are true. • the internal oscillator is the clock source • the phase-locked loop (PLL) circuitry is enabled (see PLLEN2:1 signal description) The capacitor causes a delay that enables the oscillator and PLL circuitry to stabilize before the internal CPU and peripheral clocks are enabled. The capacitor is not required if your application uses powerdown mode and if **both** of the following conditions are true. • an external clock input is the clock source • the phase-locked loop circuitry is disabled If your application does not use powerdown mode, leave this pin unconnected.
RXD	I/O	Receive Serial Data In modes 1, 2, and 3, RXD receives serial port input data. In mode 0, it functions as either an input or an open-drain output for data. RXD shares a package pin with P2.1.
T1CLK	I	Timer 1 External Clock External clock for timer 1. Timer 1 increments (or decrements) on both rising and falling edges of T1CLK. Also used in conjunction with T1DIR for quadrature counting mode. and External clock for the serial I/O baud-rate generator input (program selectable). T1CLK shares a package pin with P1.4.
T2CLK	I	Timer 2 External Clock External clock for timer 2. Timer 2 increments (or decrements) on both rising and falling edges of T2CLK. It is also used in conjunction with T2DIR for quadrature counting mode. T2CLK shares a package pin with P1.6.
T1DIR	I	Timer 1 External Direction External direction (up/down) for timer 1. Timer 1 increments when T1DIR is high and decrements when it is low. Also used in conjunction with T1CLK for quadrature counting mode. T1DIR shares a package pin with P1.5.
T2DIR	I	Timer 2 External Direction External direction (up/down) for timer 2. Timer 2 increments when T2DIR is high and decrements when it is low. It is also used in conjunction with T2CLK for quadrature counting mode. T2DIR shares a package pin with P1.7.
TXD	O	Transmit Serial Data In serial I/O modes 1, 2, and 3, TXD transmits serial port output data. In mode 0, it is the serial clock output. TXD shares a package pin with P2.0.

Table B-3. Signal Descriptions (Continued)

Name	Type	Description
V_{CC}	PWR	Digital Supply Voltage Connect each V_{CC} pin to the digital supply voltage.
V_{SS}	GND	Digital Circuit Ground These pins supply ground for the digital circuitry. Connect each V_{SS} pin to ground through the lowest possible impedance path.
WR#	O	Write† This active-low output indicates that an external write is occurring. This signal is asserted only during external memory writes. WR# shares a package pin with WRL#. † The chip configuration register 0 (CCR0) determines whether this pin functions as WR# or WRL#. CCR0.2 = 1 selects WR#; CCR0.2 = 0 selects WRL#.
WRH#	O	Write High† During 16-bit bus cycles, this active-low output signal is asserted for high-byte writes and word writes to external memory. During 8-bit bus cycles, WRH# is asserted for all write operations. WRH# shares a package pin with BHE#. † The chip configuration register 0 (CCR0) determines whether this pin functions as BHE# or WRH#. CCR0.2 = 1 selects BHE#; CCR0.2 = 0 selects WRH#.
WRL#	O	Write Low† During 16-bit bus cycles, this active-low output signal is asserted for low-byte writes and word writes to external memory. During 8-bit bus cycles, WRL# is asserted for all write operations. WRL# shares a package pin with WR#. † The chip configuration register 0 (CCR0) determines whether this pin functions as WR# or WRL#. CCR0.2 = 1 selects WR#; CCR0.2 = 0 selects WRL#.
XTAL1	I	Input Crystal/Resonator or External Clock Input Input to the on-chip oscillator, internal phase-locked loop circuitry, and the internal clock generators. The internal clock generators provide the peripheral clocks, CPU clock, and CLKOUT signal. When using an external clock source instead of the on-chip oscillator, connect the clock input to XTAL1. The external clock signal must meet the V_{IH} specification for XTAL1.
XTAL2	O	Inverted Output for the Crystal/Resonator Output of the on-chip oscillator inverter. Leave XTAL2 floating when the design uses an external clock source instead of the on-chip oscillator.

B.3 DEFAULT CONDITIONS

Table B-5 lists the values of the signals of the 80296SA during various operating conditions. Table B-4 defines the symbols used to represent the pin status. Refer to the DC Characteristics table in the datasheet for actual specifications for V_{OL}, V_{IL}, V_{OH}, and V_{IH}.

Table B-4. Definition of Status Symbols

Symbol	Definition
0	Voltage less than or equal to V_{OL}, V_{IL}
1	Voltage greater than or equal to V_{OH}, V_{IH}
HiZ	High impedance
LoZ0	Low impedance; strongly driven low
LoZ1	Low impedance; strongly driven high

Symbol	Definition
MD0	Medium pull-down
MD1	Medium pull-up
WK0	Weak pull-down
WK1	Weak pull-up
ODIO	Open-drain I/O

Table B-5. 80296SA Default Signal Conditions

Port Signals	Alternate Functions	While RESET# is Active	Immediately After RESET# is Inactive (Note 11)	Idle	Power-down and Standby	Hold	Bus Idle
P1.3:0	EPA3:0	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P1.4	T1CLK	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P1.5	T1DIR	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P1.6	T2CLK	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P1.7	T2DIR	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P2.0	TXD	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P2.1	RXD	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P2.2	EXTINT0	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P2.3	BREQ#	WK1	WK1	(Note 1)	(Note 1)	0	—
P2.4	EXTINT1	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P2.5	HOLD#	WK1	WK1	(Note 1)	(Note 1)	Force 0	—
P2.6	HLDA#	WK1	WK1	(Note 1)	(Note 1)	0	—
P2.7	CLKOUT	CLKOUT active; LoZ0/1	CLKOUT active; LoZ0/1	(Note 1)	(Note 2)	(Note 1)	—
P3.0	CS0#	WK1	0	(Note 3)	(Note 3)	(Note 4)	—
P3.5:1	CS5:1#	WK1	WK1	(Note 3)	(Note 3)	(Note 4)	—
P3.6	EXTINT2	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P3.7	EXTINT3	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P4.2:0	PWM2:0	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
P4.3	—	WK1	WK1	(Note 1)	(Note 1)	(Note 1)	—
EPORT.3:0	A19:16	WK1	1	(Note 5)	(Note 5)	(Note 6)	(Note 8)
—	A15:0	WK1	(Note 12)	(Note 7)	(Note 7)	HiZ	LoZ0
—	AD15:8	WK1	(Note 12)	(Note 7)	(Note 7)	HiZ	LoZ0
—	AD7:0	WK1	HiZ	(Note 7)	(Note 7)	HiZ	LoZ0
—	ALE	WK0	0	(Note 9)	(Note 9)	WK0	LoZ0
—	BHE#	WK1	1	(Note 10)	(Note 10)	WK1	LoZ1
—	INST	WK0	0	(Note 9)	(Note 9)	WK0	LoZ0

Table B-5. 80296SA Default Signal Conditions (Continued)

Port Signals	Alternate Functions	While RESET# is Active	Immediately After RESET# is Inactive (Note 11)	Idle	Power-down and Standby	Hold	Bus Idle
—	NMI	WK0	WK0	WK0	WK0	WK0	—
—	ONCE	MD0	MD0	MD0	MD0	MD0	—
—	PLLEN1	HiZ	HiZ	HiZ	HiZ	HiZ	—
—	PLLEN2	MD0	MD0	MD0	MD0	MD0	—
—	RD#	WK1	1	(Note 10)	(Note 10)	WK1	LoZ1
—	READY	WK1	WK1	WK1	WK1	WK1	—
—	RESET#	0	WK1	WK1	WK1	WK1	—
—	RPD	LoZ1	LoZ1	LoZ1	LoZ1	LoZ1	—
—	WR#	WK1	1	(Note 10)	(Note 10)	WK1	LoZ1
—	XTAL1	Osc input, HiZ	Osc input, HiZ	Osc input, HiZ	Osc input, HiZ	Osc input, HiZ	—
—	XTAL2	Osc output, LoZ0/1	Osc output, LoZ0/1	Osc output, LoZ0/1	(Pwrdown) HiZ (Standby) Osc output, LoZ0/1	Osc output, LoZ0/1	—

NOTE:
1. If P*x*_MODE.*y* = 0, then port is as programmed. If P*x*_MODE.*y* = 1, then as specified by the associated peripheral.
2. If P2_MODE.7 = 0, then port is as programmed. If P2_MODE.7 = 1, then 1.
3. When used as chip select: if HLDA# = 0, then WK1. If HLDA# = 1, then LoZ1. When used as port: then port is as programmed.
4. When used as chip select, WK1. When used as port, then port is as programmed.
5. When used as extended address, if HLDA# = 1, then 0; if HLDA# = 0, then HiZ
   When used as EPORT, then port value.
6. When used as extended address, then HiZ. When used as EPORT, then port value.
7. If HLDA# = 1, then LoZ0. If HLDA# = 0, then HiZ.
8. When used as extended address, then previous address. When used as EPORT, then port value.
9. If HLDA# = 1, then LoZ0. If HLDA# = 0, then WK0.
10. If HLDA# = 1, then LoZ1. If HLDA# = 0, then WK1.
11. The values in this column are valid until your software writes to P*x*_MODE.
12. These signals are driven. The value changes during different periods within the bus cycle.

C

Registers

APPENDIX C
REGISTERS

This appendix provides reference information about the microcontroller registers. Table C-1 lists the modules and major components of the microcontroller with their related configuration and status registers. Table C-2 lists the registers, arranged alphabetically by mnemonic, along with their names, addresses, and reset values. Following the tables, individual descriptions of the registers are arranged alphabetically by mnemonic.

Table C-1. Modules and Related Registes

Chip Configuration	Chip-select Units (*x* = 0–5)	CPU	DSP
CCR0	ADDRCOM*x*	ONES_REG	ACC_0*x* (*x* = 0, 2 ,4)
CCR1	ADDRMSK*x*	PSW	ACC_STAT
	BUSCON*x*	RPT_CNT	ICB*x* (*x* = 0–1)
		SP	ICX*x* (*x* = 0–1)
		ZERO_REG	IDX*x* (*x* = 0–1)
EPA (*x* = 0–3)	**Extended Port**	**I/O Ports (*x* = 1–4)**	**Interrupts**
EPA_MASK	EP_DIR	P*x*_DIR	EXTINT_CON
EPA_PEND	EP_MODE	P*x*_MODE	IN_PROG*x* (*x* = 0–1)
EPA*x*_CON	EP_PIN	P*x*_PIN	INT_CON*x* (*x* = 0–3)
EPA*x*_TIME	EP_REG	P*x*_REG	INT_MASK
			INT_MASK1
			INT_PEND
			INT_PEND1
			NMI_PEND
			VECT_ADDR
Memory Control	**PWM (*x* = 0–2)**	**Serial Port**	**Timers (*x* = 1–2)**
WSR	CON_REG0	SBUF_RX	TIMER*x*
WSR1	PWM*x*_CONTROL	SBUF_TX	T*x*CONTROL
		SP_BAUD	
		SP_CON	
		SP_STATUS	

Table C-2. Register Name, Address, and Reset State

Register Mnemonic	Register Name	Hex Address	Reset State
ACC_00	Accumulator 0	000CH	0000H
ACC_02	Accumulator 2	000EH	0000H
ACC_04	Accumulator 4	0006H	00H
ACC_STAT	Accumulator Control and Status	000BH	38H
ADDRCOM0	Address Compare 0	1F40H	FF20H
ADDRCOM1	Address Compare 1	1F48H	0000H
ADDRCOM2	Address Compare 2	1F50H	0000H
ADDRCOM3	Address Compare 3	1F58H	0000H
ADDRCOM4	Address Compare 4	1F60H	0000H
ADDRCOM5	Address Compare 5	1F68H	0000H
ADDRMSK0	Address Mask 0	1F42H	FFFFH
ADDRMSK1	Address Mask 1	1F4AH	FFFFH
ADDRMSK2	Address Mask 2	1F52H	FFFFH
ADDRMSK3	Address Mask 3	1F5AH	FFFFH
ADDRMSK4	Address Mask 4	1F62H	FFFFH
ADDRMSK5	Address Mask 5	1F6AH	FFFFH
BUSCON0	Bus Control 0	1F44H	0FH
BUSCON1	Bus Control 1	1F4CH	00H
BUSCON2	Bus Control 2	1F54H	00H
BUSCON3	Bus Control 3	1F5CH	00H
BUSCON4	Bus Control 4	1F64H	00H
BUSCON5	Bus Control 5	1F6CH	00H
CCR0	Chip Configuration 0	†	XXH
CCR1	Chip Configuration 1	†	XXH
CON_REG0	PWM Clock Prescaler Control 0	1FB6H	7CH
EP_DIR	Extended Port I/O Direction	1FE3H	FFH
EP_MODE	Extended Port Mode	1FE1H	FFH
EP_PIN	Extended Port Pin Input	1FE7H	XXH
EP_REG	Extended Port Data Output	1FE5H	00H
EPA_MASK	EPA Mask	1F9CH	AAH

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after a device reset. The CCBs reside in nonvolatile memory at addresses FF2018H (CCB0) and FF201AH (CCB1).

Table C-2. Register Name, Address, and Reset State (Continued)

Register Mnemonic	Register Name	Hex Address	Reset State
EPA_PEND	EPA Pending	1F9EH	AAH
EPA0_CON	EPA Capture/Compare 0 Control	1F80H	00H
EPA1_CON	EPA Capture/Compare 1 Control	1F84H	0000H
EPA2_CON	EPA Capture/Compare 2 Control	1F88H	00H
EPA3_CON	EPA Capture/Compare 3 Control	1F8CH	0000H
EPA0_TIME	EPA Capture/Compare 0 Time	1F82H	0000H
EPA1_TIME	EPA Capture/Compare 1 Time	1F86H	0000H
EPA2_TIME	EPA Capture/Compare 2 Time	1F8AH	0000H
EPA3_TIME	EPA Capture/Compare 3 Time	1F8EH	0000H
EXTINT_CON	External Interrupt Control	1FCCH	00H
ICB0	Index Control Byte 0	1FC3H	00H
ICB1	Index Control Byte 1	1FC7H	00H
ICX0	Index Reference 0	0010H	XXXXH
ICX1	Index Reference 1	0016H	XXXXH
IDX0	Index Pointer 0	1FC0H	XXXXXXH
IDX1	Index Pointer 1	1FC4H	XXXXXXH
IN_PROG0	Interrupt In Progress 0	1FC8H	00H
IN_PROG1	Interrupt In Progress 1	1FCAH	0000H
INT_CON0	Interrupt Control 0	1FE8H	3210H
INT_CON1	Interrupt Control 1	1FEAH	7654H
INT_CON2	Interrupt Control 2	1FECH	BA98H
INT_CON3	Interrupt Control 3	1FEEH	FEDCH
INT_MASK	Interrupt Mask	0008H	00H
INT_MASK1	Interrupt Mask 1	0013H	00H
INT_PEND	Interrupt Pending	0009H	00H
INT_PEND1	Interrupt Pending 1	0012H	00H
NMI_PEND	NMI Pending	1FC9H	00H
ONES_REG	Ones Register	0002H	FFFFH
P1_DIR	Port 1 I/O Direction	1FD2H	FFH
P2_DIR	Port 2 I/O Direction	1FD3H	7FH
P3_DIR	Port 3 I/O Direction	1FDAH	FEH

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after a device reset. The CCBs reside in nonvolatile memory at addresses FF2018H (CCB0) and FF201AH (CCB1).

Table C-2. Register Name, Address, and Reset State (Continued)

Register Mnemonic	Register Name	Hex Address	Reset State
P4_DIR	Port 4 I/O Direction	1FDBH	FFH
P1_MODE	Port 1 Mode	1FD0H	00H
P2_MODE	Port 2 Mode	1FD1H	80H
P3_MODE	Port 3 Mode	1FD8H	01H
P4_MODE	Port 4 Mode	1FD9H	00H
P1_PIN	Port 1 Pin Input	1FD6H	XXH
P2_PIN	Port 2 Pin Input	1FD7H	XXH
P3_PIN	Port 3 Pin Input	1FDEH	XXH
P4_PIN	Port 4 Pin Input	1FDFH	XXH
P1_REG	Port 1 Data Output	1FD4H	FFH
P2_REG	Port 2 Data Output	1FD5H	FFH
P3_REG	Port 3 Data Output	1FDCH	FFH
P4_REG	Port 4 Data Output	1FDDH	FFH
PSW	Processor Status Word	no direct access	
PWM0_CONTROL	PWM 0 Control	1FB0H	00H
PWM1_CONTROL	PWM 1 Control	1FB2H	00H
PWM2_CONTROL	PWM 2 Control	1FB4H	00H
RPT_CNT	Repeat Counter	0004H	XXXXH
SBUF_RX	Serial Port Receive Buffer	1FB8H	00H
SBUF_TX	Serial Port Transmit Buffer	1FBAH	00H
SP	Stack Pointer	0018H	XXXXH
SP_BAUD	Serial Port Baud Rate	1FBCH	0000H
SP_CON	Serial Port Control	1FBBH	80H
SP_STATUS	Serial Port Status	1FB9H	0BH
T1CONTROL	Timer 1 Control	1F90H	00H
T2CONTROL	Timer 2 Control	1F94H	00H
TIMER1	Timer 1 Value	1F92H	0000H
TIMER2	Timer 2 Value	1F96H	0000H
VECT_ADDR	Interrupt Vector Address Select	1FF0H	FF30H
WSR	Window Selection	0014H	00H

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after a device reset. The CCBs reside in nonvolatile memory at addresses FF2018H (CCB0) and FF201AH (CCB1).

Table C-2. Register Name, Address, and Reset State (Continued)

Register Mnemonic	Register Name	Hex Address	Reset State
WSR1	Window Selection 1	0015H	00H
ZERO_REG	Zero Register	0000H	0000H

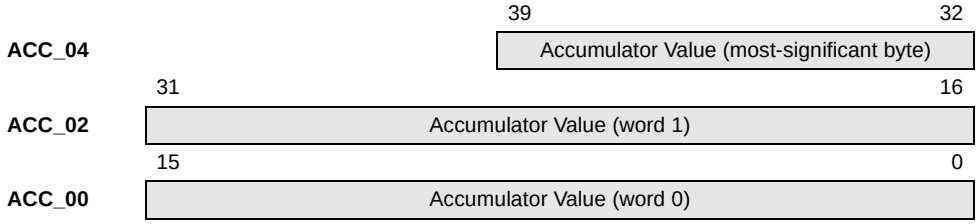
† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after a device reset. The CCBs reside in nonvolatile memory at addresses FF2018H (CCB0) and FF201AH (CCB1).

ACC_0x

ACC_0*x*
***x* = 0, 2, 4**

Address: 0CH, 0EH, 06H
Reset State: 00H

The 40-bit accumulator register (ACC_0*x*) resides at locations 0C–0FH. You must read from or write to the accumulator register as two words at locations 0CH and 0EH, and as one byte at location 06H.



Bit Number	Function
39:0	Accumulator Value You can read this register to determine the current value of the accumulator. You can write to this register to clear or preload a value into the accumulator.

ACC_STAT

ACC_STAT Address: 0BH
Reset State: 38H

The accumulator control and status (ACC_STAT) register enables and disables fractional and saturation modes and contains three status flags that indicate the status of the accumulator's contents.

7 **0**

FME	SME	—	—	—	STOVF	OVF	STSAT

Bit Number	Bit Mnemonic	Function
7	FME	Fractional Mode Enable Set this bit to enable fractional mode (see "Effect of SME and FME Bit Combinations"). In this mode, the result of a signed multiplication instruction is shifted left by one bit before it is added to the contents of the accumulator. For unsigned multiplication, this bit is ignored.
6	SME	Saturation Mode Enable Set this bit to enable saturation mode (see "Effect of SME and FME Bit Combinations"). In this mode, the result of a signed multiplication operation is **not** allowed to overflow or underflow. For unsigned multiplication, this bit is ignored.
5:3	—	Reserved; for compatibility with future devices, write zeros to these bits.
2	STOVF	Sticky Overflow Flag For unsigned multiplication, this bit is set if a carry out of bit 31 occurs. Unless saturation mode is enabled, this bit is set for signed multiplication to indicate that the sign bit of the accumulator and the sign bit of the addend are equal, but the sign bit of the result is the opposite (see "Effect of SME and FME Bit Combinations"). Software can clear this flag; hardware does **not** clear it.
1	OVF	Overflow Flag This bit indicates that an overflow occurred during the preceding accumulation (see "Effect of SME and FME Bit Combinations"). This flag is dynamic; it can change after each accumulation.
0	STSAT	Sticky Saturation Flag This bit indicates that a saturation has occurred during accumulation with saturation mode enabled (see "Effect of SME and FME Bit Combinations"). Software can clear this flag; hardware does **not** clear it.

ACC_STAT

Table C-3. Effect of SME and FME Bit Combinations

SME	FME	Description
0	0	Sets the OVF and STOVF flags if the sign bits of the accumulator and the addend (the number to be added to the contents of the accumulator) are equal, but the sign bit of the result is the opposite.
0	1	Shifts the addend (the number to be added to the contents of the accumulator) left by one bit before adding it to the accumulator. Sets the OVF and STOVF flags if the sign bits of the accumulator and the addend are equal, but the sign bit of the result is the opposite.
1	0	Accumulates a signed integer value up or down to saturation and sets the STSAT flag. Positive saturation changes the accumulator value to 7FFFFFFFH; negative saturation changes the accumulator value to 80000000H. Accumulation proceeds normally after saturation, which means that the accumulator value can increase from a negative saturation or decrease from a positive saturation.
1	1	Shifts the addend (the number to be added to the contents of the accumulator) left by one bit before adding it to the accumulator. Accumulates a signed integer value up or down to saturation and sets the STSAT flag. Positive saturation changes the accumulator value to 7FFFFFFFH; negative saturation changes the accumulator value to 80000000H. Accumulation proceeds normally after saturation, which means that the accumulator value can increase from a negative saturation or decrease from a positive saturation.

ADDRCOMx

ADDRCOM*x*
***x* = 0–5**

The address compare (ADDRCOM*x*) register specifies the base (lowest) address of the address range. The base address of a 2^n-byte address range must be on a 2^n-byte boundary.

15							8
BASE23	BASE22	BASE21	BASE20	BASE19	BASE18	BASE17	BASE16
7							**0**
BASE15	BASE14	BASE13	BASE12	BASE11	BASE10	BASE9	BASE8

Bit Number	Bit Mnemonic	Function
15:0	BASE23:8	Base Address Bits Write address bits 23–8 of the base address of the address range assigned to chip-select *x* to these bits.

Table C-4. ADDRCOM*x* Addresses and Reset States

Register	Address	Reset States
ADDRCOM0	1F40H	FF20H
ADDRCOM1	1F48H	0000H
ADDRCOM2	1F50H	0000H
ADDRCOM3	1F58H	0000H
ADDRCOM4	1F60H	0000H
ADDRCOM5	1F68H	0000H

ADDRMSKx

ADDRMSK*x*
***x* = 0–5**

The address mask (ADDRMSK*x*) register, together with the address compare register, defines the address range that is assigned to the chip-select *x* output, CS*x*#. The address mask register determines the size of the address range, which must be 2^n bytes, where $n = 8, 9, \ldots, 20$. For a 2^n-byte address range, calculate $n_1 = 24 - n$, and set the n_1 most-significant bits of MASK23:8 in the address mask register.

15							8
MASK23	MASK22	MASK21	MASK20	MASK19	MASK18	MASK17	MASK16
7							**0**
MASK15	MASK14	MASK13	MASK12	MASK11	MASK10	MASK9	MASK8

Bit Number	Bit Mnemonic	Function
15:0	MASK23:8	Address Mask Bits For a 2^n-byte address range, set the n_1 most-significant bits of MASK23:8, where $n_1 = 24 - n$. Since 20 external address lines are available, the maximum address range size is 1 Mbyte (2^{20}). Therefore, always write ones to the 4 most-significant mask bits (MASK23:20).

Table C-5. ADDRMSK*x* Addresses and Reset States

Register	Address	Reset State
ADDRMSK0	1F42H	FFFFH
ADDRMSK1	1F4AH	FFFFH
ADDRMSK2	1F52H	FFFFH
ADDRMSK3	1F5AH	FFFFH
ADDRMSK4	1F62H	FFFFH
ADDRMSK5	1F6AH	FFFFH

BUSCONx

BUSCON*x*
***x* = 0–5**

For the address range assigned to chip-select *x*, the bus control (BUSCON*x*) register specifies the number of wait states, the bus width, and the address/data multiplexing for all external bus cycles that access address range *x*. BUSCON*x* also determines whether chip-select output *x* will be activated when the address region for chip select *x*+1 is accessed. This option makes accessing a memory device using two different bus configurations possible.

The chip-select output signals share package pins with port 3. Use the port registers to configure these pins as general-purpose I/O signals or as chip-select signals (see “Chip-select Signals (Port 3)” on page 7-8). The bus configuration programmed in BUSCON*x* applies to address range *x*, regardless of the port 3 pin configurations.

7							0
DEMUX	BW16	REMAP	WRWS	WS3	WS2	WS1	WS0

Bit Number	Bit Mnemonic	Function
7	DEMUX	Address/Data Multiplexing This bit specifies the address/data multiplexing on AD15:0 for all external accesses to the address range assigned to chip-select *x* output. 0 = multiplexed 1 = demultiplexed
6	BW16	Bus Width This bit specifies the bus width for all external accesses to the address range assigned to chip-select *x* output. 0 = 8 bits 1 = 16 bits
5	REMAP	Remap Setting this bit remaps chip-select output *x*+1 (CS*x*+1#) to chip-select output x (CS*x*#). In other words, accessing chip select *x*'s address region activates CS*x*# and configures the bus as programmed in BUSCON*x*. Accessing chip select *x*+1's address region also activates CS*x*# but configures the bus as programmed in BUSCON*x*+1. See “Example of a Chip-select Setup Using the Remap Feature” on page 13-16. 0 = remapping disabled 1 = remapping enabled (CS*x*+1# is remapped to CS*x*#) **Note**: For chip-select channel 5, setting this bit remaps CS0# to CS5#. In this case, *x* = 5 and *x*+1 = 0.

BUSCONx

BUSCON*x* (Continued)
***x* = 0–5**

For the address range assigned to chip-select *x*, the bus control (BUSCON*x*) register specifies the number of wait states, the bus width, and the address/data multiplexing for all external bus cycles that access address range *x*. BUSCON*x* also determines whether chip-select output *x* will be activated when the address region for chip select *x*+1 is accessed. This option makes accessing a memory device using two different bus configurations possible.

The chip-select output signals share package pins with port 3. Use the port registers to configure these pins as general-purpose I/O signals or as chip-select signals (see "Chip-select Signals (Port 3)" on page 7-8). The bus configuration programmed in BUSCON*x* applies to address range *x*, regardless of the port 3 pin configurations.

7							0
DEMUX	BW16	REMAP	WRWS	WS3	WS2	WS1	WS0

Bit Number	Bit Mnemonic	Function
4	WRWS	Write Operation Wait State When this bit is set, the bus controller adds one state time (2t) to write operations within the address region specified by chip select *x*. 0 = data and address hold time remains unchanged 1 = data and address hold time increases by one state time (2t) See the datasheet for the write operation data and address hold time specification (T_{WHAX}).
3:0	WS3:0	Wait States These bits, along with the READY pin, control the number of wait states for all external accesses to the address range assigned to the chip-select *x* channel. Write the desired minimum number of wait states (0–15) to WS3:0. If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.

Table C-6. BUSCON*x* Addresses and Reset States

Register	Address	Reset State
BUSCON0	1F44H	0FH
BUSCON1	1F4CH	00H
BUSCON2	1F54H	00H
BUSCON3	1F5CH	00H
BUSCON4	1F64H	00H
BUSCON5	1F6CH	00H

CCR0

CCR0 no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7							0
1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5:4	WS1:0	Wait States These bits, along with the READY pin, control the number of wait states that are used for an external fetch of chip configuration byte 1 (CCB1). **WS1 WS0** 0 0 0 wait states 0 1 5 wait states 1 0 10 wait states 1 1 15 wait states If the programmed number of wait states is greater than zero and READY is low when this programmed number of wait states is reached, additional wait states are added until READY is pulled high. If the programmed number of wait states is equal to zero, hold the READY pin high. Programming the number of wait states equal to zero and holding the READY pin low produces unpredictable results.
3	DEMUX	Select Demultiplexed Bus Selects the demultiplexed bus mode for an external fetch of CCB1: 0 = multiplexed — address and data are multiplexed on AD15:0. 1 = demultiplexed — data only on AD15:0.
2	BHE#	Write-control Mode Selects the write-control mode, which determines the functions of the BHE#/WRH# and WR#/WRL# pins for external bus cycles: 0 = write strobe mode: the BHE#/WRH# pin operates as WRH#, and the WR#/WRL# pin operates as WRL#. 1 = standard write-control mode: the BHE#/WRH# pin operates as BHE#, and the WR#/WRL# pin operates as WR#.

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

CCR0

CCR0 (Continued) no direct access†

The chip configuration 0 (CCR0) register enables or disables the IDLPD #2 and IDLPD #3 instructions and selects the write-control mode. It also contains the bus-control parameters for fetching chip configuration byte 1.

7 **0**

1	1	WS1	WS0	DEMUX	BHE#	BW16	PD

Bit Number	Bit Mnemonic	Function
1	BW16	Buswidth Control Selects the bus width for an external fetch of CCB1: 0 = 8-bit bus 1 = 16-bit bus
0	PD	Powerdown Enable Enables or disables the IDLPD #2 and IDLPD #3 instructions. When enabled, the IDLPD #2 instruction causes the microcontroller to enter powerdown mode and the IDLPD #3 instruction causes the microcontroller to enter standby mode. 0 = disable powerdown and standby modes 1 = enable powerdown and standby modes If your design uses powerdown or standby mode, set this bit when you program the CCBs. If it does not, clearing this bit when you program the CCBs will prevent accidental entry into powerdown or standby mode. (Chapter 12, "Special Operating Modes," discusses powerdown and standby modes.)

† The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

CCR1

CCR1 no direct access†

The chip configuration 1 (CCR1) register selects the 64-Kbyte or 1-Mbyte addressing mode.

7							0
1	1	0	1	1	0	MODE64	0

Bit Number	Bit Mnemonic	Function
7:6	1	To guarantee proper operation, write ones to these bits.
5	0	To guarantee proper operation, write zero to this bit.
4:3	1	To guarantee proper operation, write ones to these bits.
2	0	To guarantee proper operation, write zero to this bit.
1	MODE64	Addressing Mode Selects 64-Kbyte or 1-Mbyte addressing. 0 = selects 1-Mbyte addressing 1 = selects 64-Kbyte addressing In 1-Mbyte mode, code can execute from almost anywhere in the address space. In 64-Kbyte mode, code can execute only from page FFH. (See “Fetching Code and Data in the 1-Mbyte and 64-Kbyte Modes” on page 5-22 for more information.)
0	0	Reserved; for compatibility with future devices, write zero to this bit.

The CCRs are loaded with the contents of the chip configuration bytes (CCBs) after reset. The CCBs reside at addresses FF2018H (CCB0) and FF201AH (CCB1).

CON_REG0

CON_REG0 Address: 1FB6H
Reset State: 7CH

The control (CON_REG0) register controls the clock prescaler for the three pulse-width modulators (PWM0–PWM2) and enables or disables the duty-cycle generator.

7							0
DCD†	—	—	—	—	—	CLK1	CLK0

Bit Number	Bit Mnemonic	Function
7	DCD	Duty Cycle Disable Control This bit controls the duty-cycle generator for power conservation. Upon reset, the generator is enabled. 0 = enabled; PWM duty cycle generator is turned on 1 = disabled; PWM duty cycle generator is turned off
6:2	—	Reserved; for compatibility with future devices, write zeros to these bits.
1:0	CLK1:0	Enable PWM Clock Prescaler These bits control the PWM output period on the three pulse-width modulators (PWM2:0). **CLK1 CLK0** 0 0 disable clock prescaler 0 1 enable divide-by-two prescaler; PWM output period is 1024 state times 1 X enable divide-by-four prescaler; PWM output period is 2048 state times

† This bit was called PWM_HALT in earlier documentation for the 80296SA.

EP_DIR

EP_DIR Address: 1FE3H
Reset State: FFH

In I/O mode, each bit of the extended port I/O direction (EP_DIR) register controls the direction of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as either a high-impedance input or an open-drain output. (Open-drain outputs require external pull-ups.)

Any pin that is configured for its extended-address function is forced to the complementary output mode except during reset, hold, idle, powerdown, and standby.

7							0
—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:4	—	Reserved; for compatibility with future devices, write ones to these bits.
3:0	PIN3:0	Extended Address Port Pin *x* Direction Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.

EP_MODE

EP_MODE

Address: 1FE1H
Reset State: FFH

Each bit of the extended port mode (EP_MODE) register controls whether the corresponding pin functions as a general-purpose I/O signal or as an extended-address signal. Setting a bit configures a pin as an extended-address signal; clearing a bit configures a pin as a general-purpose I/O signal.

7							0
—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:4	—	Reserved; for compatibility with future devices, write zeros to these bits.
3:0	PIN3:0	Extended Address Port Pin *x* Mode This bit determines the mode of EPORT.*x*: 0 = general-purpose I/O signal 1 = extended-address signal

EP_PIN

EP_PIN Address: 1FE7H
Reset State: XXH

Each bit of the extended port pin (EP_PIN) register reflects the current state of the corresponding pin, regardless of the pin configuration.

7							0
—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:4	—	Reserved. These bits are undefined.
3:0	PIN3:0	Extended Address Port Pin *x* Input This bit contains the current state of EPORT.*x*.

EP_REG

EP_REG

Address: 1FE5H
Reset State: 00H

Each bit of the extended port data output (EP_REG) register contains data to be driven out by the corresponding pin. When a pin is configured as a general-purpose I/O signal (EP_MODE.*x* = 0), the result of a CPU write to EP_REG is immediately visible on the pin.

During nonextended data accesses, EP_REG contains the value of the memory page that is to be accessed. For compatibility with software tools, clear the EP_REG bit for any EPORT pin that is configured as an extended-address signal (EP_MODE.*x* set).

For nonextended data accesses, the 80296SA forces the page address to 00H. You cannot change pages by modifying EP_REG.

7							0
—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:4	—	Reserved; for compatibility with future devices, write zeros to these bits.
3:0	PIN3:0	Extended Address Port Pin *x* Output If EPORT.*x* is to be used as an output, write the data that it is to drive out. If EPORT.*x* is to be used as an input, set this bit.

EPA_MASK

EPA_MASK

Address: 1F9CH
Reset State: AAH

The EPA interrupt mask (EPA_MASK) register enables or disables (masks) the shared EPA3:0 overrun interrupts (OVR3:0).

7 **0**

—	OVR3	—	OVR2	—	OVR1	—	OVR0

Bit Number	Bit Mnemonic	Function
7, 5, 3, 1	—	Reserved; for compatibility with future devices, write zeros to these bits.
6, 4, 2, 0	OVR3 OVR2 OVR1 OVR0	Setting this bit enables the corresponding source as a shared overrun interrupt source. The shared overrun interrupts (OVR0_1 and OVR2_3) are enabled by setting their interrupt enable bits in the interrupt mask 1 (INT_MASK1) register.

EPA_PEND

EPA_PEND Address: 1F9EH
Reset State: AAH

When hardware detects a pending EPA0–3 overrun interrupt request (OVR3:0), it sets the corresponding bit in the EPA interrupt pending register (EPA_PEND).

Reading EPA_PEND clears all bits.

7							0
—	OVR3	—	OVR2	—	OVR1	—	OVR0

Bit Number	Function
7, 5, 3, 1	Reserved. These bits are undefined.
6, 4, 2, 0	Any set bit indicates that the corresponding overrun interrupt source is pending.

EPA*x*_CON
***x* = 0–3**

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.

***x* = 1, 3**

15							8
—	—	—	—	—	—	—	RM
7							**0**
TB	CE	M1	M0	RE	—	ROT	ON/RT

***x* = 0, 2**

7							0
TB	CE	M1	M0	RE	—	ROT	ON/RT

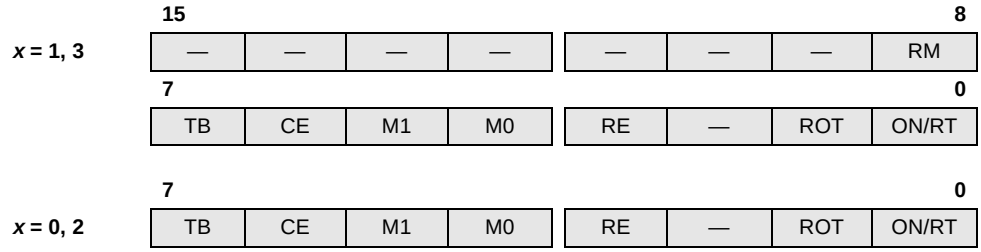
Bit Number	Bit Mnemonic	Function
15:9†	—	Reserved; always write as zeros.
8†	RM	Remap Feature The remap feature applies to the compare mode of the EPA1 and EPA3 only. When the remap feature of EPA1 is enabled, EPA capture/compare channel 0 shares output pin EPA1 with EPA capture/compare channel 1. When the remap feature of EPA3 is enabled, EPA capture/compare channel 2 shares output pin EPA3 with EPA capture/compare channel 3. 0 = remap feature disabled 1 = remap feature enabled
7	TB	Time Base Select Specifies the reference timer. 0 = timer 1 is the reference timer and timer 2 is the opposite timer 1 = timer 2 is the reference timer and timer 1 is the opposite timer A compare event (clearing, setting, or toggling an output pin; and/or resetting either timer) occurs when the reference timer matches the time programmed in the event-time register. When a capture event (falling edge, rising edge, or an edge change on the EPA*x* pin) occurs, the reference timer value is saved in the EPA event-time register (EPA*x*_TIME).
6	CE	Compare Enable Determines whether the EPA channel operates in capture or compare mode. 0 = capture mode 1 = compare mode

† These bits apply to the EPA1_CON and EPA3_CON registers only.

EPAx_CON

EPA*x*_CON (Continued)
***x* = 0–3**

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.



Bit Number	Bit Mnemonic	Function
5:4	M1:0	EPA Mode Select In capture mode, specifies the type of event that triggers an input capture. In compare mode, specifies the action that the EPA executes when the reference timer matches the event time. **M1 M0 Capture Mode Event** 0 0 no capture 0 1 capture on falling edge 1 0 capture on rising edge 1 1 capture on either edge **M1 M0 Compare Mode Action** 0 0 no output 0 1 clear output pin 1 0 set output pin 1 1 toggle output pin
3	RE	Re-enable Re-enable applies to the compare mode only. It allows a compare event to continue to execute each time the event-time register (EPA*x*_TIME) matches the reference timer rather than only upon the first time match. 0 = compare function is disabled after a single event 1 = compare function always enabled
2	—	Reserved; always write as zero.

† These bits apply to the EPA1_CON and EPA3_CON registers only.

EPA*x*_CON (Continued)
***x* = 0–3**

The EPA control (EPA*x*_CON) registers control the functions of their assigned capture/compare channels. The registers for EPA0 and EPA2 are identical. The registers for EPA1 and EPA3 have an additional bit, the remap bit. This added bit (bit 8) requires an additional byte, so EPA1_CON and EPA3_CON must be addressed as words, while the others can be addressed as bytes.

***x* = 1, 3**

15							8
—	—	—	—	—	—	—	RM
7							**0**
TB	CE	M1	M0	RE	—	ROT	ON/RT

***x* = 0, 2**

7							0
TB	CE	M1	M0	RE	—	ROT	ON/RT

Bit Number	Bit Mnemonic	Function
1	ROT	Reset Opposite Timer Controls different functions for capture and compare modes. **In Capture Mode:** 0 = causes no action 1 = resets the opposite timer **In Compare Mode:** Selects the timer that is to be reset if the RT bit is set. 0 = selects the reference timer for possible reset 1 = selects the opposite timer for possible reset
0	ON/RT	Overwrite New/Reset Timer The ON/RT bit functions as overwrite new in capture mode and reset timer in compare mode. **In Capture Mode (ON):** An overrun error is generated when an input capture occurs while the event-time register (EPA*x*_TIME) and its buffer are both full. When an overrun occurs, the ON bit determines whether old data is overwritten or new data is ignored: 0 = ignores new data 1 = overwrites old data in the buffer **In Compare Mode (RT):** 0 = disables the reset function 1 = resets the ROT-selected timer

† These bits apply to the EPA1_CON and EPA3_CON registers only.

EPAx_CON

Table C-7. EPA*x*_CON Addresses and Reset States

Register	Address	Reset State
EPA0_CON	1F80H	00H
EPA1_CON	1F84H	0000H
EPA2_CON	1F88H	00H
EPA3_CON	1F8CH	0000H

EPAx_TIME

EPA*x*_TIME
***x* = 0–3**

The EPA time (EPA*x*_TIME) registers are the event-time registers for the EPA channels. In capture mode, the value of the reference timer is captured in EPA*x*_TIME when an input transition occurs. Each event-time register is buffered, allowing the storage of two capture events at once. In compare mode, the EPA triggers a compare event when the reference timer matches the value in EPA*x*_TIME. EPA*x*_TIME is not buffered for compare mode.

15	0
EPA Timer Value	

Bit Number	Function
15:0	EPA Timer Value When an EPA channel is configured for capture mode, this register contains the value of the reference timer when the specified event occurred. When an EPA channel is configured for compare mode, write the compare event time to this register.

Table C-8. EPA*x*_TIME Addresses and Reset States

Register	Address	Reset State
EPA0_TIME	1F82H	0000H
EPA1_TIME	1F86H	0000H
EPA2_TIME	1F8AH	0000H
EPA3_TIME	1F8EH	0000H

EXTINT_CON

EXTINT_CON Address: 1FCCH
Reset State: 00H

The external interrupt control (EXTINT_CON) register enables you to individually select the action that causes an interrupt request on each external interrupt input.

7 **0**

LEV3	LEV2	LEV1	LEV0	POL3	POL2	POL1	POL0

Bit Number	Bit Mnemonic	Function
7:4	LEV3:0	These bits control what action on the external interrupt pins generates an interrupt request. LEV3 and POL3 program the EXTINT3 pin, LEV2 and POL2 program EXTINT2, and so on. **LEV*x*** **POL*x*** 0 0 rising edge on EXTINT*x* generates an interrupt request 0 1 falling edge on EXTINT*x* generates an interrupt request 1 0 high level on EXTINT*x* generates an interrupt request 1 1 low level on EXTINT*x* generates an interrupt request
3:0	POL3:0	

ICBx

ICB*x*
***x* = 0–1**

Address: 1FC3H, 1FC7H
Reset State: 00H

The index control byte (ICB*x*) register controls the automatic increment and decrement feature of the index pointers.

7			4	3	0
—	—	—	ID	Count	

Bit Number	Bit Mnemonic	Function
7:5	—	Reserved; for compatibility with future devices, write zeros to these bits.
4	ID	Increment or Decrement This bit allows the index pointer to increment and decrement. 0 = increment 1 = decrement
3:0	Count	Count Value These bits specify a count value ranging from 0H to 0FH (15 decimal).

ICXx

ICX*x*
***x* = 0–1**

Address: 0010H, 0016H
Reset State: XXXXH

The index reference register (ICX*x*) allows you to indirectly access the address location being pointed to by the index pointer.

15	0
Index Reference	

Bit Number	Function
15:0	Index Reference This register contains a word of data that indirectly addresses the index pointer.

IDXx

IDX*x*
***x* = 0–1**

Address: 1FC0H, 1FC4H
Reset State: XXXXXXH

The 24-bit index register (IDX*x*) serves as a pointer to any location within the 16-Mbyte address space. The following restrictions apply:

- IDX0 and IDX1 must be accessed with windowed direct addressing.
- IDX0 must point to either a source 1 (SRC1) or a destination (DEST) address.
- IDX1 must point to a source 2 (SRC2) address.

24	0
Index Pointer	

Bit Number	Function
24:0	Index Pointer This register contains 24 bits of data that point to a location within the address range.

IN_PROGx

IN_PROG*x*
***x* = 0–1**

Address: 1FC8H, 1FCAH
Reset State: 00H, 0000H

The interrupt in-progress registers (IN_PROG*x*) track which interrupt is currently being serviced. The IN_PROG0 register tracks the unimplemented opcode interrupt (UOP) and the software trap interrupt. The IN_PROG1 register tracks the maskable interrupts in terms of the priority that was assigned to them in the INT_CON*x* registers. IN_PROG*x* registers should only be used when priority-programming is enabled.

IN_PROG0

7							0
—	—	—	—	—	—	UOP	TRAP

IN_PROG1

15							8
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8
7							**0**
PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Bit Mnemonic	Function
IN_PROG0.7:2 IN_PROG1.2	—	Reserved; for compatibility with future devices, write zeros to these bits.
IN_PROG0.1	UOP	Any set bit indicates that the interrupt routine with the corresponding programmed priority level is executing. When processing transfers to an interrupt service routine, hardware sets the bit that corresponds to the interrupt's programmed priority level. When the return from interrupt (RETI) instruction is executed, at the end of an interrupt service routine, hardware clears the bit that corresponds to the interrupt's programmed priority level. The UOP, TRAP, and NMI are fixed priority interrupts.
IN_PROG0.0	TRAP	
IN_PROG1.15	NMI	
IN_PROG1.14:3 IN_PROG1.1:0	PR14:3 PR1:0	

INT_CONx

INT_CON*x*
***x* = 0–3**

The interrupt control registers (INT_CON*x*) allow you to program the priority of the maskable interrupts. To assign a priority to an interrupt, write the interrupt's default priority hex value to the desired priority field. Before you can use this register, you must enable the programmable priority mode by setting bit 7 in NMI_PEND.

	15 8	7 0		
INT_CON3	—	PR14	PR13	PR12
INT_CON2	PR11	PR10	PR9	PR8
INT_CON1	PR7	PR6	PR5	PR4
INT_CON0	PR3	—	PR1	PR0

Bit Number	Bit Mnemonic	Function
INT_CON3.15:12	—	Priority Fields Write to these priority fields to program the interrupt priority and vector location. To assign an interrupt to a specific priority, write its interrupt default priority hex value to the desired priority field. Write FH to any unused priority field, including reserved priority fields, 2 and 15. For example, if you were to assign interrupt source EPA3 (default priority value 10) to priority twelve (PR12), the branching scheme for the EPA3 service routine would change from vector location FF2034H to FF2038H. This is possible by simply writing AH to bit field INT_CON3.3:0.
INT_CON3.11:8	PR14	
INT_CON3.7:4	PR13	
INT_CON3.3:0	PR12	
INT_CON2.15:12	PR11	
INT_CON2.11:8	PR10	
INT_CON2.7:4	PR9	
INT_CON2.3:0	PR8	
INT_CON1.15:12	PR7	
INT_CON1.11:8	PR6	
INT_CON1.7:4	PR5	
INT_CON1.3:0	PR4	
INT_CON0.15:12	PR3	
INT_CON0.11:8	—	
INT_CON0.7:4	PR1	
INT_CON0.3:0	PR0	

INT_CONx

Table C-9. INT_CON*x* Address and Reset States

Register	Address	Reset State
INT_CON0	1FE8H	3210H
INT_CON1	1FEAH	7654H
INT_CON2	1FECH	BA98H
INT_CON3	1FEEH	FEDCH

INT_MASK

INT_MASK Address: 0008H
Reset State: 00H

The interrupt mask (INT_MASK) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK is the low byte of the processor status word (PSW). PUSHF or PUSHA saves the contents of this register onto the stack and then clears this register. Interrupt calls cannot occur immediately following this instruction. POPF or POPA restores it.

7 **0**

PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows:

Default Priority	Interrupt Source
7	EPA Capture/Compare Channel 0
6	SIO Receive
5	SIO Transmit
4	EXTINT1 pin
3	EXTINT0 pin
2	Reserved
1	Timer 2 Overflow/Underflow
0	Timer 1 Overflow/Underflow

INT_MASK1

INT_MASK1 Address: 0013H
Reset State: 00H

The interrupt mask 1 (INT_MASK1) register enables or disables (masks) individual interrupt requests. (The EI and DI instructions enable and disable servicing of all maskable interrupts.) INT_MASK1 can be read from or written to as a byte register. PUSHA saves this register on the stack and POPA restores it.

7							0
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8

Bit Number	Function
7:0	Setting a bit enables the interrupt that is assigned to the corresponding priority. The default interrupt priorities are as follows: **Default Priority** — **Interrupt Source** 15 — Nonmaskable Interrupt† 14 — EXTINT3 pin 13 — EXTINT2 pin 12 — EPA Capture Channel 2 or 3 Overrun†† 11 — EPA Capture Channel 0 or 1 Overrun†† 10 — EPA Capture/Compare Channel 3 9 — EPA Capture/Compare Channel 2 8 — EPA Capture/Compare Channel 1 † NMI is always enabled and is always assigned to priority 15. This nonfunctional mask bit exists for design symmetry with the INT_PEND1 register. Always write zero to this bit. †† An overrun on the EPA capture/compare channels can generate the shared capture overrun interrupts. Write to EPA_MASK to enable the interrupt sources; read EPA_PEND to determine which source caused the interrupt.

INT_PEND

INT_PEND Address: 0009H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending (NMI_PEND, INT_PEND, or INT_PEND1) registers. When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit.

7 **0**

PR7	PR6	PR5	PR4	PR3	—	PR1	PR0

Bit Number	Function
7:0	Any set bit indicates that the interrupt that is assigned to the corresponding priority is pending. The interrupt bit is cleared when processing transfers to the corresponding interrupt vector. The default interrupt priorities are as follows: **Default Priority** — **Interrupt Source** 7 — EPA Capture/Compare Channel 0 6 — SIO Receive 5 — SIO Transmit 4 — EXTINT1 pin 3 — EXTINT0 pin 2 — Reserved 1 — Timer 2 Overflow/Underflow 0 — Timer 1 Overflow/Underflow

INT_PEND1

INT_PEND1 Address: 0012H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending (NMI_PEND, INT_PEND, or INT_PEND1) registers. When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit.

7							0
NMI	PR14	PR13	PR12	PR11	PR10	PR9	PR8

Bit Number	Function
7:0	Any set bit indicates that the interrupt that is assigned to the corresponding priority is pending. The interrupt bit is cleared when processing transfers to the corresponding interrupt vector. The default interrupt priorities are as follows: **Default Priority — Interrupt Source** 15 — Nonmaskable Interrupt† 14 — EXTINT3 pin 13 — EXTINT2 pin 12 — EPA Capture Channel 2 or 3 Overrun†† 11 — EPA Capture Channel 0 or 1 Overrun†† 10 — EPA Capture/Compare Channel 3 9 — EPA Capture/Compare Channel 2 8 — EPA Capture/Compare Channel 1 † NMI is always assigned to priority 15. †† An overrun on the EPA capture/compare channels can generate the shared capture overrun interrupts. Write to EPA_MASK to enable the interrupt sources; read EPA_PEND to determine which source caused the interrupt.

NMI_PEND

NMI_PEND Address: 1FC9H
Reset State: 00H

When hardware detects an interrupt request, it sets the corresponding bit in the interrupt pending registers (NMI_PEND, INT_PEND, or INT_PEND1). When the vector is taken, the hardware clears the pending bit. Software can generate an interrupt by setting the corresponding interrupt pending bit. NMI_PEND also contains a programmable-priority-enable bit (PEN), which when set, causes the interrupt controller to reassign the interrupt priorities as defined by the INT_CON*x* register.

7							0
PEN	—	—	—	—	—	UOP	TRAP

Bit Number	Bit Mnemonic	Function
7	PEN	Programmable-priority Enable When PEN is set, the interrupt controller uses the interrupt priority scheme defined in the INT_CON*x* register. When PEN is cleared, the interrupt controller uses the default interrupt priorities.
6:2	—	Reserved; for compatibility with future devices, write zeros to these bits.
1:0	UOP TRAP	Any set bit indicates that the corresponding interrupt is pending. The pending bit is cleared when processing transfers to the corresponding interrupt vector. **Bit Mnemonic** **Interrupt Description** UOP Unimplemented Opcode TRAP Software Trap

ONES_REG

ONES_REG Address: 02H
Reset State: FFFFH

The two-byte ones register (ONES_REG) is always equal to FFFFH. It is useful as a fixed source of all ones for comparison operations.

15	0
Ones	

Bit Number	Function
15:0	Ones These bits are always equal to FFFFH.

Px_DIR

P*x*_DIR
***x* = 1–4**

Each pin of port *x* can operate as a complementary output, high-impedance input or an open-drain output. The port *x* I/O direction (P*x*_DIR) register determines the configuration for each port *x* pin. When a port pin is configurated as a complementary output, the microcontroller drives the signal high or low. When a port pin is configured as a high-impedance input or an open-drain output, the microcontroller drives the signal low or floats it.

	7							0
***x* = 1–3**	PIN7	PIN6	PIN5	PIN4	PIN3	PIN2	PIN1	PIN0
	7							**0**
***x* = 4**	—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:0†	PIN7:0	Port *x* Pin *y* Direction Each bit controls the configuration of the corresponding pin. Clearing a bit configures a pin as a complementary output; setting a bit configures a pin as a high-impedance input or an open-drain output.

† The bits shown as dashes (—) are reserved; for compatibility with future devices, write ones to these bits.

Table C-10. P*x*_DIR Addresses and Reset States

Register	Address	Reset State
P1_DIR	1FD2H	FFH
P2_DIR	1FD3H	7FH
P3_DIR	1FDAH	FEH
P4_DIR	1FDBH	FFH

Px_MODE

P*x*_MODE
***x* = 1–4**

Each bit of the port *x* mode (P*x*_MODE) register controls whether the corresponding pin functions as a general-purpose I/O signal or as a special-function signal.

	7							0
***x* = 1–3**	PIN7	PIN6	PIN5	PIN4	PIN3	PIN2	PIN1	PIN0
	7							0
***x* = 4**	—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:0†	PIN7:0	Port *x* Pin *y* Mode This bit determines the mode of the corresponding port pin: 0 = general-purpose I/O signal 1 = special-function signal The following table lists the special-function signals for each pin.

† The bits shown as dashes (—) are reserved; for compatibility with future devices, write zeros to these bits.

Table C-11. P*x*_MODE Addresses and Reset States

Register	Address	Reset State
P1_MODE	1FD0H	00H
P2_MODE	1FD1H	80H
P3_MODE	1FD8H	01H
P4_MODE	1FD9H	00H

Table C-12. Special-function Signals for Ports 1–4

Port 1	
Pin	**Special-function Signal**
P1.0	EPA0
P1.1	EPA1
P1.2	EPA2
P1.3	EPA3
P1.4	T1CLK
P1.5	T1DIR
P1.6	T2CLK
P1.7	T2DIR

Port 2	
Pin	**Special-function Signal**
P2.0	TXD
P2.1	RXD
P2.2	EXTINT0
P2.3	BREQ#
P2.4	EXTINT1
P2.5	HOLD#
P2.6	HLDA#
P2.7	CLKOUT

Port 3	
Pin	**Special-function Signal**
P3.0	CS0#
P3.1	CS1#
P3.2	CS2#
P3.3	CS3#
P3.4	CS4#
P3.5	CS5#
P3.6	EXTINT2
P3.7	EXTINT3

Port 4	
Pin	**Special-function Signal**
P4.0	PWM0
P4.1	PWM1
P4.2	PWM2
P4.3	—

Px_PIN

P*x*_PIN
***x* = 1–4**

Each bit of the port *x* pin (P*x*_PIN) register reflects the current state of the corresponding pin, regardless of the pin configuration.

	7							0
***x* = 1–3**	PIN7	PIN6	PIN5	PIN4	PIN3	PIN2	PIN1	PIN0
	7							**0**
***x* = 4**	—	—	—	—	PIN3	PIN2	PIN1	PIN0

Bit Number	Bit Mnemonic	Function
7:0†	PIN7:0	Port *x* Pin *y* Input Value This bit contains the current state of P*x.y.*

† The bits shown as dashes (—) are reserved; their values are undefined.

Table C-13. P*x*_PIN Addresses and Reset States

Register	Address	Reset State
P1_PIN	1FD6H	XXH
P2_PIN	1FD7H	XXH
P3_PIN	1FDEH	XXH
P4_PIN	1FDFH	XXH

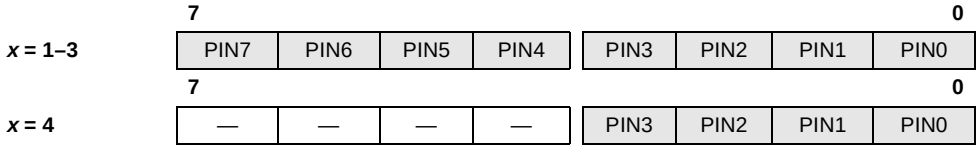
Px_REG

P*x*_REG
***x* = 1–4**

For an input, set the corresponding port *x* data output (P*x*_REG) register bit.

For an output, write the data to be driven out by each pin to the corresponding bit of P*x*_REG. When a pin is configured as a general-purpose I/O signal (P*x*_MODE.*y* = 0), the result of a CPU write to P*x*_REG is immediately visible on the pin. When a pin is configured as a special-function signal (P*x*_MODE.*y* = 1), the associated on-chip peripheral or off-chip component controls the pin. The CPU can still write to P*x*_REG, but the pin is unaffected until it is switched back to its standard I/O function.

This feature allows software to configure a pin as a general-purpose I/O signal (clear P*x*_MODE.*y*), initialize or overwrite the pin value, then configure the pin as a special-function signal (set P*x*_MODE.*y*). In this way, initialization, fault recovery, exception handling, etc., can be done without changing the operation of the associated peripheral.



Bit Number	Bit Mnemonic	Function
7:0†	PIN7:0	Port *x* Pin *y* Data Output **For I/O Mode (P*x*_MODE.*y* = 0)** When a port pin is configured as a complementary output (P*x*_DIR.*y* = 0), setting the corresponding port data output bit drives a one on the pin and clearing the corresponding port data output bit drives a zero on the pin. When a port pin is configured as a high-impedance input or an open-drain output (P*x*_DIR.*y* = 1), clearing the corresponding port data output bit drives a zero on the pin and setting the corresponding port data output bit floats the pin, making it available as a high-impedance input. **For Special-function Mode (P*x*_MODE.*y* = 1)** When a port pin is configured as an output (either complementary or open-drain), the corresponding port data output bit value is immaterial because the corresponding on-chip peripheral or system function controls the pin. To configure a pin as a high-impedance input, set both the P*x*_DIR and P*x*_REG bits.

† The bits shown as dashes (—) are reserved; for compatibility with future devices, write zeros to these bits.

Px_REG

Table C-14. P*x*_REG Addresses and Reset States

Register	Address	Reset State
P1_REG	1FD4H	FFH
P2_REG	1FD5H	FFH
P3_REG	1FDCH	FFH
P4_REG	1FDDH	FFH

PSW

PSW no direct access

The processor status word (PSW) actually consists of two bytes. The high byte is the status word, which is described here; the low byte is the INT_MASK register. The status word contains one bit (PSW.1) that globally enables or disables servicing of all maskable interrupts, one bit (PSW.2) that enables or disables the peripheral transaction server (PTS), and six Boolean flags that reflect the state of a user's program.

The status word portion of the PSW cannot be accessed directly. To access the status word, push the value onto the stack (PUSHF), then pop the value to a register (POP *test_reg*). The PUSHF and PUSHA instructions save the PSW in the system stack and then clear it; POPF and POPA restore it.

15							8
Z	N	V	VT	C	PSE	I	ST
7							**0**

See INT_MASK on page C-35

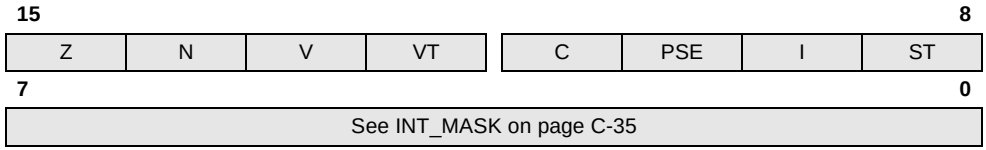
Bit Number	Bit Mnemonic	Function
15	Z	Zero Flag This flag is set to indicate that the result of an operation was zero. For multiple-precision calculations, the zero flag cannot be set by the instructions that use the carry bit from the previous calculation (e.g., ADDC, SUBC). However, these instructions can clear the zero flag. This ensures that the zero flag will reflect the result of the entire operation, not just the last calculation. For example, if the result of adding together the lower words of two double words is zero, the zero flag would be set. When the upper words are added together using the ADDC instruction, the flag remains set if the result is zero and is cleared if the result is not zero.
14	N	Negative Flag This flag is set to indicate that the result of an operation is negative. The flag is correct even if an overflow occurs. For all shift operations and the NORML instruction, the flag is set to equal the most-significant bit of the result, even if the shift count is zero.
13	V	Overflow Flag This flag is set to indicate that the result of an operation is too large to be represented correctly in the available space. For shift operations (SHL, SHLB, and SHLL), the flag is set if the most-significant bit of the operand changes during the shift. For divide operations, the quotient is stored in the low-order half of the destination operand and the remainder is stored in the high-order half. The overflow flag is set if the quotient is outside the range for the low-order half of the destination operand. (Chapter 4, "Programming Considerations," defines the operands and possible values for each. See the PSW flag descriptions in Appendix A for details.)

PSW

PSW (Continued) no direct access

The processor status word (PSW) actually consists of two bytes. The high byte is the status word, which is described here; the low byte is the INT_MASK register. The status word contains one bit (PSW.1) that globally enables or disables servicing of all maskable interrupts, one bit (PSW.2) that enables or disables the peripheral transaction server (PTS), and six Boolean flags that reflect the state of a user's program.

The status word portion of the PSW cannot be accessed directly. To access the status word, push the value onto the stack (PUSHF), then pop the value to a register (POP *test_reg*). The PUSHF and PUSHA instructions save the PSW in the system stack and then clear it; POPF and POPA restore it.



See INT_MASK on page C-35

Bit Number	Bit Mnemonic	Function
12	VT	Overflow-trap Flag This flag is set when the overflow flag is set, but it is cleared only by the CLRVT, JVT, and JNVT instructions. This allows testing for a possible overflow at the end of a sequence of related arithmetic operations, which is generally more efficient than testing the overflow flag after each operation.
11	C	Carry Flag This flag is set to indicate an arithmetic carry or the last bit shifted out of an operand. It is cleared if a subtraction operation generates a borrow. Normally, the result is rounded up if the carry flag is set. The sticky bit flag allows a finer resolution in the rounding decision. (See the PSW flag descriptions in Appendix A for details.)
10	PSE	PTS Enable This bit globally enables or disables the peripheral transaction server (PTS). The EPTS instruction sets this bit; DPTS clears it. 0 = disable PTS 1 = enable PTS
9	I	Interrupt Disable (Global) This bit globally enables or disables the servicing of all *maskable interrupts*. The bits in INT_MASK and INT_MASK1 individually enable or disable the interrupts. The EI instruction sets this bit; DI clears it. 0 = disable interrupt servicing 1 = enable interrupt servicing
8	ST	Sticky Bit Flag This flag is set to indicate that, during a right shift, a "1" was shifted into the carry flag and then shifted out. It can be used with the carry flag to allow finer resolution in rounding decisions.

PWMx_CONTROL

PWM*x*_CONTROL
***x* = 0–2**

The PWM control (PWM*x*_CONTROL) register determines the duty cycle of the PWM *x* channel. A zero loaded into this register causes the PWM to output a low continuously (0% duty cycle). An FFH in this register causes the PWM to have its maximum duty cycle (99.6% duty cycle).

7							0
PWM Duty Cycle							

Bit Number	Function
7:0	PWM Duty Cycle This register controls the PWM duty cycle. A zero loaded into this register causes the PWM to output a low continuously (0% duty cycle). An FFH in this register causes the PWM to have its maximum duty cycle (99.6% duty cycle).

Table C-15. PWM*x*_CONTROL Addresses and Reset States

Register	Address	Reset State
PWM0_CONTROL	1FB0H	00H
PWM1_CONTROL	1FB2H	00H
PWM2_CONTROL	1FB4H	00H

RPT_CNT

RPT_CNT Address: 0004H
Reset State: XXXXH

The repeat counter (RPT_CNT) register contains a counter for the repeat instruction set.

15	0
Repeat Counter Value	

Bit Number	Function
15:0	Repeat Counter Value This register contains the count value for the instruction following the repeat instruction. An initial count of zero repeats the next instruction 65,536 times. An initial count of FFFFH will repeat 65,535 times.

SBUF_RX

SBUF_RX

Address: 1FB8H
Reset State: 00H

The serial port receive buffer (SBUF_RX) register contains data received from the serial port. The serial port receiver is buffered and can begin receiving a second data byte before the first byte is read. Data is held in the receive shift register until the last data bit is received, then the data byte is loaded into SBUF_RX. If data in the shift register is loaded into SBUF_RX before the previous byte is read, the overflow error bit is set (SP_STATUS.2). The data in SBUF_RX will always be the last byte received, never a combination of the last two bytes.

7							0
Data Received							

Bit Number	Function
7:0	Data Received This register contains the last byte of data received from the serial port.

SBUF_TX

SBUF_TX Address: 1FBAH
Reset State: 00H

The serial port transmit buffer (SBUF_TX) register contains data that is ready for transmission. In modes 1, 2, and 3, writing to SBUF_TX starts a transmission. In mode 0, writing to SBUF_TX starts a transmission only if the receiver is disabled (SP_CON.3=0).

7							0
Data to Transmit							

Bit Number	Function
7:0	Data to Transmit This register contains a byte of data to be transmitted by the serial port.

SP

SP Address: 18H
Reset State: XXXXH

The system's stack pointer (SP) can point anywhere in page 00H; it must be word aligned and must always be initialized before use. The stack pointer is decremented before a PUSH and incremented after a POP, so you should initialize the stack pointer to two bytes (in 64-Kbyte mode) or four bytes (in 1-Mbyte mode) above the highest stack location. If stack operations are not being performed, locations 18H and 19H may be used as standard registers.

15	0
Stack Pointer	

Bit Number	Function
15:0	Stack Pointer This register makes up the system's stack pointer.

SP_BAUD

SP_BAUD

Address: 1FBCH
Reset State: 0000H

The serial port baud rate (SP_BAUD) register selects the clock source and serial port baud rate. The most-significant bit selects the clock source. The lower 15 bits represent baud value, an unsigned integer that determines the baud rate.

The maximum baud value is 32,767 (7FFFH). In asynchronous modes 1, 2, and 3, the minimum baud value is 0001H. In synchronous mode 0, the minimum baud value is 0001H for transmissions and 0002H for receptions.

WARNING: Writing to the SP_BAUD register during a reception or transmission can corrupt the received or transmitted data. Before writing to SP_BAUD, check SP_STATUS or the interrupt pending register to ensure that the reception or transmission is complete.

15							**8**
CLKSRC	BV14	BV13	BV12	BV11	BV10	BV9	BV8
7							**0**
BV7	BV6	BV5	BV4	BV3	BV2	BV1	BV0

Bit Number	Bit Mnemonic	Function
15	CLKSRC	Serial Port Clock Source This bit determines whether the baud-rate generator is clocked from an internal or an external source. 0 = signal on the T1CLK pin (external source) 1 = internal operating frequency (f or f/2) When CLKSRC equals one, the prescale bit in the serial port control register (SP_CON.6) determines whether the frequency of the baud-rate generator clock source is equal to the internal operating frequency (f) or half the internal operating frequency (f/2).
14:0	BV14:0	These bits constitute the baud value. Use the following equations to determine the baud value for a given baud rate. Synchronous mode 0:† $\text{Baud Value} = \frac{f}{\text{Baud Rate} \times 2} - 1$ or $\frac{\text{T1CLK}}{\text{Baud Rate}}$ Asynchronous modes 1, 2, and 3: $\text{Baud Value} = \frac{f}{\text{Baud Rate} \times 16} - 1$ or $\frac{\text{T1CLK}}{\text{Baud Rate} \times 8}$ † For mode 0 receptions, the baud value must be 0002H or greater. Otherwise, the resulting data in the receive shift register will be incorrect.

SP_CON

SP_CON

Address: 1FBBH
Reset State: 80H

The serial port control (SP_CON) register selects the communications mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables or disables even or odd parity. For modes 2 and 3, it contains the ninth data bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down counter.

7							0
BGD	PRS	PAR	TB8	REN	PEN	M1	M0

Bit Number	Bit Mnemonic	Function
7	BGD	Baud-rate Generator Disable This bit allows power conservation when the SIO is not being used. The default disables the baud-rate counter at power-up or reset. You must clear this bit to enable the counter. 0 = enable the baud-rate counter 1 = disable the baud-rate counter (default at power-up or reset)
6	PRS	Prescale The internal operating frequency (f), which can be divided by two, or an input signal on the T1CLK pin provides the baud-rate generator clock source (SP_BAUD.7 determines the clock source). The PRS bit enables the divide-by-two prescaler for the internal operating frequency: 0 = disables the prescaler (baud-rate generator clock source equals f) 1 = enables the prescaler (baud-rate generator clock source equals f/2) When T1CLK is selected as the baud-rate generator clock source (SP_BAUD.7 = 0), this bit is ignored.
5	PAR	Parity Selection Bit In modes 1 and 3, this bit selects even or odd parity. 0 = even parity 1 = odd parity For modes 0 and 2, this bit is ignored.
4	TB8	Transmit Ninth Data Bit This is the ninth data bit that will be transmitted in mode 2 or 3. This bit is cleared after each transmission, so you must write to this bit before writing to SBUF_TX. For mode 3, when parity is enabled (SP_CON.2 = 1), the transmitter sets or clears this bit so that the byte being transmitted contains the correct parity.

SP_CON

SP_CON (Continued)

Address: 1FBBH
Reset State: 80H

The serial port control (SP_CON) register selects the communications mode and enables or disables the receiver for all modes. For modes 1 and 3, it enables or disables even or odd parity. For modes 2 and 3, it contains the ninth data bit to be transmitted. It also enables or disables the divide-by-two prescaler and the baud-rate down counter.

7							0
BGD	PRS	PAR	TB8	REN	PEN	M1	M0

Bit Number	Bit Mnemonic	Function
3	REN	Receive Enable In mode 1, 2, or 3, setting this bit enables receptions. When this bit is set, a falling edge on the RXD pin starts a reception. In these modes, this bit has no effect on transmissions. In mode 0, clearing this bit enables transmissions and setting it enables receptions. Clearing this bit stops a reception in progress and inhibits further receptions. In mode 0, clearing the RI flag in the SP_STATUS register starts a reception; therefore, to avoid corrupting your reception, clear this bit before clearing the RI bit.
2	PEN	Parity Enable In modes 1 and 3, setting this bit enables parity. For mode 1, when this bit is set, the seventh data bit takes the parity value on transmissions and SP_STATUS.7 becomes the receiver parity error bit. For mode 3, when this bit is set, SP_CON.4 (TB8) takes the parity value on transmissions and SP_STATUS.7 becomes the receive parity error bit. Clear this bit for mode 2. For mode 0, this bit is ignored.
1:0	M1:0	Mode Selection These bits select the communications mode. **M1 M0** 0 0 mode 0, synchronous 0 1 mode 1, 8-bit asynchronous with optional parity 1 0 mode 2, 9-bit asynchronous with optional receive interrupt 1 1 mode 3, 9-bit asynchronous with optional parity

SP_STATUS

SP_STATUS

Address: 1FB9H
Reset State: 0BH

The serial port status (SP_STATUS) register contains bits that indicate the status of the serial port.

7							0
RPE/RB8	RI	TI	FE	TXE	OE	—	—

Bit Number	Bit Mnemonic	Function
7	RPE/RB8	Received Parity Error/Received Bit 8 For modes 1 and 3, RPE is set if parity is enabled (SP_CON.2 = 1) and the data received does not contain the correct parity, as programmed in SP_CON. For mode 2, and for mode 3 with parity disabled, this bit is the ninth data bit received. (The serial port receive buffer contains the received data bits 0–7. The received data bit 8 is written to this bit.) Reading SP_STATUS clears this bit.
6	RI	Receive Interrupt This bit indicates whether an incoming data byte has been received. For modes 0, 1, and 3, this bit is set when the last bit (eighth bit for mode 0, or stop bit for modes 1 and 3) is sampled. For mode 2, this bit is set when the stop bit is detected only if the ninth bit received (SP_STATUS, RB8) is a one. Reading SP_STATUS clears this bit.
5	TI	Transmit Interrupt This bit indicates whether a data byte has finished transmitting. For mode 0 transmissions, the SIO sets this bit immediately after it transmits the eighth data bit. For mode 1, 2, and 3 transmissions, the SIO sets this bit immediately after it starts to transmit the stop bit. Reading SP_STATUS clears this bit.
4	FE	Framing Error For modes 1, 2, and 3, this bit is set if the receiver does not detect a valid stop bit within the appropriate period of time. Reading SP_STATUS clears this bit. For mode 0, this bit has no function.
3	TXE	SBUF_TX Empty The SIO sets this bit, along with the TI flag, if the transmit buffer and the transmit shift register are both empty. When set, this bit indicates that two bytes can be written to the transmit buffer. Writing to the transmit buffer clears this bit.
2	OE	Overrun Error The SIO sets this bit if data in the receive shift register is loaded into SBUF_RX before the previous byte in SBUF_RX is read. Reading SP_STATUS clears this bit.
1:0	—	Reserved; for compatibility with future devices, write zeros to these bits.

T1CONTROL

T1CONTROL Address: 1F90H
Reset State: 00H

The timer 1 control (T1CONTROL) register determines the clock source, counting direction, and count rate for timer 1.

7							0
CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
7	CE	Counter Enable This bit enables or disables the timer. From reset, the timers are disabled and not free running. 0 = disables timer 1 = enables timer
6	UD	Up/Down This bit determines the timer counting direction, in selected modes (see mode bits, M2:0). 0 = count down 1 = count up
5:3	M2:0	EPA Clock Direction Mode Bits These bits determine the timer clocking source and direction control source. **M2 M1 M0 Clock Source Direction Source** 0 0 0 f/4 UD bit (T1CONTROL.6) X 0 1 T1CLK pin† UD bit (T1CONTROL.6) 0 1 0 f/4 T1DIR pin 0 1 1 T1CLK pin† T1DIR pin 1 1 1 T1CLK and T1DIR quadrature clocking † If an external clock is selected, the timer counts on both the rising **and** falling edges of the clock.
2:0	P2:0	EPA Clock Prescaler Bits These bits determine the clock prescaler value. The prescaler can be used only if the clock source is f/4. It has no effect on the T1CLK or quadrature clock inputs. **P2 P1 P0 Prescaler Divisor Resolution†** 0 0 0 divide by 1 (disabled) 160 ns 0 0 1 divide by 2 320 ns 0 1 0 divide by 4 640 ns 0 1 1 divide by 8 1.28 µs 1 0 0 divide by 16 2.56 µs 1 0 1 divide by 32 5.12 µs 1 1 0 divide by 64 10.24 µs 1 1 1 divide by 128 20.48 µs † At f = 25 MHz. Use the formula on page 10-6 to calculate the resolution at other frequencies.

T2CONTROL

T2CONTROL

Address: 1F94H
Reset State: 00H

The timer 2 control (T2CONTROL) register determines the clock source, counting direction, and count rate for timer 2.

7 **0**

CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
7	CE	Counter Enable This bit enables or disables the timer. From reset, the timers are disabled and not free running. 0 = disables timer 1 = enables timer
6	UD	Up/Down This bit determines the timer counting direction, in selected modes (see mode bits, M2:0). 0 = count down 1 = count up

T2CONTROL

T2CONTROL (Continued)

Address: 1F94H
Reset State: 00H

The timer 2 control (T2CONTROL) register determines the clock source, counting direction, and count rate for timer 2.

7							0
CE	UD	M2	M1	M0	P2	P1	P0

Bit Number	Bit Mnemonic	Function
5:3	M2:0	EPA Clock Direction Mode Bits These bits determine the timer clocking source and direction source. **M2 M1 M0 Clock Source Direction Source** 0 0 0 f/4 UD bit (T2CONTROL.6) X 0 1 T2CLK pin† UD bit (T2CONTROL.6) 0 1 0 f/4 T2DIR pin 0 1 1 T2CLK pin† T2DIR pin 1 0 0 timer 1 overflow UD bit (T2CONTROL.6) 1 1 0 timer 1 overflow same as timer 1 1 1 1 T2CLK and T2DIR quadrature clocking † If an external clock is selected, the timer counts on both the rising **and** falling edges of the clock.
2:0	P2:0	EPA Clock Prescaler Bits These bits determine the clock prescaler value. The prescaler can be used only if the clock source is f/4. It has no effect on the T2CLK or quadrature clock inputs. **P2 P1 P0 Prescaler Resolution†** 0 0 0 divide by 1 (disabled) 160 ns 0 0 1 divide by 2 320 ns 0 1 0 divide by 4 640 ns 0 1 1 divide by 8 1.28 µs 1 0 0 divide by 16 2.56 µs 1 0 1 divide by 32 5.12 µs 1 1 0 divide by 64 10.24 µs 1 1 1 divide by 128 20.48 µs † Resolution at f = 25 MHz.Use the formula on to calculate the resolution at other frequencies.

TIMERx

TIMER*x*
***x* = 1–2**

This register contains the value of timer *x*. This register can be written, allowing timer *x* to be initialized to a value other than zero.

15 **0**

Timer Value

Bit Number	Function
15:0	Timer Value Read the current timer *x* value from this register or write a new timer *x* value to this register.

VECT_ADDR

VECT_ADDR

Address: 1FF0H
Reset State: FF20H

The base-address register (VECT_ADDR) contains the upper sixteen address bits of the interrupt-vector table. When the CPU acknowledges an interrupt request, the vector-generation unit in the interrupt controller generates a lower byte default vector location and then adds it to the contents of the base-address register to generate the complete vector address.

15							**8**
VA23	VA22	VA21	VA20	VA19	VA18	VA17	VA16
7							**0**
VA15	VA14	VA13	VA12	VA11	VA10	VA9	VA8

Bit Number	Bit Mnemonic	Function
15:0	VA23:8	Interrupt Vector Address Bits 23 through 8 This register contains the upper address bits for the indirect interrupt-vector-address table.

WSR

WSR Address: 0014H
Reset State: 00H

The window selection register (WSR) has two functions. One bit enables and disables the bus-hold protocol. The remaining bits select windows. Windows map sections of RAM into the top of the lower register file, in 32-, 64-, or 128-byte increments. PUSHA saves this register on the stack and POPA restores it.

7							0
HLDEN	W6	W5	W4	W3	W2	W1	W0

Bit Number	Bit Mnemonic	Function
7	HLDEN	HOLD#, HLDA# Protocol Enable This bit enables and disables the bus-hold protocol (see Chapter 13, “Interfacing with External Memory”). It has no effect on windowing. 0 = disable 1 = enable
6:0	W6:0	Window Selection These bits specify the window size and number. The following table shows the WSR settings and direct addresses for windowable SFRs.

Table C-16. WSR Settings and Direct Addresses for Windowable SFRs

Register Mnemonic	Memory Location	32-byte Windows (00E0–00FFH)		64-byte Windows (00C0–00FFH)		128-byte Windows (0080–00FFH)	
		WSR	Direct Address	WSR	Direct Address	WSR	Direct Address
ADDRCOM0†	1F40H	7AH	00E0H	3DH	00C0H	1EH	00C0H
ADDRCOM1†	1F48H	7AH	00E8H	3DH	00C8H	1EH	00C8H
ADDRCOM2†	1F50H	7AH	00F0H	3DH	00D0H	1EH	00D0H
ADDRCOM3†	1F58H	7AH	00F8H	3DH	00D8H	1EH	00D8H
ADDRCOM4†	1F60H	7BH	00E0H	3DH	00E0H	1EH	00E0H
ADDRCOM5†	1F68H	7BH	00E8H	3DH	00E8H	1EH	00E8H
ADDRMSK0†	1F42H	7AH	00E2H	3DH	00C2H	1EH	00C2H
ADDRMSK1†	1F4AH	7AH	00EAH	3DH	00CAH	1EH	00CAH
ADDRMSK2†	1F52H	7AH	00F2H	3DH	00D2H	1EH	00D2H
ADDRMSK3†	1F5AH	7AH	00FAH	3DH	00DAH	1EH	00DAH
ADDRMSK4†	1F62H	7BH	00E2H	3DH	00E2H	1EH	00E2H
ADDRMSK5†	1F6AH	7BH	00EAH	3DH	00EAH	1EH	00EAH

† Must be addressed as a word.

WSR

Table C-16. WSR Settings and Direct Addresses for Windowable SFRs (Continued)

Register Mnemonic	Memory Location	32-byte Windows (00E0–00FFH)		64-byte Windows (00C0–00FFH)		128-byte Windows (0080–00FFH)	
		WSR	Direct Address	WSR	Direct Address	WSR	Direct Address
BUSCON0	1F44H	7AH	00E4H	3DH	00C4H	1EH	00C4H
BUSCON1	1F4CH	7AH	00ECH	3DH	00CCH	1EH	00CCH
BUSCON2	1F54H	7AH	00F4H	3DH	00D4H	1EH	00D4H
BUSCON3	1F5CH	7AH	00FCH	3DH	00DCH	1EH	00DCH
BUSCON4	1F64H	7BH	00E4H	3DH	00E4H	1EH	00E4H
BUSCON5	1F6CH	7BH	00ECH	3DH	00ECH	1EH	00ECH
CON_REG0	1FB6H	7DH	00F6H	3EH	00F6H	1FH	00B6H
EP_DIR	1FE3H	7FH	00E3H	3FH	00E3H	1FH	00E3H
EP_MODE	1FE1H	7FH	00E1H	3FH	00E1H	1FH	00E1H
EP_PIN	1FE7H	7FH	00E7H	3FH	00E7H	1FH	00E7H
EP_REG	1FE5H	7FH	00E5H	3FH	00E5H	1FH	00E5H
EPA_MASK†	1F9CH	7CH	00FCH	3EH	00DCH	1FH	009CH
EPA_PEND	1F9EH	7CH	00FEH	3EH	00DEH	1FH	009EH
EPA0_CON	1F80H	7CH	00E0H	3EH	00C0H	1FH	0080H
EPA1_CON†	1F84H	7CH	00E4H	3EH	00C4H	1FH	0084H
EPA2_CON	1F88H	7CH	00E8H	3EH	00C8H	1FH	0088H
EPA3_CON†	1F8CH	7CH	00ECH	3EH	00CCH	1FH	008CH
EPA0_TIME†	1F82H	7CH	00E2H	3EH	00C2H	1FH	0082H
EPA1_TIME†	1F86H	7CH	00E6H	3EH	00C6H	1FH	0086H
EPA2_TIME†	1F8AH	7CH	00EAH	3EH	00CAH	1FH	008AH
EPA3_TIME†	1F8EH	7CH	00EEH	3EH	00CEH	1FH	008EH
EXTINT_CON	1FCCH	7EH	00ECH	3FH	00CCH	1FH	00CCH
ICB0	1FC3H	7EH	00E3H	3FH	00C3H	1FH	00C3H
ICB1	1FC7H	7EH	00E7H	3FH	00C7H	1FH	00C7H
IDX0† (bits 0–15)	1FC0H	7EH	00E0H	3FH	00C0H	1FH	00C0H
IDX0 (bits 16–23)	1FC2H	7EH	00E2H	3FH	00C2H	1FH	00C2H
IDX1† (bits 0–15)	1FC4H	7EH	00E4H	3FH	00C4H	1FH	00C4H
IDX1 (bits 16–23)	1FC6H	7EH	00E6H	3FH	00C6H	1FH	00C6H
IN_PROG0	1FC8H	7EH	00E8H	3FH	00C8H	1FH	00C8H
IN_PROG1†	1FCAH	7EH	00EAH	3FH	00CAH	1FH	00CAH

† Must be addressed as a word.

Table C-16. WSR Settings and Direct Addresses for Windowable SFRs (Continued)

Register Mnemonic	Memory Location	32-byte Windows (00E0–00FFH)		64-byte Windows (00C0–00FFH)		128-byte Windows (0080–00FFH)	
		WSR	Direct Address	WSR	Direct Address	WSR	Direct Address
INT_CON0†	1FE8H	7FH	00E8H	3FH	00E8H	1FH	00E8H
INT_CON1†	1FEAH	7FH	00EAH	3FH	00EAH	1FH	00EAH
INT_CON2†	1FECH	7FH	00ECH	3FH	00ECH	1FH	00ECH
INT_CON3†	1FEEH	7FH	00EEH	3FH	00EEH	1FH	00EEH
NMI_PEND	1FC9H	7EH	00E9H	3FH	00C9H	1FH	00C9H
P1_DIR	1FD2H	7EH	00F2H	3FH	00D2H	1FH	00D2H
P2_DIR	1FD3H	7EH	00F3H	3FH	00D3H	1FH	00D3H
P3_DIR	1FDAH	7EH	00FAH	3FH	00DAH	1FH	00DAH
P4_DIR	1FDBH	7EH	00FBH	3FH	00DBH	1FH	00DBH
P1_MODE	1FD0H	7EH	00F0H	3FH	00D0H	1FH	00D0H
P2_MODE	1FD1H	7EH	00F1H	3FH	00D1H	1FH	00D1H
P3_MODE	1FD8H	7EH	00F8H	3FH	00D8H	1FH	00D8H
P4_MODE	1FD9H	7EH	00F9H	3FH	00D9H	1FH	00D9H
P1_PIN	1FD6H	7EH	00F6H	3FH	00D6H	1FH	00D6H
P2_PIN	1FD7H	7EH	00F7H	3FH	00D7H	1FH	00D7H
P3_PIN	1FDEH	7EH	00FEH	3FH	00DEH	1FH	00DEH
P4_PIN	1FDFH	7EH	00FFH	3FH	00DFH	1FH	00DFH
P1_REG	1FD4H	7EH	00F4H	3FH	00D4H	1FH	00D4H
P2_REG	1FD5H	7EH	00F5H	3FH	00D5H	1FH	00D5H
P3_REG	1FDCH	7EH	00FCH	3FH	00DCH	1FH	00DCH
P4_REG	1FDDH	7EH	00FDH	3FH	00DDH	1FH	00DDH
PWM0_CONTROL	1FB0H	7DH	00F0H	3EH	00F0H	1FH	00B0H
PWM1_CONTROL	1FB2H	7DH	00F2H	3EH	00F2H	1FH	00B2H
PWM2_CONTROL	1FB4H	7DH	00F4H	3EH	00F4H	1FH	00B4H
SBUF_RX	1FB8H	7DH	00F8H	3EH	00F8H	1FH	00B8H
SBUF_TX	1FBAH	7DH	00FAH	3EH	00FAH	1FH	00BAH
SP_BAUD	1FBCH	7DH	00FCH	3EH	00FCH	1FH	00BCH
SP_CON	1FBBH	7DH	00FBH	3EH	00FBH	1FH	00BBH
SP_STATUS	1FB9H	7DH	00F9H	3EH	00F9H	1FH	00B9H
T1CONTROL	1F90H	7CH	00F0H	3EH	00D0H	1FH	0090H

† Must be addressed as a word.

WSR

Table C-16. WSR Settings and Direct Addresses for Windowable SFRs (Continued)

Register Mnemonic	Memory Location	32-byte Windows (00E0–00FFH)		64-byte Windows (00C0–00FFH)		128-byte Windows (0080–00FFH)	
		WSR	Direct Address	WSR	Direct Address	WSR	Direct Address
T2CONTROL	1F94H	7CH	00F4H	3EH	00D4H	1FH	0094H
TIMER1†	1F92H	7CH	00F2H	3EH	00D2H	1FH	0092H
TIMER2†	1F96H	7CH	00F6H	3EH	00D6H	1FH	0096H
VECT_ADD†	1FF0H	7FH	00F0H	3FH	00F0H	1FH	00F0H

† Must be addressed as a word.

WSR1

WSR1 Address: 0015H
Reset State: 00H

Window selection 1 (WSR1) register selects a 32- or 64-byte segment of the upper register file or peripheral SFRs, or a 64-byte segment of code RAM or external memory, to be windowed into the middle of the lower register file.

NOTE: The PUSHA and POPA instructions do **not** save and restore WSR1.

7							0
W7	W6	W5	W4	W3	W2	W1	W0

Bit Number	Bit Mnemonic	Function
7:0	W7:0	Window Selection These bits specify the window size and number. The following table shows the WSR1 settings and direct addresses for windowable SFRs.

Table C-17. WSR1 Settings and Direct Addresses for Windowable SFRs

Register Mnemonic	Memory Location	32-byte Windows (0060–007FH)		64-byte Windows (0040–007FH)	
		WSR1	Direct Address	WSR1	Direct Address
ADDRCOM0†	1F40H	7AH	0060H	3DH	0040H
ADDRCOM1†	1F48H	7AH	0068H	3DH	0048H
ADDRCOM2†	1F50H	7AH	0070H	3DH	0050H
ADDRCOM3†	1F58H	7AH	0078H	3DH	0058H
ADDRCOM4†	1F60H	7BH	0060H	3DH	0060H
ADDRCOM5†	1F68H	7BH	0068H	3DH	0068H
ADDRMSK0†	1F42H	7AH	0062H	3DH	0042H
ADDRMSK1†	1F4AH	7AH	006AH	3DH	004AH
ADDRMSK2†	1F52H	7AH	0072H	3DH	0052H
ADDRMSK3†	1F5AH	7AH	007AH	3DH	005AH
ADDRMSK4†	1F62H	7BH	0062H	3DH	0062H
ADDRMSK5†	1F6AH	7BH	006AH	3DH	006AH
BUSCON0	1F44H	7AH	0064H	3DH	0044H
BUSCON1	1F4CH	7AH	006CH	3DH	004CH
BUSCON2	1F54H	7AH	0074H	3DH	0054H
BUSCON3	1F5CH	7AH	007CH	3DH	005CH

† Must be addressed as a word.

WSR1

Table C-17. WSR1 Settings and Direct Addresses for Windowable SFRs (Continued)

Register Mnemonic	Memory Location	32-byte Windows (0060–007FH)		64-byte Windows (0040–007FH)	
		WSR1	Direct Address	WSR1	Direct Address
BUSCON4	1F64H	7BH	0064H	3DH	0064H
BUSCON5	1F6CH	7BH	006CH	3DH	006CH
CON_REG0	1FB6H	7DH	0076H	3EH	0076H
EP_DIR	1FE3H	7FH	0063H	3FH	0063H
EP_MODE	1FE1H	7FH	0061H	3FH	0061H
EP_PIN	1FE7H	7FH	0067H	3FH	0067H
EP_REG	1FE5H	7FH	0065H	3FH	0065H
EPA_MASK†	1F9CH	7CH	007CH	3EH	005CH
EPA_PEND	1F9EH	7CH	007EH	3EH	005EH
EPA0_CON	1F80H	7CH	0060H	3EH	0040H
EPA1_CON†	1F84H	7CH	0064H	3EH	0044H
EPA2_CON	1F88H	7CH	0068H	3EH	0048H
EPA3_CON†	1F8CH	7CH	006CH	3EH	004CH
EPA0_TIME†	1F82H	7CH	0062H	3EH	0042H
EPA1_TIME†	1F86H	7CH	0066H	3EH	0046H
EPA2_TIME†	1F8AH	7CH	006AH	3EH	004AH
EPA3_TIME†	1F8EH	7CH	006EH	3EH	004EH
EXTINT_CON	1FCCH	7EH	006CH	3FH	004CH
ICB0	1FC3H	7EH	0063H	3FH	0043H
ICB1	1FC7H	7EH	0067H	3FH	0047H
IDX0† (bits 0–15)	1FC0H	7EH	0060H	3FH	0040H
IDX0 (bits 16–23)	1FC2H	7EH	0062H	3FH	0042H
IDX1† (bits 0–15)	1FC4H	7EH	0064H	3FH	0044H
IDX1 (bits 16–23)	1FC6H	7EH	0066H	3FH	0046H
IN_PROG0	1FC8H	7EH	0068H	3FH	0048H
IN_PROG1†	1FCAH	7EH	006AH	3FH	004AH
INT_CON0†	1FE8H	7FH	0068H	3FH	0068H
INT_CON1†	1FEAH	7FH	006AH	3FH	006AH
INT_CON2†	1FECH	7FH	006CH	3FH	006CH
INT_CON3†	1FEEH	7FH	006EH	3FH	006EH

† Must be addressed as a word.

Table C-17. WSR1 Settings and Direct Addresses for Windowable SFRs (Continued)

Register Mnemonic	Memory Location	32-byte Windows (0060–007FH)		64-byte Windows (0040–007FH)	
		WSR1	Direct Address	WSR1	Direct Address
NMI_PEND	1FC9H	7EH	0069H	3FH	0049H
P1_DIR	1FD2H	7EH	0072H	3FH	0052H
P2_DIR	1FD3H	7EH	0073H	3FH	0053H
P3_DIR	1FDAH	7EH	007AH	3FH	005AH
P4_DIR	1FDBH	7EH	007BH	3FH	005BH
P1_MODE	1FD0H	7EH	0070H	3FH	0050H
P2_MODE	1FD1H	7EH	0071H	3FH	0051H
P3_MODE	1FD8H	7EH	0078H	3FH	0058H
P4_MODE	1FD9H	7EH	0079H	3FH	0059H
P1_PIN	1FD6H	7EH	0076H	3FH	0056H
P2_PIN	1FD7H	7EH	0077H	3FH	0057H
P3_PIN	1FDEH	7EH	007EH	3FH	005EH
P4_PIN	1FDFH	7EH	007FH	3FH	005FH
P1_REG	1FD4H	7EH	0074H	3FH	0054H
P2_REG	1FD5H	7EH	0075H	3FH	0055H
P3_REG	1FDCH	7EH	007CH	3FH	005CH
P4_REG	1FDDH	7EH	007DH	3FH	005DH
PWM0_CONTROL	1FB0H	7DH	0070H	3EH	0070H
PWM1_CONTROL	1FB2H	7DH	0072H	3EH	0072H
PWM2_CONTROL	1FB4H	7DH	0074H	3EH	0074H
SBUF_RX	1FB8H	7DH	0078H	3EH	0078H
SBUF_TX	1FBAH	7DH	007AH	3EH	007AH
SP_BAUD	1FBCH	7DH	007CH	3EH	007CH
SP_CON	1FBBH	7DH	007BH	3EH	007BH
SP_STATUS	1FB9H	7DH	0079H	3EH	0079H
T1CONTROL	1F90H	7CH	0070H	3EH	0050H
T2CONTROL	1F94H	7CH	0074H	3EH	0054H
TIMER1†	1F92H	7CH	0072H	3EH	0052H
TIMER2†	1F96H	7CH	0076H	3EH	0056H
VECT_ADD†	1FF0H	7FH	0070H	3FH	0070H

† Must be addressed as a word.

ZERO_REG

ZERO_REG Address: 00H
Reset State: 0000H

The two-byte zero register (ZERO_REG) is always equal to zero. It is useful as a fixed source of the constant zero for comparisons and calculations.

15	0
Zero	

Bit Number	Function
15:0	Zero This register is always equal to zero.

Glossary

GLOSSARY

This glossary defines acronyms, abbreviations, and terms that have special meaning in this manual. (Chapter 1 discusses notational conventions and general terminology.)

1-Mbyte mode — The addressing mode that allows code to reside anywhere in the addressing space.

64-Kbyte mode — The addressing mode that allows code to reside only in page FFH.

accumulator — A register or storage location that forms the result of an arithmetic or logical operation.

The 80296SA has several new mathematical instructions and a dedicated, 40-bit accumulator that stores the result of a mathematical operation. This accumulator increases the mathematical precision of multiplication instructions while decreasing instruction execution time.

ALU — Arithmetic-logic unit. The part of the *RALU* that processes arithmetic and logical operations.

assert — The act of making a signal active (enabled). The polarity (high or low) is defined by the signal name. Active-low signals are designated by a pound symbol (#) suffix; active-high signals have no suffix. To assert RD# is to drive it low; to assert ALE is to drive it high.

barrel shifter — Logic that performs a circular shift (rotate) for multiply-accumulate operations. A circular shift circulates the bits of a register around the two ends, without losing any bits.

The 80296SA uses a 32-bit barrel shifter to extract the result of a multiply-accumulate operation from the accumulator and remove the sign extension. The barrel shifter is also useful for logically shifting the accumulator, as in a result of an encryption algorithm.

bit — A binary digit.

BIT — A single-bit operand that can take on the Boolean values, “true” and “false.”

byte — Any 8-bit unit of data.

BYTE An unsigned, 8-bit variable with values from 0 through 2^8–1.

CCBs Chip configuration bytes. The chip configuration registers (*CCRs*) are loaded with the contents of the CCBs after a reset.

CCRs Chip configuration registers. Registers that define the environment in which the microcontroller will be operating. The chip configuration registers are loaded with the contents of the *CCBs* after a reset.

chip-select unit The integrated module that selects an external memory device during an external bus cycle.

clear The "0" value of a bit or the act of giving it a "0" value. See also *set*.

deassert The act of making a signal inactive (disabled). The polarity (high or low) is defined by the signal name. Active-low signals are designated by a pound symbol (#) suffix; active-high signals have no suffix. To deassert RD# is to drive it high; to deassert ALE is to drive it low.

demultiplexed bus The configuration in which the microcontroller uses separate lines for address and data (address on A19:0; data on AD15:0 for a 16-bit bus or AD7:0 for an 8-bit bus). See also *multiplexed bus*.

digital signal processing Extracting information from complex digital signals by analyzing the signals with various mathematical algorithms. The 80296SA's signal processing hardware and increased mathematical performance and precision, along with appropriate software algorithms, enable it to perform digital signal processing functions.

doping The process of introducing a periodic table Group III or Group V element into a Group IV element (e.g., silicon). A Group III impurity (e.g., indium or gallium) results in a *p-type material*. A Group V impurity (e.g., arsenic or antimony) results in an *n-type material*.

double-word Any 32-bit unit of data.

DOUBLE-WORD An unsigned, 32-bit variable with values from 0 through 2^{32}–1.

DSP See *digital signal processing*.

EPA Event processor array. An integrated peripheral that provides high-speed input/output capability.

EPORT Extended addressing port. The port that provides the additional address lines to support extended addressing.

ESD Electrostatic discharge.

external address A 20-bit address is presented on the microcontroller's pins. The address decoded by an external device depends on how many of these address pins the external system uses. See also *internal address*.

far constants Constants that can be accessed only with extended instructions. See also *near constants*.

far data Data that can be accessed only with extended instructions. See also *near data*.

FET Field-effect transistor.

f Lowercase "f" represents the frequency of the internal clock.

fractional mode A mode of the *multiply-accumulate* function in which the multiplier result is shifted left one bit before being written to the *accumulator*. This left shift eliminates the extra sign bit when both operands are signed, leaving a correctly signed result.

hold latency The time it takes the microcontroller to assert HLDA# after an external device asserts HOLD#.

index register A register used as a pointer to a memory location. The 80296SA has two 24-bit index registers that can be automatically incremented or decremented by 1, 2, or 4 bytes. These registers are useful for indexing through data tables or coefficient tables.

input leakage Current leakage from an input pin to power or ground.

integer Any member of the set consisting of the positive and negative whole numbers and zero.

INTEGER A 16-bit, signed variable with values from -2^{15} through $+2^{15}-1$.

internal address — The 24-bit address that the microcontroller generates. See also *external address*.

interrupt controller — The module responsible for handling interrupts that are to be serviced by *interrupt service routines* that you provide. Also called the *programmable interrupt controller (PIC)*.

interrupt latency — The total delay between the time that an interrupt is generated (not acknowledged) and the time that the microcontroller begins executing the *interrupt service routine*. Determine the instruction in your code that has the longest execution time and use that execution time in calculating interrupt latency.

interrupt service routine — A software routine that you provide to service an interrupt.

interrupt vector — A location that holds the starting address of an *interrupt service routine*.

ISR — See *interrupt service routine*.

LONG-INTEGER — A 32-bit, signed variable with values from -2^{31} through $+2^{31}-1$.

LSB — Least-significant bit of a byte or least-significant byte of a word.

LSW — Least-significant word of a double-word or quad-word.

MAC — The core mnemonic for several *multiply-accumulate* instructions.

maskable interrupts — All interrupts except unimplemented opcode, software trap, and NMI. Maskable interrupts can be disabled (masked) by the individual mask bits in the interrupt mask registers, and their servicing can be disabled by the DI (disable interrupt service) instruction.

MSB — Most-significant bit of a *byte* or most-significant byte of a *word*.

MSW — Most-significant word of a double-word or quad-word.

multiplexed bus — The configuration in which the microcontroller uses both A19:0 and AD15:0 for address and also uses AD15:0 for data. See also *demultiplexed bus*.

multiply-accumulate — An operation performed by the 80296SA's new mathematical instructions and *digital signal processing* hardware. The result of the operation is stored in a dedicated, 40-bit *accumulator.*

***n*-channel FET** — A field-effect transistor with an *n*-type conducting path (channel).

***n*-type material** — Semiconductor material with introduced impurities (*doping*) causing it to have an excess of negatively charged carriers.

near constants — Constants that can be accessed with nonextended instructions. Constants in page 00H are near constants. See also *far constants*.

near data — Data that can be accessed with nonextended instructions. Data in page 00H is near data. See also *far data*.

nonmaskable interrupts — Interrupts that cannot be masked (disabled). The nonmaskable interrupts are unimplemented opcode, software trap, and NMI. The DI (disable interrupt service) and EI (enable interrupt service) instructions have no effect on nonmaskable interrupts.

***npn* transistor** — A transistor consisting of one part *p-type material* and two parts *n-type material*.

OTPROM — One-time-programmable read-only memory. Similar to *EPROM*, but it comes in an unwindowed package and cannot be erased.

***p*-channel FET** — A field-effect transistor with a *p*-type conducting path.

***p*-type material** — Semiconductor material with introduced impurities (*doping*) causing it to have an excess of positively charged carriers.

PC — Program counter.

phase-locked loop — A component of the clock generation circuitry. The phase-locked loop (PLL) and the two input pins (PLLEN1 and PLLEN2) combine to enable the microcontroller to attain its maximum operating frequency with an external clock whose frequency is either equal to, one-half, or one-fourth that maximum frequency or with an external oscillator whose frequency is either one-half or one-fourth that maximum frequency.

PIC — Programmable interrupt controller. The module responsible for handling interrupts that are to be serviced by *interrupt service routines* that you provide. Also called simply the *interrupt controller.*

pipeline — A feature of the 80296SA architecture that enables simultaneous processing of up to four instructions. The pipeline has four stages: fetch, decode, read/execute, and execute/write. This design achieves significantly faster instruction throughput than was possible with previous MCS® 96 microcontrollers.

PLL — See *phase-locked loop.*

prioritized interrupt — NMI or any *maskable interrupt*. Two of the *nonmaskable interrupts* (unimplemented opcode and software trap) are not prioritized; they vector directly to the *interrupt service routine* when executed.

program memory — A partition of memory where instructions can be stored for fetching and execution.

protected instruction — An instruction that prevents an interrupt from being acknowledged until after the next instruction executes. The protected instructions are DI, EI, RPT, RPT*xxx*, POPA, POPF, PUSHA, and PUSHF.

PSW — Processor status word. The high byte of the PSW is the status byte, which contains one bit that globally enables or disables servicing of all maskable interrupts and six Boolean flags that reflect the state of the current program. The low byte of the PSW is the INT_MASK register. A PUSHA or POPA instruction saves or restores both bytes (PSW + INT_MASK); a PUSHF or POPF saves or restores only the PSW.

PWM — Pulse-width modulator. A peripheral that generates waveforms with a fixed, selectable frequency and a variable duty cycle.

QUAD-WORD — An unsigned, 64-bit variable with values from 0 through 2^{64}–1. The QUAD-WORD variable is supported only as the operand for the EBMOVI instruction.

RALU — Register arithmetic-logic unit. A part of the CPU that consists of the *ALU*, the *PSW*, the master *PC*, the microcode engine, a loop counter, and six registers.

reserved memory — A memory location that is reserved for factory use or for future expansion. Do not use a reserved memory location except to initialize it.

sampled inputs — All input pins, with the exception of RESET#, are sampled inputs. The input pin is sampled one state time before the read buffer is enabled. Sampling occurs during PH1 (while CLKOUT is low) and resolves the value (high or low) of the pin before it is presented to the internal bus. If the pin value changes during the sample time, the new value may or may not be recorded during the read.

RESET# is a level-sensitive input.

saturation mode — Saturation occurs when the result of two positive numbers generates a negative sign bit or the result of two negative numbers generates a positive sign bit. Saturation mode prevents an underflow or overflow of the accumulated value.

set — The “1” value of a bit or the act of giving it a “1” value. See also *clear.*

SFR — Special-function register.

SHORT-INTEGER — An 8-bit, signed variable with values from -2^7 through $+2^7$–1.

sign extension — A method for converting data to a larger format by filling the upper bit positions with the value of the sign. This conversion preserves the positive or negative value of signed integers.

sink current — Current flowing **into** a device to ground. Always a positive value.

source current — Current flowing **out of** a device from V_{CC}. Always a negative value.

SP — Stack pointer.

special interrupt — Any of the three *nonmaskable interrupts* (unimplemented opcode, software trap, or NMI).

special-purpose memory — A partition of memory used for storing the *interrupt vectors*, chip configuration bytes, and several reserved locations.

standard interrupt — Any *maskable interrupt* that is assigned to the *interrupt controller* for processing by an *interrupt service routine*.

state time (or state) — The basic time unit of the microcontroller; the combined period of the two internal timing signals, PH1 and PH2. Because the microcontroller can operate at many frequencies, this manual defines time requirements in terms of *state times* rather than in specific units of time.

t — Lowercase "t" represents the period of the internal clock.

UART — Universal asynchronous receiver and transmitter. A part of the serial I/O port.

wait state — Time spent waiting for an operation to take place. Wait states are added to external bus cycles to allow a slow memory device to respond to a request from the microcontroller.

word — Any 16-bit unit of data.

WORD — An unsigned, 16-bit variable with values from 0 through 2^{16}–1.

zero extension — A method for converting data to a larger format by filling the upper bit positions with zeros.

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