



## SECTION 4 CENTRAL PROCESSOR UNIT

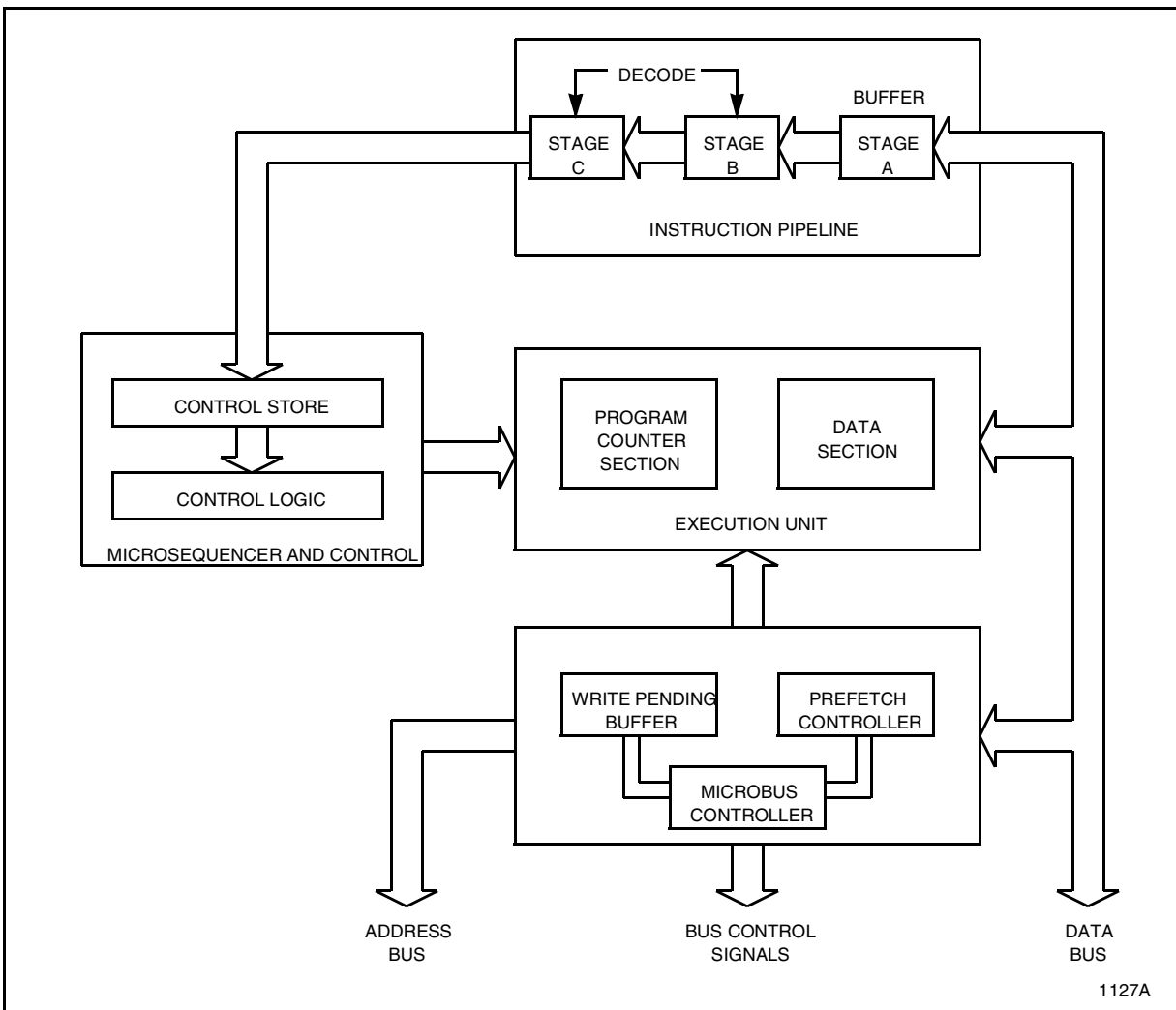
The CPU32, the instruction processing module of the M68300 family, is based on the industry-standard MC68000 processor. It has many features of the MC68010 and MC68020, as well as unique features suited for high-performance controller applications. This section is an overview of the CPU32. For detailed information concerning CPU operation, refer to the [CPU32 Reference Manual](#) (CPU32RM/AD).

### 4.1 General

Ease of programming is an important consideration in using a microcontroller. The CPU32 instruction format reflects a philosophy emphasizing register-memory interaction. There are eight multifunction data registers and seven general-purpose addressing registers.

All data resources are available to all operations requiring those resources. The data registers readily support 8-bit (byte), 16-bit (word), and 32-bit (long-word) operand lengths for all operations. Word and long-word operations support address manipulation. Although the program counter (PC) and stack pointers (SP) are special-purpose registers, they are also available for most data addressing activities. Ease of program checking and diagnosis is further enhanced by trace and trap capabilities at the instruction level.

A block diagram of the CPU32 is shown in [Figure 4-1](#). The major blocks operate in a highly independent fashion that maximizes concurrency of operation while managing the essential synchronization of instruction execution and bus operation. The bus controller loads instructions from the data bus into the decode unit. The sequencer and control unit provide overall chip control, managing the internal buses, registers, and functions of the execution unit.

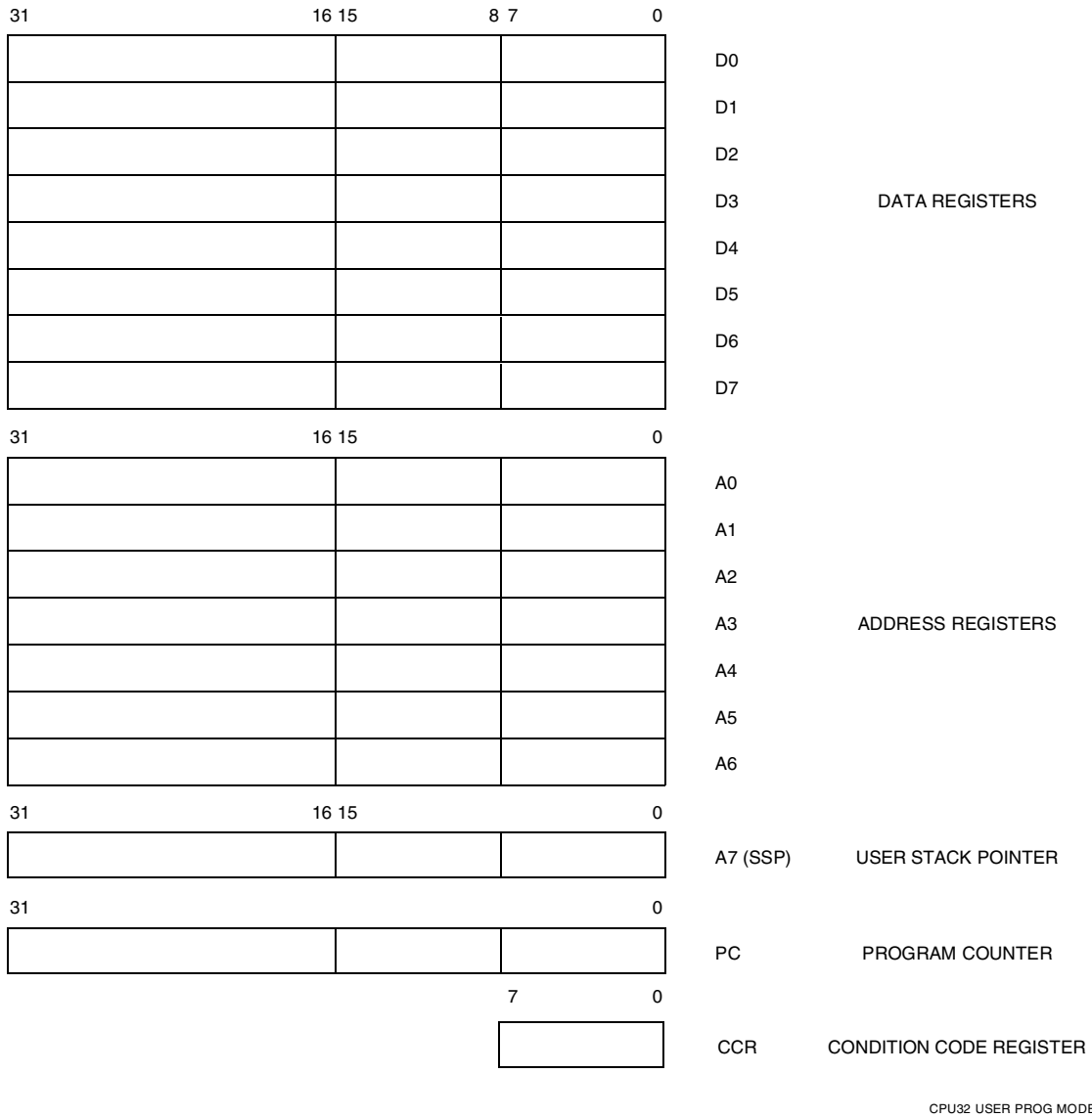


**Figure 4-1 CPU32 Block Diagram**

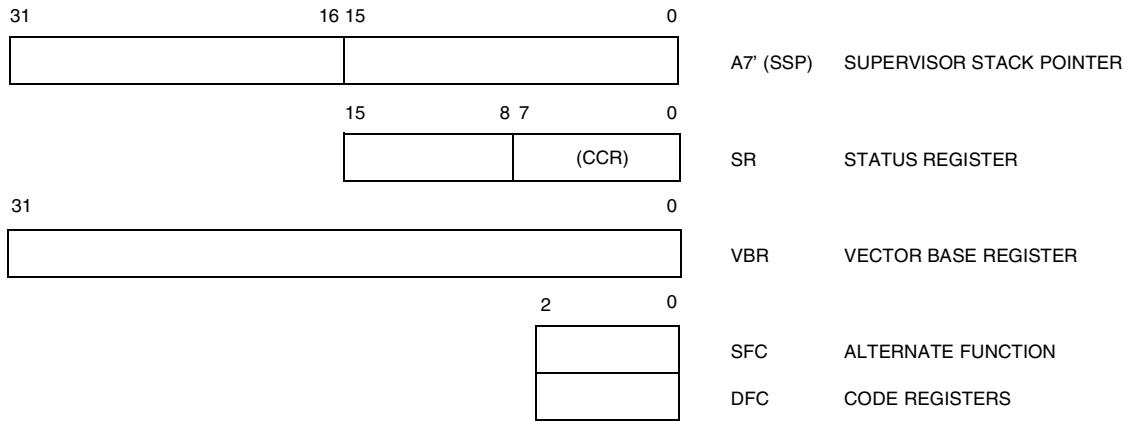
## 4.2 CPU32 Registers

The CPU32 programming model consists of two groups of registers that correspond to the user and supervisor privilege levels. User programs can use only the registers of the user model. The supervisor programming model, which supplements the user programming model, is used by CPU32 system programmers who wish to protect sensitive operating system functions. The supervisor model is identical to that of the MC68010 and later processors.

The CPU32 has eight 32-bit data registers, seven 32-bit address registers, a 32-bit program counter, separate 32-bit supervisor and user stack pointers, a 16-bit status register, two alternate function code registers, and a 32-bit vector base register. Refer to [Figure 4-2](#) and [Figure 4-3](#).



**Figure 4-2 User Programming Model**



CPU32 SUPV PROG MODEL

**Figure 4-3 Supervisor Programming Model Supplement**

### 4.2.1 Data Registers

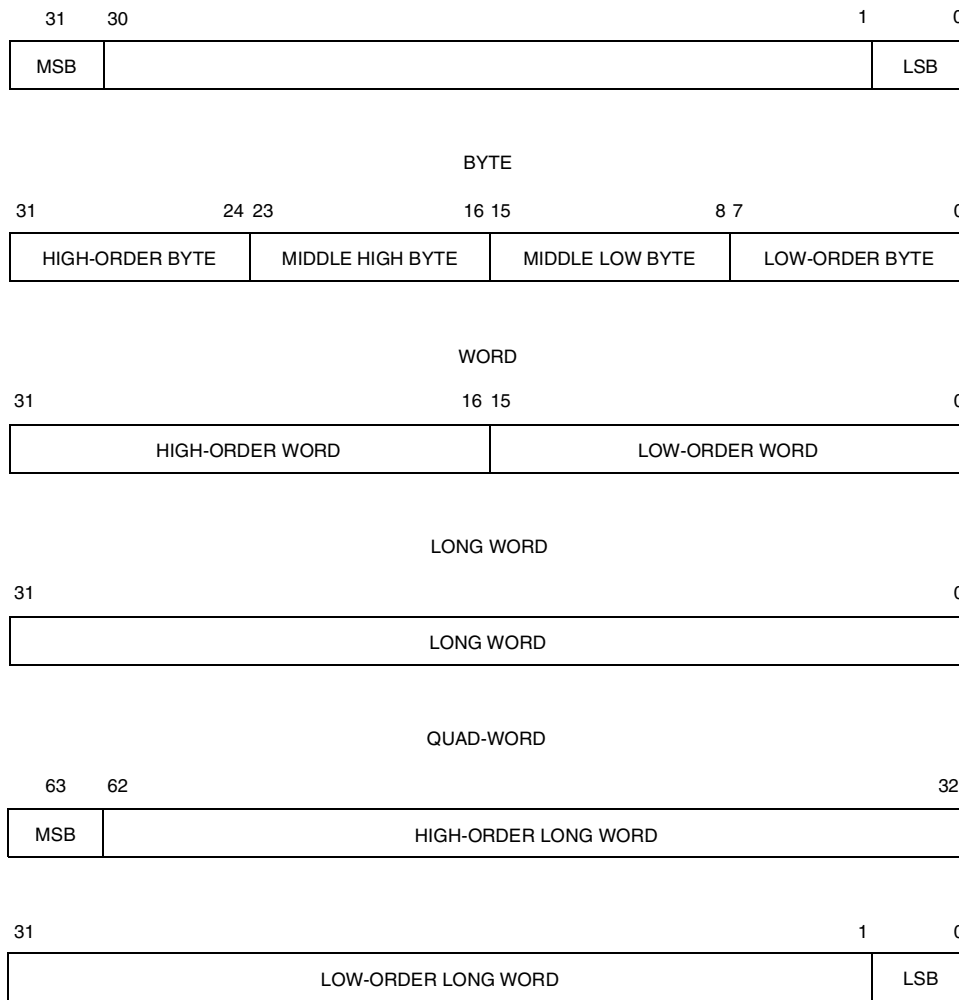
The eight data registers can store data operands of 1, 8, 16, 32, and 64 bits and addresses of 16 or 32 bits. The following data types are supported:

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

Each of data registers D7–D0 is 32 bits wide. Byte operands occupy the low-order 8 bits; word operands, the low-order 16 bits; and long-word operands, the entire 32 bits. When a data register is used as either a source or destination operand, only the appropriate low-order byte or word (in byte or word operations, respectively) is used or changed; the remaining high-order portion is unaffected. The least significant bit (LSB) of a long-word integer is addressed as bit zero, and the most significant bit (MSB) is addressed as bit 31. [Figure 4-4](#) shows the organization of various types of data in the data registers.

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

Binary-coded decimal (BCD) data represents decimal numbers in binary form. CPU32 BCD instructions use a format in which a byte contains two digits. The four LSB contain the least significant digit, and the four MSB contain the most significant digit. The ABCD, SBCD, and NBCD instructions operate on two BCD digits packed into a single byte.

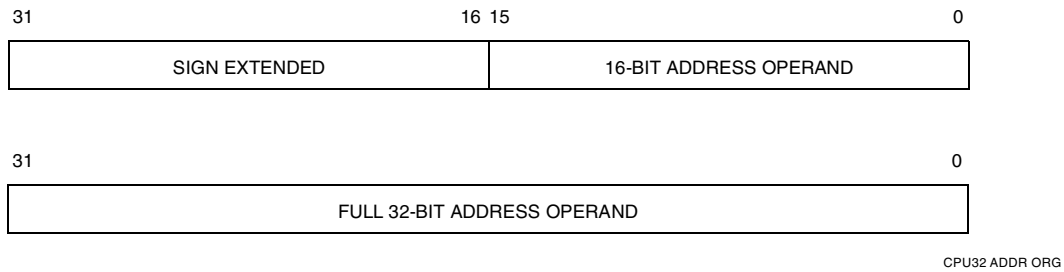


CPU32 DATA ORG

**Figure 4-4 Data Organization in Data Registers**

### 4.2.2 Address Registers

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



**Figure 4-5 Address Organization in Address Registers**

### 4.2.3 Program Counter

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

### 4.2.4 Control Registers

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

#### 4.2.4.1 Status Register

The status register (SR) stores the processor status. It contains the condition codes that reflect the results of a previous operation and can be used for conditional instruction execution in a program. The condition codes are extend (X), negative (N), zero (Z), overflow (V), and carry (C). The user (low-order) byte containing the condition codes is the only portion of the SR information available at the user privilege level; it is referenced as the condition code register (CCR) in user programs.

At the supervisor privilege level, software can access the full status register. The upper byte of this register includes the interrupt priority (IP) mask (three bits), two bits for placing the processor in one of two tracing modes or disabling tracing, and the supervisor/user bit for placing the processor at the desired privilege level.

Undefined bits in the status register are reserved by Motorola for future definition. The undefined bits are read as zeros and should be written as zeros for future compatibility.

All operations to the SR and CCR are word-size operations, but for all CCR operations, the upper byte is read as all zeros and is ignored when written, regardless of privilege level.

Refer to [APPENDIX D REGISTER SUMMARY](#) for bit/field definitions and a diagram of the status register.



#### 4.2.4.2 Alternate Function Code Registers

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

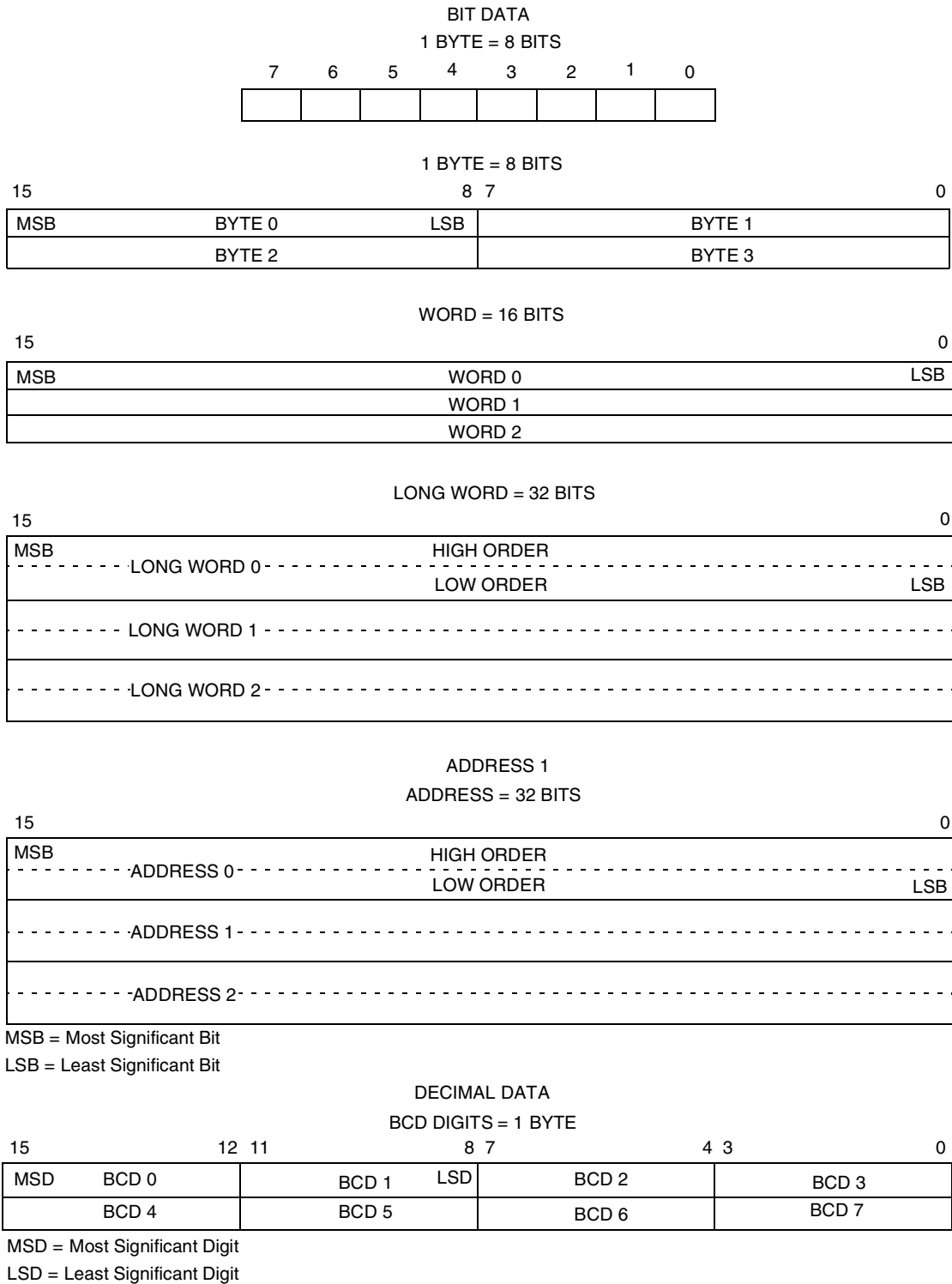
Registers SFC and DFC are used by the MOVES instruction to specify explicitly the function codes of the memory address. The MOVEC instruction is used to transfer values to and from the alternate function code registers. This is a long-word transfer; the upper 29 bits are read as zeros and are ignored when written.

#### 4.2.5 Vector Base Register (VBR)

The VBR contains the base address of the 1024-byte exception vector table, consisting of 256 exception vectors. Exception vectors contain the memory addresses of routines that begin execution at the completion of exception processing. More information on the VBR and exception processing can be found in [4.9 Exception Processing](#).

### 4.3 Memory Organization

Memory is organized on a byte-addressable basis in which lower addresses correspond to higher order bytes. For example, the address  $N$  of a long-word data item corresponds to the address of the most significant byte of the highest order word. The address of the most significant byte of the low-order word is  $N + 2$ , and the address of the least significant byte of the long word is  $N + 3$ . The CPU32 requires long-word and word data and all instructions to be aligned on word boundaries. Refer to [Figure 4-6](#). If this does not happen, an exception will occur when the CPU32 accesses the misaligned instruction or data. Data misalignment is not supported.



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**Figure 4-6 Memory Operand Addressing**



## 4.4 Virtual Memory



The full addressing range of the CPU32 on the MC68332 is 16 Mbytes in each of eight address spaces. Even though most systems implement a smaller physical memory, the system can be made to appear to have a full 16 Mbytes of memory available to each user program by using virtual memory techniques.

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

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

## 4.5 Addressing Modes

Addressing in the CPU32 is register-oriented. Most instructions allow the results of the specified operation to be placed either in a register or directly in memory. There is no need for extra instructions to store register contents in memory.

There are seven basic addressing modes:

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

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

## 4.6 Processing States

The processor is always in one of four processing states: normal, exception, halted, or background. The normal processing state is associated with instruction execution; the bus is used to fetch instructions and operands and to store results.



The exception processing state is associated with interrupts, trap instructions, tracing, and other exception conditions. The exception may be internally generated explicitly by an instruction or by an unusual condition arising during the execution of an instruction. Exception processing can be forced externally by an interrupt, a bus error, or a reset.

The halted processing state is an indication of catastrophic hardware failure. For example, if during the exception processing of a bus error another bus error occurs, the processor assumes that the system is unusable and halts.

The background processing state is initiated by breakpoints, execution of special instructions, or a double bus fault. Background processing is enabled by pulling BKPT low during  $\overline{\text{RESET}}$ . Background processing allows interactive debugging of the system via a simple serial interface.

#### 4.7 Privilege Levels

The processor operates at one of two levels of privilege: user or supervisor. Not all instructions are permitted to execute at the user level, but all instructions are available at the supervisor level. Effective use of privilege level can protect system resources from uncontrolled access. The state of the S bit in the status register determines the privilege level and whether the user stack pointer (USP) or supervisor stack pointer (SSP) is used for stack operations.

#### 4.8 Instructions

The CPU32 instruction set is summarized in [Table 4-2](#). The instruction set of the CPU32 is very similar to that of the MC68020. Two new instructions have been added to facilitate controller applications: low-power stop (LPSTOP) and table lookup and interpolate (TBL5, TBL5N, TBLU, TBLUN).

[Table 4-1](#) shows the MC68020 instructions that are not implemented on the CPU32.

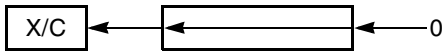
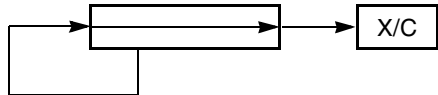
**Table 4-1 Unimplemented MC68020 Instructions**

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

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

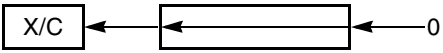
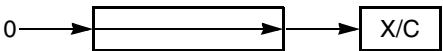
**Table 4-2 Instruction Set Summary**



Instruction	Operand Syntax	Operand Size	Description
ABCD	Dn, Dn – (An), – (An)	8 8	Source <sub>10</sub> + Destination <sub>10</sub> + X ⇒ Destination
ADD	Dn, <ea> <ea>, Dn	8, 16, 32 8, 16, 32	Source + Destination ⇒ Destination
ADDA	<ea>, An	16, 32	Source + Destination ⇒ Destination
ADDI	#<data>, <ea>	8, 16, 32	Immediate data + Destination ⇒ Destination
ADDQ	# <data>, <ea>	8, 16, 32	Immediate data + Destination ⇒ Destination
ADDX	Dn, Dn – (An), – (An)	8, 16, 32 8, 16, 32	Source + Destination + X ⇒ Destination
AND	<ea>, Dn Dn, <ea>	8, 16, 32 8, 16, 32	Source • Destination ⇒ Destination
ANDI	# <data>, <ea>	8, 16, 32	Data • Destination ⇒ Destination
ANDI to CCR	# <data>, CCR	8	Source • CCR ⇒ CCR
ANDI to SR1 <sup>1</sup>	# <data>, SR	16	Source • SR ⇒ SR
ASL	Dn, Dn # <data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
ASR	Dn, Dn # <data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
Bcc	label	8, 16, 32	If condition true, then PC + d ⇒ PC
BCHG	Dn, <ea> # <data>, <ea>	8, 32 8, 32	$\overline{((\text{bit number}) \text{ of destination})} \Rightarrow Z \Rightarrow \text{bit of destination}$
BCLR	Dn, <ea> # <data>, <ea>	8, 32 8, 32	$\overline{((\text{bit number}) \text{ of destination})} \Rightarrow Z;$ 0 ⇒ bit of destination
BGND	none	none	If background mode enabled, then enter background mode, else format/vector ⇒ – (SSP); PC ⇒ – (SSP); SR ⇒ – (SSP); (vector) ⇒ PC
BKPT	# <data>	none	If breakpoint cycle acknowledged, then execute returned operation word, else trap as illegal instruction
BRA	label	8, 16, 32	PC + d ⇒ PC
BSET	Dn, <ea> # <data>, <ea>	8, 32 8, 32	$\overline{((\text{bit number}) \text{ of destination})} \Rightarrow Z;$ 1 ⇒ bit of destination
BSR	label	8, 16, 32	SP – 4 ⇒ SP; PC ⇒ (SP); PC + d ⇒ PC
BTST	Dn, <ea> # <data>, <ea>	8, 32 8, 32	$\overline{((\text{bit number}) \text{ of destination})} \Rightarrow Z$
CHK	<ea>, Dn	16, 32	If Dn < 0 or Dn > (ea), then CHK exception
CHK2	<ea>, Rn	8, 16, 32	If Rn < lower bound or Rn > upper bound, then CHK exception
CLR	<ea>	8, 16, 32	0 ⇒ Destination

**Table 4-2 Instruction Set Summary (Continued)**



Instruction	Operand Syntax	Operand Size	Description
CMP	<ea>, Dn	8, 16, 32	(Destination – Source), CCR shows results
CMPA	<ea>, An	16, 32	(Destination – Source), CCR shows results
CMPI	# <data>, <ea>	8, 16, 32	(Destination – Data), CCR shows results
CMPM	(An) +, (An) +	8, 16, 32	(Destination – Source), CCR shows results
CMP2	<ea>, Rn	8, 16, 32	Lower bound ≤ Rn ≤ Upper bound, CCR shows result
DBcc	Dn, label	16	If condition false, then Dn – 1 ⇒ PC; if Dn ≠ (– 1), then PC + d ⇒ PC
DIVS/DIVU	<ea>, Dn	32/16 ⇒ 16 : 16	Destination / Source ⇒ Destination (signed or unsigned)
DIVSL/DIVUL	<ea>, Dr : Dq <ea>, Dq <ea>, Dr : Dq	64/32 ⇒ 32 : 32 32/32 ⇒ 32 32/32 ⇒ 32 : 32	Destination / Source ⇒ Destination (signed or unsigned)
EOR	Dn, <ea>	8, 16, 32	Source ⊕ Destination ⇒ Destination
EORI	# <data>, <ea>	8, 16, 32	Data ⊕ Destination ⇒ Destination
EORI to CCR	# <data>, CCR	8	Source ⊕ CCR ⇒ CCR
EORI to SR <sup>1</sup>	# <data>, SR	16	Source ⊕ SR ⇒ SR
EXG	Rn, Rn	32	Rn ⇒ Rn
EXT	Dn Dn	8 ⇒ 16 16 ⇒ 32	Sign extended Destination ⇒ Destination
EXTB	Dn	8 ⇒ 32	Sign extended Destination ⇒ Destination
ILLEGAL	none	none	SSP – 2 ⇒ SSP; vector offset ⇒ (SSP); SSP – 4 ⇒ SSP; PC ⇒ (SSP); SSP – 2 ⇒ SSP; SR ⇒ (SSP); Illegal instruction vector address ⇒ PC
JMP	<ea>	none	Destination ⇒ PC
JSR	<ea>	none	SP – 4 ⇒ SP; PC ⇒ (SP); destination ⇒ PC
LEA	<ea>, An	32	<ea> ⇒ An
LINK	An, # d	16, 32	SP – 4 ⇒ SP, An ⇒ (SP); SP ⇒ An, SP + d ⇒ SP
LPSTOP <sup>1</sup>	# <data>	16	Data ⇒ SR; interrupt mask ⇒ EBI; STOP
LSL	Dn, Dn # <data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
LSR	Dn, Dn # <data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
MOVE	<ea>, <ea>	8, 16, 32	Source ⇒ Destination
MOVEA	<ea>, An	16, 32 ⇒ 32	Source ⇒ Destination
MOVEA <sup>1</sup>	USP, An An, USP	32 32	USP ⇒ An An ⇒ USP
MOVE from CCR	CCR, <ea>	16	CCR ⇒ Destination
MOVE to CCR	<ea>, CCR	16	Source ⇒ CCR

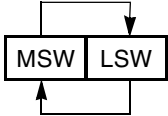
**Table 4-2 Instruction Set Summary (Continued)**



Instruction	Operand Syntax	Operand Size	Description
MOVE from SR <sup>1</sup>	SR, <ea>	16	SR ⇒ Destination
MOVE to SR <sup>1</sup>	<ea>, SR	16	Source ⇒ SR
MOVE USP <sup>1</sup>	USP, An An, USP	32 32	USP ⇒ An An ⇒ USP
MOVEC <sup>1</sup>	Rc, Rn Rn, Rc	32 32	Rc ⇒ Rn Rn ⇒ Rc
MOVEM	list, <ea> <ea>, list	16, 32 16, 32 ⇒ 32	Listed registers ⇒ Destination Source ⇒ Listed registers
MOVEP	Dn, (d16, An)  (d16, An), Dn	16, 32	Dn [31 : 24] ⇒ (An + d); Dn [23 : 16] ⇒ (An + d + 2); Dn [15 : 8] ⇒ (An + d + 4); Dn [7 : 0] ⇒ (An + d + 6)  (An + d) ⇒ Dn [31 : 24]; (An + d + 2) ⇒ Dn [23 : 16]; (An + d + 4) ⇒ Dn [15 : 8]; (An + d + 6) ⇒ Dn [7 : 0]
MOVEQ	#<data>, Dn	8 ⇒ 32	Immediate data ⇒ Destination
MOVES <sup>1</sup>	Rn, <ea> <ea>, Rn	8, 16, 32	Rn ⇒ Destination using DFC Source using SFC ⇒ Rn
MULS/MULU	<ea>, Dn <ea>, DI <ea>, Dh : DI	16 * 16 ⇒ 32 32 * 32 ⇒ 32 32 * 32 ⇒ 64	Source * Destination ⇒ Destination (signed or unsigned)
NBCD	<ea>	8 8	0 – Destination <sub>10</sub> – X ⇒ Destination
NEG	<ea>	8, 16, 32	0 – Destination ⇒ Destination
NEGX	<ea>	8, 16, 32	0 – Destination – X ⇒ Destination
NOP	none	none	PC + 2 ⇒ PC
NOT	<ea>	8, 16, 32	$\overline{\text{Destination}} \Rightarrow \text{Destination}$
OR	<ea>, Dn Dn, <ea>	8, 16, 32 8, 16, 32	Source + Destination ⇒ Destination
ORI	#<data>, <ea>	8, 16, 32	Data + Destination ⇒ Destination
ORI to CCR	#<data>, CCR	16	Source + CCR ⇒ SR
ORI to SR <sup>1</sup>	#<data>, SR	16	Source ; SR ⇒ SR
PEA	<ea>	32	SP – 4 ⇒ SP; <ea> ⇒ SP
RESET <sup>1</sup>	none	none	Assert $\overline{\text{RESET}}$ line
ROL	Dn, Dn #<data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
ROR	Dn, Dn #<data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
ROXL	Dn, Dn #<data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
ROXR	Dn, Dn #<data>, Dn <ea>	8, 16, 32 8, 16, 32 16	
RTD	#d	16	(SP) ⇒ PC; SP + 4 + d ⇒ SP

**Table 4-2 Instruction Set Summary (Continued)**



Instruction	Operand Syntax	Operand Size	Description
RTE <sup>1</sup>	none	none	(SP) ⇒ SR; SP + 2 ⇒ SP; (SP) ⇒ PC; SP + 4 ⇒ SP; Restore stack according to format
RTR	none	none	(SP) ⇒ CCR; SP + 2 ⇒ SP; (SP) ⇒ PC; SP + 4 ⇒ SP
RTS	none	none	(SP) ⇒ PC; SP + 4 ⇒ SP
SBCD	Dn, Dn – (An), – (An)	8 8	Destination <sub>10</sub> – Source <sub>10</sub> – X ⇒ Destination
Scc	<ea>	8	If condition true, then destination bits are set to one; else, destination bits are cleared to zero
STOP <sup>1</sup>	#<data>	16	Data ⇒ SR; STOP
SUB	<ea>, Dn Dn, <ea>	8, 16, 32	Destination – Source ⇒ Destination
SUBA	<ea>, An	16, 32	Destination – Source ⇒ Destination
SUBI	#<data>, <ea>	8, 16, 32	Destination – Data ⇒ Destination
SUBQ	#<data>, <ea>	8, 16, 32	Destination – Data ⇒ Destination
SUBX	Dn, Dn – (An), – (An)	8, 16, 32 8, 16, 32	Destination – Source – X ⇒ Destination
SWAP	Dn	16	
TAS	<ea>	8	Destination Tested Condition Codes bit 7 of Destination
TBLS/TBLU	<ea>, Dn Dym : Dym, Dn	8, 16, 32	Dyn – Dym ⇒ Temp (Temp * Dn [7 : 0]) ⇒ Temp (Dym * 256) + Temp ⇒ Dn
TBLSN/TBLUN	<ea>, Dn Dym : Dym, Dn	8, 16, 32	Dyn – Dym ⇒ Temp (Temp * Dn [7 : 0]) / 256 ⇒ Temp Dym + Temp ⇒ Dn
TRAP	#<data>	none	SSP – 2 ⇒ SSP; format/vector offset ⇒ (SSP); SSP – 4 ⇒ SSP; PC ⇒ (SSP); SR ⇒ (SSP); vector address ⇒ PC
TRAPcc	none #<data>	none 16, 32	If cc true, then TRAP exception
TRAPV	none	none	If V set, then overflow TRAP exception
TST	<ea>	8, 16, 32	Source – 0, to set condition codes
UNLK	An	32	An ⇒ SP; (SP) ⇒ An, SP + 4 ⇒ SP

NOTES:

1. Privileged instruction.

### 4.8.1 M68000 Family Compatibility

It is the philosophy of the M68000 family that all user-mode programs can execute unchanged on future derivatives of the M68000 family, and supervisor-mode programs and exception handlers should require only minimal alteration.

The CPU32 can be thought of as an intermediate member of the M68000 Family. Object code from an MC68000 or MC68010 may be executed on the CPU32. Many of the instruction and addressing mode extensions of the MC68020 are also supported. Refer to the *CPU32 Reference Manual* (CPU32RM/AD) for a detailed comparison of the CPU32 and MC68020 instruction set.



## 4.8.2 Special Control Instructions

Low-power stop (LPSTOP) and table lookup and interpolate (TBL) instructions have been added to the MC68000 instruction set for use in controller applications.

### 4.8.2.1 Low-Power Stop (LPSTOP)

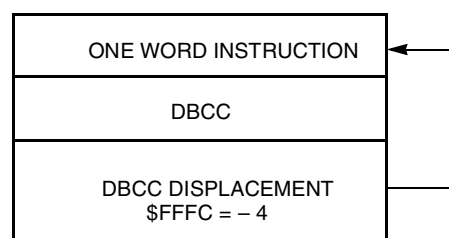
In applications where power consumption is a consideration, the CPU32 forces the device into a low-power standby mode when immediate processing is not required. The low-power stop mode is entered by executing the LPSTOP instruction. The processor remains in this mode until a user-specified (or higher)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

### 4.8.2.2 Table Lookup and Interpolate (TBL)

To maximize throughput for real-time applications, reference data is often precalculated and stored in memory for quick access. Storage of many data points can require an inordinate amount of memory. The table lookup instruction requires that only a sample of data points be stored, reducing memory requirements. The TBL instruction recovers intermediate values using linear interpolation. Results can be rounded with a round-to-nearest algorithm.

### 4.8.2.3 Loop Mode Instruction Execution

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



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**Figure 4-7 Loop Mode Instruction Sequence**

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



## 4.9 Exception Processing

An exception is a special condition that preempts normal processing. Exception processing is the transition from normal mode program execution to execution of a routine that deals with an exception.

### 4.9.1 Exception Vectors

An exception vector is the address of a routine that handles an exception. The vector base register (VBR) contains the base address of a 1024-byte exception vector table, which consists of 256 exception vectors. Sixty-four vectors are defined by the processor, and 192 vectors are reserved for user definition as interrupt vectors. Except for the reset vector, each vector in the table is one long word in length. The reset vector is two long words in length. Refer to [Table 4-3](#) for information on vector assignment.

#### CAUTION

Because there is no protection on the 64 processor-defined vectors, external devices can access vectors reserved for internal purposes. This practice is strongly discouraged.

All exception vectors, except the reset vector and stack pointer, are located in supervisor data space. The reset vector and stack pointer are located in supervisor program space. Only the initial reset vector and stack pointer are fixed in the processor memory map. When initialization is complete, there are no fixed assignments. Since the VBR stores the vector table base address, the table can be located anywhere in memory. It can also be dynamically relocated for each task executed by an operating system.





**Table 4-3 Exception Vector Assignments**

Vector Number	Vector Offset			Assignment
	Dec	Hex	Space	
0	0	000	SP	Reset: initial stack pointer
1	4	004	SP	Reset: initial program counter
2	8	008	SD	Bus error
3	12	00C	SD	Address error
4	16	010	SD	Illegal instruction
5	20	014	SD	Zero division
6	24	018	SD	CHK, CHK2 instructions
7	28	01C	SD	TRAPcc, TRAPV instructions
8	32	020	SD	Privilege violation
9	36	024	SD	Trace
10	40	028	SD	Line 1010 emulator
11	44	02C	SD	Line 1111 emulator
12	48	030	SD	Hardware breakpoint
13	52	034	SD	(Reserved, coprocessor protocol violation)
14	56	038	SD	Format error and uninitialized interrupt
15	60	03C	SD	Format error and uninitialized interrupt
16–23	64 92	040 05C	SD	(Unassigned, reserved)
24	96	060	SD	Spurious interrupt
25	100	064	SD	Level 1 interrupt autovector
26	104	068	SD	Level 2 interrupt autovector
27	108	06C	SD	Level 3 interrupt autovector
28	112	070	SD	Level 4 interrupt autovector
29	116	074	SD	Level 5 interrupt autovector
30	120	078	SD	Level 6 interrupt autovector
31	124	07C	SD	Level 7 interrupt autovector
32–47	128 188	080 0BC	SD	Trap instruction vectors (0–15)
48–58	192 232	0C0 0E8	SD	(Reserved, coprocessor)
59–63	236 252	0EC 0FC	SD	(Unassigned, reserved)
64–255	256 1020	100 3FC	SD	User defined vectors (192)

Each vector is assigned an 8-bit number. Vector numbers for some exceptions are obtained from an external device; others are supplied by the processor. The processor multiplies the vector number by four to calculate vector offset, then adds the offset to the contents of the VBR. The sum is the memory address of the vector.

#### 4.9.2 Types of Exceptions

An exception can be caused by internal or external events.



An internal exception can be generated by an instruction or by an error. The TRAP, TRAP<sub>cc</sub>, TRAPV, BKPT, CHK, CHK2, RTE, and DIV instructions can cause exceptions during normal execution. Illegal instructions, instruction fetches from odd addresses, word or long-word operand accesses from odd addresses, and privilege violations also cause internal exceptions.

Sources of external exception include interrupts, breakpoints, bus errors, and reset requests. Interrupts are peripheral device requests for processor action. Breakpoints are used to support development equipment. Bus error and reset are used for access control and processor restart.

### 4.9.3 Exception Processing Sequence

For all exceptions other than a reset exception, exception processing occurs in the following sequence. Refer to [5.7 Reset](#) for details of reset processing.

As exception processing begins, the processor makes an internal copy of the status register. After the copy is made, the processor state bits in the status register are changed — the S bit is set, establishing supervisor access level, and bits T1 and T0 are cleared, disabling tracing. For reset and interrupt exceptions, the interrupt priority mask is also updated.

Next, the exception number is obtained. For interrupts, the number is fetched from CPU space \$F (the bus cycle is an interrupt acknowledge). For all other exceptions, internal logic provides a vector number.

Next, current processor status is saved. An exception stack frame is created and placed on the supervisor stack. All stack frames contain copies of the status register and the program counter for use by RTE. The type of exception and the context in which the exception occurs determine what other information is stored in the stack frame.

Finally, the processor prepares to resume normal execution of instructions. The exception vector offset is determined by multiplying the vector number by four, and the offset is added to the contents of the VBR to determine displacement into the exception vector table. The exception vector is loaded into the program counter. If no other exception is pending, the processor will resume normal execution at the new address in the PC.

### 4.10 Development Support

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

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

### 4.10.1 M68000 Family Development Support

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

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

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

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

### 4.10.2 Background Debug Mode

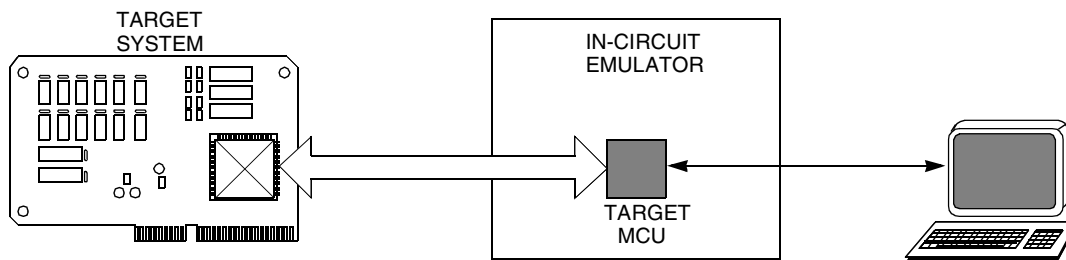
Microcomputer systems generally provide a debugger, implemented in software, for system analysis at the lowest level. The background debug mode (BDM) on the CPU32 is unique in that the debugger has been implemented in CPU microcode.

BDM incorporates a full set of debugging options: registers can be viewed or altered, memory can be read or written to, and test features can be invoked.

A resident debugger simplifies implementation of an in-circuit emulator. In a common setup (refer to [Figure 4-8](#)), emulator hardware replaces the target system processor. A complex, expensive pod-and-cable interface provides a communication path between the target system and the emulator.

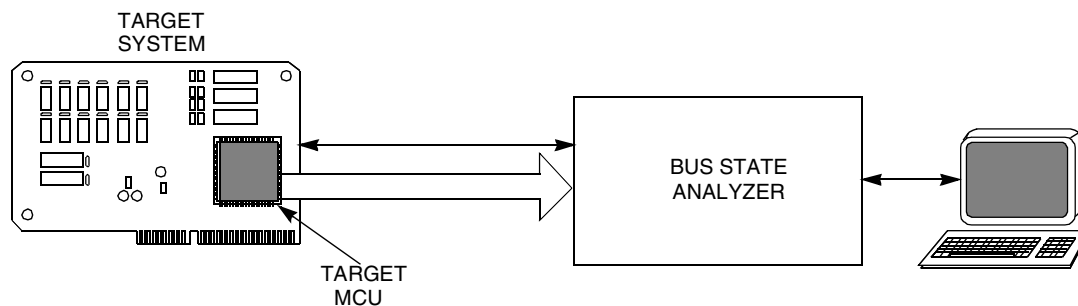
By contrast, an integrated debugger supports use of a bus state analyzer (BSA) for in-circuit emulation. The processor remains in the target system (refer to [Figure 4-9](#)) and the interface is simplified. The BSA monitors target processor operation and the on-chip debugger controls the operating environment. Emulation is much “closer” to target hardware, and many interfacing problems (for example, limitations on high-frequency operation, AC and DC parametric mismatches, and restrictions on cable length) are minimized.





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**Figure 4-8 Common In-Circuit Emulator Diagram**



1129A

**Figure 4-9 Bus State Analyzer Configuration**

### 4.10.3 Enabling BDM

Accidentally entering BDM in a non-development environment can lock up the CPU32 when the serial command interface is not available. For this reason, BDM is enabled during reset via the breakpoint ( $\overline{BKPT}$ ) signal.

BDM operation is enabled when  $\overline{BKPT}$  is asserted (low), at the rising edge of  $\overline{RESET}$ . BDM remains enabled until the next system reset. A high  $\overline{BKPT}$  signal on the trailing edge of  $\overline{RESET}$  disables BDM.  $\overline{BKPT}$  is latched again on each rising transition of  $\overline{RESET}$ .  $\overline{BKPT}$  is synchronized internally, and must be held low for at least two clock cycles prior to negation of  $\overline{RESET}$ .

BDM enable logic must be designed with special care. If hold time on  $\overline{BKPT}$  (after the trailing edge of  $\overline{RESET}$ ) extends into the first bus cycle following reset, the bus cycle could inadvertently be tagged with a breakpoint. Refer to the [SIM Reference Manual](#) (SIMRM/AD) for timing information.

### 4.10.4 BDM Sources

When BDM is enabled, any of several sources can cause the transition from normal mode to BDM. These sources include external breakpoint hardware, the BGND instruction, a double bus fault, and internal peripheral breakpoints. If BDM is not enabled when an exception condition occurs, the exception is processed normally.

**Table 4-4** summarizes the processing of each source for both enabled and disabled cases. As shown in **Table 4-4**, the  $\overline{\text{BKPT}}$  instruction never causes a transition into BDM.



**Table 4-4 BDM Source Summary**

Source	BDM Enabled	BDM Disabled
$\overline{\text{BKPT}}$	Background	Breakpoint Exception
Double Bus Fault	Background	Halted
BGND Instruction	Background	Illegal Instruction
$\overline{\text{BKPT}}$ Instruction	Opcode Substitution/ Illegal Instruction	Opcode Substitution/ Illegal Instruction

#### 4.10.4.1 External $\overline{\text{BKPT}}$ Signal

Once enabled, BDM is initiated whenever assertion of  $\overline{\text{BKPT}}$  is acknowledged. If BDM is disabled, a breakpoint exception (vector \$0C) is acknowledged. The  $\overline{\text{BKPT}}$  input has the same timing relationship to the data strobe trailing edge as does read cycle data. There is no breakpoint acknowledge bus cycle when BDM is entered.

#### 4.10.4.2 BGND Instruction

An illegal instruction, \$4AFA, is reserved for use by development tools. The CPU32 defines \$4AFA (BGND) to be a BDM entry point when BDM is enabled. If BDM is disabled, an illegal instruction trap is acknowledged.

#### 4.10.4.3 Double Bus Fault

The CPU32 normally treats a double bus fault, or two bus faults in succession, as a catastrophic system error, and halts. When this condition occurs during initial system debug (a fault in the reset logic), further debugging is impossible until the problem is corrected. In BDM, the fault can be temporarily bypassed, so that the origin of the fault can be isolated and eliminated.

#### 4.10.4.4 Peripheral Breakpoints

CPU32 peripheral breakpoints are implemented in the same way as external breakpoints — peripherals request breakpoints by asserting the  $\overline{\text{BKPT}}$  signal. Consult the appropriate peripheral user's manual for additional details on the generation of peripheral breakpoints.

#### 4.10.5 Entering BDM

When the processor detects a breakpoint or a double bus fault, or decodes a BGND instruction, it suspends instruction execution and asserts the FREEZE output. This is the first indication that the processor has entered BDM. Once FREEZE has been asserted, the CPU enables the serial communication hardware and awaits a command.

The CPU writes a unique value indicating the source of BDM transition into temporary register A (ATEMP) as part of the process of entering BDM. A user can poll ATEMP

and determine the source (refer to [Table 4-5](#)) by issuing a read system register command (RSREG). ATEMP is used in most debugger commands for temporary storage. It is imperative that the RSREG command be the first command issued after transition into BDM.



**Table 4-5 Polling the BDM Entry Source**

Source	ATEMP[31:16]	ATEMP[15:0]
Double Bus Fault	SSW <sup>1</sup>	\$FFFF
BGND Instruction	\$0000	\$0001
Hardware Breakpoint	\$0000	\$0000

NOTES:

1. Special status word (SSW) is described in detail in the [CPU32 Reference Manual](#) (CPU32RM/AD).

A double bus fault during initial stack pointer/program counter (SP/PC) fetch sequence is distinguished by a value of \$FFFFFFFF in the current instruction PC. At no other time will the processor write an odd value into this register.

#### 4.10.6 BDM Commands

BDM commands consist of one 16-bit operation word and can include one or more 16-bit extension words. Each incoming word is read as it is assembled by the serial interface. The microcode routine corresponding to a command is executed as soon as the command is complete. Result operands are loaded into the output shift register to be shifted out as the next command is read. This process is repeated for each command until the CPU returns to normal operating mode. [Table 4-6](#) is a summary of background mode commands.

**Table 4-6 Background Mode Command Summary**

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

### 4.10.7 Background Mode Registers

BDM processing uses three special purpose registers to keep track of program context during development. A description of each follows.

#### 4.10.7.1 Fault Address Register (FAR)

The FAR contains the address of the faulting bus cycle immediately following a bus or address error. This address remains available until overwritten by a subsequent bus cycle. Following a double bus fault, the FAR contains the address of the last bus cycle. The address of the first fault (if there was one) is not visible to the user.

#### 4.10.7.2 Return Program Counter (RPC)

The RPC points to the location where fetching will commence after transition from background mode to normal mode. This register should be accessed to change the

flow of a program under development. Changing the RPC to an odd value will cause an address error when normal mode prefetching begins.



#### 4.10.7.3 Current Instruction Program Counter (PCC)

The PCC holds a pointer to the first word of the last instruction executed prior to transition into background mode. Due to instruction pipelining, the instruction pointed to may not be the instruction which caused the transition. An example is a breakpoint on a released write. The bus cycle may overlap as many as two subsequent instructions before stalling the instruction sequencer. A breakpoint asserted during this cycle will not be acknowledged until the end of the instruction executing at completion of the bus cycle. PCC will contain \$00000001 if BDM is entered via a double bus fault immediately out of reset.

#### 4.10.8 Returning from BDM

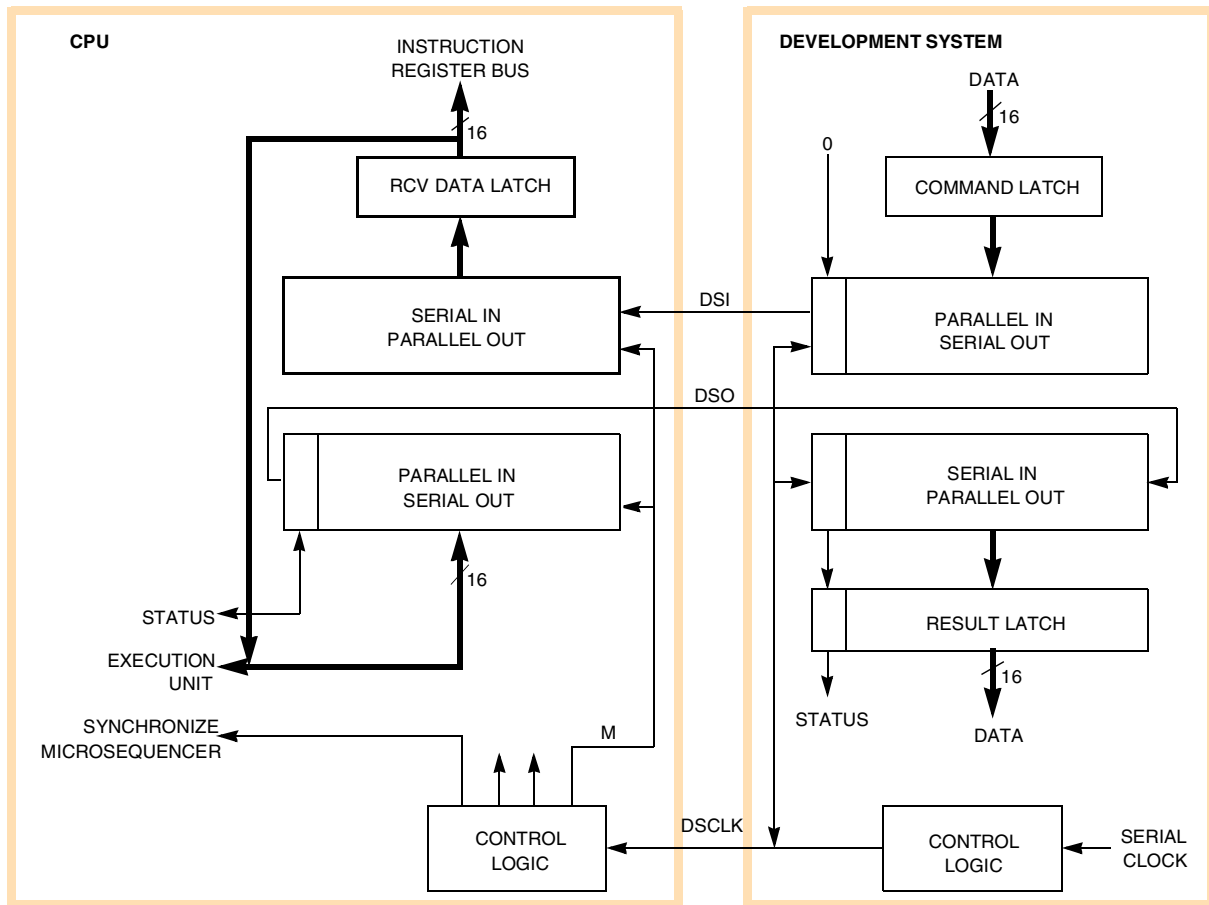
BDM is terminated when a resume execution (GO) or call user code (CALL) command is received. Both GO and CALL flush the instruction pipeline and refetch instructions from the location pointed to by the RPC.

The return PC and the memory space referred to by the status register SUPV bit reflect any changes made during BDM. FREEZE is negated prior to initiating the first prefetch. Upon negation of FREEZE, the serial subsystem is disabled, and the signals revert to IPIPE/IFETCH functionality.

#### 4.10.9 Serial Interface

Communication with the CPU32 during BDM occurs via a dedicated serial interface, which shares pins with other development features. [Figure 4-10](#) is a block diagram of the interface. The  $\overline{\text{BKPT}}$  signal becomes the serial clock (DSCLK); serial input data (DSI) is received on  $\overline{\text{IFETCH}}$ , and serial output data (DSO) is transmitted on IPIPE.





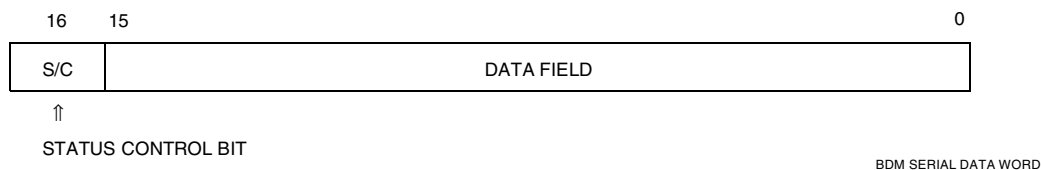
32 DEBUG I/O BLOCK

**Figure 4-10 Debug Serial I/O Block Diagram**

The serial interface uses a full-duplex synchronous protocol similar to the serial peripheral interface (SPI) protocol. The development system serves as the master of the serial link since it is responsible for the generation of DSCLK. If DSCLK is derived from the CPU32 system clock, development system serial logic is unhindered by the operating frequency of the target processor. Operable frequency range of the serial clock is from DC to one-half the processor system clock frequency.

The serial interface operates in full-duplex mode — data is transmitted and received simultaneously by both master and slave devices. In general, data transitions occur on the falling edge of DSCLK and are stable by the following rising edge of DSCLK. Data is transmitted MSB first, and is latched on the rising edge of DSCLK.

The serial data word is 17 bits wide, including 16 data bits and a status/control bit (refer to [Figure 4-11](#)). Bit 16 indicates the status of CPU-generated messages. [Table 4-7](#) shows the CPU-generated message types.



**Figure 4-11 BDM Serial Data Word**

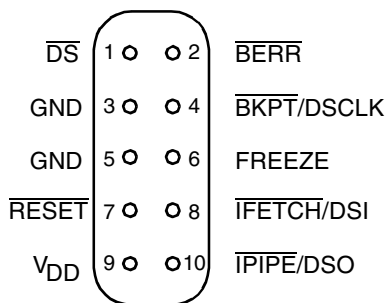
**Table 4-7 CPU Generated Message Encoding**

Bit 16	Data	Message Type
0	XXXX	Valid data transfer
0	FFFF	Command complete; Status OK
1	0000	Not ready with response; Come again
1	0001	BERR terminated bus cycle; Data invalid
1	FFFF	Illegal command

Command and data transfers initiated by the development system should clear bit 16. The current implementation ignores this bit; however, Motorola reserves the right to use this bit for future enhancements.

#### 4.10.10 Recommended BDM Connection

In order to provide for use of development tools when an MCU is installed in a system, Motorola recommends that appropriate signal lines be routed to a male Berg connector or double-row header installed on the circuit board with the MCU. Refer to [Figure 4-12](#).



32 BERG

**Figure 4-12 BDM Connector Pinout**

#### 4.10.11 Deterministic Opcode Tracking

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



#### 4.10.12 On-Chip Breakpoint Hardware

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

