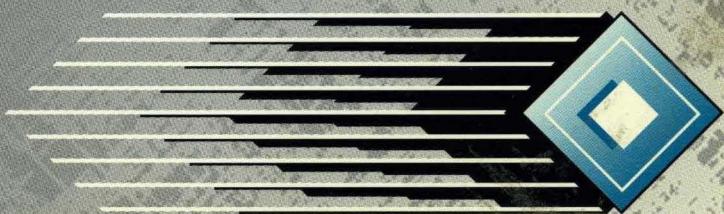


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# i960® Jx Microprocessor User's Manual

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*i960<sup>®</sup> Jx Microprocessor  
User's Manual*

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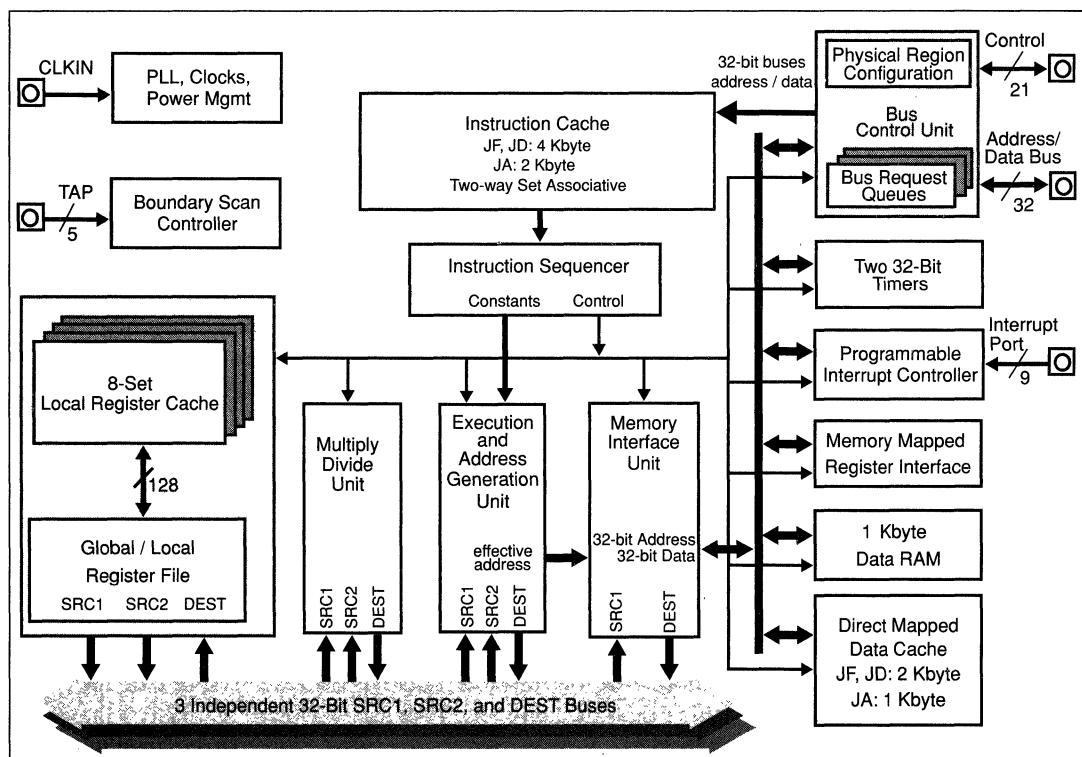
7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

# CHAPTER 1

## INTRODUCTION

The i960® Jx microprocessor provides a new set of essential enhancements for an emerging class of high-performance embedded applications. Based on the i960 core-architecture, it is implemented in a proven 0.8 micron, three-layer metal process. Figure 1-1 identifies the processor's most notable features, each of which is described in subsections that follow the figure. These features include:

- instruction cache
- data cache
- bus controller unit
- on-chip data RAM
- local register cache
- interrupt controller
- timer units
- memory-mapped control registers
- external bus



**Figure 1-1. i960® Jx Microprocessor Functional Block Diagram**

## INTRODUCTION

### 1.1 PRODUCT FEATURES

The i960 Jx processor brings many improvements to the existing i960 microprocessor family. Enhancements include:

- Improvements to the core architecture
- Low power mode
- New instructions
- Improved cache design
- Enhanced bus control unit
- Improved interrupt performance
- JTAG testability

#### 1.1.1 Instruction Cache

The i960 JF and JD processors employ a 4-Kbyte, two-way set associative instruction cache. i960 JA processors feature a 2-Kbyte instruction cache. A mechanism is provided that allows software to lock critical code within each “way” of the cache. The cache can be disabled and is managed by use of the **icctl** and **sysctl** instructions, as described in section 4.4, “INSTRUCTION CACHE” (pg. 4-4).

#### 1.1.2 Data Cache

The i960 JF and JD processors feature a 2-Kbyte, direct-mapped data cache that is write-through and write-allocate. i960 JA processors feature a 1-Kbyte data cache. These processors have a line size of four words and implement a “natural” fill policy. Each line in the cache has a valid bit; to reduce fetch latency on cache misses, each word within a line also has a valid bit. See section 4.5, “DATA CACHE” (pg. 4-6) for details.

The data cache is managed through the **dcctl** instruction; see section 6.2.23, “dcctl (80960Jx-Specific Instruction)” (pg. 6-41).

#### 1.1.3 On-chip (internal) Data RAM

The processor’s 1 Kbyte internal data RAM is accessible to software with an access time of 1 cycle per word. This RAM is mapped to the physical address range of 0 to 3FFH. The first 64 bytes are reserved for the caching of dedicated-mode interrupt vectors; this reduces interrupt latency for these interrupts. In addition, write-protection for the first 64 bytes is provided to guard against the effects of using null pointers in ‘C’ and to protect the cached interrupt vectors.

New versions of i960 processor compilers can take advantage of the internal data RAM; profiling compilers can allocate the most frequently used variables into this RAM. See Section 4.1, INTERNAL DATA RAM (pg. 4-1) for more detail.

### 1.1.4 Local Register Cache

The processor provides fast storage of local registers for call and return operations by using an internal local register cache. This cache can store up to eight local register sets; additional register sets must be saved in external memory.

The processor uses a 128-bit wide bus to store local register sets quickly to the register cache. To reduce interrupt latency for high-priority interrupts, the number of sets that can be used by code that is running at a lower priority or that is not interrupted can be restricted by programming the register configuration word in the PRCB. This ensures that there are always sets available for high-priority interrupt code without needing to save sets in external memory first. See Section 4.2, LOCAL REGISTER CACHE (pg. 4-2) for more details.

### 1.1.5 Interrupt Controller

The interrupt controller unit (ICU) provides a flexible, low-latency means for requesting interrupts. It handles the posting of interrupts requested by hardware and software sources. Acting independently from the core, the interrupt controller compares the priorities of posted interrupts with the current process priority, off-loading this task from the core. The interrupt controller is compatible with i960 CA/CF processors.

The interrupt controller provides the following features for handling hardware-requested interrupts:

- Support of up to 240 external sources.
- Eight external interrupt pins, one non-maskable interrupt (NMI) pin, and two internal timer sources for detection of hardware-requested interrupts.
- Edge or level detection on external interrupt pins.
- Debounce option on external interrupt pins.

The application program interfaces to the interrupt controller with six memory-mapped control registers. The interrupt control register (ICON) and interrupt map control registers (IMAP0-IMAP2) provide configuration information. The interrupt pending (IPND) register posts hardware-requested interrupts. The interrupt mask (IMSK) register selectively masks hardware-requested interrupts.

The interrupt inputs can be configured to be triggered on level-low or falling-edge signals. Sampling of the input pins can be either debounced sampling or fast sampling.

## INTRODUCTION

The i960 Jx processor has approximately 5 to 10 times faster interrupt servicing than the i960 Kx processor. This is accomplished through a number of features:

- a hardware priority resolver removes the need to access the external interrupt table to resolve interrupts
- caching of dedicated-mode interrupt vectors in the internal data RAM
- reserving frames in the local register cache for high-priority interrupts
- the ability to lock the code of interrupt service routines in the instruction-cache reduces the fetch latency for starting up these routines

Chapter 13, INTERRUPT CONTROLLER discusses this in more detail.

### 1.1.6 Timer Support

The i960 Jx processor provides two identical 32-bit timers. Access to the timers is through memory-mapped registers. The timers have a single-shot mode and auto-reload capabilities for continuous operation. Each timer has an independent interrupt request to the i960 Jx processor interrupt controller. See Chapter 14, TIMERS for a complete description.

### 1.1.7 Memory-Mapped Control Registers

Control registers in the i960 Jx processor are memory-mapped to allow for visibility to application software. This includes registers for memory configuration, internally cached PRCB data, breakpoint registers, and interrupt control. These registers are mapped to the architecturally reserved address space range of FF00 0000H to FFFF FFFFH. The processor ensures that accesses generate no external bus cycles.

Section 3.3, MEMORY-MAPPED CONTROL REGISTERS (pg. 3-5) discusses this in more detail.

### 1.1.8 External Bus

The 32-bit multiplexed external bus connects the i960 Jx processor to memory and I/O. This high bandwidth bus provides burst transfer capability allowing up to four successive 32-bit data word transfers at a maximum rate of one word every clock cycle. In addition to the bus signals, the i960 Jx processor provides signals to allow external bus masters. Lastly, the processor provides variable bus-width support (8-, 16-, and 32-bit).

### 1.1.9 Complete Fault Handling and Debug Capabilities

To aid in program development, the i960 Jx processor detects faults (exceptions). When a fault is detected, the processors make an implicit call to a fault handling routine. Information collected for each fault allows a program developer to quickly correct faulting code. The processors also allow automatic recovery from most faults.

To support system debug, the i960 architecture provides a mechanism for monitoring processor activities through a software tracing facility. This processor can be configured to detect as many as seven different trace events, including breakpoints, branches, calls, supervisor calls, returns, prereturns and the execution of each instruction (for single-stepping through a program). The processors also provide four breakpoint registers that allow break decisions to be made based upon instruction or data addresses.

## 1.2 ABOUT THIS MANUAL

This *i960® Jx Microprocessor User's Manual* provides detailed programming and hardware design information for the i960 Jx microprocessors. It is written for programmers and hardware designers who understand the basic operating principles of microprocessors and their systems.

This manual does not provide electrical specifications such as DC and AC parametrics, operating conditions and packaging specifications. Such information is found in the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* (order number 272504) and the *80960JD Embedded 32-bit Microprocessor Data Sheet* (order number 272596).

For information on other i960 processor family products or the architecture in general, refer to Intel's *Solutions960®* catalog (order number 270791). It lists all current i960 microprocessor family-related documents, support components, boards, software development tools, debug tools and more.

This manual is organized in three parts; each part comprises multiple chapters and/or appendices. The following briefly describes each part:

- *Part I - Programming the i960 Jx Microprocessor* (chapters 2-10) details the programming environment for the i960 Jx devices. Described here are the processor's registers, instruction set, data types, addressing modes, interrupt mechanism, external interrupt interface and fault mechanism.
- *Part II - System Implementation* (chapters 11-17) identifies requirements for designing a system around the i960 Jx components, such as external bus interface and interrupt controller. Also described are programming requirements for the bus controller and processor initialization.

- *Part III - Appendices* includes quick references for hardware design and programming. Appendices are also provided which describe the internal architecture, how to write assembly-level code to exploit the parallelism of the processor and considerations for writing software that is portable among all members of the i960 microprocessor family.

## 1.3 NOTATION AND TERMINOLOGY

This section defines terminology and textual conventions that are used throughout the manual.

### 1.3.1 Reserved and Preserved

Certain fields in registers and data structures are described as being either *reserved* or *preserved*:

- A reserved field is one that may be used by other i960 architecture implementations. Correct treatment of reserved fields ensures software compatibility with other i960 processors. The processor uses these fields for temporary storage; as a result, the fields sometimes contain unusual values.
- A preserved field is one that the processor does not use. Software may use preserved fields for any function.

Reserved fields in certain data structures should be set to 0 (zero) when the data structure is created. Set reserved fields to 0 when creating the Interrupt Table, Fault Table and System Procedure Table. Software should not modify or rely on these reserved field values after a data structure is created. When the processor creates the Interrupt or Fault Record data structure on the stack, software should not depend on the value of the reserved fields within these data structures.

Some bits or fields in data structures and registers are shown as requiring specific encoding. These fields should be treated as if they were reserved fields. They should be set to the specified value when the data structure is created or when the register is initialized and software should not modify or rely on the value after that.

Reserved bits in the Arithmetic Controls (AC) register can be set to 0 after initialization to ensure compatibility with other i960 processor implementations. Reserved bits in the Process Controls (PC) register and Trace Controls (TC) register should not be initialized. When the AC, PC and TC registers are modified using **modac**, **modpc** or **modtc** instructions, the reserved locations in these registers must be masked.

Certain areas of memory may be referred to as *reserved memory* in this reference manual. Reserved — when referring to memory locations — implies that an implementation of the i960 architecture may use this memory for some special purpose. For example, memory-mapped peripherals might be located in reserved memory areas on future implementations.

### 1.3.2 Specifying Bit and Signal Values

The terms *set* and *clear* in this manual refer to bit values in register and data structures. If a bit is set, its value is 1; if the bit is clear, its value is 0. Likewise, setting a bit means giving it a value of 1 and clearing a bit means giving it a value of 0.

The terms *assert* and *deassert* refer to the logically active or inactive value of a signal or bit, respectively. A signal is specified as an active 0 signal by an overbar. For example, the input is active low and is asserted by driving the signal to a logic 0 value.

### 1.3.3 Representing Numbers

All numbers in this manual can be assumed to be base 10 unless designated otherwise. In text, binary numbers are sometimes designated with a subscript 2 (for example, 001<sub>2</sub>). If it is obvious from the context that a number is a binary number, the “2” subscript may be omitted.

Hexadecimal numbers are designated in text with the suffix H (for example, FFFF FF5AH). In pseudo-code action statements in the instruction reference section and occasionally in text, hexadecimal numbers are represented by adding the C-language convention “0x” as a prefix. For example “FF7AH” appears as “0xFF7A” in the pseudo-code.

### 1.3.4 Register Names

Memory-mapped registers and several of the global and local registers are referred to by their generic register names, as well as descriptive names which describe their function. The global register numbers are g0 through g15; local register numbers are r0 through r15. However, when programming the registers in user-generated code, make sure to use the *instruction operand*. i960 microprocessor compilers recognize only the instruction operands listed in Table 1-1. Throughout this manual, the registers’ descriptive names, numbers, operands and acronyms are used interchangeably, as dictated by context.

Table 1-1. Register Terminology Conventions

| Register Descriptive Name  | Register Number | Instruction Operand | Acronym |
|----------------------------|-----------------|---------------------|---------|
| Global Registers           | g0 - g15        | g0 - g14            |         |
| Frame Pointer              | g15             | fp                  | FP      |
| Local Registers            | r0 - r15        | r3 - r15            |         |
| Previous Frame Pointer     | r0              | pfp                 | PFP     |
| Stack Pointer              | r1              | sp                  | SP      |
| Return Instruction Pointer | r2              | rip                 | RIP     |



## INTRODUCTION

Groups of bits and single bits in registers and control words are called either *bits*, *flags* or *fields*. These terms have a distinct meaning in this manual:

|       |  |
|-------|--|
| bit   | Controls a processor function; programmed by the user.                                 |
| flag  | Indicates status. Generally set by the processor; certain flags are user programmable. |
| field | A grouping of bits (bit field) or flags (flag field).                                  |

Specific bits, flags and fields in registers and control words are usually referred to by a register abbreviation (in upper case) followed by a bit, flag or field name (in lower case). These items are separated with a period. A position number designates individual bits in a field. For example, the return type (rt) field in the previous frame pointer (PFP) register is designated as "PFP.rt". The least significant bit of the return type field is then designated as "PFP.rt0".

## 1.4 RELATED DOCUMENTS

The following is a list of additional documentation that is useful when designing with and programming the i960 microprocessor. Contact your local sales representative for more information on obtaining Intel documents.

- *80960JA/JF Embedded 32-bit Microprocessor Data Sheet*  
Intel Order No. 272493
- *80960JD Embedded 32-bit Microprocessor Data Sheet*  
Intel Order No. 272596
- *Solutions960 Development Tools Catalog*  
Intel Order No. 270791



2

## DATA TYPES AND MEMORY ADDRESSING MODES



# CHAPTER 2

## DATA TYPES AND MEMORY ADDRESSING MODES

### 2.1 DATA TYPES

The instruction set references or produces several data lengths and formats. The i960® Jx processor supports the following data types:

- Integer (8, 16 and 32 bits)
- Triple Word (96 bits)
- Bit
- Bit Field
- Ordinal (unsigned integer 8, 16, 32 and 64 bits)
- Quad Word (128 bits)

Figure 2-1 illustrates the data types (including the length and numeric range of each) supported by the i960 architecture.

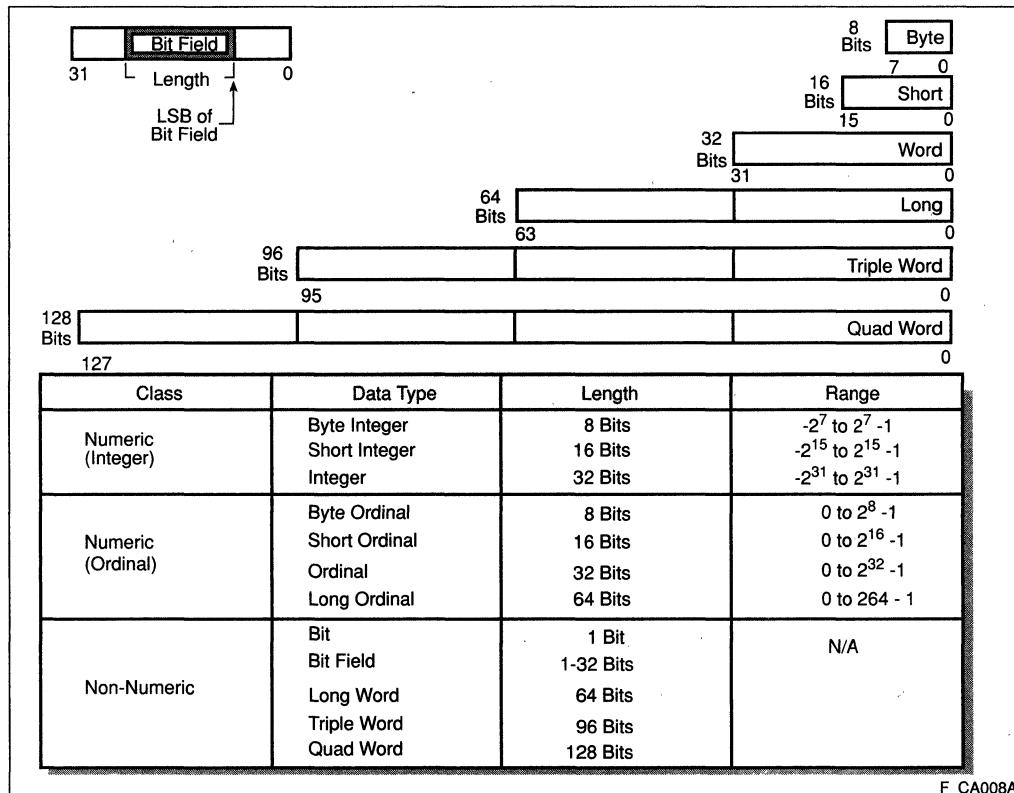


Figure 2-1. Data Types and Ranges

## DATA TYPES AND MEMORY ADDRESSING MODES

### 2.1.1 Integers

Integers are signed whole numbers that are stored and operated on in two's complement format by the integer instructions. Most integer instructions operate on 32-bit integers. Byte and short integers are referenced by the byte and short classes of the load, store and compare instructions only. Table 2-1 shows the supported integer sizes.

**Table 2-1. 80960Jx Supported Integer Sizes**

| Integer size | Descriptive name | Range                                  |
|--------------|------------------|--|
| 8 bit        | byte integers    | -2 <sup>7</sup> to 2 <sup>7</sup> -1   |
| 16 bit       | short integer    | -2 <sup>15</sup> to 2 <sup>15</sup> -1 |
| 32 bit       | integers         | -2 <sup>31</sup> to 2 <sup>31</sup> -1 |

Integer load or store size (byte, short or word) determines how sign extension or data truncation is performed when data is moved between registers and memory.

For instructions **ldib** (load integer byte) and **ldis** (load integer short), a byte or short word in memory is considered a two's complement value. The value is sign-extended and placed in the 32-bit register that is the destination for the load.

For instructions **stib** (store integer byte) and **stis** (store integer short), a 32-bit two's complement number in a register is stored to memory as a byte or short-word. If register data is too large to be stored as a byte or short word, the value is truncated and the integer overflow condition is signalled. When an overflow occurs, either an AC register flag is set or the integer overflow fault is generated. CHAPTER 9, FAULTS describes the integer overflow fault.

For instructions **ld** (load word) and **st** (store word), data is moved directly between memory and a register with no sign extension or data truncation.

### 2.1.2 Ordinals

Ordinals or unsigned integer data types are stored and operated on as positive binary values. Table 2-2 shows the supported ordinal sizes.

**Table 2-2. 80960Jx Supported Ordinal Sizes**

| Ordinal size | Descriptive name | Range                   |
|--------------|------------------|-------------------------|
| 8-bit        | byte ordinals    | 0 to 2 <sup>8</sup> -1  |
| 16-bit       | short ordinals   | 0 to 2 <sup>16</sup> -1 |
| 32-bit       | ordinals         | 0 to 2 <sup>32</sup> -1 |
| 64-bit       | long ordinals    | 0 to 2 <sup>64</sup> -1 |

The large number of instructions that perform logical, bit manipulation and unsigned arithmetic operations reference 32-bit ordinal operands. When ordinals are used to represent Boolean values, 1 = TRUE and 0 = FALSE. Several extended arithmetic instructions reference the long ordinal data type. Only load (**llobb** and **llosb**) store (**stob** and **stosb**) and compare ordinal instructions reference the byte and short ordinal data types.

Sign and sign extension are not considered when ordinal loads and stores are performed; the values may, however, be zero-extended or truncated. A short word or byte load to a register causes the value loaded to be zero-extended to 32 bits. A short word or byte store to memory may cause an ordinal value in a register to be truncated to fit its destination in memory. No overflow condition is signalled in this case.

### 2.1.3 Bits and Bit Fields

The processor provides several instructions that perform operations on individual bits or bit fields within register operands. An individual bit is specified for a bit operation by giving its bit number and register. Internal registers always follow little endian byte order; the least significant bit is bit 0 and the most significant bit is bit 31.

A bit field is any contiguous group of bits (up to 31 bits long) in a 32-bit register. Bit fields do not span register boundaries. A bit field is defined by giving its length in bits (0-31) and the bit number of its lowest numbered bit (0-31).

Loading and storing bit and bit field data is normally performed using the ordinal load and store instructions. Integer load and store instructions operate on two's complement numbers. Depending on the value, a byte or short integer load can result in sign extension of data in a register. A byte or short store can signal an integer overflow condition.

### 2.1.4 Triple and Quad Words

Triple- and quad-words refer to consecutive words in memory or in registers. Triple- and quad-word loads, stores and move instructions use these data types. These instructions facilitate data block movement. No data manipulation (sign extension, zero extension or truncation) is performed in these instructions.

Triple- and quad-word data types can be considered a superset of — or as encompassing — the other data types described. The data in each word subset of a quad word is likely to be the operand or result of an ordinal, integer, bit or bit field instruction.

### **2.1.5 Register Data Alignment**

Data in registers must adhere to specific alignment requirements:

- Long-word operands in registers must be aligned to double-register boundaries.
- Triple- and quad-word operands in registers must be aligned to quad-register boundaries.

For the i960 Jx processor, data alignment in memory is not required. User software can be programmed to automatically handle unaligned memory accesses or to cause a fault.

### **2.1.6 Literals**

The architecture defines a set of 32 literals that can be used as operands in many instructions. These literals are ordinal (unsigned) values that range from 0 to 31 (5 bits). When a literal is used as an operand, the processor expands it to 32 bits by adding leading zeros. If the instruction requires an operand larger than 32 bits, the processor zero-extends the value to the operand size. If a literal is used in an instruction that requires integer operands, the processor treats the literal as a positive integer value.

## **2.2 BIT AND BYTE ORDERING IN MEMORY**

All occurrences of numeric and non-numeric data types, except bits and bit fields, must start on a byte boundary. Any data item occupying multiple bytes is stored as big-endian or little endian. The following sections further describe byte ordering.

### **2.2.1 Bit Ordering**

Bits within bytes are numbered such that if the byte is viewed as a value, bit 0 is the least significant bit and bit 7 is the most significant bit. For numeric values spanning several bytes, bit numbers higher than 7 indicate successively higher bit numbers in bytes with higher addresses. Unless otherwise noted, bits in illustrations in this manual are ordered such that the higher-numbered bits are to the left.

### **2.2.2 Byte Ordering**

This i960 Jx processor can be programmed to use little or big endian byte ordering for memory accesses. Byte ordering refers to how data items larger than one byte are assembled:

- For little endian byte order, the byte with the lowest address in a multi-byte data item has the *least* significance.
- For big endian byte order, the byte with the lowest address in a multi-byte data item has the *most* significance.

For example, Table 2-3 shows four bytes of data in memory. Table 2-4 shows the differences between little and big endian accesses for byte, short, word and long word data. Figure 2-2 shows the resultant data placement in registers.

Once data is read into registers, byte order is no longer relevant. The lowest significant bit is always bit 0. The most significant bit is always bit 31 for words, bit 15 for short words, and bit 7 for bytes.

Byte ordering affects the way the i960 Jx processor handles bus accesses. See section 15.2.6, “Byte Ordering and Bus Accesses” (pg. 15-28) for more information.

**Table 2-3. Memory Contents For Little and Big Endian Example**

| ADDRESS | DATA |
|---------|------|
| 1000H   | 12H  |
| 1001H   | 34H  |
| 1002H   | 56H  |
| 1003H   | 78H  |

**Table 2-4. Byte Ordering for Little and BigEndian Accesses**

| Access             | Example         | Register Contents<br>(Little Endian) | Register Contents<br>(Big Endian) |
|--------------------|-----------------|--------------------------------------|-----------------------------------|
| Byte at 1000H      | ldob 0x1000, r3 | 12H                                  | 12H                               |
| Short at 1002H     | ldos 0x1002, r3 | 7856H                                | 5678H                             |
| Word at 1000H      | ld 0x1000, r3   | 78563412H                            | 12345678H                         |
| Long Word at 1000H | ldl 0x1000, r4  | 78563412H (r4)<br>F0DEBC9AH (r5)     | 12345678H (r4)<br>F0DEBC9AH (r5)  |

|  |       |                 |                 |                 |                 |   |
|--|-------|-----------------|-----------------|-----------------|-----------------|---|
|  |       | 31              | 24 23           | 16 15           | 8 7             | 0 |
|  |       | XX              | XX              | XX              | DD <sub>0</sub> |   |
|  |       | 31              | 24 23           | 16 15           | 8 7             | 0 |
|  | SHORT | XX              | XX              | DD <sub>1</sub> | DD <sub>0</sub> |   |
|  | WORD  | 31              | 24 23           | 16 15           | 8 7             | 0 |
|  |       | DD <sub>3</sub> | DD <sub>2</sub> | DD <sub>1</sub> | DD <sub>0</sub> |   |

**NOTES:**

- D's are data transferred to/from memory
- X's are zeros for ordinal data
- X's are sign bit extensions for integer data

**Figure 2-2. Data Placement in Registers**

## 2.3 MEMORY ADDRESSING MODES

The processor provides nine modes for addressing operands in memory. Each addressing mode is used to reference a byte in the processor's address space. Table 2-5 shows the memory addressing modes, a brief description of each mode's address elements and assembly code syntax. See Table B-5 in Appendix B for more on addressing modes.

**Table 2-5. Memory Addressing Modes**

| Mode                                       | Description                                 | Assembler Syntax                    |
|--|---|-------------------------------------|
| Absolute<br><i>offset</i>                  | <i>offset</i>                               | <i>exp</i>                          |
|  | <i>displacement</i>                         | <i>exp</i>                          |
| Register Indirect                          | <i>abase</i>                                | ( <i>reg</i> )                      |
|  | <i>abase + offset</i>                       | <i>exp (reg)</i>                    |
|  | <i>abase + displacement</i>                 | <i>exp (reg)</i>                    |
|  | <i>abase + (index*scale)</i>                | ( <i>reg</i> ) [ <i>reg*scale</i> ] |
|  | <i>abase + (index*scale) + displacement</i> | <i>exp (reg) [reg*scale]</i>        |
| Index with displacement                    | <i>(index*scale) + displacement</i>         | <i>exp [reg*scale]</i>              |
| instruction pointer (IP) with displacement | <i>IP + displacement + 8</i>                | <i>exp (IP)</i>                     |

**NOTE:** *reg* is register and *exp* is an expression or symbolic label.

### 2.3.1 Absolute

Absolute addressing modes allow a memory location to be referenced directly as an offset from address 0H. At the instruction encoding level, two absolute addressing modes are provided: absolute offset and absolute displacement, depending on offset size.

- For the absolute offset addressing mode, the offset is an ordinal number ranging from 0 to 4095. The absolute offset addressing mode is encoded in the MEMA machine instruction format.
- For the absolute displacement addressing mode the offset is an integer (a displacement) ranging from - $2^{31}$  to  $2^{31}-1$ . The absolute displacement addressing mode is encoded in the MEMB format.

Addressing modes and encoding instruction formats are described in CHAPTER 6, INSTRUCTION SET REFERENCE.

At the assembly language level, the two absolute addressing modes use the same syntax. Typically, development tools allow absolute addresses to be specified through arithmetic expressions (e.g.,  $x + 44$ ) or symbolic labels. After evaluating an address specified with the absolute addressing mode, the assembler converts the address into an offset or displacement and selects the appropriate instruction encoding format and addressing mode.

### 2.3.2 Register Indirect

Register indirect addressing modes use a register's 32-bit value as a base for address calculation. The register value is referred to as the address base (designated *abase* in Table 2-5). Depending on the addressing mode, an optional scaled-index and offset can be added to this address base.

Register indirect addressing modes are useful for addressing elements of an array or record structure. When addressing array elements, the abase value provides the address of the first array element; an offset (or displacement) selects a particular array element.

In register-indirect-with-index addressing mode, the index is specified using a value contained in a register. This index value is multiplied by a scale factor. Allowable factors are 1, 2, 4, 8 and 16.

The two versions of register-indirect-with-offset addressing mode at the instruction encoding level are register-indirect-with-offset and register-indirect-with-displacement. As with absolute addressing modes, the mode selected depends on the size of the offset from the base address.

At the assembly language level, the assembler allows the offset to be specified with an expression or symbolic label, then evaluates the address to determine whether to use register-indirect-with-offset (MEMA format) or register-indirect-with-displacement (MEMB format) addressing mode.

Register-indirect-with-index-and-displacement addressing mode adds both a scaled index and a displacement to the address base. There is only one version of this addressing mode at the instruction encoding level, and it is encoded in the MEMB instruction format.

### **2.3.3 Index with Displacement**

A scaled index can also be used with a displacement alone. Again, the index is contained in a register and multiplied by a scaling constant before displacement is added.

### **2.3.4 IP with Displacement**

This addressing mode is used with load and store instructions to make them instruction pointer (IP) relative. IP-with-displacement addressing mode references the next instruction's address plus the displacement plus a constant of 8. The constant is added because in a typical processor implementation the address has incremented beyond the next instruction address at the time of address calculation. The constant simplifies IP-with-displacement addressing mode implementation.

### **2.3.5 Addressing Mode Examples**

The following examples show how i960 addressing modes are encoded in assembly language. Example 2-1 shows addressing mode mnemonics. Example 2-2 illustrates the usefulness of scaled index and scaled index plus displacement addressing modes. In this example, a procedure named array\_op uses these addressing modes to fill two contiguous memory blocks separated by a constant offset. A pointer to the top of the block is passed to the procedure in g0, the block size is passed in g1 and the fill data in g2. Refer to APPENDIX D, MACHINE-LEVEL INSTRUCTION FORMATS.

**Example 2-1. Addressing Mode Mnemonics**

```

st      g4,xyz          # Absolute; word from g4 stored at memory
        # location designated with label xyz.
ldob    (r3),r4          # Register indirect; ordinal byte from
        # memory location given in r3 loaded
        # into register r4 and zero extended.
stl    g6,xyz(g5)        # Register indirect with displacement;
        # double word from g6,g7 stored at memory
        # location xyz + g5.
ldq    (r8)[r9*4],r4     # Register indirect with index; quad-word
        # beginning at memory location r8 + (r9
        # scaled by 4) loaded into r4 through r7.
st      g3,xyz(g4)[g5*2]  # Register indirect with index and
        # displacement; word in g3 loaded to mem
        # location g4 + xyz + (g5 scaled by 2).
ldis   xyz[r12*1],r13    # Index with displacement; load short
        # integer at memory location xyz + r12
        # into r13 and sign extended.
st      r4,xyz(IP)       # IP with displacement; store word in r4
        # at memory location IP + xyz + 8.

```

**Example 2-2. Use of Index Plus Scaled Index Mode**

```

array_op:
    mov      g0,r4          # Pointer to array is moved to r4.
    subi    1,g1,r3          # Calculate index for the last array
                           # element to be filled.
.I34:
    st       g2,(r4)[r3*4]   # Fill array at index.
    st       g2,0x30(r4)[r3*4] # Fill array at index+constant offset.
    subi    1,r3,r3          # Decrement index.
.I33:
    cmpible 0,r3,.I34       # Store next array elements if
                           # index is not 0.
    ret

```





3

# PROGRAMMING ENVIRONMENT



# CHAPTER 3

## PROGRAMMING ENVIRONMENT

This chapter describes the i960® Jx microprocessor's programming environment including global and local registers, control registers, literals, processor-state registers and address space.

### 3.1 OVERVIEW

The i960 architecture defines a programming environment for program execution, data storage and data manipulation. Figure 3-1 shows the programming environment elements which include a 4 Gbyte ( $2^{32}$  byte) flat address space, an instruction cache, global and local general-purpose registers, a set of literals, control registers and a set of processor state registers. A register cache saves the 16 procedure-specific local registers.

The processor defines several data structures located in memory as part of the programming environment. These data structures handle procedure calls, interrupts and faults and provide configuration information at initialization. These data structures are:

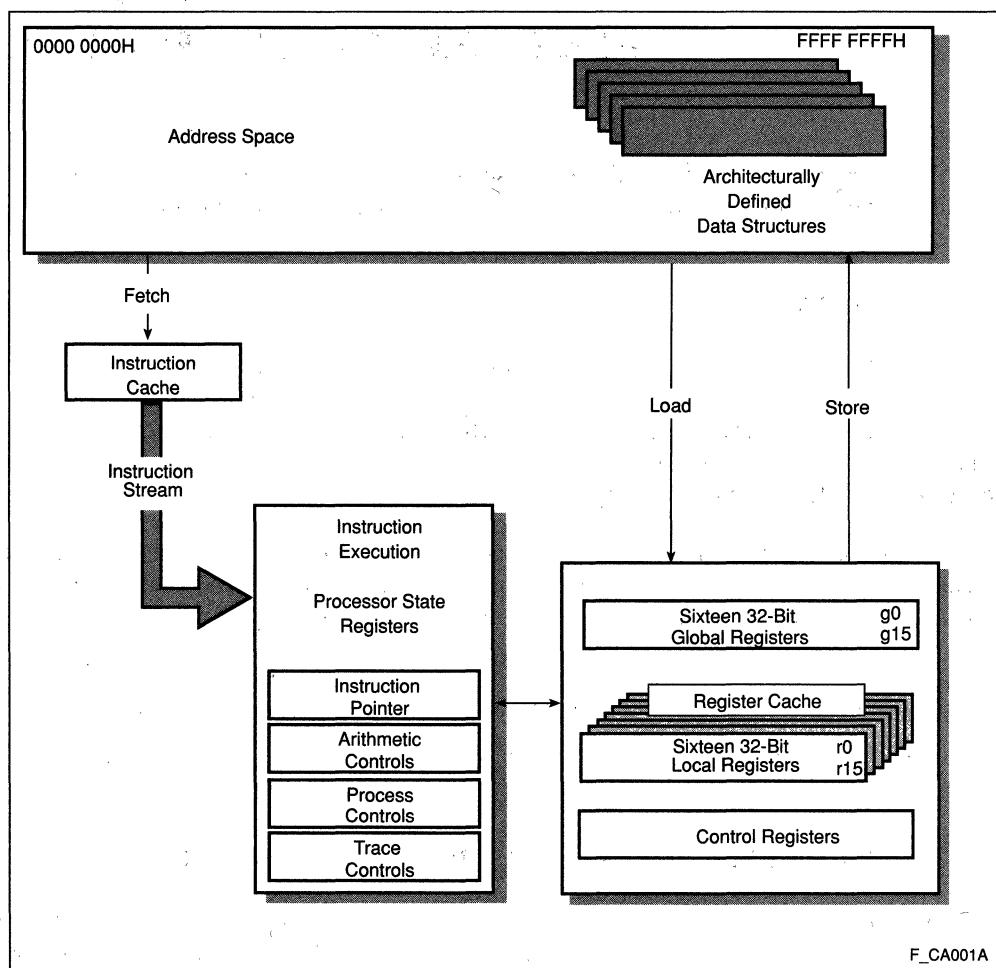
- interrupt stack
- local stack
- supervisor stack
- control table
- fault table
- interrupt table
- system procedure table
- process control block
- initialization boot record

### 3.2 REGISTERS AND LITERALS AS INSTRUCTION OPERANDS

The i960 Jx processor uses only simple load and store instructions to access memory. All operations take place at the register level. The processor uses 16 global registers, 16 local registers and 32 literals (constants 0-31) as instruction operands.

The global register numbers are g0 through g15; local register numbers are r0 through r15. Several of these registers are used for a dedicated function. For example, register r0 is the previous frame pointer, often referred to as *pfp*. i960 processor compilers and assemblers recognize only the instruction operands listed in Table 3-1. Throughout this manual, the registers' descriptive names, numbers, operands and acronyms are used interchangeably, as dictated by context.

## PROGRAMMING ENVIRONMENT



**Figure 3-1. i960® Jx Microprocessor Programming Environment**

### 3.2.1 Global Registers

Global registers are general-purpose 32-bit data registers that provide temporary storage for a program's computational operands. These registers retain their contents across procedure boundaries. As such, they provide a fast and efficient means of passing parameters between procedures.

**Table 3-1. Registers and Literals Used as Instruction Operands**

| Instruction Operand | Register Name (number) | Function                   | Acronym |
|---------------------|------------------------|----------------------------|---------|
| g0 - g14            | global (g0-g14)        | general purpose            |         |
| fp                  | global (g15)           | frame pointer              | FP      |
| pfp                 | local (r0)             | previous frame pointer     | PFP     |
| sp                  | local (r1)             | stack pointer              | SP      |
| rip                 | local (r2)             | return instruction pointer | RIP     |
| r3 - r15            | local (r3-r15)         | general purpose            |         |
| 0-31                |                        | literals                   |         |

The i960 architecture supplies 16 global registers, designated g0 through g15. Register g15 is reserved for the current Frame Pointer (FP), which contains the address of the first byte in the current (topmost) stack frame. See section 7.1, “CALL AND RETURN MECHANISM” (pg. 7-2) for a description of the FP and procedure stack.

After the processor is reset, register g0 contains device identification and stepping information. The Device Identification sections in the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet* describe information contained in g0. g0 retains this information until it is written over by the user program. The device identification and stepping information is also stored in a memory-mapped register located at FF008710H.

### 3.2.2 Local Registers

The i960 architecture provides a separate set of 32-bit local data registers (r0 through r15) for each active procedure. These registers provide storage for variables that are local to a procedure. Each time a procedure is called, the processor allocates a new set of local registers and saves the calling procedure’s local registers. The processor performs local register management; a program need not explicitly save and restore these registers.

r3 through r15 are general purpose registers; r0 contains the Previous Frame Pointer (PFP); r1 contains the Stack Pointer (SP); r2 contains the Return Instruction Pointer (RIP). These are discussed in CHAPTER 7, PROCEDURE CALLS.

The processor does not always clear or initialize the set of local registers assigned to a new procedure. Therefore, initial register contents are unpredictable. Also, because the processor does not initialize the local register save area in the newly created stack frame for the procedure, its contents are equally unpredictable.

## PROGRAMMING ENVIRONMENT

### 3.2.3 Register Scoreboarding

The processor uses register scoreboard to allow concurrent execution of sequential instructions. When an instruction that targets a destination register or group of registers executes, the processor sets a register-scoreboard bit to indicate that this register or group of registers are being used in an operation. If the instructions that follow do not require data from registers already in use, the processor can execute those instructions before the prior instruction execution completes.

Software can use this feature to execute one or more single-cycle instructions concurrently with a multi-cycle instruction (e.g., multiply or divide). Example 3-1 shows a case where register scoreboarding prevents a subsequent instruction from executing. It also illustrates overlapping instructions that do not have register dependencies.

#### Example 3-1. Register Scoreboarding

```
muli r4,r5,r6          # r6 is scoreboarded  
addi r6,r7,r8          # addi must wait for the previous multiply  
                        # to complete  
  
muli r4,r5,r10         # r10 is scoreboarded  
and r6,r7,r8           # and instruction is executed concurrently
```

### 3.2.4 Literals

The architecture defines a set of 32 literals that can be used as operands in many instructions. These literals are ordinal (unsigned) values that range from 0 to 31 (5 bits). When a literal is used as an operand, the processor expands it to 32 bits by adding leading zeros. If the instruction requires an operand larger than 32 bits, the processor zero-extends the value to the operand size. If a literal is used in an instruction that requires integer operands, the processor treats the literal as a positive integer value.

### 3.2.5 Register and Literal Addressing and Alignment

Several instructions operate on multiple-word operands. For example, the load long instruction (**ldl**) loads two words from memory into two consecutive registers. The register for the less-significant word is specified in the instruction. The more-significant word is automatically loaded into the next higher-numbered register.

In cases where an instruction specifies a register number and multiple, consecutive registers are implied, the register number must be even if two registers are accessed (e.g., g0, g2) and an integral multiple of 4 if three or four registers are accessed (e.g., g0, g4). If a register reference for a source value is not properly aligned, the source value is undefined and an **OPERATION.INVALID\_OPERAND** fault is generated. If a register reference for a destination value is not properly aligned, the registers to which the processor writes and the values written are

undefined. The processor then generates an OPERATION.INVALID\_OPERAND fault. The assembly language code in Example 3-2 shows an example of correct and incorrect register alignment.

### Example 3-2. Register Alignment

```
movl g3,g8          # INCORRECT ALIGNMENT - resulting value
.
.
.
movl g4,g8          # CORRECT ALIGNMENT
```

Global registers, local registers and literals are used directly as instruction operands. Table 3-2 lists instruction operands for each machine-level instruction format and positions which can be filled by each register or literal.

**Table 3-2. Allowable Register Operands**

|                      |                                 | Operand (1)    |                 |         |
|----------------------|---------------------------------|----------------|-----------------|---------|
| Instruction Encoding | Operand Field                   | Local Register | Global Register | Literal |
| <b>REG</b>           | <i>src1</i>                     | X              | X               | X       |
|                      | <i>src2</i>                     | X              | X               | X       |
|                      | <i>src/dst</i> (as <i>src</i> ) | X              | X               | X       |
|                      | <i>src/dst</i> (as <i>dst</i> ) | X              | X               |         |
|                      | <i>src/dst</i> (as both)        | X              | X               |         |
| <b>MEM</b>           | <i>src/dst</i>                  | X              | X               |         |
|                      | <i>abase</i>                    | X              | X               |         |
|                      | <i>index</i>                    | X              | X               |         |
| <b>COBR</b>          | <i>src1</i>                     | X              | X               |         |
|                      | <i>src2</i>                     | X              | X               |         |
|                      | <i>dst</i>                      | X (2)          | X (2)           |         |

**NOTES:**

1. "X" denotes the register can be used as an operand in a particular instruction field.
2. The **COBR** destination operands apply only to **TEST** instructions.

## 3.3 MEMORY-MAPPED CONTROL REGISTERS

The i960 Jx family gives software the interface to easily read and modify internal control registers. Each of these registers is accessed as a memory-mapped, 32-bit register with a unique memory address. Access is accomplished through regular word load and store instructions; the processor ensures that these accesses do not generate external bus cycles.

## PROGRAMMING ENVIRONMENT

### 3.3.1 Memory-Mapped Registers (MMR)

Portions of the Jx address space (addresses FF00 0000H through FFFF FFFFH) are reserved for memory-mapped registers. These memory-mapped registers (MMR) are accessed through word-operand memory instructions (**atmod**, **sysctl**, **ld** and **st** instructions) only. Accesses to this address space do not generate external bus cycles. The latency in accessing each of these registers is one cycle.

Each register has an associated access mode (user and supervisor modes) and access type (read and write accesses). Table 3-3, Table 3-4 and Table 3-5 show all the memory-mapped registers and the application mode of access.

The registers are partitioned into user and supervisor spaces based on their addresses. Addresses FF00 0000H through FF00 7FFFH are allocated to user space memory-mapped registers; Addresses FF00 8000H to FFFF FFFFH are allocated to supervisor space registers.

#### 3.3.1.1 Restrictions on Instructions that Access Memory-Mapped Registers

The majority of memory-mapped registers can be accessed by both load (**ld**) and store (**st**) instructions. However some registers have restrictions on the types of accesses they allow. To ensure correct operation, the access type restrictions for each register should be followed. The various access types are listed in Table 3-3. The allowed access types for each register are indicated in the access type column of Table 3-4 and Table 3-5.

Unless otherwise indicated by its access type, the modification of a memory-mapped register by a **st** instruction is ensured to take effect completely before the next instruction starts execution.

Some operations require an atomic-read-modify-write sequence to a register -- most notably IPND and IMSK. The **atmod** instruction provides a special mechanism to quickly modify the IPND and IMSK registers in an atomic manner; on the i960 Jx microprocessor, it should not be used on any other memory-mapped registers.

The **sysctl** instruction can also atomically modify the contents of a memory-mapped register; in addition, it is the only method to read the breakpoint registers on the i960 Jx microprocessor; the breakpoints can not be read using a **ld** instruction.

At initialization, the control table is automatically loaded into the on-chip control registers. This action simplifies the user's startup code by providing a transparent setup of the processor's peripherals. See CHAPTER 11, INITIALIZATION AND SYSTEM REQUIREMENTS.

### 3.3.1.2 Access Faults

Memory-mapped registers are meant to be accessed only as aligned, word-size registers with adherence to the appropriate access mode. Accessing these registers in any other way can result in faults or undefined operation. An access is performed using the following fault model:

1. The access must be a word-sized, word-aligned access; otherwise, an `operation.unimplemented` fault is generated.
2. If the access is a store in user mode to an implemented supervisor location, a `type.mismatch` fault is generated. It is unpredictable whether stores to unimplemented supervisor locations cause a fault.
3. If the access is neither of the above, the access is attempted. Note that a MMR may generate faults based on conditions specific to that MMR. (Example: trying to write the timer registers in user mode when they have been allocated to supervisor only.)
4. When a store access to a register faults, the processor ensures that the store does not take effect.
5. A load access of a reserved location returns an unpredictable value.
6. A store access to a reserved location should be avoided and is bad programming practice; such a store can result in undefined operation of the processor if the location is in supervisor space.

The i960 Jx microprocessor will ensure that faults resulting from MMR accesses are precise.

Instruction fetches from the memory-mapped register space are not allowed and result in an `operation.unimplemented` fault.

**Table 3-3. Access Types**

| <b>Access Type</b> |                                    | <b>Description</b>  |
|--------------------|------------------------------------|---|
| R                  | Read                               | Read ( <b>ld</b> instruction) accesses are allowed.   |
| RO                 | Read Only                          | Only Read ( <b>ld</b> instruction) accesses are allowed. Write ( <b>st</b> instruction) accesses are ignored.   |
| W                  | Write                              | Write ( <b>st</b> instruction) accesses allowed.  |
| R/W                | Read/Write                         | <b>ld</b> , <b>st</b> , and <b>sysctl</b> instructions are allowed access.  |
| WwG                | Write when Granted                 | Writing or Modifying (through a <b>st</b> or <b>sysctl</b> instruction) the register is only allowed when modification-rights to the register have been granted. An OPERATION.UNIMPLEMENTED fault occurs if an attempt is made to write the register before rights are granted. See section 10.2.7.2, "Hardware Breakpoints" (pg. 10-5).                        |
| Sysctl-RwG         | <b>sysctl</b><br>Read when Granted | The value of the register can only be read by executing a <b>sysctl</b> instruction issued with the modify memory-mapped register message type. Modification rights to the register must be granted first or an OPERATION.UNIMPLEMENTED fault occurs when the <b>sysctl</b> is executed. A <b>ld</b> instruction to the register returns unpredictable results. |
| AtMod              | <b>atmod</b><br>update             | Register can be updated quickly through the <b>atmod</b> instruction. The <b>atmod</b> ensures correct operation by performing the update of the register in an atomic manner which provides synchronization with previous and subsequent operations. This is a faster update mechanism than <b>sysctl</b> and is optimized for a few special registers,        |

Table 3-4. Supervisor Space Family Registers and Tables (Sheet 1 of 3)

| Register Name  | Memory-Mapped Address    | Access Type     |
|--|--------------------------|-----------------|
| <i>Reserved</i>  | FF00 8000H to FF00 80FFH | —               |
| (DLMCON) Default Logical Memory Configuration Register | FF00 8100H               | R/W             |
| <i>Reserved</i>  | FF00 8104H               | —               |
| (LMADR0) Logical Memory Address Register 0             | FF00 8108H               | R/W             |
| (LMMR0) Logical Memory Mask Register 0                 | FF00 810CH               | R/W             |
| (LMADR1) Logical Memory Address Register 1             | FF00 8110H               | R/W             |
| (LMMR1) Logical Memory Mask Register 1                 | FF00 8114H               | R/W             |
| <i>Reserved</i>  | FF00 8118H to FF00 83FFH | —               |
| (IPB0) Instruction Address Breakpoint Register 0       | FF00 8400H               | Sysctl- RwG/WwG |
| (IPB1) Instruction Address Breakpoint Register 1       | FF00 8404H               | Sysctl- RwG/WwG |
| <i>Reserved</i>  | FF00 8408H to FF00 841FH | —               |
| (DAB0) Data Address Breakpoint Register 0              | FF00 8420H               | R/W, WwG        |
| (DAB1) Data Address Breakpoint Register 1              | FF00 8424H               | R/W, WwG        |
| <i>Reserved</i>  | FF00 8428H to FF00 843FH | —               |
| (BPCON) Breakpoint Control Register                    | FF00 8440H               | R/W, WwG        |
| <i>Reserved</i>  | FF00 8444H to FF00 84FFH | —               |
| (IPND) Interrupt Pending Register                      | FF00 8500H               | R/W, AtMod      |
| (IMSK) Interrupt Mask Register                         | FF00 8504H               | R/W, AtMod      |
| <i>Reserved</i>  | FF00 8508H to FF00 850FH | —               |
| (ICON) Interrupt Control Word                          | FF00 8510H               | R/W             |
| <i>Reserved</i>  | FF00 8514H to FF00 851FH | —               |
| (IMAP0) Interrupt Map Register 0                       | FF00 8520H               | R/W             |
| (IMAP1) Interrupt Map Register 1                       | FF00 8524H               | R/W             |
| (IMAP2) Interrupt Map Register 2                       | FF00 8528H               | R/W             |
| <i>Reserved</i>  | FF00 852CH to FF00 85FFH | —               |

## PROGRAMMING ENVIRONMENT

**Table 3-4. Supervisor Space Family Registers and Tables (Sheet 2 of 3)**

| Register Name                                   | Memory-Mapped Address    | Access Type |
|---|--------------------------|-------------|
| (PMCON0_1) Physical Memory Control Register 0   | FF00 8600H               | R/W         |
| <i>Reserved</i>                                 | FF00 8604H               | —           |
| (PMCON2_3) Physical Memory Control Register 1   | FF00 8608H               | R/W         |
| <i>Reserved</i>                                 | FF00 860CH               | —           |
| (PMCON4_5) Physical Memory Control Register 2   | FF00 8610H               | R/W         |
| <i>Reserved</i>                                 | FF00 8614H               | —           |
| (PMCON6_7) Physical Memory Control Register 3   | FF00 8618H               | R/W         |
| <i>Reserved</i>                                 | FF00 861CH               | —           |
| (PMCON8_9) Physical Memory Control Register 4   | FF00 8620H               | R/W         |
| <i>Reserved</i>                                 | FF00 8624H               | —           |
| (PMCON10_11) Physical Memory Control Register 5 | FF00 8628H               | R/W         |
| <i>Reserved</i>                                 | FF00 862CH               | —           |
| (PMCON12_13) Physical Memory Control Register 6 | FF00 8630H               | R/W         |
| <i>Reserved</i>                                 | FF00 8634H               | —           |
| (PMCON14_15) Physical Memory Control Register 7 | FF00 8638H               | R/W         |
| <i>Reserved</i>                                 | FF00 863CH to FF00 86F8H | —           |
| (BCON) Bus Configuration Control Register       | FF00 86FCH               | R/W         |

**Table 3-4. Supervisor Space Family Registers and Tables (Sheet 3 of 3)**

| Register Name                          | Memory-Mapped Address    | Access Type |
|--|--------------------------|-------------|
| (PRCB) Processor Control Block Pointer | FF00 8700H               | RO          |
| (ISP) Interrupt Stack Pointer          | FF00 8704H               | R/W         |
| (SSP) Supervisor Stack Pointer         | FF00 8708H               | R/W         |
| <i>Reserved</i>                        | FF00 870CH               | —           |
| (DEVICEID) i960 Jx Device ID           | FF00 8710H               | RO          |
| <i>Reserved</i>                        | FF00 8714H to FFFF FFFFH | —           |

**Table 3-5. User Space Family Registers and Tables**

| Register Name                  | Memory-Mapped Address     | Access Type |
|--------------------------------|---------------------------|-------------|
| <i>Reserved</i>                | FF00 0000H to FF00 02FFH  | —           |
| (TRR0) Timer Reload Register 0 | FF00 0300H                | R/W         |
| (TCR0) Timer Count Register 0  | FF00 0304H                | R/W         |
| (TMR0) Timer Mode Register 0   | FF00 0308H                | R/W         |
| <i>Reserved</i>                | FF00 030CH                | —           |
| (TRR1) Timer Reload Register 1 | FF00 0310H                | R/W         |
| (TCR1) Timer Count Register 1  | FF00 0314H                | R/W         |
| (TMR1) Timer Mode Register 1   | FF00 0318H                | R/W         |
| <i>Reserved</i>                | FF00 031CH to FF00 7FFFFH | —           |

### 3.4 ARCHITECTURE-DEFINED DATA STRUCTURES

The architecture defines a set of data structures including stacks, interfaces to system procedures, interrupt handling procedures and fault handling procedures. Table 3-6 defines the data structures and references other sections of this manual where detailed information can be found.

**Table 3-6. Data Structure Descriptions**

| Structure (see also)  | Description   |
|---|---|
| <b>User and Supervisor Stacks</b><br>section 7.6, "USER AND SUPERVISOR STACKS" (pg. 7-19)   | The processor uses these stacks when executing application code.  |
| <b>System Procedure Table</b><br>section 3.7, "USER SUPERVISOR PROTECTION MODEL" (pg. 3-22)<br>section 7.5, "SYSTEM CALLS" (pg. 7-16)         | Contains pointers to system procedures. Application code uses the system call instruction ( <b>calls</b> ) to access system procedures through this table. A system supervisor call switches execution mode from user mode to supervisor mode. When the processor switches modes, it also switches to the supervisor stack.   |
| <b>Interrupt Table and Stack</b><br>section 8.4, "INTERRUPT TABLE" (pg. 8-3)<br>section 8.5, "INTERRUPT STACK AND INTERRUPT RECORD" (pg. 8-5) | Contains vectors (pointers) to interrupt handling procedures. When an interrupt is serviced, a particular interrupt table entry is specified. A separate interrupt stack is provided to ensure that interrupt handling does not interfere with application programs.  |
| <b>Fault Table</b><br>section 9.3, "FAULT TABLE" (pg. 9-4)  | Contains pointers to fault handling procedures. When the processor detects a fault, it selects a particular entry in the fault table. The architecture does not require a separate fault handling stack. Instead, a fault handling procedure uses the supervisor stack, user stack or interrupt stack, depending on processor execution mode in which the fault occurred and type of call made to the fault handling procedure. |
| <b>Control Table</b><br>section 11.3.3, "Control Table" (pg. 11-19)   | Contains on-chip control register values. Control table values are moved to on-chip registers at initialization or with <b>sysctl</b> .   |

The i960 Jx processor defines two initialization data structures: Initialization Boot Record (IBR) and Process Control Block (PRCB). These structures provide initialization data and pointers to other data structures in memory. When the processor is initialized, these pointers are read from the initialization data structures and cached for internal use.

Pointers to the system procedure table, interrupt table, interrupt stack, fault table and control table are specified in the processor control block. Supervisor stack location is specified in the system procedure table. User stack location is specified in the user's startup code. Of these structures, the system procedure table, fault table, control table and initialization data structures may be in ROM; the interrupt table and stacks must be in RAM. For software interrupts, the interrupt table must be located in RAM. This is to allow the processor to modify the interrupt table.

### 3.5 MEMORY ADDRESS SPACE

The i960 Jx processor's address space is byte-addressable with addresses running contiguously from 0 to  $2^{32}$ -1. Some is reserved or assigned special functions as shown in Figure 3-2.

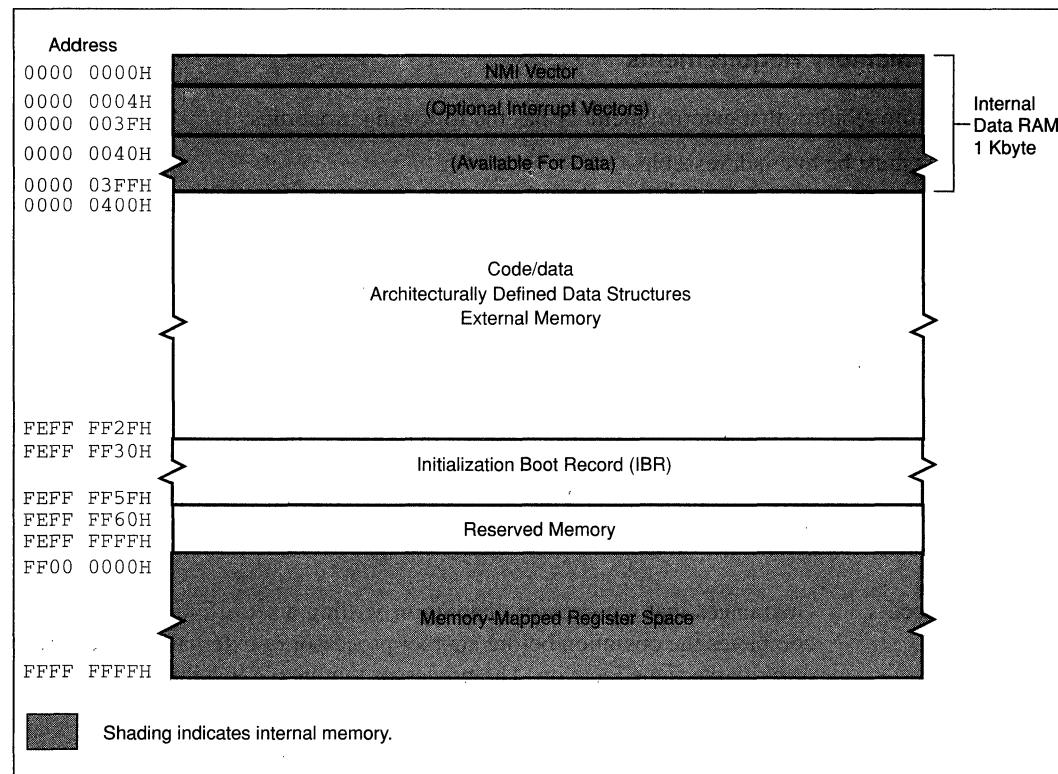


Figure 3-2. Memory Address Space

Physical addresses can be mapped to read-write memory, read-only memory and memory-mapped I/O. The architecture does not define a dedicated, addressable I/O space. There are no subdivisions of the address space such as segments. For memory management, an external memory management unit (MMU) may subdivide memory into pages or restrict access to certain areas of memory to protect a kernel's code, data and stack. However, the processor views this address space as linear.

## PROGRAMMING ENVIRONMENT

An address in memory is a 32-bit value in the range 0H to FFFF FFFFH. Depending on the instruction, an address can reference in memory a single byte, short word (2 bytes), word (4 bytes), double-word (8 bytes), triple-word (12 bytes) or quad-word (16 bytes). Refer to load and store instruction descriptions in CHAPTER 6, INSTRUCTION SET REFERENCE for multiple-byte addressing information.

### 3.5.1 Memory Requirements

The architecture requires that external memory has the following properties:

- Memory must be byte-addressable.
- Memory must support burst transfers (i.e., transfer blocks of up to 16 contiguous bytes or four sequential transfers).
- Physical memory must not be mapped to reserved addresses that are specifically used by the processor implementation.
- Memory must guarantee indivisible access (read or write) for addresses that fall within 16-byte boundaries.
- Memory must guarantee atomic access for addresses that fall within 16-byte boundaries.

The latter two capabilities — *indivisible* and *atomic* access — are required only when multiple processors or other external agents, such as DMA or graphics controllers, share a common memory.

indivisible access      Guarantees that a processor, reading or writing a set of memory locations, completes the operation before another processor or external agent can read or write the same location. The processor requires indivisible access within an aligned 16-byte block of memory.

atomic access      A read-modify-write operation. Here the external memory system must guarantee that — once a processor begins a read-modify-write operation on an aligned, 16-byte block of memory — it is allowed to complete the operation before another processor or external agent is allowed access to the same location. An atomic memory system can be implemented by using the LOCK signal to qualify hold requests from external bus agents. LOCK is asserted for the duration of an atomic memory operation.

The upper 16 Mbytes of the address space — addresses FF00 0000H through FFFF FFFFH — are reserved for implementation-specific functions. 80960Jx programs cannot use this address space except for accesses to memory-mapped registers. The processor will not generate any external bus cycles to this memory. As shown in Figure 3-2, the initialization boot record is located just below the i960 Jx processor's reserved memory.

The i960 Jx processor requires some special consideration when using the lower 1 Kbyte of address space (addresses 0000H-03FFH). Loads and stores directed to these addresses access internal memory; instruction fetches from these addresses are not allowed for this processor. See section 4.1, "INTERNAL DATA RAM" (pg. 4-1). No external bus cycles are generated to this address space.

### 3.5.2 Data and Instruction Alignment in the Address Space

Instructions, program data and architecturally defined data structures can be placed anywhere in non-reserved address space while adhering to these alignment requirements:

- Align instructions on word boundaries.
- Align all architecturally defined data structures on the boundaries specified in Table 3-7.
- Align instruction operands for the atomic instructions (**atadd**, **atmod**) to word boundaries in memory.

The i960 Jx processor can perform unaligned load or store accesses. The processor handles a non-aligned load or store request by:

- Automatically servicing a non-aligned memory access with microcode assistance as described in section 15.2.5, "Data Alignment" (pg. 15-22).
- After the access is completed, the processor generates an OPERATION.UNALIGNED fault.

The method of handling faults is selected at initialization based on the value of the Fault Configuration Word in the Process Control Block. See section 11.3.1.2, "Process Control Block (PRCB)" (pg. 11-14).

**Table 3-7. Alignment of Data Structures in the Address Space**

| Data Structure             | Alignment           |
|----------------------------|---------------------|
| System Procedure Table     | 4 byte              |
| Interrupt Table            | 4 byte              |
| Fault Table                | 4 byte              |
| Control Table              | 16 byte             |
| User Stack                 | 16 byte             |
| Supervisor Stack           | 16 byte             |
| Interrupt Stack            | 16 byte             |
| Process Control Block      | 16 byte             |
| Initialization Boot Record | Fixed at FFFF FF30H |

### 3.5.3 Byte, Word and Bit Addressing

The processor provides instructions for moving data blocks of various lengths from memory to registers (**LOAD**) and from registers to memory (**STORE**). Allowable sizes for blocks are bytes, short words (2 bytes), words (4 bytes), double words, triple words and quad words. For example, **stl** (store long) stores an 8 byte (double word) data block in memory.

The most efficient way to move data blocks longer than 16 bytes is to move them in quad-word increments, using quad-word instructions **ldq** and **stq**.

When a data block is stored in memory, normally the block's least significant byte is stored at a base memory address and the more significant bytes are stored at successively higher byte addresses. This method of ordering bytes in memory is referred to as "little endian" ordering.

The i960 Jx processor also provides the option for ordering bytes in an opposite manner in memory. The block's most significant byte is stored at the base address and the less significant bytes are stored at successively higher addresses. This byte ordering scheme — referred to as "big endian" — applies to data blocks which are short words or words. For more about byte ordering, see section 15.2.5, "Data Alignment" (pg. 15-22).

When loading a byte, short word or word from memory to a register, the block's least significant bit is always loaded in register bit 0. When loading double words, triple words and quad words, the least significant word is stored in the base register. The more significant words are then stored at successively higher numbered registers. Bits can only be addressed in data that resides in a register: bit 0 in a register is the least significant bit, bit 31 is the most significant bit.

### 3.5.4 Internal Data RAM

The i960 Jx processor has 1 Kbyte of on-chip data RAM. Only data accesses are allowed in this region. Portions of the data RAM can also be reserved for functions such as caching interrupt vectors. The internal RAM is fully described in CHAPTER 4, CACHE AND ON-CHIP DATA RAM.

### 3.5.5 Instruction Cache

The instruction cache enhances performance by reducing the number of instruction fetches from external memory. The cache provides fast execution of cached code and loops of code in the cache and also provides more bus bandwidth for data operations in external memory. The i960 JF and JD processors' instruction cache is a 4 Kbyte, two-way set associative cache, organized in two sets of four-word lines. i960 JA processors feature a 2 Kbyte instruction cache. For more information, see CHAPTER 4, CACHE AND ON-CHIP DATA RAM.

### 3.5.6 Data Cache

The data cache on the i960 JF and JD processors is a write-through 2 Kbyte direct-mapped cache. i960 JA processors feature a 1 Kbyte data cache. For more information, see CHAPTER 4, CACHE AND ON-CHIP DATA RAM.

## 3.6 PROCESSOR-STATE REGISTERS

The architecture defines four 32-bit registers that contain status and control information:

- Instruction Pointer (IP) register
- Process Controls (PC) register
- Arithmetic Controls (AC) register
- Trace Controls (TC) register

### 3.6.1 Instruction Pointer (IP) Register

The IP register contains the address of the instruction currently being executed. This address is 32 bits long; however, since instructions are required to be aligned on word boundaries in memory, the IP's two least-significant bits are always 0 (zero).

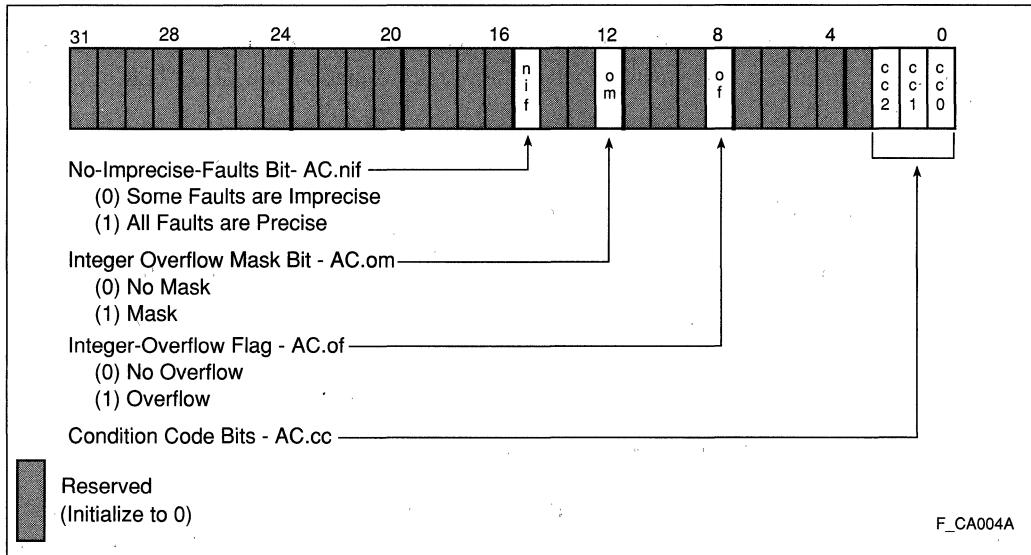
All i960 processor instructions are either one or two words long. The IP gives the address of the lowest-order byte of the first word of the instruction.

The IP register cannot be read directly. However, the IP-with-displacement addressing mode allows the IP to be used as an offset into the address space. This addressing mode can also be used with the **lda** (load address) instruction to read the current IP value.

When a break occurs in the instruction stream — due to an interrupt, procedure call or fault — the IP of the next instruction to be executed is stored in local register r2 which is usually referred to as the return IP or RIP register. Refer to CHAPTER 7, PROCEDURE CALLS for further discussion.

### 3.6.2 Arithmetic Controls (AC) Register

The AC register (Figure 3-3) contains condition code flags, integer overflow flag, mask bit and a bit that controls faulting on imprecise faults. Unused AC register bits are reserved.


**Figure 3-3. Arithmetic Controls (AC) Register**

### 3.6.2.1 Initializing and Modifying the AC Register

At initialization, the AC register is loaded from the Initial AC image field in the Process Control Block. Reserved bits are set to 0 in the AC Register Initial Image. Refer to CHAPTER 11, INITIALIZATION AND SYSTEM REQUIREMENTS.

After initialization, software must not modify or depend on the AC register's initial image in the PRCB. The modify arithmetic controls (**modac**) instruction can be used to examine and/or modify any of the register bits. This instruction provides a mask operand that can be used to limit access to the register's specific bits or groups of bits, such as the reserved bits.

The processor automatically saves and restores the AC register when it services an interrupt or handles a fault. The processor saves the current AC register state in an interrupt record or fault record, then restores the register upon returning from the interrupt or fault handler.

### 3.6.2.2 Condition Code

The processor sets the AC register's *condition code flags* (bits 0-2) to indicate the results of certain instructions, such as compare instructions. Other instructions, such as conditional branch instructions, examine these flags and perform functions as dictated by the state of the condition code flags. Once the processor sets the condition code flags, the flags remain unchanged until another instruction executes that modifies the field.

Condition code flags show true/false conditions, inequalities (greater than, equal or less than conditions) or carry and overflow conditions for the extended arithmetic instructions. To show true or false conditions, the processor sets the flags as shown in Table 3-8. To show equality and inequalities, the processor sets the condition code flags as shown in Table 3-9.

**Table 3-8. Condition Codes for True or False Conditions**

| Condition Code | Condition |
|----------------|-----------|
| $010_2$        | true      |
| $000_2$        | false     |

**Table 3-9. Condition Codes for Equality and Inequality Conditions**

| Condition Code | Condition           |
|----------------|---------------------|
| $000_2$        | unordered (false)   |
| $001_2$        | greater than (true) |
| $010_2$        | equal               |
| $100_2$        | less than           |

The terms *ordered* and *unordered* are used when comparing floating point numbers, which are not supported by the i960 Jx processor implementation.

To show carry out and overflow, the processor sets the condition code flags as shown in Table 3-10.

**Table 3-10. Condition Codes for Carry Out and Overflow**

| Condition Code | Condition |
|----------------|-----------|
| $01X_2$        | carry out |
| $0X1_2$        | overflow  |

Certain instructions, such as the branch-if instructions, use a 3 bit mask to evaluate the condition code flags. For example, the branch-if-greater-or-equal instruction (**bge**) uses a mask of  $011_2$  to determine if the condition code is set to either greater-than or equal. Conditional instructions use similar masks for the remaining conditions such as: greater-or-equal ( $011_2$ ), less-or-equal ( $110_2$ ) and not-equal ( $101_2$ ). The mask is part of the instruction opcode; the instruction performs a bitwise AND of the mask and condition code.

## PROGRAMMING ENVIRONMENT

The AC register *integer overflow flag* (bit 8) and *integer overflow mask bit* (bit 12) are used in conjunction with the arithmetic-integer-overflow fault. The mask bit disables fault generation. When the fault is masked and integer overflow is encountered, the processor — instead of generating a fault — sets the integer overflow flag. If the fault is not masked, the fault is allowed to occur and the flag is not set.

Once the processor sets this flag, it never implicitly clears it; the flag remains set until the program clears it. Refer to the discussion of the arithmetic-integer-overflow fault in CHAPTER 9, FAULTS for more information about the integer overflow mask bit and flag.

The *no imprecise faults bit* (bit 15) determines whether or not faults are allowed to be imprecise. If set, all faults are required to be precise; if clear, certain faults can be imprecise. See section 9.9, “PRECISE AND IMPRECISE FAULTS” (pg. 9-19) for more information.

### 3.6.3 Process Controls (PC) Register

The PC register (Figure 3-4) is used to control processor activity and show the processor’s current state. PC register *execution mode flag* (bit 1) indicates that the processor is operating in either user mode (0) or supervisor mode (1). The processor automatically sets this flag on a system call when a switch from user mode to supervisor mode occurs and it clears the flag on a return from supervisor mode. (User and supervisor modes are described in section 3.7, “USER SUPERVISOR PROTECTION MODEL” (pg. 3-22).

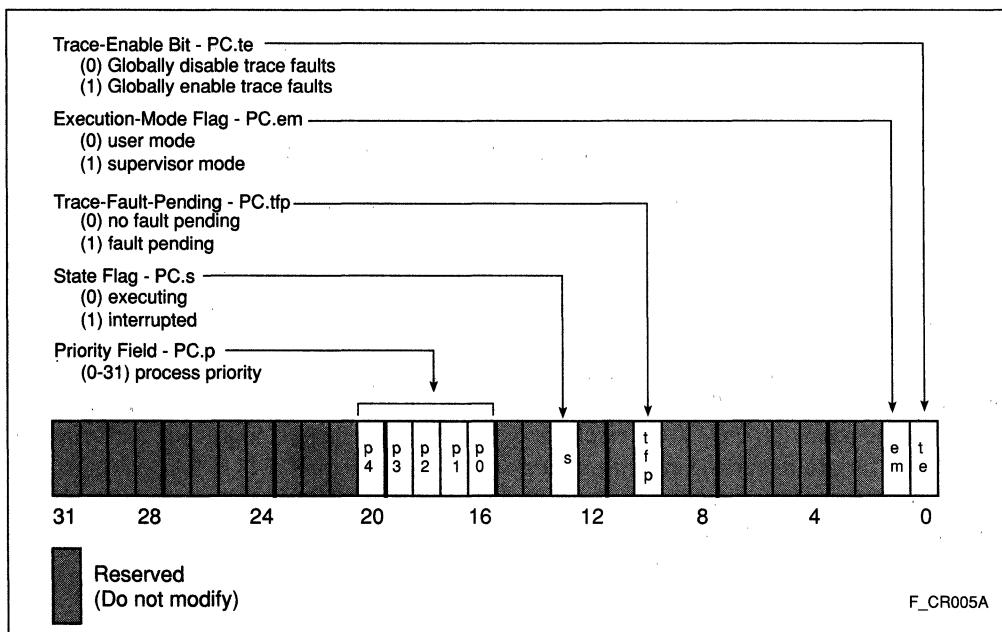


Figure 3-4. Process Controls (PC) Register

PC register *state flag* (bit 13) indicates processor state: executing (0) or interrupted (1). If the processor is servicing an interrupt, its state is interrupted. Otherwise, the processor's state is executing.

While in the interrupted state, the processor can receive and handle additional interrupts. When nested interrupts occur, the processor remains in the interrupted state until all interrupts are handled, then switches back to executing state on the return from the initial interrupt procedure.

PC register *priority field* (bits 16 through 20) indicates the processor's current executing or interrupted priority. The architecture defines a mechanism for prioritizing execution of code, servicing interrupts and servicing other implementation-dependent tasks or events. This mechanism defines 32 priority levels, ranging from 0 (the lowest priority level) to 31 (the highest). The priority field always reflects the current priority of the processor. Software can change this priority by use of the **modpc** instruction.

The processor uses the priority field to determine whether to service an interrupt immediately or to post the interrupt. The processor compares the priority of a requested interrupt with the current process priority. When the interrupt priority is greater than the current process priority or equal to 31, the interrupt is serviced; otherwise it is posted. When an interrupt is serviced, the process priority field is automatically changed to reflect interrupt priority. See CHAPTER 13, INTERRUPT CONTROLLER.

PC register *trace enable bit* (bit 0) and *trace fault pending flag* (bit 10) control the tracing function. The trace enable bit determines whether trace faults are globally enabled (1) or globally disabled (0). The trace fault pending flag indicates that a trace event has been detected (1) or not detected (0). The tracing function are further described in Chapter 10.

### 3.6.3.1 Initializing and Modifying the PC Register

Any of the following three methods can be used to change bits in the PC register:

- Modify process controls instruction (**modpc**)
- Alter the saved process controls prior to a return from an interrupt handler
- Alter the saved process controls prior to a return from a fault handler

**modpc** directly reads and modifies the PC register. A TYPE.MISMATCH fault is generated if **modpc** is executed in user mode with a non-zero mask. As with **modac**, **modpc** provides a mask operand that can be used to limit access to specific bits or groups of bits in the register. **modpc** can be used in user mode to read the current PC register.

In the latter two methods, the interrupt or fault handler changes process controls in the interrupt or fault record that is saved on the stack. Upon return from the interrupt or fault handler, the modified process controls are copied into the PC register. The processor must be in supervisor mode prior to return for modified process controls to be copied into the PC register.

## PROGRAMMING ENVIRONMENT

When process controls are changed as described above, the processor recognizes the changes immediately except for one situation: if **modpc** is used to change the trace enable bit, the processor may not recognize the change before the next four non-branch instructions are executed.

After initialization (hardware reset), the process controls reflect the following conditions:

- priority = 31
- execution mode = supervisor
- trace enable = disabled
- state = interrupted

When the processor is reinitialized with a **sysctl** reinitialize message, the PC register is not changed.

Normally, **modpc** is not used to modify execution mode or trace fault state flags except under special circumstances, such as in initialization code.

### 3.6.4 Trace Controls (TC) Register

The TC register, in conjunction with the PC register, controls processor tracing facilities. It contains trace mode enable bits and trace event flags which are used to enable specific tracing modes and record trace events, respectively. Trace controls are described in CHAPTER 10, TRACING AND DEBUGGING.

## 3.7 USER SUPERVISOR PROTECTION MODEL

The processor can be in either of two execution modes: user or supervisor. The capability of a separate user and supervisor execution mode creates a code and data protection mechanism referred to as the user supervisor protection model. This mechanism allows code, data and stack for a kernel (or system executive) to reside in the same address space as code, data and stack for the application. The mechanism restricts access to all or parts of the kernel by the application code. This protection mechanism prevents application software from inadvertently altering the kernel.

### 3.7.1 Supervisor Mode Resources

Supervisor mode is a privileged mode which provides several additional capabilities over user mode.

- When the processor switches to supervisor mode, it also switches to the supervisor stack. Switching to the supervisor stack helps maintain a kernel's integrity. For example, it allows system debugging software or a system monitor to be accessed, even if an application's program destroys its own stack.

- In supervisor mode, the processor is allowed access to a set of supervisor-only functions and instructions. For example, the processor uses supervisor mode to handle interrupts and trace faults. Operations that can modify interrupt controller behavior or reconfigure bus controller characteristics can only be performed in supervisor mode. These functions include modification of control registers or internal data RAM that is dedicated to interrupt controllers. A fault is generated if supervisor-only operations are attempted while the processor is in user mode. Table 3-11 lists supervisor-only operations and the fault which is generated if the operation is attempted in user mode.

The PC register execution mode flag specifies processor execution mode. The processor automatically sets and clears this flag when it switches between the two execution modes.

**Table 3-11. Supervisor-Only Operations and Faults Generated in User Mode**

| Supervisor-Only Operation                                 | User-Mode Fault |
|---|-----------------|
| dcctl (data cache control)                                | TYPE.MISMATCH   |
| halt (halt CPU)   | TYPE.MISMATCH   |
| icctl (instruction cache control)                         | TYPE.MISMATCH   |
| intctl (global interrupt enable and disable)              | TYPE.MISMATCH   |
| intdis (global interrupt disable)                         | TYPE.MISMATCH   |
| inten (global interrupt enable)                           | TYPE.MISMATCH   |
| <b>modpc</b> (modify process controls w/ non-zero mask)   | TYPE.MISMATCH   |
| <b>sysctl</b> (system control)                            | TYPE.MISMATCH   |
| Protected internal data RAM or Supervisor MMR space write | TYPE.MISMATCH   |
| Protected timer unit registers                            | TYPE.MISMATCH   |

### 3.7.2 Using the User-Supervisor Protection Model

A program switches from user mode to supervisor mode by making a system-supervisor call (also referred to as a supervisor call). A system-supervisor call is a call executed with the call-system instruction (**calls**). With **calls**, the IP for the called procedure comes from the system procedure table. An entry in the system procedure table can specify an execution mode switch to supervisor mode when the called procedure is executed. **calls** and the system procedure table thus provide a tightly controlled interface to procedures which can execute in supervisor mode. Once the processor switches to supervisor mode, it remains in that mode until a return is performed to the procedure that caused the original mode switch.

## PROGRAMMING ENVIRONMENT

Interrupts and faults can cause the processor to switch from user to supervisor mode. When the processor handles an interrupt, it automatically switches to supervisor mode. However, it does not switch to the supervisor stack. Instead, it switches to the interrupt stack. Fault table entries determine if a particular fault will transition the processor from user to supervisor mode.

If an application does not require a user-supervisor protection mechanism, the processor can always execute in supervisor mode. At initialization, the processor is placed in supervisor mode prior to executing the first instruction of the application code. The processor then remains in supervisor mode indefinitely, as long as no action is taken to change execution mode to user mode. The processor does not need a user stack in this case.



4

## CACHE AND ON-CHIP DATA RAM



# CHAPTER 4

## CACHE AND ON-CHIP DATA RAM

This chapter describes the structure and user configuration of all forms of on-chip storage, including caches (data, local register and instruction) and data RAM.

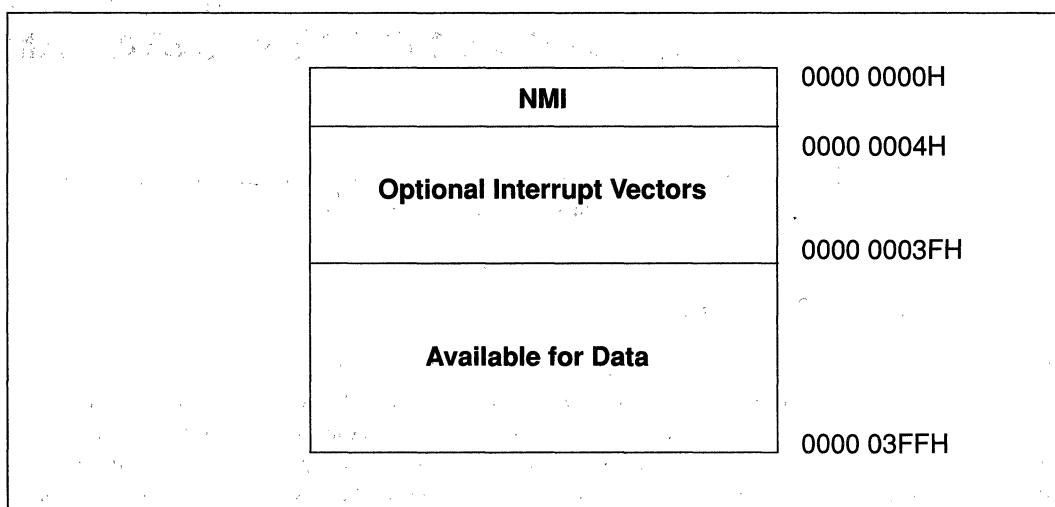
### 4.1 INTERNAL DATA RAM

Internal data RAM is mapped to the lower 1 Kbyte (0 to 03FFH) of the address space. Loads and stores, with target addresses in internal data RAM, operate directly on the internal data RAM; no external bus activity is generated. Data RAM allows time-critical data storage and retrieval without dependence on external bus performance. Only data accesses are allowed to the internal data RAM; instructions cannot be fetched from the internal data RAM. Instruction fetches directed to the data RAM cause an OPERATION.UNIMPLEMENTED fault to occur.

Internal data RAM locations are never cached in the data cache. Logical Memory Template bits controlling caching are ignored for data RAM accesses. However, the byte-ordering of the internal data RAM is controlled by the byte-endian control bit in the DLMCON register.

Some internal data RAM locations are reserved for alternate functions other than general data storage. The first 64 bytes of data RAM may be used to cache interrupt vectors; this reduces latency for these interrupts. The word at location 0000H is always reserved for the cached NMI vector. With the exception of the cached NMI vector, other reserved portions of the data RAM can be used for data storage when the alternate function is not used. All locations of the internal data RAM can be read in both supervisor and user mode.

The first 64 bytes (0000H to 003FH) of internal RAM are always user-mode write-protected. This portion of data RAM can be read while executing in user or supervisor mode; however, it can only be modified in supervisor mode. This area can also be write-protected from supervisor mode writes by setting the BCON.SIRP bit. See section 12.4, “Physical Memory Attributes at Initialization” (pg. 12-6). Protecting this portion of the data RAM from user and supervisor rights preserves the interrupt vectors that may be cached there. See section 13.5.2.1, “Vector Caching Option” (pg. 13-22).



**Figure 4-1. Internal Data RAM**

The remainder of the internal data RAM can always be written from supervisor mode. User mode write protection is optionally selected for the rest of the data RAM (40H to 3FFH) by setting the Bus Configuration Register RAM protection bit (BCON.irp). Writes to internal data RAM locations while they are protected generate a TYPE.MISMATCH fault. See section 12.4.1, “Bus Control (BCON) Register” (pg. 12-6), for the format of the BCON register.

New versions of i960 processor compilers can take advantage of internal data RAM; profiling compilers, such as those offered by Intel, can allocate the most frequently used variables into this RAM.

## 4.2 LOCAL REGISTER CACHE

The i960 Jx processor provides fast storage of local registers for call and return operations by using an internal local register cache (also known as a stack frame cache). Up to eight local register sets can be contained in the cache before sets must be saved in external memory. The register set is all the registers (i.e. r0 through r15). The processor uses a 128-bit wide bus to store local register sets quickly to the register cache. An integrated procedure call mechanism saves the current local register set when a call is executed. A local register set is saved into a frame in the local register cache, one frame per register set. When the eighth frame is saved, the oldest set of local registers is flushed to the stack in external memory, which frees one frame.

To decrease interrupt latency, software can reserve a number of frames in the local register cache solely for high priority interrupts (interrupted state and process priority greater than or equal to 28). The remaining frames in the cache can be used by all code including high-priority interrupts. When a frame is reserved for high-priority interrupts, the local registers of the code interrupted by a high-priority interrupt can be saved to the local register cache without causing a frame flush to memory. This providing that the local register cache is not already full. Thus, the register allocation for the implicit interrupt call does not incur the latency of a frame flush.

Software can reserve frames for high-priority interrupt code by writing bits 10 through 8 of the register cache configuration word in the PRCB. This value indicates the number of free frames within the register cache that can be used by high-priority interrupts only. Any attempt by non-critical code to reduce the number of free frames below this value will result in a frame flush to external memory. The free frame check is performed only when a frame is pushed, which occurs only for an implicit or explicit call. The following pseudo-code illustrates the operation of the register cache when a frame is pushed:

```
frames_for_non_critical = 7 - RCW[10:8];
    if (interrupt_request)
        set_interrupt_handler_PC;
    push_frame;
    number_of_frames = number_of_frames + 1;
    if (number_of_frames = 8) {
        flush_register_frame(bottom_of_stack);
        number_of_frames = number_of_frames - 1; }
    else if ( number_of_frames = (frames_for_non_critical + 1)
&&
        (PC.priority < 28 || PC.state != interrupted) )
        { flush_register_frame(bottom_of_stack);
        number_of_frames = number_of_frames - 1; }
```

The valid range for the number of reserved free frames is 0 to 7. Setting the value to 0 reserves no frames for exclusive-use by high-priority interrupts. Setting the value to 1, reserves 1 frame for high-priority interrupts and 6 frames to be shared by all code. Setting the value to 7 causes the register cache to become disabled for non-critical code.

#### 4.3 BIG ENDIAN ACCESSES TO INTERNAL RAM AND DATA CACHE

Big-endian accesses to the internal data-RAM and data cache are supported. The default byte-order for data accesses is programmed in DLMCON.be to be either little or big-endian. On the i960 Jx processor DLMCON.be controls the default byte-order for all internal (i.e. on-chip data ram and data cache) and external accesses. See section 12.6, “Programming the Logical Memory Attributes” (pg. 12-8) for more details.

## CACHE AND ON-CHIP DATA RAM

### 4.4 INSTRUCTION CACHE

The i960 JF and JD processors feature a 4 Kbyte, 2-way set associative instruction cache organized in lines of four 32-bit words. The JA processor features a 2 Kbyte, 2-way set associative instruction cache. The cache provides fast execution of cached code and loops of code in the cache and provides more bus bandwidth for data operations in external memory. To optimize cache updates when branches or interrupts are executed, each word in the line has a separate valid bit. When requested instructions are found in the cache, the instruction fetch time is one cycle for up to four words.

A mechanism to lock critical code within a way of the cache is provided as well as a mechanism to disable the cache. The cache is managed through the **icctl** and **sysctl** instructions.

Cache misses cause the processor to issue a double-word or a quad-word fetch, based on the location of the Instruction Pointer:

- If the IP is at word 0 or word 1 of a 16-byte block, a four-word fetch is initiated.
- If the IP is at word 2 or word 3 of a 16-byte block, a two-word fetch is initiated.

#### 4.4.1 Enabling and Disabling the Instruction Cache

Enabling the instruction cache is controlled on reset or initialization by the instruction cache configuration word in the Process Control Block (PRCB), see Figure 11-6. If bit 16 in the instruction cache configuration word is set, the instruction cache is disabled and all instruction fetches are directed to external memory. Disabling the instruction cache is useful for tracing execution in a software debug environment.

The instruction cache remains disabled until one of three operations is performed:

- The processor is reinitialized with a new value in the instruction cache configuration word
- **icctl** is issued with the enable instruction cache operation
- **sysctl** is issued with the configure instruction cache message type and cache configuration mode other than disable cache

#### 4.4.2 Operation While The Instruction Cache Is Disabled

Disabling the instruction cache *does not* disable the instruction buffering that may occur within the instruction fetch unit. A four-word instruction buffer is always enabled, even when the cache is disabled.

There is one tag and four word-valid bits associated with the buffer. Because there is only one tag for the buffer, any “miss” within the buffer causes the following:

- All four words of the buffer are invalidated.
- A new tag value for the required instruction is loaded.
- The required instruction(s) are fetched from external memory.

Depending on the alignment of the “missed” instruction, either two or four words of instructions are fetched and only the valid bits corresponding to the fetched words are set in the buffer. No external instruction fetches are generated until there is a “miss” within the buffer, even in the presence of forward and backward branches.

#### 4.4.3 Locking Instructions in the Instruction Cache

The processor can be directed to load a block of instructions into the cache and then disable all normal updates to the cache. This cache load-and-lock mechanism is provided to minimize latency on program control transfers to key operations such as interrupt service routines. The block size that can be loaded and locked on the i960 Jx microprocessor is one way of the cache.

An **icctl** or **sysctl** instruction is issued with a configure-instruction-cache message type to select the load-and-lock mechanism. When the lock option is selected, the processor loads the cache starting at an address specified as an operand to the instruction.

#### 4.4.4 Instruction Cache Visibility

Instruction cache status can be determined with an **icctl** issued with an instruction-cache status message. To facilitate debugging, the instruction cache contents, instructions, tags and valid bits can be written to memory. This is done by an **icctl** that is issued with the store cache operation.

#### 4.4.5 Instruction Cache Coherency

Bus snooping is not implemented in the i960 Jx instruction cache. The cache does not detect modification to program memory by loads, stores or actions of other bus masters. Several situations may require program memory modification, such as uploading code at initialization or uploading code from a backplane bus or a disk drive.

The application program is responsible for synchronizing its own code modification and cache invalidation. In general, a program must ensure that modified code space is not accessed until modification and cache-invalidate are completed. To achieve cache coherency, instruction cache contents should be invalidated after code modification is complete. Both the **icctl** and the **sysctl** instruction can be used to invalidate the instruction cache for the i960 Jx component.

## CACHE AND ON-CHIP DATA RAM

### 4.5 DATA CACHE

The i960 JF and JD processors feature a 2 Kbyte, direct-mapped cache which enhances performance by reducing the number of data load and store accesses to external memory. i960 JA processors have a 1 Kbyte data cache. The cache is write-through and write-allocate (as is the i960 CF processor data cache). It has a line size of 4 words and implement a “natural” fill policy. Each line in the cache has a valid bit. To reduce fetch latency on cache misses, each word within a line also has a valid bit. Caches are managed through the **dcctl** instruction.

User settings in the memory region configuration registers LMCON0-1 and DLMCON determine which data accesses are cacheable or non-cacheable based on memory region.

#### 4.5.1 Enabling and Disabling the Data Cache

To cache data, two conditions must be ensured:

1. The data cache must be globally enabled. A **dcctl** issued with an enable data cache message will enable the cache. On reset or initialization, the data cache is always disabled and all valid bits are set to zero.
2. Data caching for a location must be enabled by the corresponding logical memory template, or by the default logical memory template if no other template applies. See section 12.6, “Programming the Logical Memory Attributes” (pg. 12-8) for more details on logical memory templates.

When the data cache is disabled, all data fetches are directed to external memory. Disabling the data cache is useful for debugging or monitoring a system. To disable the data cache, issue a **dcctl** with a disable data cache message. The enable and disable status of the data cache and various attributes of the cache can be determined by an **dcctl** issued with a data-cache status message.

#### 4.5.2 Multi-Word Data Access that Partially Hit the Data Cache

The following applies only when data caching is enabled for an access.

For a multi-word load access (**ldl**, **ldt**, **ldq**) in which none of the requested words hit the data cache, an external bus transaction is started to acquire all the words of the access.

For a multi-word load access that partially hits the data-cache, the processor may either:

- Load or reload all words of the access (even those that hit) from the external bus.
- Load only missing words from the external bus and interleave them with words found in the data cache.

The multi-word alignment determines which of the above methods is used:

- Naturally aligned multi-word causes all words to be reloaded.
- An unaligned multi-word access causes only missing words to be loaded.

Regardless of which method is used, only locations within the data-cache that missed are updated by the results of the external memory request. Locations that hit are not updated by the external memory request. (This ensures coherency between word stores and multi-word loads.) In each case, the external bus accesses used to acquire the data may consist of none, one, or several burst accesses based on the alignment of the data and the bus-width of the memory region that contains the data. (See Chapter 15, EXTERNAL BUS for more details.)

A multi-word load access that completely hits in the data cache does not cause external bus accesses.

For a multi-word store access (**stl**, **stt**, **stq**) an external bus transaction is started to write all words of the access regardless if any or all words of the access hit the data cache. External bus accesses used to write the data may consist of none, one, or several burst accesses based on data alignment and the bus-width of the memory region that receives the data. (See Chapter 15, EXTERNAL BUS for more details.) The cache is also updated accordingly as described earlier in this chapter.

#### 4.5.3 Data Cache Fill Policy

The i960 Jx processor always uses a “natural” fill policy for cacheable loads. The processor fetches only the amount of data that is requested by a load (i.e. a word, long word, etc.) on a data cache miss. Exceptions are byte and short-word accesses, which are always promoted to words. This allows a complete word to be brought into the cache and marked valid.

#### 4.5.4 Data Cache Write Policy

The write policy determines what happens on cacheable writes (stores). The i960 Jx processor always uses a write-through policy. The result of a store is always propagated to external memory regardless of whether the store is a hit or miss. Stores are always seen on the external bus; this maintains coherency between the data cache and external memory.

## CACHE AND ON-CHIP DATA RAM

The i960 Jx processor always uses a write-allocate policy for data. For a cacheable location, data is always written to the data cache regardless of whether the access is a hit or miss. The following cases are relevant to consider:

1. In the case of a hit for a word or multi-word store, the appropriate line and word(s) are updated with the data.
2. In the case of a miss for a word or multi-word store, a tag and cache line are allocated, if needed, and the appropriate valid bits, line, and word(s) are updated.
3. In the case of a byte or short-word datum that hits a valid word in the cache, both the word in cache and external memory are updated with the datum; the cache word remains valid.
4. In the case of a byte or short-word datum that falls within a valid line, but, misses because the appropriate word is invalid, both the word and external memory are updated with the datum; however, the cache word remains invalid.
5. In the case of a byte or short-word datum that does not fall within a valid line: a tag and cache line are allocated; the appropriate cache word and external memory are updated with the datum; and the cache line and all cache words are made invalid.

For cacheable stores that are equal to or greater than a word in length, cache tags and appropriate valid bits are updated whenever data is written into the cache. Consider a word store as an example. The tag is always updated and its valid bit is set. The appropriate valid bit for that word is always set and the other three valid bits are always cleared.

Cacheable stores that are less than a word in length are handled differently. Byte and short-word stores that hit the cache (i.e., are contained in valid words within valid cache lines) do not change the tag and valid bits. The processor writes the data into the cache and external memory as usual. A byte or short-word store to an invalid word within a valid cache line leaves the word valid bit cleared because the rest of the word is still invalid. In all cases the processor simultaneously writes the data into the cache and the external memory.

### 4.5.5 Data Cache Coherency and Non-cacheable Accesses

The i960 Jx processor ensures that the data cache is always kept coherent with accesses that it initiates and performs. The most visible application of this requirement concerns non-cacheable accesses discussed below. However, the processor does not provide data-cache coherency for accesses on the external bus that it did not initiate. Software is responsible for maintaining coherency in a multi-processor environment.

An access is defined as non-cacheable if any of the following are true:

1. The access falls into an address range mapped by an enabled LMC0N pair or DLMCON and the data-caching enabled bit in the matching LMC0N is clear.
2. The entire data cache is disabled.
3. The access is a read operation of the read-modify-write sequence performed by an **atmod** or **atadd** instruction.
4. The access is an implicit read access to the interrupt table to post or deliver a software interrupt.

If the address for a non-cacheable store matches a tag (“tag hit”), the corresponding cache line will still remain valid, but the appropriate word valid bit will be marked invalid. This is because the word is not actually updated with the value of the store. This ensures that the data cache never contains stale data in a single-processor system. A simple case illustrates the necessity of this behavior: a read of a datum previously stored by a non-cacheable access must return the new value of the datum, not the value in the cache. Because the processor invalidates the appropriate word in the cache line on a store hit when the cache is disabled, coherency can be maintained when the data cache is enabled and disabled dynamically.

#### 4.5.6 External I/O and Bus Masters and Cache Coherency

The i960 Jx processor implements a single processor coherency mechanism. There is no hardware mechanism — such as bus snooping — to support multiprocessing. If another bus master can change shared memory, there is no guarantee that the data cache contains the most recent data. The user must manage such data coherency issues in software.

A suggested practice is to program the LMC0N0-1 registers such that I/O regions are non-cacheable. Partitioning the system in this fashion eliminates I/O as a source of coherency problems.

#### 4.5.7 Data Cache Visibility

Data cache status can be determined by an **dcctl** issued with a data-cache status message.

Data cache contents, data, tags and valid bits can be written to memory as an aid for debugging. This is accomplished by a **dcctl** that is issued with the dump cache operand.

## CACHE AND ON-CHIP DATA RAM





5

## INSTRUCTION SET OVERVIEW



# CHAPTER 5 INSTRUCTION SET OVERVIEW

This chapter provides an overview of the i960® microprocessor family's instruction set and i960 Jx processor-specific instruction set extensions. Also discussed are the assembly-language and instruction-encoding formats, various instruction groups and each group's instructions.

CHAPTER 6, INSTRUCTION SET REFERENCE describes each instruction — including assembly language syntax — and the action taken when the instruction executes and examples of how to use the instruction.

## 5.1 INSTRUCTION FORMATS

80960Jx instructions may be described in two formats: assembly language and instruction encoding. The following subsections briefly describe these formats.

### 5.1.1 Assembly Language Format

Throughout this manual, instructions are referred to by their assembly language mnemonics. For example, the add ordinal instruction is referred to as **addo**. Examples use Intel 80960 assembler assembly language syntax which consists of the instruction mnemonic followed by zero to three operands, separated by commas. In the following assembly language statement example for **addo**, ordinal operands in global registers g5 and g9 are added together; the result is stored in g7:

addo g5, g9, g7    # g7 = g9 + g5

In the assembly language listings in this chapter, registers are denoted as:

|   |                               |   |                |
|---|-------------------------------|---|----------------|
| g | global register               | r | local register |
| # | pound sign precedes a comment |   |                |

All numbers used as literals or in address expressions are assumed to be decimal. Hexadecimal numbers are denoted with a “0x” prefix (e.g., 0xffff0012). Several assembly language instruction statement examples follow. Additional assembly language examples are given in section 2.3.5, “Addressing Mode Examples” (pg. 2-8). Further information about syntax can be found in an assembly language manual for the Intel i960® Processor.

```
subi r3, r5, r6      #r6 ← r5 - r3
setbit 13, g4, g5    #g5 ← g4 with bit 13 set
lda 0xfab3, r12     #r12← 0xfab3
ld (r4), g3          #g3 ← memory location that r4 points to
st g10, (r6)[r7*2]  #g10← memory location that r6+2*r7 points to
```

## INSTRUCTION SET OVERVIEW

### 5.1.2 Instruction Encoding Formats

All instructions are encoded in one 32-bit machine language instruction — also known as an *opword* — which must be word aligned in memory. An opword's most significant eight bits contain the opcode field. The opcode field determines the instruction to be performed and how the remainder of the machine language instruction is interpreted. Instructions are encoded in opwords in one of four formats (see Figure 5-1).

| Instruction Type   | Format | Description  |
|--------------------|--------|--|
| register           | REG    | Most instructions are encoded in this format. Used primarily for instructions which perform register-to-register operations.   |
| compare and branch | COBR   | An encoding optimization which combines compare and branch operations into one opword. Other compare and branch operations are also provided as REG and CTRL format instructions.  |
| control            | CTRL   | Used for branches and calls that do not depend on registers for address calculation.   |
| memory             | MEM    | Used for referencing an operand which is a memory address. Load and store instructions — and some branch and call instructions — use this format. MEM format has two encodings: MEMA or MEMB. Usage depends upon the addressing mode selected. MEMB-formatted addressing modes use the word in memory immediately following the instruction opword as a 32-bit constant. |

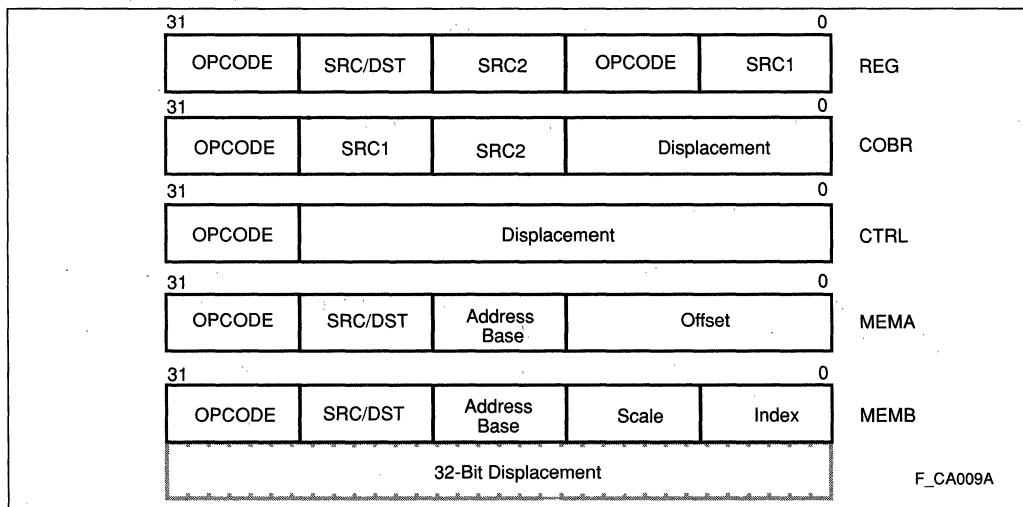


Figure 5-1. Machine-Level Instruction Formats

### 5.1.3 Instruction Operands

This section identifies and describes operands that can be used with the instruction formats.

| Format | Operand(s)                      | Description  |
|--------|---------------------------------|--|
| REG    | <i>src1, src2, src/dst</i>      | <i>src1</i> and <i>src2</i> can be global registers, local registers or literals. <i>src/dst</i> is either a global or a local register.   |
| CTRL   | <i>displacement</i>             | CTRL format is used for branch and call instructions. <i>displacement</i> value indicates the target instruction of the branch or call.  |
| COBR   | <i>src1, src2, displacement</i> | <i>src1, src2</i> indicate values to be compared; <i>displacement</i> indicates branch target. <i>src1</i> can specify a global register, local register or a literal. <i>src2</i> can specify a global or local register.   |
| MEM    | <i>src/dst, efa</i>             | Specifies source or destination register and an effective address ( <i>efa</i> ) formed by using the processor's addressing modes as described in section 2.3, "MEMORY ADDRESSING MODES" (pg. 2-6). Registers specified in a MEM format instruction must be either a global or local register. |

## 5.2 INSTRUCTION GROUPS

The i960 processor instruction set can be categorized into the following functional groups:

- Data Movement
- Bit, Bit Field and Byte
- Call/Return
- Atomic
- Arithmetic (Ordinal and Integer)
- Comparison
- Fault
- Processor Management
- Logical
- Branch
- Debug

Notice that the i960 Jx processor does not support the floating point instruction group of the 80960KB and 80960SB microprocessors. Table 5-1 shows the instructions in each group. The actual number of instructions is greater than those shown in this list because — for some operations — several unique instructions are provided to handle various operand sizes, data types or branch conditions. The following sections briefly overview the instructions in each group.

### 5.2.1 Data Movement

These instructions are used to move data from memory to global and local registers, from global and local registers to memory, and between local and global registers.



## INSTRUCTION SET OVERVIEW

Table 5-1. 80960JA/JF Instruction Set

| Data Movement         | Arithmetic                 | Logical         | Bit, Bit Field and Byte |
|-----------------------|----------------------------|-----------------|-------------------------|
| Load                  | Add                        | And             | Set Bit                 |
| Store                 | Subtract                   | Not And         | Clear Bit               |
| Move                  | Multiply                   | And Not         | Not Bit                 |
| *Conditional Select   | Divide                     | Or              | Alter Bit               |
| Load Address          | Remainder                  | Exclusive Or    | Scan For Bit            |
|                       | Modulo                     | Not Or          | Span Over Bit           |
|                       | Shift                      | Or Not          | Extract                 |
|                       | Extended Shift             | Nor             | Modify                  |
|                       | Extended Multiply          | Exclusive Nor   | Scan Byte for Equal     |
|                       | Extended Divide            | Not             | *Byte Swap              |
|                       | Add with Carry             | Nand            |                         |
|                       | Subtract with Carry        |                 |                         |
|                       | *Conditional Add           |                 |                         |
|                       | *Conditional Subtract      |                 |                         |
|                       | Rotate                     |                 |                         |
| Comparison            | Branch                     | Call/Return     | Fault                   |
| Compare               | Unconditional Branch       | Call            | Conditional Fault       |
| Conditional Compare   | Conditional Branch         | Call Extended   | Synchronize Faults      |
| Compare and Increment | Compare and Branch         | Call System     |                         |
| Compare and Decrement |                            | Return          |                         |
| Test Condition Code   |                            | Branch and Link |                         |
| Check Bit             |                            |                 |                         |
| Debug                 | Processor Management       | Atomic          |                         |
| Modify Trace Controls | Flush Local Registers      | Atomic Add      |                         |
| Mark                  | Modify Arithmetic Controls | Atomic Modify   |                         |
| Force Mark            | Modify Process Controls    |                 |                         |
|                       | *Halt                      |                 |                         |
|                       | System Control             |                 |                         |
|                       | *Cache Control             |                 |                         |
|                       | *Interrupt Control         |                 |                         |

\* Denotes new instructions unavailable on 80960CA/CF, 80960KA/KB and 80960SA/SB implementations.

Rules for register alignment must be followed when using load, store and move instructions that move 8, 12 or 16 bytes at a time. See section 3.5, "MEMORY ADDRESS SPACE" (pg. 3-13) for alignment requirements for code portability across implementations.

### 5.2.1.1 Load and Store Instructions

Load instructions listed below copy bytes or words from memory to local or global registers or to a group of registers. Each load instruction requires a corresponding store instruction to copy to memory bytes or words from a selected local or global register or group of registers. All load and store instructions use the MEM format.

|             |                    |             |                     |
|-------------|--------------------|-------------|---------------------|
| <b>ld</b>   | load word          | <b>st</b>   | store word          |
| <b>ldob</b> | load ordinal byte  | <b>stob</b> | store ordinal byte  |
| <b>ldos</b> | load ordinal short | <b>stos</b> | store ordinal short |
| <b>ldib</b> | load integer byte  | <b>stib</b> | store integer byte  |
| <b>ldis</b> | load integer short | <b>stis</b> | store integer short |
| <b>ldl</b>  | load long          | <b>stl</b>  | store long          |
| <b>ldt</b>  | load triple        | <b>stt</b>  | store triple        |
| <b>ldq</b>  | load quad          | <b>stq</b>  | store quad          |

**ld** copies 4 bytes from memory into successive registers; **ldl** copies 8 bytes; **ldt** copies 12 bytes; **ldq** copies 16 bytes.

**st** copies 4 bytes from successive registers into memory; **stl** copies 8 bytes; **stt** copies 12 bytes; **stq** copies 16 bytes.

For **ld**, **ldob**, **ldos**, **ldib** and **ldis**, the instruction specifies a memory address and register; the memory address value is copied into the register. The processor automatically extends byte and short (half-word) operands to 32 bits according to data type. Ordinals are zero-extended; integers are sign-extended.

For **st**, **stob**, **stos**, **stib** and **stis**, the instruction specifies a memory address and register; the register value is copied into memory. For byte and short instructions, the processor automatically reformats the source register's 32-bit value for the shorter memory location. For **stib** and **stis**, this reformatting can cause integer overflow if the register value is too large for the shorter memory location. When integer overflow occurs, either an integer-overflow fault is generated or the integer-overflow flag in the AC register is set, depending on the integer-overflow mask bit setting in the AC register.

For **stob** and **stos**, the processor truncates the operand and does not create a fault if truncation resulted in the loss of significant bits.

## INSTRUCTION SET OVERVIEW

### 5.2.1.2 Move

Move instructions copy data from a local or global register or group of registers to another register or group of registers. These instructions use the REG format.

|             |                  |
|-------------|------------------|
| <b>mov</b>  | move word        |
| <b>movl</b> | move long word   |
| <b>movt</b> | move triple word |
| <b>movq</b> | move quad word   |

### 5.2.1.3 Load Address

The Load Address instruction (**lda**) computes an effective address in the address space from an operand presented in one of the addressing modes. **lda** is commonly used to load a constant into a register. This instruction uses the MEM format and can operate upon local or global registers.

On the i960 Jx processors, **lda** is useful for performing simple arithmetic operations. The processor's parallelism allows **lda** to execute in the same clock as another arithmetic or logical operation.

### 5.2.2 Select Conditional

Given the proper condition code bits setting, these instructions move one of two pieces of data from its source to the specified destination.

|              |                                  |
|--------------|----------------------------------|
| <b>selno</b> | Select Based on Unordered        |
| <b>selg</b>  | Select Based on Greater          |
| <b>sele</b>  | Select Based on Equal            |
| <b>selge</b> | Select Based on Greater or Equal |
| <b>sell</b>  | Select Based on Less             |
| <b>selne</b> | Select Based on Not Equal        |
| <b>selle</b> | Select Based on Less or Equal    |
| <b>selo</b>  | Select Based on Ordered          |

### 5.2.3 Arithmetic

Table 5-2 lists arithmetic operations and data types for which the i960 Jx processors provide instructions. "X" in this table indicates that the microprocessor provides an instruction for the specified operation and data type. All arithmetic operations are carried out on operands in registers. Refer to section 5.2.12, "Atomic Instructions" (pg. 5-17) for instructions which handle specific requirements for in-place memory operations.

All arithmetic instructions use the REG format and can operate on local or global registers. The following subsections describe arithmetic instructions for ordinal and integer data types.

**Table 5-2. Arithmetic Operations**

| Arithmetic Operations        | Data Types |         |
|------------------------------|------------|---------|
|                              | Integer    | Ordinal |
| Add                          | X          | X       |
| Add with Carry               | X          | X       |
| Conditional Add              | X          | X       |
| Subtract                     | X          | X       |
| Subtract with Carry          | X          | X       |
| Conditional Subtract         | X          | X       |
| Multiply                     | X          | X       |
| Extended Multiply            |            | X       |
| Divide                       | X          | X       |
| Extended Divide              |            | X       |
| Remainder                    | X          | X       |
| Modulo                       | X          |         |
| Shift Left                   | X          | X       |
| Shift Right                  | X          | X       |
| Extended Shift Right         |            | X       |
| Shift Right Dividing Integer | X          |         |

### 5.2.3.1 Add, Subtract, Multiply and Divide

These instructions perform add, subtract, multiply or divide operations on integers and ordinals:

|                      |                  |
|----------------------|------------------|
| <b>addi</b>          | Add Integer      |
| <b>addo</b>          | Add Ordinal      |
| <b>ADD&lt;cc&gt;</b> | Conditional Add  |
| <b>subi</b>          | Subtract Integer |
| <b>subo</b>          | Subtract Ordinal |

## INSTRUCTION SET OVERVIEW

**SUB<cc>** Conditional Subtract

**muli** Multiply Integer

**mulo** Multiply Ordinal

**divi** Divide Integer

**divo** Divide Ordinal

**addi**, **ADDI<cc>**, **subi**, **SUBI<cc>**, **muli** and **divi** generate an integer-overflow fault if the result is too large to fit in the 32-bit destination. **divi** and **divo** generate a zero-divide fault if the divisor is zero.

### 5.2.3.2 Extended Arithmetic

These instructions support extended-precision arithmetic; i.e., arithmetic operations on operands greater than one word in length:

**addc** add ordinal with carry

**subc** subtract ordinal with carry

**emul** extended multiply

**ediv** extended divide

**addc** adds two word operands (literals or contained in registers) plus the AC Register condition code bit 1 (used here as a carry bit). If the result has a carry, bit 1 of the condition code is set; otherwise, it is cleared. This instruction's description in CHAPTER 6, INSTRUCTION SET REFERENCE gives an example of how this instruction can be used to add two long-word (64-bit) operands together.

**subc** is similar to **addc**, except it is used to subtract extended-precision values. Although **addc** and **subc** treat their operands as ordinals, the instructions also set bit 0 of the condition codes if the operation would have resulted in an integer overflow condition. This facilitates a software implementation of extended integer arithmetic.

**emul** multiplies two ordinals (each contained in a register), producing a long ordinal result (stored in two registers). **ediv** divides a long ordinal by an ordinal, producing an ordinal quotient and an ordinal remainder (stored in two adjacent registers).

### 5.2.3.3 Remainder and Modulo

These instructions divide one operand by another and retain the remainder of the operation:

**remi** remainder integer

**remo** remainder ordinal

**modi** modulo integer

The difference between the remainder and modulo instructions lies in the sign of the result. For **remi** and **remo**, the result has the same sign as the dividend; for **modi**, the result has the same sign as the divisor.

### 5.2.3.4 Shift and Rotate

These shift instructions shift an operand a specified number of bits left or right:

|               |                              |
|---------------|------------------------------|
| <b>shlo</b>   | shift left ordinal           |
| <b>shro</b>   | shift right ordinal          |
| <b>shli</b>   | shift left integer           |
| <b>shri</b>   | shift right integer          |
| <b>shrdi</b>  | shift right dividing integer |
| <b>rotate</b> | rotate left                  |

Except for **rotate**, these instructions discard bits shifted beyond the register boundary.

**shlo** shifts zeros in from the least significant bit; **shro** shifts zeros in from the most significant bit. These instructions are equivalent to **mulo** and **divo** by the power of 2, respectively.

**shli** shifts zeros in from the least significant bit. If a shift of the specified places would result in an overflow, an integer-overflow fault is generated (if enabled). The destination register is written with the source shifted as much as possible without overflow and an integer-overflow fault is signaled.

**shri** performs a conventional arithmetic shift right operation by shifting the sign bit in from the most significant bit. However, when this instruction is used to divide a negative integer operand by the power of 2, it may produce an incorrect quotient. (Discarding the bits shifted out has the effect of rounding the result toward negative.)

**shrdi** is provided for dividing integers by the power of 2. With this instruction, 1 is added to the result if the bits shifted out are non-zero and the operand is negative, which produces the correct result for negative operands. **shli** and **shrdi** are equivalent to **muli** and **divi** by the power of 2, respectively.

**rotate** rotates operand bits to the left (toward higher significance) by a specified number of bits. Bits shifted beyond register's left boundary (bit 31) appear at the right boundary (bit 0).

## INSTRUCTION SET OVERVIEW

### 5.2.4 Logical

These instructions perform bitwise Boolean operations on the specified operands:

|               |                            |
|---------------|----------------------------|
| <b>and</b>    | <i>src2 AND src1</i>       |
| <b>notand</b> | <i>(NOT src2) AND src1</i> |
| <b>andnot</b> | <i>src2 AND (NOT src1)</i> |
| <b>xor</b>    | <i>src2 XOR src1</i>       |
| <b>or</b>     | <i>src2 OR src1</i>        |
| <b>nor</b>    | <i>NOT (src2 OR src1)</i>  |
| <b>xnor</b>   | <i>src2 XNOR src1</i>      |
| <b>not</b>    | <i>NOT src1</i>            |
| <b>notor</b>  | <i>(NOT src2) or src1</i>  |
| <b>ornot</b>  | <i>src2 or (NOT src1)</i>  |
| <b>nand</b>   | <i>NOT (src2 AND src1)</i> |

These all use the REG format and can specify literals or local or global registers.

The processor provides logical operations in addition to **and**, **or** and **xor** as a performance optimization. This optimization reduces the number of instructions required to perform a logical operation and reduces the number of registers and instructions associated with bitwise mask storage and creation.

### 5.2.5 Bit and Bit Field

These instructions perform operations on a specified bit or bit field in an ordinal operand. All use the REG format and can specify literals or local or global registers.

#### 5.2.5.1 Bit Operations

These instructions operate on a specified bit:

|                 |               |
|-----------------|---------------|
| <b>setbit</b>   | set bit       |
| <b>clrbit</b>   | clear bit     |
| <b>notbit</b>   | not bit       |
| <b>alterbit</b> | alter bit     |
| <b>scanbit</b>  | scan for bit  |
| <b>spanbit</b>  | span over bit |

**setbit**, **clrbit** and **notbit** set, clear or complement (toggle) a specified bit in an ordinal.

**alterbit** alters the state of a specified bit in an ordinal according to the condition code. If the condition code is 010, the bit is set; if the condition code is 000, the bit is cleared.

**chkbit**, described in section 5.2.7, “Comparison” (pg. 5-11), can be used to check the value of an individual bit in an ordinal.

**scanbit** and **spanbit** find the most significant set bit or clear bit, respectively, in an ordinal.

### 5.2.5.2 Bit Field Operations

The two bit field instructions are **extract** and **modify**.

**extract** converts a specified bit field, taken from an ordinal value, into an ordinal value. In essence, this instruction shifts right a bit field in a register and fills in the bits to the left of the bit field with zeros. (**eshro** also provides the equivalent of a 64-bit extract of 32 bits).

**modify** copies bits from one register, under control of a mask, into another register. Only unmasked bits in the destination register are modified. **modify** is equivalent to a bit field move.

### 5.2.6 Byte Operations

**scanbyte** performs a byte-by-byte comparison of two ordinals to determine if any two corresponding bytes are equal. The condition code is set based on the results of the comparison. **scanbyte** uses the REG format and can specify literals or local or global registers.

**bswap** alters the order of bytes in a word, reversing its “endianess.”

### 5.2.7 Comparison

The processor provides several types of instructions for comparing two operands, as described in the following subsections.

#### 5.2.7.1 Compare and Conditional Compare

These instructions compare two operands then set the condition code bits in the AC register according to the results of the comparison:

|              |                       |
|--------------|-----------------------|
| <b>cmpi</b>  | Compare Integer       |
| <b>cmpib</b> | Compare Integer Byte  |
| <b>cmpis</b> | Compare Integer Short |
| <b>cmwo</b>  | Compare Ordinal       |

## INSTRUCTION SET OVERVIEW

|                |                             |
|----------------|-----------------------------|
| <b>cmpob</b>   | Compare Ordinal Byte        |
| <b>cmpos</b>   | Compare Ordinal Short       |
| <b>concmpi</b> | Conditional Compare Integer |
| <b>concmpo</b> | Conditional Compare Ordinal |
| <b>chkbit</b>  | Check Bit                   |

These all use the REG format and can specify literals or local or global registers. The condition code bits are set to indicate whether one operand is less than, equal to or greater than the other operand. See section 3.6.2, “Arithmetic Controls (AC) Register” (pg. 3-17) for a description of the condition codes for conditional operations.

**cmpi** and **cmpos** simply compare the two operands and set the condition code bits accordingly. **concmpi** and **concmpo** first check the status of condition code bit 2:

- If not set, the operands are compared as with **cmpi** and **cmpos**.
- If set, no comparison is performed and the condition code flags are not changed.

The conditional-compare instructions are provided specifically to optimize two-sided range comparisons to check if A is between B and C (i.e.,  $B \leq A \leq C$ ). Here, a compare instruction (**cmpi** or **cmpos**) checks one side of the range (e.g.,  $A \geq B$ ) and a conditional compare instruction (**concmpi** or **concmpo**) checks the other side (e.g.,  $A \leq C$ ) according to the result of the first comparison. The condition codes following the conditional comparison directly reflect the results of both comparison operations. Therefore, only one conditional branch instruction is required to act upon the range check; otherwise, two branches would be needed.

**chkbit** checks a specified bit in a register and sets the condition code flags according to the bit state. The condition code is set to  $010_2$  if the bit is set and  $000_2$  otherwise.

### 5.2.7.2 Compare and Increment or Decrement

These instructions compare two operands, set the condition code bits according to the results, then increment or decrement one of the operands:

|                |                               |
|----------------|-------------------------------|
| <b>cmpinci</b> | compare and increment integer |
| <b>cmpinco</b> | compare and increment ordinal |
| <b>cmpdeci</b> | compare and decrement integer |
| <b>cmpdeco</b> | compare and decrement ordinal |

These all use the REG format and can specify literals or local or global registers. They are an architectural performance optimization which allows two register operations (e.g., compare and add) to execute in a single cycle. These are intended for use at the end of iterative loops.

### 5.2.7.3 Test Condition Codes

These test instructions allow the state of the condition code flags to be tested:

|               |                           |
|---------------|---------------------------|
| <b>teste</b>  | test for equal            |
| <b>testne</b> | test for not equal        |
| <b>testl</b>  | test for less             |
| <b>testle</b> | test for less or equal    |
| <b>testg</b>  | test for greater          |
| <b>testge</b> | test for greater or equal |
| <b>testo</b>  | test for ordered          |
| <b>testno</b> | test for unordered        |

If the condition code matches the instruction-specified condition, these cause a TRUE (01H) to be stored in a destination register; otherwise, a FALSE (00H) is stored. All use the COBR format and can operate on local and global registers.

### 5.2.8 Branch

Branch instructions allow program flow direction to be changed by explicitly modifying the IP. The processor provides three branch instruction types:

- unconditional branch
- conditional branch
- compare and branch

Most branch instructions specify the target IP by specifying a signed displacement to be added to the current IP. Other branch instructions specify the target IP's memory address, using one of the processor's addressing modes. This latter group of instructions is called extended addressing instructions (e.g., branch extended, branch-and-link extended).

#### 5.2.8.1 Unconditional Branch

These instructions are used for unconditional branching:

|             |                          |
|-------------|--------------------------|
| <b>b</b>    | Branch                   |
| <b>bx</b>   | Branch Extended          |
| <b>bal</b>  | Branch and Link          |
| <b>balx</b> | Branch and Link Extended |

## INSTRUCTION SET OVERVIEW

**b** and **bal** use the CTRL format. **bx** and **balx** use the MEM format and can specify local or global registers as operands. **b** and **bx** cause program execution to jump to the specified target IP. These two instructions perform the same function; however, their determination of the target IP differs. The target IP of a **b** instruction is specified at link time as a relative displacement from the current IP. The target IP of the **bx** instruction is the absolute address resulting from the instruction's use of a memory addressing mode during execution.

**bal** and **balx** store the next instruction's address in a specified register, then jump to the specified target IP. (For **bal**, the RIP is automatically stored in register g14; for **balx**, the RIP location is specified with an instruction operand.) As described in section 7.9, “BRANCH-AND-LINK” (pg. 7-22), branch and link instructions provide a method of performing procedure calls that do not use the processor’s integrated call/return mechanism. Here, the saved instruction address is used as a return IP. Branch and link is generally used to call leaf procedures (that is, procedures that do not call other procedures).

**bx** and **balx** can make use of any memory addressing mode.

### 5.2.8.2 Conditional Branch

With conditional branch (**BRANCH IF**) instructions, the processor checks the AC register condition code flags. If these flags match the value specified with the instruction, the processor jumps to the target IP. These instructions use the displacement-plus-IP method of specifying the target IP:

|            |                            |
|------------|----------------------------|
| <b>be</b>  | branch if equal/true       |
| <b>bne</b> | branch if not equal        |
| <b>bl</b>  | branch if less             |
| <b>ble</b> | branch if less or equal    |
| <b>bg</b>  | branch if greater          |
| <b>bge</b> | branch if greater or equal |
| <b>bo</b>  | branch if ordered          |
| <b>bno</b> | branch if unordered/false  |

All use the CTRL format. **bo** and **bno** are used with real numbers. Refer to section 3.6.2.2, “Condition Code” (pg. 3-18) for a discussion of the condition code for conditional operations.

### 5.2.8.3 Compare and Branch

These instructions compare two operands then branch according to the comparison result. Three instruction subtypes are compare integer, compare ordinal and branch on bit:

|                |  |
|----------------|--|
| <b>cmpibe</b>  | compare integer and branch if equal            |
| <b>cmpibne</b> | compare integer and branch if not equal        |
| <b>cmpibl</b>  | compare integer and branch if less             |
| <b>cmpible</b> | compare integer and branch if less or equal    |
| <b>cmpibg</b>  | compare integer and branch if greater          |
| <b>cmpibge</b> | compare integer and branch if greater or equal |
| <b>cmpibo</b>  | compare integer and branch if ordered          |
| <b>cmpibno</b> | compare integer and branch if unordered        |
| <b>cmpobe</b>  | compare ordinal and branch if equal            |
| <b>cmpobne</b> | compare ordinal and branch if not equal        |
| <b>cmpobl</b>  | compare ordinal and branch if less             |
| <b>cmpoble</b> | compare ordinal and branch if less or equal    |
| <b>cmpobg</b>  | compare ordinal and branch if greater          |
| <b>cmpobge</b> | compare ordinal and branch if greater or equal |
| <b>bbs</b>     | check bit and branch if set                    |
| <b>bbc</b>     | check bit and branch if clear                  |

All use the COBR machine instruction format and can specify literals, local registers or global registers as operands. With compare ordinal and branch and compare integer and branch instructions, two operands are compared and the condition code bits are set as described in section 5.2.7, “Comparison” (pg. 5-11). A conditional branch is then executed as with the conditional branch (**BRANCH IF**) instructions.

With check bit and branch instructions, one operand specifies a bit to be checked in the other operand. The condition code flags are set according to the state of the specified bit:  $010_2$  (true) if the bit is set and  $000_2$  (false) if the bit is clear. A conditional branch is then executed according to condition code bit settings.

These instructions optimize execution performance time. When it is not possible to separate adjacent compare and branch instructions with other unrelated instructions, replacing two instructions with a single compare and branch instruction increases performance.

## INSTRUCTION SET OVERVIEW

### 5.2.9 Call and Return

The processor offers an on-chip call/return mechanism for making procedure calls. Refer to section 7.1, “CALL AND RETURN MECHANISM” (pg. 7-2). These instructions support this mechanism:

|              |               |
|--------------|---------------|
| <b>call</b>  | call          |
| <b>callx</b> | call extended |
| <b>calls</b> | call system   |
| <b>ret</b>   | return        |

**call** and **ret** use the CTRL machine-instruction format. **callx** uses the MEM format and can specify local or global registers. **calls** uses the REG format and can specify local or global registers.

**call** and **callx** make local calls to procedures. A local call is a call that does not require a switch to another stack. **call** and **callx** differ only in the method of specifying the target procedure’s address. The target procedure of a call is determined at link time and is encoded in the opword as a signed displacement relative to the call IP. **callx** specifies the target procedure as an absolute 32-bit address calculated at run time using any one of the addressing modes. For both instructions, a new set of local registers and a new stack frame are allocated for the called procedure.

**calls** is used to make calls to system procedures — procedures that provide a kernel or system-executive services. This instruction operates similarly to **call** and **callx**, except that it gets its target-procedure address from the system procedure table. An index number included as an operand in the instruction provides an entry point into the procedure table.

Depending on the type of entry being pointed to in the system procedure table, **calls** can cause either a system-supervisor call or a system-local call to be executed. A system-supervisor call is a call to a system procedure that also switches the processor to supervisor mode and the supervisor stack. A system-local call is a call to a system procedure that does not cause an execution mode or stack change. Supervisor mode is described throughout CHAPTER 7, PROCEDURE CALLS.

**ret** performs a return from a called procedure to the calling procedure (the procedure that made the call). **ret** obtains its target IP (return IP) from linkage information that was saved for the calling procedure. **ret** is used to return from all calls — including local and supervisor calls — and from implicit calls to interrupt and fault handlers.

### 5.2.10 Conditional Faults

Generally, the processor generates faults automatically as the result of certain operations. Fault handling procedures are then invoked to handle various fault types without explicit intervention by the currently running program. These conditional fault instructions permit a program to explicitly generate a fault according to the state of the condition code flags. All use the CTRL format.

|                |                           |
|----------------|---------------------------|
| <b>faulte</b>  | fault if equal            |
| <b>faultne</b> | fault if not equal        |
| <b>faultl</b>  | fault if less             |
| <b>faultle</b> | fault if less or equal    |
| <b>faultg</b>  | fault if greater          |
| <b>faultge</b> | fault if greater or equal |
| <b>faulto</b>  | fault if ordered          |
| <b>faultno</b> | fault if unordered        |

### 5.2.11 Debug

The processor supports debugging and monitoring of program activity through the use of trace events. These instructions support these debugging and monitoring tools:

|              |                         |
|--------------|-------------------------|
| <b>modpc</b> | modify process controls |
| <b>modtc</b> | modify trace controls   |
| <b>mark</b>  | mark                    |
| <b>fmark</b> | force mark              |

These all use the REG format. Trace functions are controlled with bits in the Trace Control (TC) register which enable or disable various types of tracing. Other TC register flags indicate when an enabled trace event is detected. Refer to CHAPTER 10, TRACING AND DEBUGGING.

**modpc** can enable/disable trace fault generation; **modtc** permits trace controls to be modified. **mark** causes a breakpoint trace event to be generated if breakpoint trace mode is enabled. **fmark** generates a breakpoint trace independent of the state of the breakpoint trace mode bits.

The **sysctl** instruction also provides control over breakpoint trace event generation. This instruction is used, in part, to load and control the i960 Jx microprocessors' breakpoint registers.

### 5.2.12 Atomic Instructions

Atomic instructions perform read-modify-write operations on operands in memory. They allow a system to ensure that, when an atomic operation is performed on a specified memory location, the operation completes before another agent is allowed to perform an operation on the same memory. These instructions are required to enable synchronization between interrupt handlers and

## INSTRUCTION SET OVERVIEW

background tasks in any system. They are also particularly useful in systems where several agents — processors, coprocessors or external logic — have access to the same system memory for communication.

The atomic instructions are atomic add (**atadd**) and atomic modify (**atmod**). **atadd** causes an operand to be added to the value in the specified memory location. **atmod** causes bits in the specified memory location to be modified under control of a mask. Both instructions use the REG format and can specify literals or local or global registers.

### 5.2.13 Processor Management

These instructions control processor-related functions:

|                 |  |
|-----------------|--|
| <b>modpc</b>    | Modify the process controls register       |
| <b>flushreg</b> | Flush cached local register sets to memory |
| <b>modac</b>    | Modify the AC register                     |
| <b>sysctl</b>   | Perform system control function            |
| <b>icctl</b>    | Instruction cache control                  |
| <b>dcctl</b>    | Data cache control                         |
| <b>halt</b>     | Halt processor                             |
| <b>inten</b>    | Global interrupt enable                    |
| <b>intdis</b>   | Global interrupt disable                   |
| <b>intctl</b>   | Global interrupt enable and disable        |

All use the REG format and can specify literals or local or global registers.

**modpc** provides a method of reading and modifying PC register contents. Only programs operating in supervisor mode may modify the PC register; however, any program may read it.

The processor provides a flush local registers instruction (**flushreg**) to save the contents of the cached local registers to the stack. The flush local registers instruction automatically stores the contents of all the local register sets — except the current set — in the register save area of their associated stack frames.

The modify arithmetic controls instruction (**modac**) allows the AC register contents to be copied to a register and/or modified under the control of a mask. The AC register cannot be explicitly addressed with any other instruction; however, it is implicitly accessed by instructions that use the condition codes or set the integer overflow flag.

**sysctl** is used to configure the interrupt controller, breakpoint registers and instruction cache. It also permits software to signal an interrupt or cause a processor reset and reinitialization. **sysctl** may only be executed by programs operating in supervisor mode.

**icctl** and **dcctl** provide cache control functions including: enabling, disabling, loading and locking, (instruction cache only) invalidating, getting status and storing cache information out to memory. **halt** puts the processor in low-power halt mode. **intctl**, **inten** and **intdis** are used to enable and disable interrupts and to determine current interrupt enable status.

## 5.3 PERFORMANCE OPTIMIZATION

Performance optimization are categorized into two sections: instructions optimizations and miscellaneous optimizations.

5

### 5.3.1 Instruction Optimizations

The instruction optimizations are broken down by the instruction classification.

#### 5.3.1.1 Load / Store Execution Model

Because the i960 Jx processor has a 32-bit external data bus, multiple word accesses require multiple cycles. The Jx uses microcode to sequence the multi-word accesses. Because the microcode can ensure that aligned multi-words are bursted together on the external bus, software should not substitute multiple single-word instructions for one multi-word instruction for data that is not likely to be in cache. For example a **ldq** provides better bus performance than four **ld** instructions.

Once a load is issued, the processor attempts to execute other instructions while the load is outstanding. It is important to note that if the load misses the data cache, the processor does not stall the issuing of subsequent instructions (other than stores) that do not depend on the load.

Software should avoid following a load with an instruction that depends on the result of the load. For a load that hits the data cache, there will be a one-cycle stall if the instruction immediately after the load requires the data. If the load fails to hit the data cache, the instruction depending on the load will be stalled until the outstanding load request is resolved.

Multiple, back-to-back load instructions do not stall the processor until the bus queue becomes full.

The processor delays issuing a store instruction until all previously-issued load instructions complete. This happens regardless of whether the store is dependent on the load. This ordering between loads and stores ensures that the return data from a previous cache-read miss does not overwrite the cache line updated by a subsequent store.

## INSTRUCTION SET OVERVIEW

### 5.3.1.2 Compare Operations

Byte and short word data is more efficiently compared using the new byte and short compare instructions (**cmpob**, **cmpib**, **cmpos**, **cmpis**), rather than shifting the data and using a word compare instruction.

### 5.3.1.3 Microcoded Instructions

While the majority of instructions on the i960 Jx processor are single cycle and are executed directly by processor hardware, some require microcode emulation. Entry into a microcode routine requires two cycles. Exit from microcode typically requires two cycles. For some routines, one cycle of the exit process can execute in parallel with another instruction, thus saving one cycle of execution time.

### 5.3.1.4 Multiply-Divide Unit Instructions

The Multiply-Divide Unit (MDU) of the Jx performs a number of multi-cycle arithmetic operations. These can range from 2 cycles for a 16-bitx32-bit **mulo**, 4 cycles for a 32-bitx32-bit **mulo**, to 30+ cycles for an **ediv**.

Once issued, these MDU instructions are executed in parallel with other non-MDU instructions that do not depend on the result of the MDU operation. Attempting to issue another MDU instruction while a current MDU instruction is executing, stalls the processor until the first one completes.

### 5.3.1.5 Multi-Cycle Register Operations

A few register operations can also take multiple cycles. The following instructions are all performed in microcode:

- |                |                  |                  |                  |                 |                 |
|----------------|------------------|------------------|------------------|-----------------|-----------------|
| • <b>bswap</b> | • <b>extract</b> | • <b>eshro</b>   | • <b>modify</b>  | • <b>movl</b>   | • <b>movt</b>   |
| • <b>movq</b>  | • <b>shrdi</b>   | • <b>scanbit</b> | • <b>spanbit</b> | • <b>testno</b> | • <b>testo</b>  |
| • <b>testl</b> | • <b>testle</b>  | • <b>teste</b>   | • <b>testne</b>  | • <b>testg</b>  | • <b>testge</b> |

On the Jx, **test<cc> dst** is microcoded and takes many more cycles than **SEL<cc> 0,1,dst**, which is executed in one cycle directly by processor hardware.

Multi-register move operation execution time can be decreased at the expense of cache utilization and code density by using **mov** the appropriate number of times instead of **movl**, **movt** and **movq** instructions.

### 5.3.1.6 Simple Control Transfer

There is no branch lookahead or branch prediction mechanism on the i960 Jx microprocessor. Simple branch instructions take one cycle to execute, and one more cycle is needed to fetch the target instruction if the branch is actually taken.

#### **b, bal, bno, bo, bl, ble, be, bne, bg, bge**

One mode of the **bx** (branch-extended) instruction, **bx** (base), is also a simple branch and takes one cycle to execute and one cycle to fetch the target.

As a result, a **bal(g14)** or **bx (g14)** sequence provides a two-cycle call and return mechanism for efficient leaf procedure implementation.

Compare-and-branch instructions have been optimized on the i960 Jx microprocessor. They require 2 cycles to execute, and one more cycle to fetch the target instruction if the branch is actually taken. The instructions are:

- **cmpobno**    • **cmpobo**    • **cmpobl**    • **cmpoble**    • **cmpobe**    • **cmpobne**
- **cmpobg**    • **cmpobge**    • **cmpibno**    • **cmpibo**    • **cmpibl**    • **cmpible**
- **cmpibe**    • **cmpibg**    • **cmpibne**    • **cmpibge**    • **bbc**    • **bbs**

### 5.3.1.7 Memory Instructions

The 80960Jx provides efficient support for naturally aligned byte, short, and word accesses that use one of 6 optimized addressing modes. These accesses require only 1 to 2 cycles to execute; additional cycles are needed for a load to return its data.

The byte, short and word memory instructions are:

#### **ldob, ldib, ldos, ldis, ld, lda stob, stib, stos, stis, st**

The remainder of accesses require multiple cycles to execute. These include:

- Unaligned short, and word accesses
- Byte, short, and word accesses that do not use one of the 6 optimized addressing modes
- Multi-word accesses

The multi-word accesses are:

#### **ldl, ldt, ldq, stl, stt, stq**

### 5.3.1.8 Unaligned Memory Accesses

Unaligned memory accesses are performed by microcode. Microcode sequences the access into smaller aligned pieces and does any merging of data that is needed. As a result, these accesses are not as efficient as aligned accesses. In addition, no bursting on the external bus is performed for these accesses. Whenever possible, unaligned accesses should be avoided.

## 5.3.2 Miscellaneous Optimizations

### 5.3.2.1 Masking of Integer Overflow

The i960 core architecture inserts an implicit **syncf** before performing a call operation or delivering an interrupt so that a fault handler can be dispatched first, if necessary. The **syncf** can require a number of cycles to complete if a multi-cycle integer-multiply (**muli**) or integer-divide (**divi**) instruction was issued previously and integer-overflow faults are unmasked (allowed to occur). Call performance and interrupt latency can be improved by masking integer-overflow faults (AC.om = 1), which allows the implicit **syncf** to complete more quickly.

### 5.3.2.2 Avoid Using PFP, SP, R3 As Destinations for MDU Instructions

When performing a call operation or delivering an interrupt, the processor typically attempts to push the first four local registers (pfp, sp, rip, and r3) onto the local register cache as early as possible. Because of register-interlock, this operation will be stalled until previous instructions return their results to these registers. In most cases, this is not a problem; however, in the case of multi-cycle instructions (**divo**, **divi**, **ediv**, **modi**, **remo**, and **remi**), the processor could be stalled for many cycles waiting for the result and unable to proceed to the next step of call processing or interrupt delivery.

Call performance and interrupt latency can be improved by avoiding the first four registers as the destination for a MDU instruction. Generally, registers pfp, sp, and rip should be avoided they are used for procedure linking.

### 5.3.2.3 Use Global Registers (g0 - g14) As Destinations for MDU Instructions

Using the same rationale as in the previous item, call processing and interrupt performance are improved even further by using global registers (g0-g14) as the destination for multi-cycle MDU instructions. This is because there is no dependency between g0-g14 and implicit or explicit call operations (i.e., global registers are not pushed onto the local register cache).

### 5.3.2.4 Execute in Imprecise Fault Mode

Significant performance improvement is possible by allowing imprecise faults (AC.nif = 0). In precise fault mode (AC.nif = 1), the processor will not issue a new instruction until the previous one has completed. This ensures that a fault from the previous instruction is delivered before the next instruction can begin execution. Imprecise fault mode allows new instructions to be issued before previous ones have completed, thus increasing the instruction issue rate. Many applications can tolerate the imprecise fault reporting for the performance gain. A **syncf** can be used in imprecise fault mode to isolate faults at desired points of execution when necessary.





6

# INSTRUCTION SET REFERENCE





# CHAPTER 6

## INSTRUCTION SET REFERENCE

This chapter provides detailed information about each instruction available to the i960® Jx processors. Instructions are listed alphabetically by assembly language mnemonic. Format and notation used in this chapter are defined in section 6.1, "NOTATION" (pg. 6-1).

Information in this chapter is oriented toward programmers who write assembly language code for the i960 Jx processors. Information provided for each instruction includes:

- Alphabetic listing of all instructions
- Assembly language mnemonic, name and format
- Description of the instruction's operation
- Opcode and instruction encoding format
- Faults that can occur during execution
- Action (or algorithm) and other side effects of executing an instruction
- Assembly language example
- Related instructions

Additional information about the instruction set can be found in the following chapters and appendices in this manual:

- CHAPTER 5, INSTRUCTION SET OVERVIEW - Summarizes the instruction set by group and describes the assembly language instruction format.
- APPENDIX B, OPCODES AND EXECUTION TIMES - A quick-reference listing of instruction encodings assists debug with a logic analyzer.
- APPENDIX D, INSTRUCTION SET QUICK REFERENCE - A tabular quick reference of each instruction's operation.
- APPENDIX E, MACHINE-LEVEL INSTRUCTION FORMATS - Describes instruction set opword encodings.
- i960 Jx PROCESSOR INSTRUCTION SET QUICK REFERENCE (order number 272597) - A pocket-sized quick reference to all Jx instructions.

6

### 6.1 NOTATION

In general, notation in this chapter is consistent with usage throughout the manual; however, there are a few exceptions. Read the following subsections to understand notations that are specific to this chapter.

## INSTRUCTION SET REFERENCE

### 6.1.1 Alphabetic Reference

Instructions are listed alphabetically by assembly language mnemonic. If several instructions are related and fall together alphabetically, they are described as a group on a single page.

The instruction's assembly language mnemonic is shown in bold at the top of the page (e.g., **subc**). Occasionally, it is not practical to list all mnemonics at the page top. In these cases, the name of the instruction group is shown in capital letters (e.g., **BRANCH<cc>** or **FAULT<cc>**).

The i960 Jx processor-specific extensions to the i960 microprocessor instruction set are indicated in the header text for each such instruction. This type of notation is also used to indicate new core architecture instructions. Sections describing new core instructions provide notes as to which i960-series processors do not implement these instructions.

Generally, instruction set extensions are not portable to other i960 processor implementations. Further, new core instructions are not typically portable to earlier i960 processor family implementations such as the i960 KX-series microprocessors.

### 6.1.2 Mnemonic

The *Mnemonic* section gives the mnemonic (in boldface type) and instruction name for each instruction covered on the page, for example:

**subi**      Subtract Integer

This name is the actual assembly language instruction name recognized by assemblers.

### 6.1.3 Format

The *Format* section gives the instruction's assembly language format and allowable operand types. Format is given in two or three lines. The following is a two-line format example:

|             |             |             |            |
|-------------|-------------|-------------|------------|
| <b>sub*</b> | <i>src1</i> | <i>src2</i> | <i>dst</i> |
|             | reg/lit     | reg/lit     | reg        |

The first line gives the assembly language mnemonic (boldface type) and operands (italics). When the format is used for two or more instructions, an abbreviated form of the mnemonic is used. An \* (asterisk) at the end of the mnemonic indicates a variable: in the above example, **sub\*** is either **subi** or **subo**. Capital letters indicate an instruction class. For example, **ADD<cc>** refers to the class of conditional add instructions (e.g., **addio**, **addig**, **addoo**, **addog**).

Operand names are designed to describe operand function (e.g., *src*, *len*, *mask*).

The second line shows allowable entries for each operand. Notation is as follows:

reg      Global (g0 ... g15) or local (r0 ... r15) register

|      |   |
|------|---|
| lit  | Literal of the range 0 ... 31   |
| disp | Signed displacement of range (-2 <sup>22</sup> ... 2 <sup>22</sup> - 1) |
| mem  | Address defined with the full range of addressing modes                 |

In some cases, a third line is added to show register or memory location contents. For example, it may be useful to know that a register is to contain an address. The notation used in this line is as follows:

|      |                   |
|------|-------------------|
| addr | Address           |
| efa  | Effective Address |

### 6.1.4 Description

The *Description* section is a narrative description of the instruction's function and operands. It also gives programming hints when appropriate.

### 6.1.5 Action

The *Action* section gives an algorithm written in a "C-like" pseudo-code that describes direct effects and possible side effects of executing an instruction. Algorithms document the instruction's net effect on the programming environment; they do not necessarily describe how the processor actually implements the instruction. The following is an example of the action algorithm for the **alterbit** instruction:

```
if((AC.cc & 0102)==0)
    dst = src2 & ~(2** (src1%32));
else
    dst = src2 | 2** (src1%32);
```

Table 6-1 defines each abbreviation used in the instruction reference pseudo-code.

The pseudo-code has been written to comply as closely as possible with standard C programming language notation. Table 6-2 lists the pseudocode symbol definitions.

**Table 6-1. Abbreviations in Pseudo-code**

|         |  |
|---------|--|
| AC.xxx  | Arithmetic Controls Register fields<br>AC.cc Condition Code flags (AC.cc2:0)<br>AC.cc[0] Condition Code Bit 0<br>AC.cc[1] Condition Code Bit 1<br>AC.cc[2] Condition Code Bit 2<br>AC.nif No Imprecise Faults flag<br>AC.of Integer Overflow flag<br>AC.om Integer Overflow Mask Bit |
| PC.xxx  | Process Controls Register fields<br>PC.em Execution Mode flag<br>PC.s State Flag<br>PC.tfp Trace Fault Pending flag<br>PC.p Priority Field (PC.p5:0)<br>PC.te Trace Enable Bit   |
| TC.xxx  | Trace Controls Register fields<br>TC.i Instruction Trace Mode Bit<br>TC.c Call Trace Mode Bit<br>TC.p Pre-return Trace Mode Bit<br>TC.br Mark Trace Mode Bit<br>TC.b Branch Trace Mode Bit<br>TC.r Return Trace Mode Bit<br>TC.s Supervisor Trace Mode Bit                           |
| PFP.xxx | Previous Frame Pointer (r0)<br>PFP.add Address (PFP.add31:4)<br>PFP.rrr Return Type Field (PFP.rt2:0)<br>PFP.p Pre-return Trace flag   |
| sp      | Stack Pointer (r1)   |
| fp      | Frame Pointer (g15)  |
| rip     | Return Instruction Pointer (r2)  |
| SPT     | System Procedure Table<br>SSP Supervisor Stack Base Address<br>SPT( <i>targ</i> ) Address of SPT Entry <i>targ</i><br>SSP.te Trace Enable  |

**Table 6-2. Pseudo-code Symbol Definitions (Sheet 1 of 2)**

|        |   |
|--------|---|
| =      | Assignment                                      |
| ==, != | Comparison: equal, not equal                    |
| <, >   | less than, greater than                         |
| <=, >= | less than or equal to, greater than or equal to |
| <<, >> | Logical Shift                                   |
| **     | Exponentiation                                  |
| &, &&  | Bitwise AND, logical AND                        |

**Table 6-2. Pseudo-code Symbol Definitions** (Sheet 2 of 2)

|      |                                     |
|------|-------------------------------------|
| =    | Assignment                          |
| ,    | Bitwise OR, logical OR              |
| ^    | Bitwise XOR                         |
| ~    | One's Complement                    |
| %    | Modulo                              |
| +, - | Addition, Subtraction               |
| *    | Multiplication (Integer or Ordinal) |
| /    | Division (Integer or Ordinal)       |
| #    | Comment delimiter                   |

**Table 6-3. Faults Applicable to All Instructions**

| Fault Type | Subtype              | Description  |
|------------|----------------------|--|
| Operation  | <i>Unimplemented</i> | An attempt to execute any instruction fetched from internal data RAM or a memory-mapped region causes an operation unimplemented fault.                                |
| Trace      | <i>Mark</i>          | A Mark Trace Event is signaled after completion of an instruction for which there is a hardware breakpoint condition match. A Trace fault is generated if PC.m is set. |
|            | <i>Instruction</i>   | An Instruction Trace Event is signaled after instruction completion. A Trace fault is generated if both PC.te and TC.i=1.  |

**Table 6-4. Common Faulting Conditions**

| Fault Type | Subtype                | Description  |
|------------|------------------------|--|
| Operation  | <i>Unaligned</i>       | Any instruction that causes an unaligned memory access causes an operation aligned fault if unaligned faults are not masked in the fault configuration word in the Processor Control Block (PRCB). |
|            | <i>Invalid Opcode</i>  | This fault is generated when the processor tries to execute words from memory that do not contain code.  |
|            | <i>Invalid Operand</i> | This fault is caused by a non-defined operand in a supervisor mode only instruction or by an operand reference to an unaligned long-, triple- or quad-register group.                              |
|            | <i>Unimplemented</i>   | This fault can occur due to an attempt to perform a non-word or unaligned access to a memory-mapped region or if trying to execute from MMR space or internal data RAM.                            |
| Type       | <i>Mismatch</i>        | Any instruction that attempts to write to internal data RAM or a memory-mapped register while not in supervisor mode causes a type mismatch fault.   |

### 6.1.6      **Faults**

The *Faults* section lists faults that can be signaled as a direct result of instruction execution. Table 6-3 shows the possible faulting conditions that are common to the entire instruction set and could directly result from any instruction. These fault types are not included in the instruction reference. Table 6-4 shows the possible faulting conditions that are common to large subsets of the instruction set. If an instruction can generate a fault, it is noted in that instruction's *Faults* section. Other instructions can generate faults in addition to those shown in the following tables. If an instruction can generate a fault, it is noted in that instruction's *Faults* section.

### 6.1.7      **Example**

The *Example* section gives an assembly language example of an application of the instruction.

### 6.1.8      **Opcode and Instruction Format**

The *Opcode and Instruction Format* section gives the opcode and instruction format for each instruction, for example:

**subi**        593H        REG

The opcode is given in hexadecimal format. The format is one of four possible formats: REG, COBR, CTRL and MEM. Refer to APPENDIX D, MACHINE-LEVEL INSTRUCTION FORMATS for more information on the formats.

### 6.1.9      **See Also**

The *See Also* section gives the mnemonics of related instructions which are also alphabetically listed in this chapter.

### 6.1.10     **Side Effects**

This section indicates whether the instruction causes changes to the condition code bits in the Arithmetic Controls.

**6.1.11 Notes**

This section provides additional information about an instruction such as whether it is implemented in other i960 processor families.

**6.2 INSTRUCTIONS**

This section contains reference information on the processor's instructions. It is arranged alphabetically by instruction or instruction group.

## 6.2.1 ADD<CC> (New 80960 Core Instruction Class)

|           |               |                                 |
|-----------|---------------|---------------------------------|
| Mnemonic: | <b>addono</b> | Add Ordinal if Unordered        |
|           | <b>addog</b>  | Add Ordinal if Greater          |
|           | <b>addoe</b>  | Add Ordinal if Equal            |
|           | <b>addoge</b> | Add Ordinal if Greater or Equal |
|           | <b>addol</b>  | Add Ordinal if Less             |
|           | <b>addone</b> | Add Ordinal if Not Equal        |
|           | <b>addole</b> | Add Ordinal if Less or Equal    |
|           | <b>addoo</b>  | Add Ordinal if Ordered          |
|           | <b>addino</b> | Add Integer if Unordered        |
|           | <b>addig</b>  | Add Integer if Greater          |
|           | <b>addie</b>  | Add Integer if Equal            |
|           | <b>addige</b> | Add Integer if Greater or Equal |
|           | <b>addil</b>  | Add Integer if Less             |
|           | <b>addine</b> | Add Integer if Not Equal        |
|           | <b>addile</b> | Add Integer if Less or Equal    |
|           | <b>addio</b>  | Add Integer if Ordered          |

Format: **add\***      *src1*,                  *src2*,                  *dst*  
                   reg/lit                    reg/lit                    reg

Description: Conditionally adds *src2* and *src1* values and stores the result in *dst* based on the AC register condition code. If for Unordered the condition code is 0, or if for all other cases the logical AND of the condition code and the mask part of the opcode is not 0, then the values are added and placed in the destination. Otherwise the destination is left unchanged. Table 6-5 shows the condition code mask for each instruction. The mask is in opcode bits 4-6.

Action:

```

addo<cc>:
if((mask & AC.cc) || (mask == AC.cc))
    dst = (src1 + src2)[31:1];

addi<cc>:
if((mask & AC.cc) || (mask == AC.cc))
    dst = (src1 + src2)[31:1];
if((src2[31] == src1[31]) && ((src2[31] != dst[31]))
{   if(AC.om == 1)
        AC.of = 1;
    else
        generate_fault(ARITHMETIC.OVERFLOW);
}

```

Faults: STANDARD                          Refer to section 6.1.6, "Faults" (pg. 6-6).
                   ARITHMETIC.OVERFLOW      Occurs only with **addi\*<cc>**.

**Table 6-5. ADD Condition Codes**

| Instruction   | Mask    | Condition        |
|---------------|---------|------------------|
| <b>addono</b> |         |                  |
| <b>addino</b> | $000_2$ | Unordered        |
| <b>addog</b>  |         |                  |
| <b>addig</b>  | $001_2$ | Greater          |
| <b>addoe</b>  |         |                  |
| <b>addie</b>  | $010_2$ | Equal            |
| <b>addoge</b> |         |                  |
| <b>addige</b> | $011_2$ | Greater or equal |
| <b>addol</b>  |         |                  |
| <b>addil</b>  | $100_2$ | Less             |
| <b>addone</b> |         |                  |
| <b>addine</b> | $101_2$ | Not equal        |
| <b>addole</b> |         |                  |
| <b>addile</b> | $110_2$ | Less or equal    |
| <b>addoo</b>  |         |                  |
| <b>addio</b>  | $111_2$ | Ordered          |

**Example:**

```
# Assume (AC.cc AND 0012) ≠ 0.  
addig r4, r8, r10      # r10 = r8 + r4
```

```
# Assume (AC.cc AND 1012) = 0.  
addone r4, r8, r10     # r10 is not changed.
```

## INSTRUCTION SET REFERENCE



|         |               |      |     |
|---------|---------------|------|-----|
| Opcode: | <b>addono</b> | 780H | REG |
|         | <b>addog</b>  | 790H | REG |
|         | <b>addeo</b>  | 7A0H | REG |
|         | <b>addoge</b> | 7B0H | REG |
|         | <b>addol</b>  | 7C0H | REG |
|         | <b>addone</b> | 7D0H | REG |
|         | <b>addole</b> | 7E0H | REG |
|         | <b>addoo</b>  | 7F0H | REG |
|         | <b>addino</b> | 781H | REG |
|         | <b>addig</b>  | 791H | REG |
|         | <b>addie</b>  | 7A1H | REG |
|         | <b>addige</b> | 7B1H | REG |
|         | <b>addil</b>  | 7C1H | REG |
|         | <b>addine</b> | 7D1H | REG |
|         | <b>addile</b> | 7E1H | REG |
|         | <b>addio</b>  | 7F1H | REG |

See Also: **addc, SUB<cc>, addi, addo**

Notes: This class of core instructions is not implemented on 80960Cx, Kx and Sx processors.

## 6.2.2 addc

|               |  |   |
|---------------|--|---|
| Mnemonic:     | <b>addc</b>  | Add Ordinal With Carry  |
| Format:       | <b>addc</b>  | <i>src1</i> , <i>src2</i> , <i>dst</i><br>reg/lit                  reg/lit                  reg |
| Description:  | Adds <i>src2</i> and <i>src1</i> values and condition code bit 1 (used here as a carry-in) and stores the result in <i>dst</i> . If ordinal addition results in a carry out, condition code bit 1 is set; otherwise, bit 1 is cleared. If integer addition results in an overflow, condition code bit 0 is set; otherwise, bit 0 is cleared. Regardless of addition results, condition code bit 2 is always set to 0.                    |   |
|               | <b>addc</b> can be used for ordinal or integer arithmetic. <b>addc</b> does not distinguish between ordinal and integer source operands. Instead, the processor evaluates the result for both data types and sets condition code bits 0 and 1 accordingly.   |   |
|               | An integer overflow fault is never signaled with this instruction.   |   |
| Action:       | <pre>dst = (src1 + src2 + AC.cc[1])[31:0]; AC.cc[2:0] = 000<sub>2</sub>; if((src2[31] == src1[31]) &amp;&amp; (src2[31] != dst[31]))     AC.cc[0] = 1;                                # Overflow bit.     AC.cc[1] = (src2 + src1 + AC.cc[1])[32];      # Carry out.</pre>   |   |
| Faults:       | <b>STANDARD</b>  | Refer to section 6.1.6, “Faults” (pg. 6-6).   |
| Example:      | <pre># Example of double-precision arithmetic. # Assume 64-bit source operands # in g0,g1 and g2,g3 cmpo 1, 0          # Clears Bit 1 (carry bit) of                      # the AC.cc. addc g0, g2, g0    # Add low-order 32 bits:                      # g0 = g2 + g0 + carry bit addc g1, g3, g1    # Add high-order 32 bits:                      # g1 = g3 + g1 + carry bit                      # 64-bit result is in g0, g1.</pre> |   |
| Opcode:       | <b>addc</b>  | 5B0H                   REG  |
| See Also:     | <b>ADD, SUB</b>  |   |
| Side Effects: | Sets the condition code in the arithmetic controls.  |   |

## 6.2.3 addi, addo

|              |  |   |     |
|--------------|--|---|-----|
| Mnemonic:    | <b>addo</b>  | Add Ordinal   |     |
|              | <b>addi</b>  | Add Integer   |     |
| Format:      | <b>add*</b>  | <i>src1,</i><br>reg/lit <i>src2,</i><br>reg/lit <i>dst</i><br>reg |     |
| Description: | Adds <i>src2</i> and <i>src1</i> values and stores the result in <i>dst</i> . The binary results from these two instructions are identical. The only difference is that <b>addi</b> can signal an integer overflow.  |   |     |
| Action:      | <p><b>addo:</b></p> $\text{dst} = (\text{src2} + \text{src1})[31:0];$ <p><b>addi:</b></p> $\text{dst} = (\text{src2} + \text{src1})[31:0];$ <pre> if((src2[31] == src1[31]) &amp;&amp; (src2[31] != dst[31])) {     if(AC.om == 1)         AC.of = 1;     else         generate_fault(ARITHMETIC_OVERFLOW); } </pre> |   |     |
| Faults:      | STANDARD   | Refer to section 6.1.6, "Faults" (pg. 6-6).                       |     |
|              | ARITHMETIC.OVERFLOW  | Occurs only with <b>addi</b> .                                    |     |
| Example:     | <b>addi r4, g5, r9 # r9 = g5 + r4</b>  |   |     |
| Opcode:      | <b>addo</b>  | 590H  | REG |
|              | <b>addi</b>  | 591H  | REG |
| See Also:    | <b>addc, subi, subo, subc, ADD</b>   |   |     |

## 6.2.4 alterbit

Mnemonic: **alterbit** Alter Bit

Format: **alterbit** *bitpos*, *src*, *dst*  
              reg/lit      reg/lit      reg

Description: Copies *src* value to *dst* with one bit altered. *bitpos* operand specifies bit to be changed; condition code determines value to which the bit is set. If condition code is X1X<sub>2</sub>, bit 1 = 1, the selected bit is set; otherwise, it is cleared. Typically this instruction is used to set the *bitpos* bit in the *targ* register if the result of a compare instruction is the equal condition code (010<sub>2</sub>).

Action:

```
if((AC.cc & 0102)==0)
    dst = src2 & ~(2**(SRC1%32));
else
    dst = src2 | 2**(src1%32);
```

Faults: **STANDARD** Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:

```
# Assume AC.cc = 0102
alterbit 24, g4,g9      # g9 = g4, with bit 24 set.
```

Opcode: **alterbit** 58FH REG

See Also: **chkbit, clrbit, notbit, setbit**

## 6.2.5 and, andnot

Mnemonic:      **and**      And  
**andnot**      And Not

Format:      **and**      *src1*,  
                        reg/lit      *src2*,  
                        *andnot*      *src1*,      *src2*,  
                        reg/lit      *dst*  
                        *dst*  
                        reg

Description:      Performs a bitwise AND (**and**) or AND NOT (**andnot**) operation on *src2* and *src1* values and stores result in *dst*. Note in the action expressions below, *src2* operand comes first, so that with **andnot** the expression is evaluated as:

{*src2* and not (*src1*)}  
 rather than

{*src1* and not (*src2*)}.

Action:      **and:**  
*dst* = *src2* & *src1*;

**andnot:**  
*dst* = *src2* & ~*src1*;

Faults:      STANDARD      Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:      and 0x7, g8, g2      # Put lower 3 bits of g8 in g2.  
 andnot 0x7, r12, r9      # Copy r12 to r9 with lower  
                         # three bits cleared.

Opcode:      **and**      581H      REG  
**andnot**      582H      REG

See Also:      **nand, nor, not, notand, notor, or, ornot, xnor, xor**

## 6.2.6 atadd

|              |  |   |                        |                   |
|--------------|--|---|------------------------|-------------------|
| Mnemonic:    | <b>atadd</b>   | Atomic Add                                  |                        |                   |
| Format:      | <b>atadd</b>   | <i>addr,</i><br>reg/lit                     | <i>src,</i><br>reg/lit | <i>dst</i><br>reg |
| Description: | Adds <i>src</i> value (full word) to value in the memory location specified with <i>addr</i> operand. The operation is performed on the actual data in memory and never on a cached value on chip. Initial value from memory is stored in <i>dst</i> . |   |                        |                   |
|              | Memory read and write are done atomically (i.e., other bus masters must be prevented from accessing the word of memory containing the word specified by <i>src/dst</i> operand until operation completes).   |   |                        |                   |
|              | Memory location in <i>addr</i> is the word's first byte (LSB) address. Address is automatically aligned to a word boundary. (Note that <i>addr</i> operand maps to <i>src1</i> operand of the REG format.)   |   |                        |                   |
| Action:      | <pre>implicit_syncf(); tempa = addr &amp; 0xFFFFFFFF; temp = atomic_read(tempa); atomic_write(tempa, temp+src); dst = temp;</pre>  |   |                        |                   |
| Faults:      | <b>STANDARD</b>  | Refer to section 6.1.6, "Faults" (pg. 6-6). |                        |                   |
| Example:     | <pre>atadd r8, r3, r11 # r8 contains the address of # memory location. # r11 = (r8) # (r8) = r11 + r3.</pre>   |   |                        |                   |
| Opcode:      | <b>atadd</b>   | <b>612H</b>                                 | REG                    |                   |
| See Also:    | <b>atmod</b>   |   |                        |                   |

## 6.2.7 atmod

Mnemonic: **atmod** Atomic Modify

Format: **atmod** *addr* *mask*, *src/dst*  
           *reg*      *reg/lit*     *reg*

Description: Copies the selected bits of *src/dst* value into memory location specified in *addr*. The operation is performed on the actual data in memory and never on a cached value on chip. Bits set in *mask* operand select bits to be modified in memory. Initial value from memory is stored in *src/dst*.

Memory read and write are done atomically (i.e., other bus masters must be prevented from accessing the word of memory containing the word specified with the *src/dst* operand until operation completes).

Memory location in *addr* is the modified word's first byte (LSB) address. Address is automatically aligned to a word boundary.

Action:

```
implicit_syncf();
tempa = addr & 0xFFFFFFFFC;
temp = atomic_read(tempa);
temp = (temp &~ mask) | (src_dst & mask);
atomic_write(tempa, temp);
src_dst = temp;
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:

```
atmod g5, g7, g10 # tempa = (g5)
                   # temp = (tempa andnot g7) or
                   # (g10 and g7)
                   # (g5) = temp
                   # g10 = tempa
```

Opcode: **atmod** 610H REG

See Also:

**atadd**

## 6.2.8 b, bx

Mnemonic:      **b**      Branch  
                 **bx**      Branch Extended

Format:      **b**      *targ*  
                          disp  
**bx**      *targ*  
                          mem

Description:      Branches to the specified target.

With the **b** instruction, IP specified with *targ* operand can be no farther than  $-2^{23}$  to  $(2^{23}-4)$  bytes from current IP. When using the Intel i960® processor assembler, *targ* operand must be a label which specifies target instruction's IP.

**bx** performs the same operation as **b** except the target instruction can be farther than  $-2^{23}$  to  $(2^{23}-4)$  bytes from current IP. Here, the target operand is an effective address, which allows the full range of addressing modes to be used to specify target instruction's IP. The "IP + displacement" addressing mode allows the instruction to be IP-relative. Indirect branching can be performed by placing target address in a register then using a register-indirect addressing mode.

Refer to section 2.3, "MEMORY ADDRESSING MODES" (pg. 2-6) for information on this subject.

Action:  
**b:**  
temp[31:2] = sign\_extension(targ[23:2]);  
IP[31:2] = IP[31:2] + temp[31:2];  
IP[1:0] = 0;

**bx:**  
IP[31:2] = effective\_address(targ[31:2]);  
IP[1:0] = 0;

Faults:      STANDARD      Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:      b xyz      # IP = xyz;  
                 bx 1332 (ip)      # IP = IP + 8 + 1332;  
                                  # this example uses IP-relative addressing

Opcode:      **b**      08H      CTRL  
                 **bx**      84H      MEM

See Also:      **bal, balx, BRANCH, COMPARE AND BRANCH, bbc, bbs**

## 6.2.9 **bal, balx**

|              |  |                                     |
|--------------|--|-------------------------------------|
| Mnemonic:    | <b>bal</b>   | Branch and Link                     |
|              | <b>balx</b>  | Branch and Link Extended            |
| Format:      | <b>bal</b>   | <i>targ</i><br>disp                 |
|              | <b>balx</b>  | <i>targ</i> , <i>dst</i><br>mem reg |
| Description: | Stores address of instruction following <b>bal</b> or <b>balx</b> in a register then branches to the instruction specified with the <i>targ</i> operand.   |                                     |
|              | The <b>bal</b> and <b>balx</b> instructions are used to call leaf procedures (procedures that do not call other procedures). The IP saved in the register provides a return IP that the leaf procedure can branch to (using a <b>b</b> or <b>bx</b> instruction) to perform a return from the procedure. Note that these instructions do not use the processor's call-and-return mechanism, so the calling procedure shares its local-register set with the called (leaf) procedure.   |                                     |
|              | With <b>bal</b> , address of next instruction is stored in register g14. <i>targ</i> operand value can be no farther than $-2^{23}$ to $(2^{23} - 4)$ bytes from current IP. When using the Intel i960 processor assembler, <i>targ</i> must be a label which specifies the target instruction's IP.   |                                     |
|              | <b>balx</b> performs same operation as <b>bal</b> except next instruction address is stored in <i>dst</i> (allowing the return IP to be stored in any available register). With <b>balx</b> , the full address space can be accessed. Here, the target operand is an effective address, which allows full range of addressing modes to be used to specify target IP. "IP + displacement" addressing mode allows instruction to be IP-relative. Indirect branching can be performed by placing target address in a register and then using a register-indirect addressing mode. |                                     |
|              | See section 2.3, "MEMORY ADDRESSING MODES" (pg. 2-6) for a complete discussion of addressing modes available with memory-type operands.  |                                     |
| Action:      | <b>bal:</b><br>$g14 = IP + 4;$<br>$IP[31:2] = \text{effective\_address}(targ[31:2]);$<br>$IP[1:0] = 0;$  |                                     |
|              | <b>balx:</b><br>$dst = IP + \text{instruction\_length};$<br># Instruction_length = 4 or 8 depending on the size of target address.<br>$IP[31:2] = \text{effective\_address}(targ[31:2]);$ # Resume execution at the new IP.<br>$IP[1:0] = 0;$  |                                     |

|           |  |  |
|-----------|--|--|
| Faults:   | STANDARD   | Refer to section 6.1.6, “Faults” (pg. 6-6).                  |
| Example:  | bal xyz<br>balx (g2), g4                           | # g14 = IP + 4<br># IP = xyz<br># g4 = IP + 4<br># IP = (g2) |
| Opcode:   | bal<br>balx  | 0BH<br>85H   |
|           |  | CTRL<br>MEM  |
| See Also: | <b>b, bx, BRANCH, COMPARE AND BRANCH, bbc, bbs</b> |  |

## INSTRUCTION SET REFERENCE

6.2.10    **bbc, bbs**

Mnemonic:    **bbc**    Check Bit and Branch If Clear  
**bbs**    Check Bit and Branch If Set

Format:    **bb\***    *bitpos*,              *src*,              *targ*  
                    reg/lit              reg              disp

Description: Checks bit in *src* (designated by *bitpos*) and sets AC register condition code according to *src* value. The processor then performs conditional branch to instruction specified with *targ*, based on condition code state.

For **bbc**, if selected bit in *src* is clear, the processor sets condition code to  $000_2$  and branches to instruction specified by *targ*; otherwise, it sets condition code to  $010_2$  and goes to next instruction.

For **bbs**, if selected bit is set, the processor sets condition code to  $010_2$  and branches to *targ*; otherwise, it sets condition code to  $000_2$  and goes to next instruction.

*targ* can be no farther than  $-2^{12}$  to  $(2^{12} - 4)$  bytes from current IP. When using the Intel i960 processor assembler, *targ* must be a label which specifies target instruction's IP.

Action:

**bbs:**

```
if((src2 & 2**((src1%32)) == 1)
{   AC.cc = 0102;
    temp[31:2] = sign_extension(targ[12:2]);
    IP[31:2] = IP[31:2] + temp[31:2];
    IP[1:0] = 0;
}
else
    AC.cc = 0002;
```

**bbc:**

```
if((src2 & 2**((src1%32)) == 0)
{   AC.cc = 0002;
    temp[31:2] = sign_extension(targ[12:2]);
    IP[31:2] = IP[31:2] + temp[31:2];
    IP[1:0] = 0;
}
else
    AC.cc = 0102;
```

Faults:

STANDARD

Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:           # Assume bit 10 of r6 is clear.  
          bbc 10, r6, xyz    # Bit 10 of r6 is checked  
                          # and found clear:  
                          # AC.cc = 000  
                          # IP = xyz;

Opcode:           **bbc**       30H           COBR  
          **bbs**       37H           COBR

See Also:          **chkbit, COMPARE AND BRANCH<cc>, BRANCH<cc>**

Side Effects:      Sets the condition code in the arithmetic controls.

## 6.2.11 BRANCH<cc>

|           |            |                            |
|-----------|------------|----------------------------|
| Mnemonic: | <b>be</b>  | Branch If Equal            |
|           | <b>bne</b> | Branch If Not Equal        |
|           | <b>bl</b>  | Branch If Less             |
|           | <b>ble</b> | Branch If Less Or Equal    |
|           | <b>bg</b>  | Branch If Greater          |
|           | <b>bge</b> | Branch If Greater Or Equal |
|           | <b>bo</b>  | Branch If Ordered          |
|           | <b>bno</b> | Branch If Unordered        |
| Format:   | <b>b*</b>  | <i>targ</i><br><i>disp</i> |

Description: Branches to instruction specified with *targ* operand according to AC register condition code state.

For all branch<cc> instructions except **bno**, the processor branches to instruction specified with *targ*, if the logical AND of condition code and mask-part of opcode is not zero. Otherwise, it goes to next instruction.

For **bno**, the processor branches to instruction specified with *targ* if the condition code is zero. Otherwise, it goes to next instruction.

For instance, **bno** (unordered) can be used as a branch if false instruction when coupled with **chkbit**. For **bno**, branch is taken if condition code equals  $000_2$ . **be** can be used as branch-if true instruction.

The *targ* operand value can be no farther than  $-2^{23}$  to  $(2^{23} - 4)$  bytes from current IP.

The following table shows condition code mask for each instruction. The mask is in opcode bits 0-2.

| Instruction | Mask    | Condition        |
|-------------|---------|------------------|
| bno         | $000_2$ | Unordered        |
| bg          | $001_2$ | Greater          |
| be          | $010_2$ | Equal            |
| bge         | $011_2$ | Greater or equal |
| bl          | $100_2$ | Less             |
| bne         | $101_2$ | Not equal        |
| ble         | $110_2$ | Less or equal    |
| bo          | $111_2$ | Ordered          |

Action:

```
if((mask & AC.cc) || (mask == AC.cc))
{    temp[31:2] = sign_extension(targ[23:2]);
    IP[31:2] = IP[31:2] + temp[31:2];
    IP[1:0] = 0;
}
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:

```
# Assume (AC.cc AND 1002) ≠ 0
bl xyz           # IP = xyz;
```

Opcode:

|            |     |      |
|------------|-----|------|
| <b>be</b>  | 12H | CTRL |
| <b>bne</b> | 15H | CTRL |
| <b>bl</b>  | 14H | CTRL |
| <b>ble</b> | 16H | CTRL |
| <b>bg</b>  | 11H | CTRL |
| <b>bge</b> | 13H | CTRL |
| <b>bo</b>  | 17H | CTRL |
| <b>bno</b> | 10H | CTRL |

See Also: **b, bx, bbc, bbs, COMPARE AND BRANCH, bal, balx, BRANCH**

## 6.2.12 **bswap** (New 80960 Core Instruction)

Mnemonic: **bswap** Byte Swap

Format: **bswap** *src1:src*      *src2:dst*  
              reg/lit                  reg

Description: Alter the order of bytes in a word, reversing its “endianess.”

Copies bytes 3:0 of *src1* to *src2* reversing order of the bytes. Byte 0 of *src1* becomes byte 3 of *src2*, byte 1 of *src1* becomes byte 2 of *src2*, etc.

Action: 
$$\begin{aligned} \text{dst} = & (\text{rotate\_left}(\text{src} 8) \& 0x00FF00FF) \\ & +(\text{rotate\_left}(\text{src} 24) \& 0xFF00FF00); \end{aligned}$$

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:  $\begin{aligned} & \# \text{ g8} = 0x89ABCDEF \\ & \text{bswap g8, g10} \quad \# \text{ Reverse byte order.} \\ & \quad \quad \quad \# \text{ g10 now } 0xEFCDAB89 \end{aligned}$

Opcode: **bswap** 5ADH REG

See Also: **scanbyte, rotate**

Notes: This core instruction is not implemented on Cx, Kx and Sx 80960 processors.

## 6.2.13 call

Mnemonic: **call** Call

Format: **call** *targ*  
              *disp*

Description: Calls a new procedure. *targ* operand specifies the IP of called procedure's first instruction. When using the Intel i960 processor assembler, *targ* must be a label.

In executing this instruction, the processor performs a local call operation as described in section 7.1.3.1, "Call Operation" (pg. 7-7). As part of this operation, the processor saves the set of local registers associated with the calling procedure and allocates a new set of local registers and a new stack frame for the called procedure. Processor then goes to the instruction specified with *targ* and begins execution.

*targ* can be no farther than  $-2^{23}$  to  $(2^{23} - 4)$  bytes from current IP.

Action:

```
# Wait for any uncompleted instructions to finish.  
implicit_syncf();  
temp = (SP + (SALIGN*16 - 1)) & ~(SALIGN*16 - 1)  
      # Round stack pointer to next boundary.  
      # SALIGN=1 on i960 Jx processors.  
RIP = IP;  
if (register_set_available)  
    allocate_new_frame( );  
else  
{   save_register_set( );      # Save register set in memory at its FP.  
   allocate_new_frame( );  
}  
# Local register references now refer to new frame.  
IP = targ  
PFP = FP;  
FP = temp;  
SP = temp + 64;
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example: **call xyz** # IP = xyz

Opcode: **call** 09H CTRL

See Also: **bal, calls, callx**

## 6.2.14 calls

Mnemonic: **calls** Call System

Format: **calls** *targ*  
              *reg/lit*

Description: Calls a system procedure. The *targ* operand gives the number of the procedure being called. For **calls**, the processor performs system call operation described in section 7.5, "SYSTEM CALLS" (pg. 7-16). *targ* provides an index to a system procedure table entry from which the processor gets the called procedure's IP.

The called procedure can be a local or supervisor procedure, depending on system procedure table entry type. If it is a supervisor procedure, the processor switches to supervisor mode (if not already in this mode).

As part of this operation, processor also allocates a new set of local registers and a new stack frame for called procedure. If the processor switches to supervisor mode, the new stack frame is created on the supervisor stack.

```
Action:
# Wait for any uncompleted instructions to finish.
implicit_syncf();
If (targ > 259)
    generate_fault(PROTECTION.LENGTH);
temp = get_sys_proc_entry(sptbase + 48 + 4*targ);
# sptbase is address of supervisor procedure table.

if (frame_available)
    allocate_new_frame( );
else
{   save_frame();           # Save a frame in memory at its FP.
    allocate_new_frame( );
# Local register references now refer to new frame.
}
RIP = IP;
IP = temp;
if ((temp.type == local) || (PC.em == supervisor))
{               # Local call or supervisor call from supervisor mode.
    temp = (SP + (SALIGN*16 - 1)) & ~ (SALIGN*16 - 1)
# Round stack pointer to next boundary.
# SALIGN=1 on i960 Jx processors.
    temp.RRR = 0002;
}
else          # Supervisor call from user mode.
{   tempa = SSP;           # Get Supervisor Stack pointer.
```

```
temp.RRR = 0102 | PC.te;  
PC.em = supervisor;  
PC.te = temp.te;  
}  
PFP = FP;  
PFP.rrr = tempRRR;  
FP = tempa;
```

|           |                               |  |
|-----------|-------------------------------|--|
| Faults:   | STANDARD<br>PROTECTION.LENGTH | Refer to section 6.1.6, "Faults" (pg. 6-6).<br>Specifies a procedure number greater than 259.                  |
| Example:  | calls r12<br>calls 3          | # IP = value obtained from<br># procedure table for procedure<br># number given in r12.<br># Call procedure 3. |
| Opcode:   | calls 660H                    | REG  |
| See Also: | bal, call, callx              |  |

## 6.2.15 **callx**

Mnemonic: **callx** Call Extended

Format: **callx** *targ*  
              *mem*

Description: Calls new procedure. *targ* specifies IP of called procedure's first instruction.

In executing **callx**, the processor performs a local call as described in section 7.1.3.1, "Call Operation" (pg. 7-7). As part of this operation, the processor allocates a new set of local registers and a new stack frame for the called procedure. Processor then goes to the instruction specified with *targ* and begins execution of new procedure.

**callx** performs the same operation as **call** except the target instruction can be farther than  $-2^{23}$  to  $(2^{23} - 4)$  bytes from current IP.

The *targ* operand is a memory type, which allows the full range of addressing modes to be used to specify the IP of the target instruction. The "IP + displacement" addressing mode allows the instruction to be IP-relative. Indirect calls can be performed by placing the target address in a register and then using one of the register-indirect addressing modes.

Refer to Chapter 2, DATA TYPES AND MEMORY ADDRESSING MODES for more information.

Action:

```

# Wait for any uncompleted instructions to finish;
implicit_syncf();
temp = (SP + (SALIGN*16 - 1)) & ~(SALIGN*16 - 1)
# Round stack pointer to next boundary.
# SALIGN=1 on i960 Jx processors.

RIP = IP;
if (register_set_available)
    allocate_new_frame( );
else
    { save_register_set( );      # Save register set in memory at its FP;
      allocate_new_frame( );
    }
# Local register references now refer to new frame.

IP = targ
PFP = FP;
FP = temp;
SP = temp + 64;
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:      **callx (g5)**      # IP = (g5), where the address in g5  
                  # is the address of the new procedure.

Opcode:      **callx**      86H      MEM

See Also:      **call, calls, bal**

**6.2.16 chkbit**

|               |   |  |
|---------------|---|--|
| Mnemonic:     | <b>chkbit</b>   | Check Bit  |
| Format:       | <b>chkbit</b>   | <i>bitpos</i> ,<br>reg/lit <i>src2</i><br>reg/lit                  |
| Description:  | Checks bit in <i>src2</i> designated by <i>bitpos</i> and sets condition code according to value found. If bit is set, condition code is set to $010_2$ ; if bit is clear, condition code is set to $000_2$ . |  |
| Action:       | if (((src2 & 2**(bitpos % 32)) == 0)<br>AC.cc = $000_2$ ;<br>else<br>AC.cc = $010_2$ ;  |  |
| Faults:       | STANDARD  | Refer to section 6.1.6, "Faults" (pg. 6-6).                        |
| Example:      | chkbit 13, g8   | # Checks bit 13 in g8 and sets<br># AC.cc according to the result. |
| Opcode:       | <b>chkbit</b>   | 5AEH            REG  |
| See Also:     | <b>alterbit, cirbit, notbit, setbit, cmpi, cmpo</b>   |  |
| Side Effects: | Sets the condition code in the arithmetic controls.   |  |

## 6.2.17 **clrbit**

Mnemonic: **clrbit** Clear Bit

Format: **clrbit** *bitpos*, *src*, *dst*  
              reg/lit    reg/lit    reg

Description: Copies *src* value to *dst* with one bit cleared. *bitpos* operand specifies bit to be cleared.

Action:  $dst = src2 \& \sim(2^{**}(src1\%32));$

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example: `clrbit 23, g3, g6 # g6 = g3 with bit 23 cleared.`

Opcode: **clrbit** 58CH REG

See Also: **alterbit, chkbit, notbit, setbit**

## 6.2.18 cmpdeci, cmpdeco

Mnemonic:      **cmpdeci**      Compare and Decrement Integer  
**cmpdeco**      Compare and Decrement Ordinal

Format:      **cmpdec\***      *src1*,                    *src2*,                    *dst*  
                          reg/lit                        reg/lit                        reg

Description:      Compares *src2* and *src1* values and sets the condition code according to comparison results. *src2* is then decremented by one and result is stored in *dst*. The following table shows condition code setting for the three possible results of the comparison.

| Condition Code | Comparison    |
|----------------|---------------|
| $100_2$        | $src1 < src2$ |
| $010_2$        | $src1 = src2$ |
| $001_2$        | $src1 > src2$ |

These instructions are intended for use in ending iterative loops. For **cmpdeci**, integer overflow is ignored to allow looping down through the minimum integer values.

Action:

```
if(src1 < src2)
    AC.cc = 1002;
else if(src1 == src2)
    AC.cc = 0102;
else
    AC.cc = 0012;
dst = src2 - 1;      # Overflow suppressed for cmpdeci.
```

Faults:      STANDARD                                  Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:

```
cmpdeci 12, g7, g1 # Compares g7 with 12 and sets
                      # AC.cc to indicate the result
                      # g1 = g7 - 1.
```

Opcode:

|                |      |     |
|----------------|------|-----|
| <b>cmpdeci</b> | 5A7H | REG |
| <b>cmpdeco</b> | 5A6H | REG |

See Also:

**cmpinco, cmpo, cmpi, cmpinci, COMPARE AND BRANCH**

Side Effects:

Sets the condition code in the arithmetic controls.

## 6.2.19 cmpinci, cmpinco

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>cmpinci</b>  | Compare and Increment Integer                                     |
|              | <b>cmpinco</b>  | Compare and Increment Ordinal                                     |
| Format:      | <b>cmpinc*</b>  | <i>src1,</i><br>reg/lit <i>src2,</i><br>reg/lit <i>dst</i><br>reg |
| Description: | Compares <i>src2</i> and <i>src1</i> values and sets the condition code according to comparison results. <i>src2</i> is then incremented by one and result is stored in <i>dst</i> . The following table shows condition code settings for the three possible comparison results. |   |

| Condition Code | Comparison    |
|----------------|---------------|
| $100_2$        | $src1 < src2$ |
| $010_2$        | $src1 = src2$ |
| $001_2$        | $src1 > src2$ |

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These instructions are intended for use in ending iterative loops. For **cmpinci**, integer overflow is ignored to allow looping up through the maximum integer values.

Action:

```
if (src1 < src2)
    AC.cc = 1002;
else if (src1 == src2)
    AC.cc = 0102;
else
    AC.cc = 0012;
```

**cmpinco:**

*dst* = *src2* + 1;

**cmpinci:**

*dst* = *src2* + 1; # Overflow suppressed.

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example: **cmpinco r8, g2, g9** # Compares the values in *g2*  
# and *r8* and sets AC.cc to  
# indicate the result:  
# *g9* = *g2* + 1

Opcode: **cmpinci** 5A5H REG  
**cmpinco** 5A4H REG

See Also: **cmpdeco, cmipo, cmpi, cmpdeci, COMPARE AND BRANCH**

Side Effects: Sets the condition code in the arithmetic controls.

## 6.2.20 COMPARE (Includes New 80960 Core Instructions)

| Mnemonic:      | <b>cmpi</b>   | Compare Integer  |                |            |         |               |         |               |         |               |
|----------------|---|--|----------------|------------|---------|---------------|---------|---------------|---------|---------------|
|                | <b>cmpib</b>  | Compare Integer Byte   |                |            |         |               |         |               |         |               |
|                | <b>cmpis</b>  | Compare Integer Short  |                |            |         |               |         |               |         |               |
|                | <b>cmpos</b>  | Compare Ordinal  |                |            |         |               |         |               |         |               |
|                | <b>cmpob</b>  | Compare Ordinal Byte   |                |            |         |               |         |               |         |               |
|                | <b>cmpos</b>  | Compare Ordinal Short  |                |            |         |               |         |               |         |               |
| Format:        | <b>cmp*</b>   | <i>src1,</i><br><i>reg/lit</i> <i>src2</i><br><i>reg/lit</i> |                |            |         |               |         |               |         |               |
| Description:   | Compares <i>src2</i> and <i>src1</i> values and sets condition code according to comparison results. The following table shows condition code settings for the three possible comparison results.   |  |                |            |         |               |         |               |         |               |
|                | <table border="1"> <thead> <tr> <th>Condition Code</th><th>Comparison</th></tr> </thead> <tbody> <tr> <td><math>100_2</math></td><td><math>src1 &lt; src2</math></td></tr> <tr> <td><math>010_2</math></td><td><math>src1 = src2</math></td></tr> <tr> <td><math>001_2</math></td><td><math>src1 &gt; src2</math></td></tr> </tbody> </table> |  | Condition Code | Comparison | $100_2$ | $src1 < src2$ | $010_2$ | $src1 = src2$ | $001_2$ | $src1 > src2$ |
| Condition Code | Comparison  |  |                |            |         |               |         |               |         |               |
| $100_2$        | $src1 < src2$   |  |                |            |         |               |         |               |         |               |
| $010_2$        | $src1 = src2$   |  |                |            |         |               |         |               |         |               |
| $001_2$        | $src1 > src2$   |  |                |            |         |               |         |               |         |               |
| Action:        | <p># For cmpos, cmpis N = 31.<br/> # For cmpob, cmpib N = 15.<br/> # For cmpo, cmpi N = 7.</p> <pre> if (src1[N:0] &lt; src2[N:0])     AC.cc = 100<sub>2</sub>; else if (src1[N:0] == src2[N:0])     AC.cc = 010<sub>2</sub>; else if (src1[N:0] &gt; src2[N:0])     AC.cc = 001<sub>2</sub>; </pre>  |  |                |            |         |               |         |               |         |               |
| Faults:        | STANDARD  | Refer to section 6.1.6, "Faults" (pg. 6-6).                  |                |            |         |               |         |               |         |               |

Example:      **cmwo r9, 0x10**    # Compares the value in r9 with 0x10  
                  # and sets AC.cc to indicate the  
                  # result.

**bg xyz**                # Branches to xyz if the value of r9  
                  # was greater than 0x10.

|         |              |      |     |
|---------|--------------|------|-----|
| Opcode: | <b>cmpi</b>  | 5A1H | REG |
|         | <b>cmpib</b> | 595H | REG |
|         | <b>cmpis</b> | 597H | REG |
|         | <b>cmwo</b>  | 5A0H | REG |
|         | <b>cmpob</b> | 594H | REG |
|         | <b>cmpos</b> | 596H | REG |

See Also:      **COMPARE AND BRANCH**, **cmpdeci**, **cmpdeco**, **cmpincli**, **cmpinco**,  
**concmpli**, **concmwo**

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Side Effects: Sets the condition code in the arithmetic controls.

Notes:          The core instructions **cmpib**, **cmpis**, **compob** and **compos** are not implemented on Cx, Kx and Sx 80960 processors.

## 6.2.21 COMPARE AND BRANCH

Mnemonic:

|                |  |
|----------------|--|
| <b>cmpibe</b>  | Compare Integer and Branch If Equal            |
| <b>cmpibne</b> | Compare Integer and Branch If Not Equal        |
| <b>cmpibl</b>  | Compare Integer and Branch If Less             |
| <b>cmpible</b> | Compare Integer and Branch If Less Or Equal    |
| <b>cmpibg</b>  | Compare Integer and Branch If Greater          |
| <b>cmpibge</b> | Compare Integer and Branch If Greater Or Equal |
| <b>cmpibo</b>  | Compare Integer and Branch If Ordered          |
| <b>cmpibno</b> | Compare Integer and Branch If Not Ordered      |
| <br>           |  |
| <b>cmpobe</b>  | Compare Ordinal and Branch If Equal            |
| <b>cmpobne</b> | Compare Ordinal and Branch If Not Equal        |
| <b>cmpobi</b>  | Compare Ordinal and Branch If Less             |
| <b>cmpoble</b> | Compare Ordinal and Branch If Less Or Equal    |
| <b>cmpobg</b>  | Compare Ordinal and Branch If Greater          |
| <b>cmpobge</b> | Compare Ordinal and Branch If Greater Or Equal |

Format:

|               |                          |                      |                     |
|---------------|--------------------------|----------------------|---------------------|
| <b>cmpib*</b> | <i>src1</i> ,<br>reg/lit | <i>src2</i> ,<br>reg | <i>targ</i><br>disp |
| <b>cmpob*</b> | <i>src1</i> ,<br>reg/lit | <i>src2</i> ,<br>reg | <i>targ</i><br>disp |

Description:

Compares *src2* and *src1* values and sets AC register condition code according to comparison results. If logical AND of condition code and mask part of opcode is not zero, the processor branches to instruction specified with *targ*; otherwise, the processor goes to next instruction.

*targ* can be no farther than  $-2^{12}$  to  $(2^{12} - 4)$  bytes from current IP. When using the Intel i960 processor assembler, *targ* must be a label which specifies target instruction's IP.

Functions these instructions perform can be duplicated with a **cmpl** or **cmpl** followed by a branch-if instruction, as described in section 6.2.20, "COMPARE (Includes New 80960 Core Instructions)" (pg. 6-34).

The following table shows the condition-code mask for each instruction. The mask is in bits 0-2 of the opcode.

| Instruction    | Mask             | Branch Condition      |
|----------------|------------------|-----------------------|
| <b>cmpibno</b> | 000 <sub>2</sub> | No Condition          |
| <b>cmpibg</b>  | 001 <sub>2</sub> | <i>src1 &gt; src2</i> |
| <b>cmpibe</b>  | 010 <sub>2</sub> | <i>src1 = src2</i>    |
| <b>cmpibge</b> | 011 <sub>2</sub> | <i>src1 ≥ src2</i>    |
| <b>cmpibl</b>  | 100 <sub>2</sub> | <i>src1 &lt; src2</i> |
| <b>cmpibne</b> | 101 <sub>2</sub> | <i>src1 ≠ src2</i>    |
| <b>cmpible</b> | 110 <sub>2</sub> | <i>src1 ≤ src2</i>    |
| <b>cmpibo</b>  | 111 <sub>2</sub> | Any Condition         |
| <b>cmpobg</b>  | 001 <sub>2</sub> | <i>src1 &gt; src2</i> |
| <b>cmpobe</b>  | 010 <sub>2</sub> | <i>src1 = src2</i>    |
| <b>cmpobge</b> | 011 <sub>2</sub> | <i>src1 ≥ src2</i>    |
| <b>cmpobl</b>  | 100 <sub>2</sub> | <i>src1 &lt; src2</i> |
| <b>cmpobne</b> | 101 <sub>2</sub> | <i>src1 ≠ src2</i>    |
| <b>cmpoble</b> | 110 <sub>2</sub> | <i>src1 ≤ src2</i>    |

**NOTE:** **cmpibo** always branches; **cmpibno** never branches.

|          |   |   |
|----------|---|---|
| Action:  | <pre> if(src1 &lt; src2)     AC.cc = 100<sub>2</sub>; else if(src1 == src2)     AC.cc == 010<sub>2</sub>; else     AC.cc = 001<sub>2</sub>; if((mask &amp;&amp; AC.cc) != 000<sub>2</sub>)     IP[31:2] = efa[31:2];      # Resume execution at the new IP.     IP[1:0] = 0; </pre> |   |
| Faults:  | STANDARD  | Refer to section 6.1.6, “Faults” (pg. 6-6). |
| Example: | <pre> cmpibl g3, g9, xyz # assume g3 &lt; g9 # g9 is compared with g3; # IP = xyz.  cmpobge r9, r7, xyz # r9 is compared with r7; # IP = xyz. </pre>  |   |

**INSTRUCTION SET REFERENCE**

|         |                |     |      |
|---------|----------------|-----|------|
| Opcode: | <b>cmpibe</b>  | 3AH | COBR |
|         | <b>cmpibne</b> | 3DH | COBR |
|         | <b>cmpibl</b>  | 3CH | COBR |
|         | <b>cmpible</b> | 3EH | COBR |
|         | <b>cmpibg</b>  | 39H | COBR |
|         | <b>cmpibge</b> | 3BH | COBR |
|         | <b>cmpibo</b>  | 3FH | COBR |
|         | <b>cmpibno</b> | 38H | COBR |
|         | <b>cmpobe</b>  | 32H | COBR |
|         | <b>cmpobne</b> | 35H | COBR |
|         | <b>cmpobl</b>  | 34H | COBR |
|         | <b>cmpoble</b> | 36H | COBR |
|         | <b>cmpobg</b>  | 31H | COBR |
|         | <b>cmpobge</b> | 33H | COBR |

See Also: **BRANCH<cc>, cmpi, cmo, bal, balx**

Side Effects: Sets the condition code in the arithmetic controls.

## 6.2.22 concmpi, concmpo

|              |  |   |
|--------------|--|---|
| Mnemonic:    | <b>concmphi</b>  | Conditional Compare Integer                                 |
|              | <b>concmpo</b>   | Conditional Compare Ordinal                                 |
| Format:      | <b>concmphi*</b>   | <i>src1</i> , <i>src2</i><br>reg/lit                reg/lit |
| Description: | Compares <i>src2</i> and <i>src1</i> values if condition code bit 2 is not set. If comparison is performed, condition code is set according to comparison results. Otherwise, condition codes are not altered. |   |

These instructions are provided to facilitate bounds checking by means of two-sided range comparisons (e.g., is A between B and C?). They are generally used after a compare instruction to test whether a value is inclusively between two other values.

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The example below illustrates this application by testing whether g3 value is between g5 and g6 values, where g5 is assumed to be less than g6. First a comparison (**cmpo**) of g3 and g6 is performed. If g3 is less than or equal to g6 (i.e., condition code is either  $010_2$  or  $001_2$ ), a conditional comparison (**concmphi**) of g3 and g5 is then performed. If g3 is greater than or equal to g5 (indicating that g3 is within the bounds of g5 and g6), condition code is set to  $010_2$ ; otherwise, it is set to  $001_2$ .

Action:

```
if (AC.cc != 1XX2)
{
    if(src1 <= src2)
        AC.cc = 0102;
    else
        AC.cc = 0012;
}
```

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:

|                 |   |
|-----------------|---|
| cmpo g6, g3     | # Compares g6 and g3                    |
|                 | # and sets AC.cc.                       |
| concmphi g5, g3 | # If AC.cc < 100 <sub>2</sub> (g6 ≥ g3) |
|                 | # g5 is compared with g3.               |

At this point, depending on the register ordering, the condition code is one of those listed on Table 6.6.

**Table 6.6. concmpo example: register ordering and CC**

| Order        | CC      |
|--------------|---------|
| g5 < g6 < g3 | $100_2$ |
| g5 < g6 = g3 | $010_2$ |
| g5 < g3 < g6 | $010_2$ |
| g5 = g3 < g6 | $010_2$ |
| g3 < g5 < g6 | $001_2$ |

Opcode:           **concmphi**   5A3H           REG  
              **concmipo**   5A2H           REG

See Also:          **cmpo, cmphi, cmpdeci, cmpdeco, cmpinici, cmpinico, COMPARE AND BRANCH**

Side Effects:      Sets the condition code in the arithmetic controls.

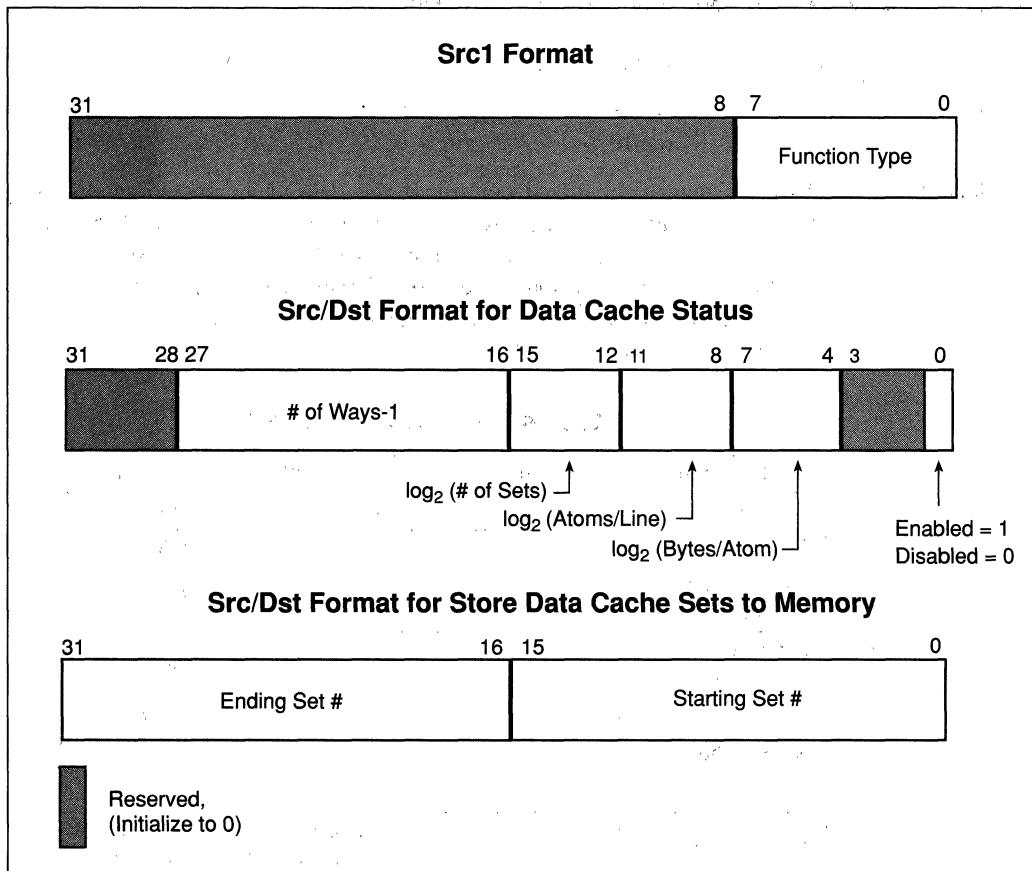
## 6.2.23 dcctl (80960Jx-Specific Instruction)

|              |  |  |
|--------------|--|--|
| Mnemonic:    | <b>dcctl</b>   | Data-cache Control                             |
| Format:      | <i>src1</i> ,<br>reg/lit   | <i>src2</i> ,<br>reg/lit <i>src/dst</i><br>reg |
| Description: | Performs management and control of the data cache including disabling, enabling, invalidating, ensuring coherency, getting status, and storing cache contents to memory. Operations are indicated by the value of <i>src1</i> . <i>src2</i> and <i>src/dst</i> are also used by some operations. When needed by the operation, the processor orders the effects of the operation with previous and subsequent operations to ensure correct behavior. |  |

**Table 6-7. DCCTL Operand Fields**

| Function                               | <i>src1</i> | <i>src2</i>                              | <i>src/dst</i>  |
|--|-------------|--|---|
| Disable Dcache                         | 0           | NA                                       | NA  |
| Enable Dcache                          | 1           | NA                                       | NA  |
| Global invalidate<br>Dcache            | 2           | NA                                       | NA  |
| Ensure cache<br>coherency <sup>1</sup> | 3           | NA                                       | NA  |
| Get Dcache status                      | 4           | NA                                       | <i>src</i> : N/A<br><i>dst</i> : Receives<br>Dcache status<br>(see Figure 6-1). |
| Store Dcache to<br>memory              | 6           | Destination<br>address for cache<br>sets | <i>src</i> : Dcache set<br>#s to be stored<br>(see Figure 6-1).                 |

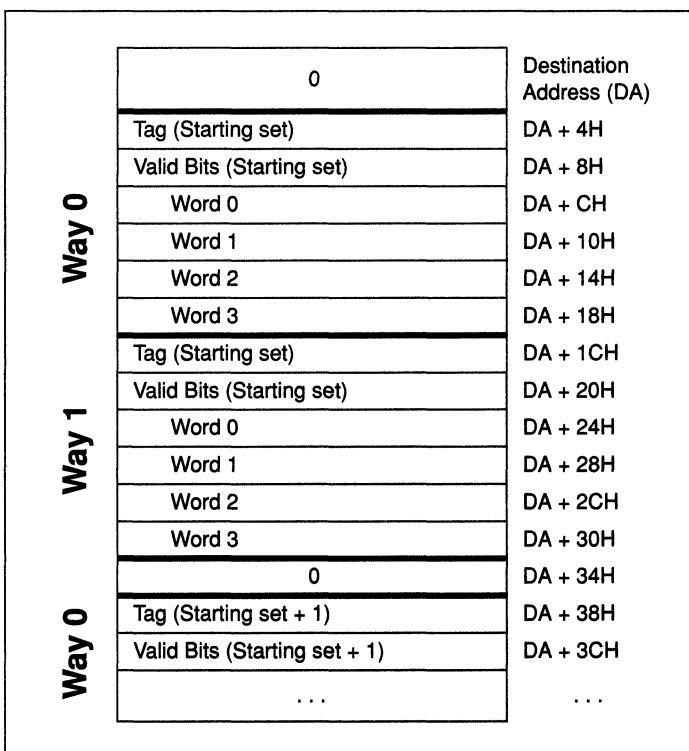
1. Invalidates data cache on 80960Jx.



**Figure 6-1. DCCTL src1 and src/dst Formats**

**Table 6.8. DCCTL Status Values and D-Cache Parameters**

| Value   | Value on i960JA CPU | Value on i960JD/JF CPU |
|---|---------------------|------------------------|
| bytes per atom                                    | 4                   | 4                      |
| atoms per line                                    | 4                   | 4                      |
| number of sets                                    | 64                  | 128 (full)             |
| number of ways                                    | 1 (Direct)          | 1 (Direct)             |
| cache size  | 1-Kbytes            | 2-Kbytes(full)         |
| Status[0] (enable / disable)                      | 0 or 1              | 0 or 1                 |
| Status[1:3] (reserved)                            | 0                   | 0                      |
| Status[7:4] ( $\log_2(\text{bytes per atom})$ )   | 2                   | 2                      |
| Status[11:8] ( $\log_2(\text{atoms per line})$ )  | 2                   | 2                      |
| Status[15:12] ( $\log_2(\text{number of sets})$ ) | 6                   | 7 (full)               |
| Status[27:16] (number of ways - 1)                | 0                   | 0                      |

**Figure 6-2. Store Data Cache to Memory Output Format**

**Table 6-9. Valid\_Bits Values**

| Bit  | Meaning                                     |
|------|---|
| 0    | Tag Valid bit for current Set and Way       |
| 1    | Valid Bit for Word 0 of current Set and Way |
| 2    | Valid Bit for Word 1 of current Set and Way |
| 3    | Valid Bit for Word 2 of current Set and Way |
| 4    | Valid Bit for Word 3 of current Set and Way |
| 5-31 | Reserved, Read as Zero.                     |

```

Action:
if (PC.em != supervisor)
    generate_fault(TYPE.MISMATCH);
order_wrt(previous_operations);
switch (src1[7:0]) {
    case 0:      # Disable data cache.
        disable_Dcache( );
        break;
    case 1:      # Enable data cache.
        enable_Dcache( );
        break;
    case 2:      # Global invalidate data cache.
        invalidate_Dcache( );
        break;
    case 3:      # Ensure coherency of data cache with memory.
        # Causes data cache to be invalidated on this processor.
        ensure_Dcache_coherency( );
        break;
    case 4:      # Get data cache status into src/dst.
        if (Dcache_enabled) src/dst[0] = 1;
        else src/dst[0] = 0;
        # Atom is 4 bytes.
        src/dst[7:4] = log2(bytes per atom);
        # 4 atoms per line.
        src/dst[11:8] = log2(atoms per line);
        src/dst[15:12] = log2(number of sets);
        src/dst[27:16] = number of ways-1; # in lines per set
        # cache size = ([27:16]+1) << ([7:4] + [11:8] + [15:12]).
        break;
}

```

Action:

```

case 6:          # Store data cache sets to memory pointed to by src2.
    start = src/dst[15:0]      # Starting set number.
    end   = src/dst[31:16]      # Ending set number.
                           # (zero-origin).
    if (end >= Dcache_max_sets) end = Dcache_max_sets - 1;
    if (start > end) generate_fault
        (OPERATION.INVALID_OPERAND);
    memadr = src2;            # Must be word-aligned.
    if (0x3 & memadr! = 0)
        generate_fault(OPERATION.INVALID_OPERAND)
    for (set = start; set <= end; set++){
        # Set_Data is described at end of this code flow.
        memory[memadr] = Set_Data[set];
        memadr += 4;
        for (way = 0; way < numb_ways; way++)
            {memory[memadr] = tags[set][way];
             memadr += 4;
             memory[memadr] = valid_bits[set][way];
             memadr += 4;
             for (word = 0; word < words_in_line; word++)
                 {memory[memadr] =
                  Dcache_line[set][way][word];
                  memadr += 4;
                 }
            }
        }
        break;
    default:          # Reserved.
        generate_fault(OPERATION.INVALID_OPERAND);
        break;
    }
order_wrt(subsequent_operations)

```

|         |                           |  |
|---------|---------------------------|--|
| Faults: | STANDARD                  | Refer to section 6.1.6,<br>“Faults” (pg. 6-6).                     |
|         | TYPE.MISMATCH             | Attempt to execute<br>instruction while not in<br>supervisor mode. |
|         | OPERATION.INVALID_OPERAND |  |

**INSTRUCTION SET REFERENCE****Example:**

```
dcctl g0,g1,g2      # g0 = 6, g1 = 0x10000000,  
                      # g2 = 0x001F0001  
                      # Store the status of Dcache  
                      # sets 1-0x1F to memory starting  
                      # at 0x10000000.
```

**Opcode:** **dcctl** 65CH REG

**See Also:** **sysctl**

**Notes:** DCCTL function 6 stores data-cache sets to a target range in external memory. For any memory location that is cached and also within the target range for function 6, the corresponding word-valid bit will be cleared after function 6 completes to ensure data-cache coherency. Thus, **dcctl** function 6 can alter the state of the cache after it completes, but only the word-valid bits. In all cases, even when the cache sets to store to external memory overlap the cache sets which map the target range in external memory, DCCTL function 6 always returns the state of the cache as it existed when the DCCTL was issued.

This instruction is implemented on the 80960Jx processor family only, and may or may not be implemented on future i960 processors.

## 6.2.24 divi, divo

|              |  |   |
|--------------|--|---|
| Mnemonic:    | <b>divi</b>  | Divide Integer  |
|              | <b>divo</b>  | Divide Ordinal  |
| Format:      | <b>div*</b>  | <i>src1</i> ,<br>reg/lit <i>src2</i> ,<br>reg/lit <i>dst</i><br>reg   |
| Description: | Divides <i>src2</i> value by <i>src1</i> value and stores the result in <i>dst</i> . Remainder is discarded.   |   |
|              | For <b>divi</b> , an integer-overflow fault can be signaled.   |   |
| Action:      | <b>divo:</b><br>if (src1 == 0)<br>generate_fault (ARITHMETIC.ZERO_DIVIDE);<br>else<br>dst = src2/src1;   |   |
|              | <b>divi:</b><br>if (src1 == 0)<br>{   dst = undefined_value;<br>generate_fault (ARITHMETIC.ZERO_DIVIDE);}<br>else if ((src2 == -2**31) && (src1 == -1))<br>{   dst = -2**31<br>if (AC.om == 1)<br>AC.of = 1;<br>else<br>generate_fault (ARITHMETIC.OVERFLOW);<br>}<br>else<br>dst = src2 / src1; |   |
| Faults:      | STANDARD<br>ARITHMETIC.ZERO_DIVIDE<br>ARITHMETIC.OVERFLOW  | Refer to Section 6.1.6 on page 6-6.<br>The <i>src1</i> operand is 0.<br>Result too large for destination register ( <b>divi</b> only). If overflow occurs and AC.om=1, fault is suppressed and AC.of is set to 1. Result's least significant 32 bits are stored in <i>dst</i> . |
| Example:     | divo r3, r8, r13 # r13 = r8/r3   |   |
| Opcode:      | <b>divi</b>  | 74BH  |
|              | <b>divo</b>  | 70BH  |
| See Also:    | <b>ediv, mulo, muli, emul</b>  |   |

## 6.2.25 ediv

|              |   |  |
|--------------|---|--|
| Mnemonic:    | <b>ediv</b>   | Extended Divide  |
| Format:      | <b>ediv</b>   | <i>src1</i> ,<br>reg/lit <i>src2</i> ,<br>reg/lit <i>dst</i><br>reg/lit      reg |
| Description: | <p>Divides <i>src2</i> by <i>src1</i> and stores result in <i>dst</i>. The <i>src2</i> value is a long ordinal (64 bits) contained in two adjacent registers. <i>src2</i> specifies the lower numbered register which contains operand's least significant bits. <i>src2</i> must be an even numbered register (i.e., g0, g2, ... or r4, r6, r8... ). <i>src1</i> value is a normal ordinal (i.e., 32 bits).</p> <p>The result consists of a one-word remainder and a one-word quotient. Remainder is stored in the register designated by <i>dst</i>; quotient is stored in the next highest numbered register. <i>dst</i> must be an even numbered register (i.e., or g0, g2, ... r4, r6, r8, ...).</p> |  |
|              | <p>This instruction performs ordinal arithmetic.</p>  |  |
|              | <p>If this operation overflows (quotient or remainder do not fit in 32 bits), no fault is raised and the result is undefined.</p>   |  |
| Action:      | <pre>if((reg_number(src2)%2 != 0)    (reg_number(dst[0])%2 != 0)) {     dst[0] = undefined_value;     dst[1] = undefined_value;     generate_fault(OPERATION.INVALID_OPERAND); } else if(src1 == 0) {     dst[0] = undefined_value;     dst[1] = undefined_value;     generate_fault(ARITHMETIC.DIVIDE_ZERO); } else    # Quotient {     dst[1] = ((src2 + reg_value(src2[1]) * 2**32) / src1)[31:0];     #Remainder     dst[0] = (src2 + reg_value(src2[1]) * 2**32               - ((src2 + reg_value(src2[1]) * 2**32 / src1) * src1)); }</pre>  |  |
| Faults:      | STANDARD<br>ARITHMETIC.ZERO_DIVIDE<br>OPERATION.INVALID_OPERAND   | Refer to section 6.1.6, "Faults" (pg. 6-6).<br>The <i>src1</i> operand is 0.     |

**Example:**      **ediv** g3, g4, g10    # g10 = remainder of g4,g5/g3  
                                  # g11 = quotient of g4,g5/g3

**Opcode:**      **ediv**                671H                REG

**See Also:**      **emul, divi, divo**

## 6.2.26 emul

Mnemonic: **emul** Extended Multiply

Format: **emul** *src1*, *src2*, *dst*  
           reg/lit      reg/lit      reg

Description: Multiplies *src2* by *src1* and stores the result in *dst*. Result is a long ordinal (64 bits) stored in two adjacent registers. *dst* specifies lower numbered register, which receives the result's least significant bits. *dst* must be an even numbered register (i.e., or g0, g2, ... r4, r6, r8, ...).

This instruction performs ordinal arithmetic.

Action:

```

if(reg_number(dst)%2 != 0)
{
    dst[0] = undefined_value;
    dst[1] = undefined_value;
    generate_fault(OPERATION.INVALID_OPERAND);
}
else
{
    dst[0] = (src1 * src2)[31:0];
    dst[1] = (src1 * src2)[63:32];
}
```

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example: **emul r4, r5, g2 # g2,g3 = r4 \* r5.**

Opcode: **emul** 670H REG

See Also: **ediv, muli, mulo**

## 6.2.27 eshro

Mnemonic: **eshro** Extended Shift Right Ordinal

Format: **eshro**      *src1*      *src2*      *dst*  
              reg/lit      reg/lit      reg

Description: Shifts *src2* right by (*src1* mod 32) places and stores the result in *dst*. Bits shifted beyond the least-significant bit are discarded.

*src2* value is a long ordinal (i.e., 64 bits) contained in two adjacent registers. *src2* operand specifies the lower numbered register, which contains operand's least significant bits. *src2* operand must be an even numbered register (i.e., r4, r6, r8, ... or g0, g2).

*src1* operand is a single 32-bit register or literal where the lower 5 bits specify the number of places that the *src2* operand is to be shifted.

The least significant 32 bits of the shift operation result are stored in *dst*.

Action:

```
if(reg_number(src2)%2 != 0)
    { dst[0] = undefined_value;
      dst[1] = undefined_value;
      generate_fault(OPERATION.INVALID_OPERAND);
    }
  else
    dst = shift_right((src2 + reg_value(src2[1]) * 2**32),(src1%32))[31:0];
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example: eshro g3, g4, g11 # g11 = g4,5 shifted right by  
# (g3 MOD 32).

Opcode: **eshro** 5D8 REG

See Also: **SHIFT, extract**

Notes: This core instruction is not implemented on the Kx and Sx 80960 processors.

## 6.2.28 extract

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>extract</b>  | Extract   |
| Format:      | <b>extract</b>  | <i>bitpos</i> <i>len</i> <i>src/dst</i><br><i>reg/lit</i> <i>reg/lit</i> <i>reg</i> |
| Description: | Shifts a specified bit field in <i>src/dst</i> right and zero fills bits to left of shifted bit field. <i>bitpos</i> value specifies the least significant bit of the bit field to be shifted; <i>len</i> value specifies bit field length. |   |
| Action:      | $\text{src\_dst} = (\text{src\_dst} / 2^{**(\text{src1}\%32)}) \& ((2^{**\text{src2}}) - 1);$   |   |
| Faults:      | STANDARD      Refer to section 6.1.6, "Faults" (pg. 6-6).   |   |
| Example:     | extract 5, 12, g4      # g4 = g4 with bits 5 through<br># 16 shifted right.   |   |
| Opcode:      | <b>extract</b>  | 651H      REG   |
| See Also:    | <b>modify</b>   |   |

## 6.2.29 FAULT&lt;CC&gt;

|           |                |                           |
|-----------|----------------|---------------------------|
| Mnemonic: | <b>faulte</b>  | Fault If Equal            |
|           | <b>faultne</b> | Fault If Not Equal        |
|           | <b>faultl</b>  | Fault If Less             |
|           | <b>faultle</b> | Fault If Less Or Equal    |
|           | <b>faultg</b>  | Fault If Greater          |
|           | <b>faultge</b> | Fault If Greater Or Equal |
|           | <b>faulto</b>  | Fault If Ordered          |
|           | <b>faultno</b> | Fault If Not Ordered      |

Format: **fault\***

Description: Raises a constraint-range fault if the logical AND of the condition code and opcode's mask-part is not zero. For **faultno** (unordered), fault is raised if condition code is equal to  $000_2$ .

6

**faulto** and **faultno** are provided for use by implementations with a floating point coprocessor. They are used for compare and branch (or fault) operations involving real numbers.

The following table shows the condition-code mask for each instruction. The mask is opcode bits 0-2.

| Instruction    | Mask    | Condition        |
|----------------|---------|------------------|
| <b>faultno</b> | $000_2$ | Unordered        |
| <b>faultg</b>  | $001_2$ | Greater          |
| <b>faulte</b>  | $010_2$ | Equal            |
| <b>faultge</b> | $011_2$ | Greater or equal |
| <b>faultl</b>  | $100_2$ | Less             |
| <b>faultne</b> | $101_2$ | Not equal        |
| <b>faultle</b> | $110_2$ | Less or equal    |
| <b>faulto</b>  | $111_2$ | Ordered          |

Action:

**For all except faultno:**

```
if(mask && AC.cc != 0002)
    generate_fault(CONSTRAINT.RANGE);
```

**faultno:**

```
if(AC.cc = 0002)
    generate_fault(CONSTRAINT.RANGE);
```

Faults:

STANDARD

Refer to section 6.1.6, "Faults" (pg. 6-6).

CONSTRAINT.RANGE

If condition being tested is true.

**INSTRUCTION SET REFERENCE**

**Example:**      # Assume (AC.cc AND 110<sub>2</sub>) ≠ 000<sub>2</sub>  
                faultle        # Constraint Range Fault is generated.

|                |                |     |      |
|----------------|----------------|-----|------|
| <b>Opcode:</b> | <b>faulte</b>  | 1AH | CTRL |
|                | <b>faultne</b> | 1DH | CTRL |
|                | <b>faultl</b>  | 1CH | CTRL |
|                | <b>faultle</b> | 1EH | CTRL |
|                | <b>faultg</b>  | 19H | CTRL |
|                | <b>faultge</b> | 1BH | CTRL |
|                | <b>faulto</b>  | 1FH | CTRL |
|                | <b>faultno</b> | 18H | CTRL |

**See Also:**      **BRANCH<cc>, TEST<cc>**

## 6.2.30 flushreg

Mnemonic: **flushreg** Flush Local Registers

Format: **flushreg**

Description: Copies the contents of every cached register set—except the current set—to its associated stack frame in memory. The entire register cache is then marked as purged (or invalid). On a return to a stack frame for which the local registers are not cached, the processor reloads the locals from memory.

**flushreg** is provided to allow a debugger or application program to circumvent the processor's normal call/return mechanism. For example, a debugger may need to go back several frames in the stack on the next return, rather than using the normal return mechanism that returns one frame at a time. Since the local registers of an unknown number of previous stack frames may be cached, a **flushreg** must be executed prior to modifying the FPF to return to a frame other than the one directly below the current frame.

Action: Each local cached register set except the current one is flushed to its associated stack frame in memory and marked as purged, meaning that they will be reloaded from memory if and when they become the current local register set.

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example: **flushreg**

Opcode: **flushreg** 66D REG

### 6.2.31 fmark

Mnemonic: **fmark** Force Mark

Format: **fmark**

Description: Generates a mark trace event. Causes a mark trace event to be generated, regardless of mark trace mode flag setting, providing the trace enable bit, bit 0 in the Process Controls, is set.

For more information on trace fault generation, refer to CHAPTER 10, TRACING AND DEBUGGING.

Action: A mark trace event is generated, independent of the setting of the mark-trace-mode flag.

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).  
TRACE.MARK A TRACE.MARK fault is generated if PC.te=1.

Example:  
# Assume PC.te = 1  
fmark  
# Mark trace event is generated at this point in the  
# instruction stream.

Opcode: **fmark** 66CH REG

See Also: **mark**

### 6.2.32 halt (80960Jx-Specific Instruction)

Mnemonic: **halt** Halt CPU

Format: **halt** *src1*  
reg/lit

Description: Causes the processor to enter HALT mode which is described in Chapter 16, HALT MODE. Entry into Halt mode allows the interrupt enable state to be conditionally changed based on the value of *src1*.

| <b>src1</b> | <b>Operation</b>                             |
|-------------|--|
| 0           | Disable interrupts and halt                  |
| 1           | Enable interrupts and halt                   |
| 2           | Use current interrupt enable state and halt. |

6

The processor exits Halt mode on a hardware reset or upon receipt of an interrupt that should be delivered based on the current process priority. After executing the interrupt that forced the processor out of Halt mode, execution resumes at the instruction immediately after the **halt** instruction. The processor must be in supervisor mode to use this instruction.

Action:

```
implicit_syncf;
if (PC.em != supervisor)
    generate_fault( TYPE.MISMATCH);
switch(src1) {
    case 0: # Disable interrupts. Clear ICON.gie.
        global_interrupt_enable = false;           break;
    case 1: # Enable interrupts. Set ICON.gie.
        global_interrupt_enable = true;            break;
    case 2: # Use the current interrupt enable state.
        break;
    default:
        generate_fault( OPERATION.INVALID_OPERAND );
        break;
}
```

```
ensure_bus_is_quiescent;
enter_HALT_mode;
```

Faults:

STANDARD

Refer to section 6.1.6, “Faults” (pg. 6-6).

TYPE.MISMATCH

Attempt to execute instruction while not in supervisor mode.

OPERATION.INVALID\_OPERAND

Opcode: **halt** 65DH REG

**Notes:** This instruction is implemented on the 80960Jx processor family only, and may or may not be implemented on future i960 processors.

### 6.2.33 **icctl** (80960Jx-Specific Instruction)

Mnemonic: **icctl** Instruction-cache Control

Format: **icctl** *src1*, *src2*, *src/dst*  
           reg/lit      reg/lit      reg

Description: Performs management and control of the instruction cache including disabling, enabling, invalidating, loading and locking, getting status, and storing cache sets to memory. Operations are indicated by the value of *src1*. Some operations also use *src2* and *src/dst*. When needed by the operation, the processor orders the effects of the operation with previous and subsequent operations to ensure correct behavior. For specific function setup, see the following tables and diagrams:

**Table 6-10. ICCTL Operand Fields**

| Function                       | <i>src1</i> | <i>src2</i>  | <i>src/dst</i>   |
|--------------------------------|-------------|--|--|
| Disable Icache                 | 0           | NA   | NA   |
| Enable Icache                  | 1           | NA   | NA   |
| Invalidate Icache              | 2           | NA   | NA   |
| Load and lock<br>Icache        | 3           | <i>src</i> : Starting<br>address of code<br>to lock. | Number of blocks<br>to lock.                                     |
| Get Icache status              | 4           | NA   | <i>dst</i> : Receives<br>status (see<br>Figure 6-3).             |
| Get Icache<br>locking status   | 5           | NA   | <i>dst</i> : Receives<br>status (see<br>Figure 6-3)              |
| Store Icache sets<br>to memory | 6           | Destination<br>address for<br>cache sets             | <i>src</i> : Icache set<br>#’s to be stored<br>(see Figure 6-3). |

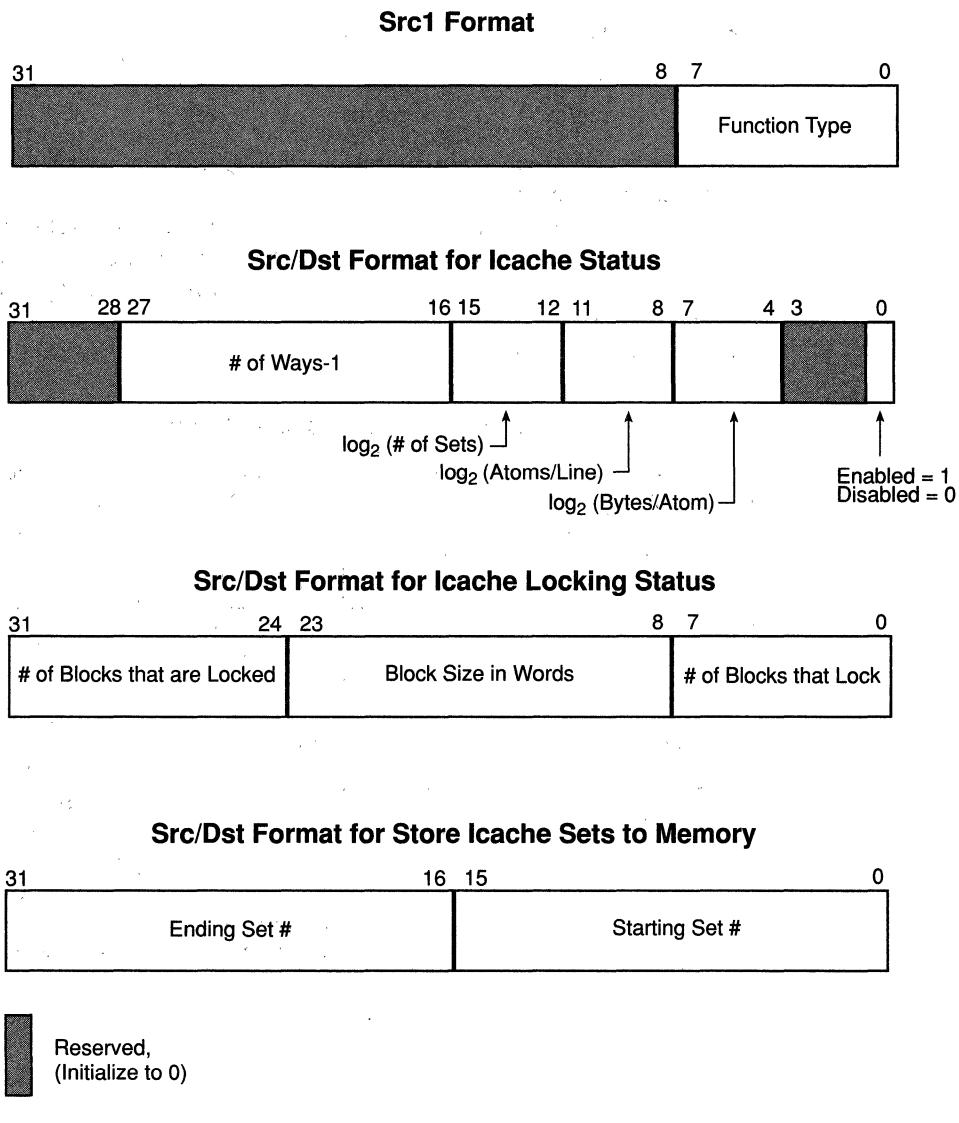


Figure 6-3. ICCTL Src1 and Src/Dst Formats

**Table 6-11. ICCTL Status Values and Instruction Cache Parameters**

| Value   | Value on i960JA CPU | Value on i960JD/JF CPU |
|---|---------------------|------------------------|
| bytes per atom  | 4                   | 4                      |
| atoms per line  | 4                   | 4                      |
| number of sets  | 64                  | 128                    |
| number of ways  | 2                   | 1 (Direct)             |
| cache size  | 2-Kbytes            | 4-Kbytes               |
| Status[0] (enable / disable)                          | 0 or 1              | 0 or 1                 |
| Status[1:3] (reserved)                                | 0                   | 0                      |
| Status[7:4] ( $\log_2(\text{bytes per atom})$ )       | 2                   | 2                      |
| Status[11:8] ( $\log_2(\text{atoms per line})$ )      | 2                   | 2                      |
| Status[15:12] ( $\log_2(\text{number of sets})$ )     | 6                   | 7                      |
| Status[27:16] (number of ways - 1)                    | 1                   | 1                      |
| Lock Status[7:0] (number of blocks that lock)         | 1                   | 1                      |
| Lock Status[23:8] (block size in words)               | 256                 | 512                    |
| Lock Status[31:24] (number of blocks that are locked) | 0 or 1              | 0 or 1                 |

|              |                                      |                          |
|--------------|--------------------------------------|--------------------------|
|              | <b>Set_Data [Starting Set]</b>       | Destination Address (DA) |
|              | <b>Tag (Starting set)</b>            | DA + 4H                  |
|              | <b>Valid Bits (Starting set)</b>     | DA + 8H                  |
| <b>Way 0</b> | Word 0                               | DA + CH                  |
|              | Word 1                               | DA + 10H                 |
|              | Word 2                               | DA + 14H                 |
|              | Word 3                               | DA + 18H                 |
|              | <b>Tag (Starting set)</b>            | DA + 1CH                 |
| <b>Way 1</b> | <b>Valid Bits (Starting set)</b>     | DA + 20H                 |
|              | Word 0                               | DA + 24H                 |
|              | Word 1                               | DA + 28H                 |
|              | Word 2                               | DA + 2CH                 |
|              | Word 3                               | DA + 30H                 |
|              | <b>Set_Data [Starting Set + 1]</b>   | DA + 34H                 |
| <b>Way 0</b> | <b>Tag (Starting set + 1)</b>        | DA + 38H                 |
|              | <b>Valid Bits (Starting set + 1)</b> | DA + 3CH                 |
|              |                                      | ...                      |

**Figure 6-4. Store Instruction Cache to Memory Output Format**

**Table 6-12. Valid\_Bits Value For i960Jx Processor**

| Bit  | Meaning                                     |
|------|---|
| 0    | Tag Valid bit for current Set and Way       |
| 1    | Valid Bit for Word 0 of current Set and Way |
| 2    | Valid Bit for Word 1 of current Set and Way |
| 3    | Valid Bit for Word 2 of current Set and Way |
| 4    | Valid Bit for Word 3 of current Set and Way |
| 5-31 | Reserved, Read as Zero.                     |

Table 6-13. Set\_Data I-Cache Values

| Set_Data[set]<br>I-Cache Value | Meaning                           |
|--------------------------------|-----------------------------------|
| 0                              | I-Cache Way 0 is LRU for the set. |
| 1                              | I-Cache Way 1 is LRU for the set. |
| x                              | Other values are reserved         |

Action:

```

if (PC.em != supervisor)
    generate_fault(TYPE.MISMATCH);
switch (src1[7:0]) {
    case 0:      # Disable instruction cache.
        disable_instruction_cache( );
        break;
    case 1:      # Enable instruction cache.
        enable_instruction_cache( );
        break;
    case 2:      # Globally invalidate instruction cache.
        # Includes locked lines also.
        invalidate_instruction_cache( );
        unlock_icache( );
        break;
    case 3:      # Load & Lock code into Instruction-Cache
        # src/dest has number of contiguous blocks to lock
        # src2 has starting address of code to lock.
        # On the i960Jx, src2 is aligned to a quadword boundary
        aligned_addr = src2 & 0xffffffff0;
        invalidate(I-cache); unlock(I-cache);
        for (j = 0; j < src/dest; j++)
            { way = way_associated_with_block(j);
              start = src2 + j*block_size;
              end = start + block_size;
              for (i = start; i < end; i=i+4)
                  { set = set_associated_with(i);
                    word = word_associated_with(i);
                    Icache_line[set][way][word] =
                        memory[i];
                    update_tag_n_valid_bits(set,way,word)
                    lock_icache(set,way,word);
                  } } break;
}

```

```

Action:           case 4:      # Get instruction cache status into src/dst.
                  if (Icache_enabled) src/dst[0] = 1;
                           else src/dst[0] = 0;
                           # Atom is 4 bytes.
                           src/dst[7:4] = log2(bytes per atom);
                           # 4 atoms per line.
                           src/dst[11:8] = log2(atoms per line);
                           src/dst[15:12] = log2(number of sets);
                           src/dst[27:16] = number of ways-1; #in lines per set
                           # cache size = ([27:16]+1) << ([7:4] + [11:8] + [15:12])
                           break;
case 5:          # Get instruction cache locking status into dst.
                  src/dst[7:0] = number_of_blocks_that_lock;
                  src/dst[23:8] = block_size_in_words;
                  src/dst[31:24] = number_of_blocks_that_are_locked;
                  break;
case 6:          # Store instr cache sets to memory pointed to by src2.
                  start = src/dst[15:0]      # Starting set number
                  end   = src/dst[31:16]     # Ending set number
                           # (zero-origin).
                  if (end >= Icache_max_sets)
                      end = Icache_max_sets - 1;
                  if (start > end)
                      generate_fault(OPERATION.INVALID_OPERAND);
                  memadr = src2;           # Must be word-aligned.
                  if(0x3 & memadr != 0)
                      generate_fault(OPERATION.INVALID_OPERAND);
                  for (set = start; set <= end; set++){
                      # Set_Data is described at end of this code flow.
                      memory[memadr] = Set_Data[set];
                      memadr += 4;
                      for (way = 0; way < numb_ways; way++)
                          {memory[memadr] = tags[set][way];
                           memadr += 4;
                           memory[memadr] = valid_bits[set][way];
                           memadr += 4;
                           for (word = 0; word < words_in_line;
                                word++)
                               {memory[memadr] =
                                 Icache_line[set][way][word];
                                  memadr += 4;
                               }
                           }
                      } } break;

```

|           |                           |  |   |
|-----------|---------------------------|--|---|
|           | default:                  | # Reserved.<br>generate_fault(OPERATION.INVALID_OPERAND);<br>break;} |   |
| Faults:   | STANDARD                  |  | Refer to section 6.1.6, "Faults"<br>(pg. 6-6).  |
|           | TYPE.MISMATCH             |  | Attempt to execute instruction<br>while not in supervisor mode.   |
|           | OPERATION.INVALID_OPERAND |  |   |
| Example:  |                           | # g0 = 3, g1=0x10000000, g2=1<br>icctl g0,g1,g2                      | # Load and lock 1 block of cache<br># (one way) with<br># location of code at starting<br># 0x10000000.                               |
| Opcode:   | <b>icctl</b>              | 65BH   | REG   |
| See Also: |                           | <b>sysctl</b>  |   |
| Notes:    |                           |  | This instruction is implemented on the 80960Jx processor family only, and<br>may or may not be implemented on future i960 processors. |

### 6.2.34 intctl (80960Jx-Specific Instruction)

Mnemonic: **intctl** Global Enable and Disable of Interrupts

Format: **intctl** *src1* *dst*  
               reg/lit      reg

Description: Globally enables, disables or returns the current status of interrupts depending on the value of *src1*. Returns the previous interrupt enable state (1 for enabled or 0 for disabled) in *dst*. When the state of the global interrupt enable is changed, the processor ensures that the new state is in full effect before the instruction completes. (This instruction is implemented by manipulating ICON.gie.)

| <i>src1</i> Value | Operation                               |
|-------------------|---|
| 0                 | Disables interrupts                     |
| 1                 | Enables interrupts                      |
| 2                 | Returns current interrupt enable status |

```

Action: if (PC.em != supervisor)
        generate_fault(TYPE.MISMATCH);
        old_interrupt_enable = global_interrupt_enable;
        switch(src1) {
            case 0: # Disable. Set ICON.gie to one.
                globally_disable_interrupts;
                global_interrupt_enable = false;
                order_wrt(subsequent_instructions);
                break;
            case 1: # Enable. Clear ICON.gie to zero.
                globally_enable_interrupts;
                global_interrupt_enable = true;
                order_wrt(subsequent_instructions);
                break;
            case 2: # Return status. Return ICON.gie
                break;
            default:
                generate_fault(OPERATION.INVALID_OPERAND);
                break;
        }
        if(old_interrupt_enable)
            dst = 1;
        else
            dst = 0;
    
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

## OPERATION.INVALID\_OPERAND TYPE.MISMATCH

Opcode: **intctl** 658H REG

**See Also:** [intdis](#), [inten](#)

**Notes:** This instruction is implemented on the 80960Jx processor family only, and may or may not be implemented on future i960 processors.

## 6.2.35 **intdis** (80960Jx-Specific Instruction)

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>intdis</b>                           | Global Interrupt Disable  |
| Format:      | <b>intdis</b>                           |   |
| Description: |   | Globally disables interrupts and ensures that the change takes effect before the instruction completes. This operation is implemented by setting ICON.gie to one.   |
| Action:      |   | <pre>if (PC.em != supervisor)     generate_fault(TYPE.MISMATCH); # Implemented by setting ICON.gie to one. globally_disable_interrupts; interrupt_enable = false; order_wrt(subsequent_instructions);</pre> |
| Faults:      | <b>STANDARD</b><br><b>TYPE.MISMATCH</b> | Refer to section 6.1.6, "Faults" (pg. 6-6).   |
| Example:     |   | <pre># ICON.gie = 0, interrupts enabled intdis          # Disable interrupts. # ICON.gie = 1</pre>  |
| Opcode:      | <b>intdis</b>                           | <b>5B4H</b>   |
| See Also:    |   | <b>intctl</b> , <b>inten</b>  |
| Notes:       |   | This instruction is implemented on the 80960Jx processor family only, and may or may not be implemented on future i960 processors.  |

## 6.2.36 inten (80960Jx-Specific Instruction)

Mnemonic: **inten** global interrupt enable

Format: **inten**

Description: Globally enables interrupts and ensures that the change takes effect before the instruction completes. This operation is implemented by clearing ICON.gie to zero.

Action:

```
if (PC.em != supervisor)
    generate_fault(TYPE.MISMATCH);
# Implemented by clearing ICON.gie to zero.
globally_enable_interrupts;
interrupt_enable = true;
order_wrt(subsequent_instructions);
```

6

Faults: TYPE.MISMATCH

Example:

```
# ICON.gie = 1, interrupts disabled.
inten          # Enable interrupts.
               # ICON.gie = 0
```

Opcode: **inten** 5B5H REG

See Also: **intctl, intdis**

Notes: This instruction is implemented on the 80960Jx processor family only, and may or may not be implemented on future i960 processors.

## 6.2.37

**LOAD**

Mnemonic:

|             |                    |
|-------------|--------------------|
| <b>ld</b>   | Load               |
| <b>ldob</b> | Load Ordinal Byte  |
| <b>ldos</b> | Load Ordinal Short |
| <b>ldib</b> | Load Integer Byte  |
| <b>ldis</b> | Load Integer Short |
| <b>ldl</b>  | Load Long          |
| <b>ldt</b>  | Load Triple        |
| <b>ldq</b>  | Load Quad          |

Format:

|            |            |            |
|------------|------------|------------|
| <b>ld*</b> | <i>src</i> | <i>dst</i> |
|            | mem        | reg        |

Description:

Copies byte or byte string from memory into a register or group of successive registers.

The *src* operand specifies the address of first byte to be loaded. The full range of addressing modes may be used in specifying *src*.

Refer to Chapter 2, DATA TYPES AND MEMORY ADDRESSING MODES for more information.

*dst* specifies a register or the first (lowest numbered) register of successive registers.

**ldob** and **ldib** load a byte and **ldos** and **ldis** load a half word and convert it to a full 32-bit word. Data being loaded is sign-extended during integer loads and zero-extended during ordinal loads.

**ld**, **ldl**, **ldt** and **ldq** instructions copy 4, 8, 12 and 16 bytes, respectively, from memory into successive registers.

For **ldl**, *dst* must specify an even numbered register (i.e., g0, g2...). For **ldt** and **ldq**, *dst* must specify a register number that is a multiple of four (i.e., g0, g4, g8, g12, r4, r8, r12). Results are unpredictable if data extends beyond register g15 or r15 for **ldl**, **ldt** or **ldq**.

Action:

**ld:**

```
dst = read_memory(effective_address)[31:0];
if((effective_address[1:0] != 002) && unaligned_fault_enabled)
    generate_fault(OPERATION.UNALIGNED);
```

**ldob:**

```
dst[7:0] = read_memory(effective_address)[7:0];
dst[31:8] = 0x000000;
```

**ldib:**

```
dst[7:0] = read_memory(effective_address)[7:0];
if(dst[7] == 0)
    dst[31:8] = 0x000000;
else
    dst[31:8] = 0xFFFFFFF;
```

**ldos:**

```
dst = read_memory(effective_address)[15:0];
# Order depends on endianism. See
# section 2.2.2, "Byte Ordering" (pg. 2-4)
dst[31:16] = 0x0000;
if((effective_address[0] != 02) && unaligned_fault_enabled)
    generate_fault(OPERATION.UNALIGNED);
```

**ldis:**

```
dst[15:0] = read_memory(effective_address)[15:0];
# Order depends on endianism. See
# section 2.2.2, "Byte Ordering" (pg. 2-4)
if(dst[15] == 02)
    dst[31:16] = 0x0000;
else
    dst[31:16] = 0xFFFF;
if((effective_address[0] != 02) && unaligned_fault_enabled)
    generate_fault(OPERATION.UNALIGNED);
```

**ldl:**

```
if((reg_number(dst) % 2) != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
# dst not modified.
else
{   dst = read_memory(effective_address)[31:0];
    dst_+_1 = read_memory(effective_address_+_4)[31:0];
    if((effective_address[2:0] != 0002) && unaligned_fault_enabled)
        generate_fault(OPERATION.UNALIGNED);
}
```

**ldt:**

```
if((reg_number(dst) % 4) != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
# dst not modified.
else
{   dst = read_memory(effective_address)[31:0];
    dst_+_1 = read_memory(effective_address_+_4)[31:0];
```

```

    dst_+_2 = read_memory(effective_address_+_8)[31:0];
    if((effective_address[3:0] != 00002) && unaligned_fault_enabled)
        generate_fault(OPERATION.UNALIGNED);
}

ldq:
if((reg_number(dst) % 4) != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
    # dst not modified.
else :
{   dst = read_memory(effective_address)[31:0];
    # Order depends on endianism.
    # See section 2.2.2, "Byte Ordering" (pg. 2-4)
    dst_+_1 = read_memory(effective_address_+_4)[31:0];
    dst_+_2 = read_memory(effective_address_+_8)[31:0];
    dst_+_3 = read_memory(effective_address_+_12)[31:0];
    if((effective_address[3:0] != 00002) && unaligned_fault_enabled)
        generate_fault(OPERATION.UNALIGNED);
}

```

Faults:                    **OPERATION.UNALIGNED**  
                           **STANDARD**                    Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:    ldl 2450 (r3), r10      # r10, r11 = r3 + 2450 in  
     # memory

|         |             |     |     |
|---------|-------------|-----|-----|
| Opcode: | <b>ld</b>   | 90H | MEM |
|         | <b>ldob</b> | 80H | MEM |
|         | <b>ldos</b> | 88H | MEM |
|         | <b>ldib</b> | C0H | MEM |
|         | <b>ldis</b> | C8H | MEM |
|         | <b>ldl</b>  | 98H | MEM |
|         | <b>ldt</b>  | A0H | MEM |
|         | <b>ldq</b>  | B0H | MEM |

See Also:                **MOVE, STORE**

## 6.2.38 lda

Mnemonic: **lda** Load Address

Format: **lda** *src*, *dst*  
             mem            reg  
             efa

Description: Computes the effective address specified with *src* and stores it in *dst*. The *src* address is not checked for validity. Any addressing mode may be used to calculate *efa*.

An important application of this instruction is to load a constant longer than 5 bits into a register. (To load a register with a constant of 5 bits or less, **mov** can be used with a literal as the *src* operand.)

Action: *dst* = effective\_address;

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:  
lda 58 (g9), g1 # g1 = g9+58  
lda 0x749, r8 # r8 = 0x749

Opcode: **lda** 8CH MEM

## 6.2.39 mark

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>mark</b>   | Mark  |
| Format:      | <b>mark</b>   |   |
| Description: | Generates mark trace fault if mark trace mode is enabled. Mark trace mode is enabled if the PC register trace enable bit (bit 0) and the TC register mark trace mode bit (bit 7) are set. |   |
|              | If mark trace mode is not enabled, <b>mark</b> behaves like a no-op.  |   |
|              | For more information on trace fault generation, refer to CHAPTER 10, TRACING AND DEBUGGING.   |   |
| Action:      | if(PC.te && TC.mk)<br>generate_fault(TRACE.MARK)  |   |
| Faults:      | STANDARD<br>TRACE.MARK  | Refer to section 6.1.6, "Faults" (pg. 6-6).<br>Trace fault is generated if PC.te=1 and TC.mk=1. |
| Example:     | # Assume that the mark trace mode is enabled.<br>ld xyz, r4<br>addi r4, r5, r6<br>mark<br># Mark trace event is generated at this point in the<br># instruction stream.                   |   |
| Opcode:      | <b>mark</b>   | 66BH  |
| See Also:    | <b>fmark, modpc, modtc</b>  |   |

## 6.2.40 modac

|               |  |  |
|---------------|--|--|
| Mnemonic:     | <b>modac</b>   | Modify AC  |
| Format:       | <b>modac</b>   | <i>mask,</i><br>reg/lit <i>src,</i><br>reg/lit <i>dst</i><br>reg |
| Description:  | Reads and modifies the AC register. <i>src</i> contains the value to be placed in the AC register; <i>mask</i> specifies bits that may be changed. Only bits set in <i>mask</i> are modified. Once the AC register is changed, its initial state is copied into <i>dst</i> . |  |
| Action:       | <pre>temp = AC;<br/>AC = (src &amp; mask)   (AC &amp; ~mask);<br/>dst = temp;</pre>  |  |
| Faults:       | <b>STANDARD</b>  | Refer to section 6.1.6, “Faults” (pg. 6-6).                      |
| Example:      | <pre>modac g1, g9, g12 # AC = g9, masked by g1.<br/># g12 = initial value of AC.</pre>   |  |
| Opcode:       | <b>modac</b>   | 645H              REG  |
| See Also:     | <b>modpc, modtc</b>  |  |
| Side Effects: | Sets the condition code in the arithmetic controls.  |  |

## 6.2.41 modi

|              |  |  |                          |
|--------------|--|--|--------------------------|
| Mnemonic:    | <b>modi</b>  | Modulo Integer   |                          |
| Format:      | <b>modi</b>  | <i>src1</i> ,<br>reg/lit   | <i>src2</i> ,<br>reg/lit |
|              |  |  | <i>dst</i><br>reg        |
| Description: | Divides <i>src2</i> by <i>src1</i> , where both are integers and stores the modulo remainder of the result in <i>dst</i> . If the result is nonzero, <i>dst</i> has the same sign as <i>src1</i> .     |  |                          |
| Action:      | <pre> if(src1 == 0)     generate_fault(ARITHMETIC.ZERO_DIVIDE);     dst = undefined.value dst = src2 - (src2/src1) * src1; if((src2 *src1 &lt; 0 ) &amp;&amp; (dst != 0))     dst = dst + src1; </pre> |  |                          |
| Faults:      | ARITHMETIC.ZERO_DIVIDE<br>STANDARD   | The <i>src1</i> operand is zero.<br>Refer to section 6.1.6,<br>“Faults” (pg. 6-6). |                          |
| Example:     | modi r9, r2, r5 # r5 = modulo (r2/r9)  |  |                          |
| Opcode:      | <b>modi</b> 749H   | REG  |                          |
| See Also:    | <b>divi, divo, remi, remo</b>  |  |                          |
| Notes:       | <b>modi</b> generates the correct result (0) when computing $-2^{31} \bmod -1$ , although the corresponding 32 bit division would overflow.  |  |                          |

## 6.2.42 modify

Mnemonic: **modify** Modify

Format: **modify** *mask*, *src*, *src/dst*  
                reg/lit      reg/lit      reg

Description: Modifies selected bits in *src/dst* with bits from *src*. The *mask* operand selects the bits to be modified: only bits set in the *mask* operand are modified in *src/dst*.

Action:  $\text{src}/\text{dst} = (\text{src} \& \text{mask}) | (\text{src}/\text{dst} \& \sim\text{mask});$

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example: `modify g8, g10, r4 # r4 = g10 masked by g8.`

Opcode: **modify** 650H REG

See Also: **alterbit, extract**

## 6.2.43 modpc

Mnemonic: **modpc** Modify Process Controls

Format: **modpc** *src*, *mask*, *src/dst*  
*reg/lit*            *reg/lit*            *reg*

Description: Reads and modifies the PC register as specified with mask and *src/dst*. *src/dst* operand contains the value to be placed in the PC register; *mask* operand specifies bits that may be changed. Only bits set in the *mask* are modified. Once the PC register is changed, its initial value is copied into *src/dst*. The *src* operand is a dummy operand that should specify a literal or the same register as the *mask* operand.

The processor must be in supervisor mode to use this instruction with a non-zero mask value. If mask=0, this instruction can be used to read the process controls, without the processor being in supervisor mode.

Changing the PC register reserved fields can lead to unpredictable behavior as described in section 3.6.3, “Process Controls (PC) Register” (pg. 3-20).

Action:

```

if(mask != 0)
{
    if(PC.em != 1)
        generate_fault(TYPE.MISMATCH);
    temp = PC;
    PC = (mask & src_dst) | (PC & ~mask);
    src_dst = temp;
    if(temp.priority > PC.priority)
        check_pending_interrupts;
}
else
    src_dst = PC;

```

Faults: **STANDARD** Refer to section 6.1.6, “Faults” (pg. 6-6).  
**TYPE.MISMATCH**

Example: `modpc g9, g9, g8 # process controls = g8  
# masked by g9.`

Opcode: **modpc** **655H** **REG**

See Also: **modac**, **modtc**

Notes: Since **modpc** does not switch stacks, it should not be used to switch the mode of execution from supervisor to user (the supervisor stack can get corrupted in this case). The call and return mechanism should be used instead.

## 6.2.44 modtc

|  |   |   |
|--|---|---|
| Mnemonic:  | <b>modtc</b>  | Modify Trace Controls   |
| Format:  | <b>modtc</b>  | <i>mask</i> , <i>src2</i> , <i>dst</i><br>reg/lit                   reg/lit                   reg |
| Description:   | Reads and modifies TC register as specified with <i>mask</i> and <i>src2</i> . The <i>src2</i> operand contains the value to be placed in the TC register; <i>mask</i> operand specifies bits that may be changed. Only bits set in <i>mask</i> are modified. <i>mask</i> must not enable modification of reserved bits. Once the TC register is changed, its initial state is copied into <i>dst</i> . |   |
| The changed trace controls may take effect immediately or may be delayed. If delayed, the changed trace controls may not take effect until after the first non-branching instruction is fetched from memory or after four non-branching instructions are executed. |   | 6   |
| For more information on the trace controls, refer to CHAPTER 9, FAULTS and CHAPTER 10, TRACING AND DEBUGGING.  |   |   |
| Action:  | temp = TC;<br>tempa = 0x0FFF0OFF & mask;<br>TC = (tempa & src2)   (TC & ~tempa);<br>dst = temp;   |   |
| Faults:  | <b>STANDARD</b>   | Refer to section 6.1.6, “Faults” (pg. 6-6).   |
| Example:   | modtc g12, g10, g2       # trace controls = g10 masked<br># by g12; previous trace<br># controls stored in g2.  |   |
| Opcode:  | <b>modtc</b>  | 654H  |
| See Also:  | <b>modac</b> , <b>modpc</b>   |   |

## 6.2.45 MOVE

|           |             |             |
|-----------|-------------|-------------|
| Mnemonic: | <b>mov</b>  | Move        |
|           | <b>movl</b> | Move Long   |
|           | <b>movt</b> | Move Triple |
|           | <b>movq</b> | Move Quad   |

|         |             |              |            |
|---------|-------------|--------------|------------|
| Format: | <b>mov*</b> | <i>src1,</i> | <i>dst</i> |
|         |             | reg/lit      | reg        |

Description: Copies the contents of one or more source registers (specified with *src*) to one or more destination registers (specified with *dst*).

For **movl**, **movt** and **movq**, *src1* and *dst* specify the first (lowest numbered) register of several successive registers. *src1* and *dst* registers must be even numbered (e.g., g0, g2, ... or r4, r6, ...) for **movl** and an integral multiple of four (e.g., g0, g4, ... or r4, r8, ...) for **movt** and **movq**.

The moved register values are unpredictable when: 1) the *src* and *dst* operands overlap; 2) registers are not properly aligned.

Action:

```

mov:
if(is_reg(src1))
    dst = src1;
else
{   dst[5:0] = src1;  #src1 is a 5-bit literal.
    dst[31:5] = 0;
}
movl:
if((reg_num(src1)%2 != 0) || (reg_num(dst)%2 != 0))
{   dst = undefined_value;
    dst_+_1 = undefined_value;
    generate_fault(OPERATION.INVALID_OPERAND);
}
else if(is_reg(src1))
{   dst = src1;
    dst_+_1 = src1_+_1;
}
else
{   dst[4:0] = src1;  #src1 is a 5-bit literal.
    dst[31:5] = 0;
    dst_+_1[31:0] = 0;
}

```

**movt:**

```
if((reg_num(src1)%4 != 0) || (reg_num(dst)%4 != 0))
{   dst = undefined_value;
    dst_+_1 = undefined_value;
    dst_+_2 = undefined_value;
    generate_fault(OPERATION.INVALID_OPERAND);
}
else if(is_reg(src1))
{   dst = src1;
    dst_+_1 = src1_+_1;
    dst_+_2 = src1_+_2;
}
else
{   dst[4:0] = src1;  #src1 is a 5-bit literal.
    dst[31:5] = 0;
    dst_+_1[31:0] = 0;
    dst_+_2[31:0] = 0;
}
```

**movq:**

```
if((reg_num(src1)%4 != 0) || (reg_num(dst)%4 != 0))
{   dst = undefined_value;
    dst_+_1 = undefined_value;
    dst_+_2 = undefined_value;
    dst_+_3 = undefined_value;
    generate_fault(OPERATION.INVALID_OPERAND);
}
else if(is_reg(src1))
{   dst = src1;
    dst_+_1 = src1_+_1;
    dst_+_2 = src1_+_2;
    dst_+_3 = src1_+_3;
}
else
{   dst[4:0] = src1;  #src1 is a 5 bit literal.
    dst[31:5] = 0;
    dst_+_1[31:0] = 0;
    dst_+_2[31:0] = 0;
    dst_+_3[31:0] = 0;
}
```

6

Faults:

STANDARD

Refer to section 6.1.6, “Faults”  
(pg. 6-6).

OPERATION.INVALID\_OPERAND

## INSTRUCTION SET REFERENCE



Example:      **movt g8, r4**      # r4, r5, r6 = g8, g9, g10

|         |             |      |     |
|---------|-------------|------|-----|
| Opcode: | <b>mov</b>  | 5CCH | REG |
|         | <b>movl</b> | 5DCH | REG |
|         | <b>movt</b> | 5ECH | REG |
|         | <b>movq</b> | 5FCH | REG |

See Also:      **LOAD, STORE, Ida**

## 6.2.46 muli, mulo

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>muli</b>   | Multiply Integer  |
|              | <b>mulo</b>   | Multiply Ordinal  |
| Format:      | <b>mul*</b>   | <i>src1</i> ,<br>reg/lit <i>src2</i> ,<br>reg/lit <i>dst</i><br>reg   |
| Description: | Multiplies the <i>src2</i> value by the <i>src1</i> value and stores the result in <i>dst</i> . The binary results from these two instructions are identical. The only difference is that muli can signal an integer overflow.  |   |
| Action:      | <b>mulo:</b><br><code>dst = (src2 * src1)[31:0];</code>   |   |
|              | <b>muli:</b><br><code>dst = (src2 * src1)[31:0];</code><br><code>if((src2[31] == src1[31]) &amp;&amp; (src2[31] != dst[31]))</code><br><code>{   if(AC.om == 1)</code><br><code>    AC.of = 1;</code><br><code>    else</code><br><code>        generate_fault(ARITHMETIC.OVERFLOW);</code><br><code>}</code> | 6   |
| Faults:      | STANDARD<br>ARITHMETIC.OVERFLOW.  | Refer to section 6.1.6, “Faults” (pg. 6-6).<br>Result is too large for destination register ( <b>muli</b> only). If a condition of overflow occurs, the least significant 32 bits of the result are stored in the destination register. |
| Example:     | <code>muli r3, r4, r9 # r9 = r4 * r3</code>   |   |
| Opcode:      | <b>muli</b>   | 741H  |
|              | <b>mulo</b>   | 701H  |
| See Also:    | <b>emul, ediv, divi, divo</b>   |   |

## 6.2.47 nand

Mnemonic: **nand** Nand

Format: **nand** *src1*, *src2*, *dst*  
                reg/lit      reg/lit      reg

Description: Performs a bitwise NAND operation on *src1* and *src2* values and stores the result in *dst*.

Action:  $dst = \sim src2 \mid \sim src1;$

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example: nand g5, r3, r7 # r7 = r3 NAND g5

Opcode: **nand** 58EH REG

See Also: **and, andnot, nor, not, notand, notor, or, ornot, xnor, xor**

### 6.2.48 nor

Mnemonic:      **nor**      Nor

Format:      **nor**      *src1*,  
                  reg/lit      *src2*,  
                  reg/lit      *dst*  
                  reg

Description:      Performs a bitwise NOR operation on the *src2* and *src1* values and stores the result in *dst*.

Action:       $dst = \sim src2 \& \sim src1;$

Faults:      STANDARD      Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:      nor g8, 28, r5      # r5 = 28 NOR g8

Opcode:      **nor**      588H      REG

See Also:      **and, andnot, nand, not, notand, notor, or, ornot, xnor, xor**

## 6.2.49 not, notand

|              |  |                          |   |
|--------------|--|--------------------------|---|
| Mnemonic:    | <b>not</b>   | Not                      |   |
|              | <b>notand</b>  | Not And                  |   |
| Format:      | <b>not</b>   | <i>src</i> ,<br>reg/lit  | <i>dst</i>                                  |
|              | <b>notand</b>  | <i>src1</i> ,<br>reg/lit | <i>src2</i> ,<br>reg/lit <i>dst</i><br>reg  |
| Description: | Performs a bitwise NOT ( <b>not</b> instruction) or NOT AND ( <b>notand</b> instruction) operation on the <i>src2</i> and <i>src1</i> values and stores the result in <i>dst</i> . |                          |   |
| Action:      | <b>not:</b><br><i>dst</i> = $\sim$ <i>src1</i> ;<br><br><b>notand:</b><br><i>dst</i> = $\sim$ <i>src2</i> & <i>src1</i> ;  |                          |   |
| Faults:      | <b>STANDARD</b>  |                          | Refer to section 6.1.6, "Faults" (pg. 6-6). |
| Example:     | not g2, g4   | # g4 = NOT g2            |   |
|              | notand r5, r6, r7  | # r7 = NOT r6 AND r5     |   |
| Opcode:      | <b>not</b>   | 58AH                     | REG   |
|              | <b>notand</b>  | 584H                     | REG   |
| See Also:    | <b>and, andnot, nand, nor, notor, or, ornot, xnor, xor</b>   |                          |   |

## 6.2.50 notbit

Mnemonic:      **notbit**      Not Bit

Format:      **notbit**      *bitpos*,  
                  *reg/lit*      *src2*,  
                  *reg/lit*      *dst*  
                  *reg*

Description:      Copies the *src2* value to *dst* with one bit toggled. The *bitpos* operand specifies the bit to be toggled.

Action:       $dst = src2 \wedge 2^{**}(src1\%32);$

Faults:      STANDARD      Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:      `notbit r3, r12, r7`      # *r7* = *r12* with the bit  
                  # specified in *r3* toggled.

Opcode:      **notbit**      580H      REG

See Also:      **alterbit, chkbit, clrbit, setbit**

## 6.2.51 **notor**

|              |  |   |
|--------------|--|---|
| Mnemonic:    | <b>notor</b>   | Not Or  |
| Format:      | <b>notor</b>   | <i>src1</i> ,<br>reg/lit <i>src2</i> ,<br>reg/lit <i>dst</i><br>reg |
| Description: | Performs a bitwise NOTOR operation on <i>src2</i> and <i>src1</i> values and stores result in <i>dst</i> . |   |
| Action:      | $dst = \sim(src2) \mid src1;$  |   |
| Faults:      | STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).   |   |
| Example:     | notor g12, g3, g6 # g6 = NOT g3 OR g12   |   |
| Opcode:      | <b>notor</b>   | 58DH REG  |
| See Also:    | <b>and, andnot, nand, nor, not, notand, or, ornot, xnor, xor</b>   |   |

## 6.2.52 or, ornot

|              |   |   |   |
|--------------|---|---|---|
| Mnemonic:    | <b>or</b>   | Or  |   |
|              | <b>ornot</b>  | Or Not  |   |
| Format:      | <b>or</b>   | <i>src1,</i><br>reg/lit                                       | <i>src2,</i><br>reg/lit                     |
|              | <b>ornot</b>  | <i>src1,</i><br>reg/lit                                       | <i>src2,</i><br>reg/lit                     |
| Description: | Performs a bitwise OR ( <b>or</b> instruction) or ORNOT ( <b>ornot</b> instruction) operation on the <i>src2</i> and <i>src1</i> values and stores the result in <i>dst</i> . |   |   |
| Action:      | <b>or:</b><br><i>dst</i> = <i>src2</i>   <i>src1</i> ;  | <b>ornot:</b><br><i>dst</i> = <i>src2</i>   ~( <i>src1</i> ); | Refer to section 6.1.6, “Faults” (pg. 6-6). |
| Faults:      | STANDARD  |   |   |
| Example:     | <b>or</b> 14, g9, g3<br><b>ornot</b> r3, r8, r11  | # g3 = g9 OR 14<br># r11 = r8 OR NOT r3                       |   |
| Opcode:      | <b>or</b>   | 587H  | REG   |
|              | <b>ornot</b>  | 58BH  | REG   |
| See Also:    | <b>and, andnot, nand, nor, not, notand, notor, xnor, xor</b>  |   |   |

## 6.2.53 remi, remo

|              |   |  |
|--------------|---|--|
| Mnemonic:    | <b>remi</b>   | Remainder Integer  |
|              | <b>remo</b>   | Remainder Ordinal  |
| Format:      | <b>rem*</b>   | <i>src1</i> , <i>src2</i> , <i>dst</i><br>reg/lit      reg/lit      reg  |
| Description: | Divides <i>src2</i> by <i>src1</i> and stores the remainder in <i>dst</i> . The sign of the result (if nonzero) is the same as the sign of <i>src2</i> .          |  |
| Action:      | <b>remi, remo:</b><br>if( <i>src1</i> == 0)<br>generate_fault(ARITHMETIC.ZERO_DIVIDE);<br><i>dst</i> = <i>src2</i> - ( <i>src1</i> / <i>src2</i> )* <i>src1</i> ; |  |
| Faults:      | ARITHMETIC.ZERO_DIVIDE<br>ARITHMETIC.INTEGER_OVERFLOW   | The <i>src1</i> operand is 0.<br>The result is too large for destination register ( <b>remi</b> only). If overflow occurs and AC.om=1, the fault is suppressed and AC.of is set to 1. The least significant 32 bits of the result are stored in <i>dst</i> . |
| Example:     | <b>remo r4, r5, r6 # r6 = r5 rem r4</b>   |  |
| Opcode:      | <b>remi</b>   | 748H REG   |
|              | <b>remo</b>   | 708H REG   |
| See Also:    | <b>modi</b>   |  |
| Notes:       | <b>remi</b> produces the correct result (0) even when computing $-2^{31}$ <b>remi</b> -1, which would cause the corresponding division to overflow.               |  |

## 6.2.54 ret

Mnemonic: **ret**      Return

Format: **ret**

Description: Returns program control to the calling procedure. The current stack frame (i.e., that of the called procedure) is deallocated and the FP is changed to point to the calling procedure's stack frame. Instruction execution is continued at the instruction pointed to by the RIP in the calling procedure's stack frame, which is the instruction immediately following the call instruction.

As shown in the action statement below, the return-status field and prereturn-trace flag determine the action that the processor takes on the return. These fields are contained in bits 0 through 3 of register r0 of the called procedure's local registers.

See section CHAPTER 7, "PROCEDURE CALLS" (pg. 7-1) for more on **ret**.

Action:

```
implicit_syncf();
if(pfp.p && PC.te && TC.p)
{
    pfp.p = 0;
    generate_fault(TRACE.PRERETURN);
}
switch(return_status_field)
{
    case 0002:          #local return
        get_FP_and_IP();
        break;
    case 0012:          #fault return
        tempa = memory(FP-16);
        tempb = memory(FP-12);
        get_FP_and_IP();
        AC = tempb;
        if(execution_mode == supervisor)
            PC = tempa;
        break;
    case 0102:          #supervisor return, trace on return disabled
        if(execution_mode != supervisor)
            get_FP_and_IP();
        else
            {  PC.te = 0;
                execution_mode = user;
                get_FP_and_IP();
            }
}
```

## INSTRUCTION SET REFERENCE



```
        break;
case 0112:      # supervisor return, trace on return enabled
    if(execution_mode != supervisor)
        get_FP_and_IP();
    else
    {
        PC.te = 1;
        execution_mode = user;
        get_FP_and_IP();
    }
    break;
case 1002:    #reserved - unpredictable behavior
    break;
case 1012:    #reserved - unpredictable behavior
    break;
case 1102:    #reserved - unpredictable behavior
    break;
case 1112:    #interrupt return
    tempa = memory(FP-16);
    tempb = memory(FP-12);
    get_FP_and_IP();
    AC = tempb;
    if(execution_mode == supervisor)
        PC = tempa;
    check_pending_interrupts();
    break;
}

get_FP_and_IP()
{
    FP = PFP;
    free(current_register_set);
    if(not_allocated(FP))
        retrieve_from_memory(FP);
    IP = RIP;
}
```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

OPERATION.UNIMPLEMENTED  
TRACE.PRERETURN

Example: ret # Program control returns to context of
# calling procedure.

Opcode: ret 0AH CTRL

See Also: call, calls, callx

## 6.2.55 rotate

Mnemonic: **rotate**      Rotate

Format:      **rotate**      *len*,  
                  reg/lit      *src2*,  
                  reg/lit      *dst*  
                  reg

Description: Copies *src2* to *dst* and rotates the bits in the resulting *dst* operand to the left (toward higher significance). Bits shifted off left end of word are inserted at right end of word. The *len* operand specifies number of bits that the *dst* operand is rotated.

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This instruction can also be used to rotate bits to the right. The number of bits the word is to be rotated right should be subtracted from 32 and the result used as the *len* operand.

Action: *src2* is rotated by *len* mod 32. This value is stored in *dst*.

Faults: **STANDARD**      Refer to section 6.1.6, “Faults” (pg. 6-6).

Example: **rotate 13, r8, r12**      # r12 = r8 with bits rotated  
    # 13 bits to left.

Opcode: **rotate**      59DH      REG

See Also: **SHIFT, eshro**

## 6.2.56 scanbit

Mnemonic: **scanbit** Scan For Bit

Format: **scanbit** *src1*, *dst*  
           reg/lit reg

Description: Searches *src1* for a set bit (1 bit). If a set bit is found, the bit number of the most significant set bit is stored in the *dst* and the condition code is set to  $000_2$ . If *src* value is zero, all 1's are stored in *dst* and condition code is set to  $000_2$ .

Action:

```

dst = 0xFFFFFFFF;
AC.cc = 0002;
for(i = 31; i >= 0; i--)
{
    if((src1 & 2**i) != 0)
    {
        dst = i;
        AC.cc = 0102;
        break;
    }
}

```

Faults: STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

Example:

```

# assume g8 is nonzero
scanbit g8, g10      # g10 = bit number of most-
                      # significant set bit in g8;
                      # AC.cc = 0102.

```

Opcode: **scanbit** 641H REG

See Also: **spanbit, setbit**

Side Effects: Sets the condition code in the arithmetic controls.

## 6.2.57 scanbyte

|               |   |   |
|---------------|---|---|
| Mnemonic:     | <b>scanbyte</b>   | Scan Byte Equal                             |
| Format:       | <b>scanbyte</b>   | $src1,$<br>reg/lit $src2$<br>reg/lit        |
| Description:  | Performs byte-by-byte comparison of $src1$ and $src2$ and sets condition code to $010_2$ if any two corresponding bytes are equal. If no corresponding bytes are equal, condition code is set to $000_2$ .  |   |
| Action:       | <pre>if((src1 &amp; 0x000000FF) == (src2 &amp; 0x000000FF)       (src1 &amp; 0x0000FF00) == (src2 &amp; 0x0000FF00)       (src1 &amp; 0x00FF0000) == (src2 &amp; 0x00FF0000)       (src1 &amp; 0xFF000000) == (src2 &amp; 0xFF000000))    AC.cc = 010<sub>2</sub>; else    AC.cc = 000<sub>2</sub>;</pre> |   |
| Faults:       | STANDARD  | Refer to section 6.1.6, “Faults” (pg. 6-6). |
| Example:      | # Assume r9 = 0x11AB1100<br>scanbyte 0x00AB0011, r9       # AC.cc = 010 <sub>2</sub>  |   |
| Opcode:       | <b>scanbyte</b>   | 5ACH                  REG                   |
| See Also:     | <b>bswap</b>  |   |
| Side Effects: | Sets the condition code in the arithmetic controls.   |   |

## 6.2.58 SEL<CC> (New 80960 Core Instruction Class)

|           |              |                                  |
|-----------|--------------|----------------------------------|
| Mnemonic: | <b>selno</b> | Select Based on Unordered        |
|           | <b>selg</b>  | Select Based on Greater          |
|           | <b>sele</b>  | Select Based on Equal            |
|           | <b>selge</b> | Select Based on Greater or Equal |
|           | <b>sell</b>  | Select Based on Less             |
|           | <b>selne</b> | Select Based on Not Equal        |
|           | <b>selle</b> | Select Based on Less or Equal    |
|           | <b>selo</b>  | Select Based on Ordered          |

|         |             |                          |                          |                   |
|---------|-------------|--------------------------|--------------------------|-------------------|
| Format: | <b>sel*</b> | <i>src1</i> ,<br>reg/lit | <i>src2</i> ,<br>reg/lit | <i>dst</i><br>reg |
|---------|-------------|--------------------------|--------------------------|-------------------|

Description: Selects either *src1* or *src2* to be stored in *dst* based on the condition code bits in the arithmetic controls. If for Unordered the condition code is 0, or if for the other cases the logical AND of the condition code and the mask-part of the opcode is not zero, then the value of *src2* is stored in the destination. Else, the value of *src1* is stored in the destination.

| Instruction  | MASK             | Condition        |
|--------------|------------------|------------------|
| <b>selno</b> | 000 <sub>2</sub> | Unordered        |
| <b>selg</b>  | 001 <sub>2</sub> | Greater          |
| <b>sele</b>  | 010 <sub>2</sub> | Equal            |
| <b>selge</b> | 011 <sub>2</sub> | Greater or equal |
| <b>sell</b>  | 100 <sub>2</sub> | Less             |
| <b>selne</b> | 101 <sub>2</sub> | Not equal        |
| <b>selle</b> | 110 <sub>2</sub> | Less or equal    |
| <b>selo</b>  | 111 <sub>2</sub> | Ordered          |

Action:

```

if ((mask & AC.cc) || (mask == AC.cc))
    dst = src2;
else
    dst = src1;

```

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:

```
sele g0,g1,g2      # AC.cc = 0102
# g2 = g1
```

```
sell g0,g1,g2      # AC.cc = 0012
# g2 = g0
```

Opcode:

|              |      |     |
|--------------|------|-----|
| <b>selno</b> | 784H | REG |
| <b>selg</b>  | 794H | REG |
| <b>sele</b>  | 7A4H | REG |
| <b>selge</b> | 7B4H | REG |
| <b>sell</b>  | 7C4H | REG |
| <b>selne</b> | 7D4H | REG |
| <b>selle</b> | 7E4H | REG |
| <b>selo</b>  | 7F4H | REG |

See Also:

**MOVE, test, cmpi, cmpo, SUB<cc>**

Notes:

This core instruction is not implemented on Cx, Kx and Sx 80960 processors.

## 6.2.59 setbit

|              |  |  |
|--------------|--|--|
| Mnemonic:    | <b>setbit</b>  | Set Bit  |
| Format:      | <b>setbit</b>  | <i>bitpos,</i><br><i>src,</i><br><i>reg/lit</i> <i>dst</i><br><i>reg</i> |
| Description: | Copies <i>src</i> value to <i>dst</i> with one bit set. <i>bitpos</i> specifies bit to be set. |  |
| Action:      | $dst = src2 \mid (2^{**}(src1\%32));$  |  |
| Faults:      | NA   |  |
| Example:     | setbit 15, r9, r1 # r1 = r9 with bit 15 set.   |  |
| Opcode:      | <b>setbit</b>  | 583H      REG  |
| See Also:    | <b>alterbit, chkbit, clrbit, notbit</b>  |  |

## 6.2.60 SHIFT

|           |              |                              |
|-----------|--------------|------------------------------|
| Mnemonic: | <b>shlo</b>  | Shift Left Ordinal           |
|           | <b>shro</b>  | Shift Right Ordinal          |
|           | <b>shli</b>  | Shift Left Integer           |
|           | <b>shri</b>  | Shift Right Integer          |
|           | <b>shrdi</b> | Shift Right Dividing Integer |

|         |            |                        |                        |                   |
|---------|------------|------------------------|------------------------|-------------------|
| Format: | <b>sh*</b> | <i>len,</i><br>reg/lit | <i>src,</i><br>reg/lit | <i>dst</i><br>reg |
|---------|------------|------------------------|------------------------|-------------------|

Description: Shifts *src* left or right by the number of bits indicated with the *len* operand and stores the result in *dst*. Bits shifted beyond register boundary are discarded. For values of *len* greater than 32, the processor interprets the value as 32.

6

**shlo** shifts zeros in from the least significant bit; **shro** shifts zeros in from the most significant bit. These instructions are equivalent to **mulo** and **divo** by the power of 2, respectively.

**shli** shifts zeros in from the least significant bit. An overflow fault is generated if the bits shifted out are not the same as the most significant bit (bit 31). If overflow occurs, *dst* will equal *src* shifted left as much as possible without overflowing.

**shri** performs a conventional arithmetic shift-right operation by shifting in the most significant bit (bit 31). When this instruction is used to divide a negative integer operand by the power of 2, it produces an incorrect quotient (discarding the bits shifted out has the effect of rounding the result toward negative).

**shrdi** is provided for dividing integers by the power of 2. With this instruction, 1 is added to the result if the bits shifted out are non-zero and the *src* operand was negative, which produces the correct result for negative operands.

**shli** and **shrdi** are equivalent to **muli** and **divi** by the power of 2.

Action:

```
shlo:
if(src1 < 32)
    dst = src2 * (2**src1);
else
    dst = 0;
```

**INSTRUCTION SET REFERENCE**

Action:

```

shro:
if(src1 < 32)
    dst = src2 / (2**src1);
else
    dst = 0;

shli:
if(src1 > 32)
    count = 32;
else
    count = src1;
temp = src2;
while((temp[31] == temp[30]) && (count > 0))
{
    temp = (temp * 2)[31:0];
    count = count - 1;
}
dst = temp;
if(count > 0)
{
    if(AC.cc == 1)
        AC.of = 1;
    else
        generate_fault(ARITHMETIC.OVERFLOW);
}

shri:
if(src1 > 32)
    count = 32;
else
    count = src1;
temp = src2;
while(count > 0)
{
    temp = (temp >> 1)[31:0];
    temp[31] = src2[31];
    count = count - 1;
}
dst = temp;

shrdi:
dst = src2 / (2**src1);

```

Faults: ARITHMETIC.OVERFLOW For **shli**

Example: shli 13, g4, r6 # g6 = g4 shifted left 13 bits.

|         |              |      |     |
|---------|--------------|------|-----|
| Opcode: | <b>shlo</b>  | 59CH | REG |
|         | <b>shro</b>  | 598H | REG |
|         | <b>shli</b>  | 59EH | REG |
|         | <b>shri</b>  | 59BH | REG |
|         | <b>shrdi</b> | 59AH | REG |

See Also: **divi, muli, rotate, eshro**

Notes: **shli** and **shrdi** are identical to multiplications and divisions for all positive and negative values of *src2*. **shri** is the conventional arithmetic right shift that does not produce a correct quotient when *src2* is negative.

## 6.2.61 **spanbit**

Mnemonic: **spanbit** Span Over Bit

Format: **spanbit** *src*, *dst*  
           reg/lit      reg

Description: Searches *src* value for the most significant clear bit (0 bit). If a most significant 0 bit is found, its bit number is stored in *dst* and condition code is set to  $010_2$ . If *src* value is all 1's, all 1's are stored in *dst* and condition code is set to  $000_2$ .

Action:

```

dst = 0xFFFFFFFF;
AC.cc = 0002;
for(i = 32; i >= 0; i--)
{
    if((src1 & 2**i) == 0)
    {
        dst = i;
        AC.cc = 0102;
        break;
    }
}

```

Faults: NA

Example:

```

# Assume r2 is not 0xffffffff
spanbit r2, r9      # r9 = bit number of most-
                      # significant clear bit in r2;
                      # AC.cc = 0102

```

Opcode: **spanbit** 640H REG

See Also: **scanbit**

Side Effects: Sets the condition code in the arithmetic controls.

## 6.2.62 STORE

|           |             |                     |
|-----------|-------------|---------------------|
| Mnemonic: | <b>st</b>   | Store               |
|           | <b>stob</b> | Store Ordinal Byte  |
|           | <b>stos</b> | Store Ordinal Short |
|           | <b>stib</b> | Store Integer Byte  |
|           | <b>stis</b> | Store Integer Short |
|           | <b>stl</b>  | Store Long          |
|           | <b>stt</b>  | Store Triple        |
|           | <b>stq</b>  | Store Quad          |

Format:      **st\***      *src1,*      *dst*  
                        *reg*                  *mem*

Description: Copies a byte or group of bytes from a register or group of registers to memory. *src* specifies a register or the first (lowest numbered) register of successive registers.

*dst* specifies the address of the memory location where the byte or first byte or a group of bytes is to be stored. The full range of addressing modes may be used in specifying *dst*. Refer to section 2.3, “MEMORY ADDRESSING MODES” (pg. 2-6) for a complete discussion.

**stob** and **stib** store a byte and **stos** and **stis** store a half word from the *src* register’s low order bytes. Data for ordinal stores is truncated to fit the destination width. If the data for integer stores cannot be represented correctly in the destination width, an Arithmetic Integer Overflow fault is signaled.

**st**, **stl**, **stt** and **stq** copy 4, 8, 12 and 16 bytes, respectively, from successive registers to memory.

For **stl**, *src* must specify an even numbered register (e.g., g0, g2, ... or r0, r2, ...). For **stt** and **stq**, *src* must specify a register number that is a multiple of four (e.g., g0, g4, g8, ... or r0, r4, r8, ...).

Action:

```
st:  
if (illegal_write_to_on_chip_RAM)  
    generate_fault(TYPE.MISMATCH);  
else if ((effective_address[1:0] != 002) && unaligned_fault_enabled)  
    { store_to_memory(effective_address)[31:0] = src1;  
    generate_fault(OPERATION.UNALIGNED);}  
else  
    store_to_memory(effective_address)[31:0] = src1;
```

Action:

```

stob:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else
    store_to_memory(effective_address)[7:0] = src1[7:0];

stib:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if ((src1[31:8] != 0) && (src1[31:8] != 0xFFFF))
    {
        store_to_memory(effective_address)[7:0] = src1[7:0];
        if (AC.om == 1)
            AC.of == 1;
        else
            generate_fault(ARITHMETIC.OVERFLOW);
    }
else
    store_to_memory(effective_address)[7:0] = src1[7:0];
end if;

stos:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if ((effective_address[0] != 0_2) && unaligned_fault_enabled)
    {
        store_to_memory(effective_address)[15:0] = src1[15:0];
        generate_fault(OPERATION.UNALIGNED);
    }
else
    store_to_memory(effective_address)[15:0] = src1[15:0];

stis:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if ((effective_address[0] != 0_2) && unaligned_fault_enabled)
    {
        store_to_memory(effective_address)[15:0] = src1[15:0];
        generate_fault(OPERATION.UNALIGNED);
    }
else if ((src1[31:8] != 0) && (src1[31:8] != 0xFFFF))
    {
        store_to_memory(effective_address)[15:0] = src1[15:0];
        if (AC.om == 1)
            AC.of = 1;
        else
            generate_fault(ARITHMETIC.OVERFLOW);
    }

```

```
else
    store_to_memory(effective_address)[15:0] = src1[15:0];

stl:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if (reg_number(src1) % 2 != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
else if ((effective_address[2:0] != 0002) && unaligned_fault_enabled)
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
    generate_fault (OPERATION.UNALIGNED);
}
else
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
}

stt:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if (reg_number(src1) % 4 != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
else if ((effective_address[3:0] != 00002) && unaligned_fault_enabled)
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
    store_to_memory(effective_address + 8)[31:0] = src1_+_2;
    generate_fault (OPERATION.UNALIGNED);
}
else
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
    store_to_memory(effective_address + 8)[31:0] = src1_+_2;
}

stq:
if (illegal_write_to_on_chip_RAM_or_MMR)
    generate_fault(TYPE.MISMATCH);
else if (reg_number(src1) % 4 != 0)
    generate_fault(OPERATION.INVALID_OPERAND);
else if ((effective_address[3:0] != 00002) && unaligned_fault_enabled)
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
    store_to_memory(effective_address + 8)[31:0] = src1_+_2;
```

## INSTRUCTION SET REFERENCE

```

        store_to_memory(effective_address + 12)[31:0] = src1_+_3;
        generate_fault(OPERATION.UNALIGNED);
    }
else
{
    store_to_memory(effective_address)[31:0] = src1;
    store_to_memory(effective_address + 4)[31:0] = src1_+_1;
    store_to_memory(effective_address + 8)[31:0] = src1_+_2;
    store_to_memory(effective_address + 12)[31:0] = src1_+_3;
}

```

**Faults:**

**TYPE.MISMATCH**  
**OPERATION.UNALIGNED**  
**ARITHMETIC.OVERFLOW** For **stib, stis.**  
**OPERATION.INVALID\_OPERAND**

**Example:**

**st g2, 1254 (g6)** # Word beginning at offset  
# 1254 + (g6) = g2.

**Opcode:**

|             |     |     |
|-------------|-----|-----|
| <b>st</b>   | 92H | MEM |
| <b>stob</b> | 82H | MEM |
| <b>stos</b> | 8AH | MEM |
| <b>stib</b> | C2H | MEM |
| <b>stis</b> | CAH | MEM |
| <b>stl</b>  | 9AH | MEM |
| <b>stt</b>  | A2H | MEM |
| <b>stq</b>  | B2H | MEM |

**See Also:**

**LOAD, MOVE**

**Notes:**

`illegal_write_to_on_chip_RAM` is an implementation-dependent mechanism. The mapping of register bits to memory(efa) depends on the endianism of the memory region and is implementation-dependent.

## 6.2.63 subc

Mnemonic: **subc** Subtract Ordinal With Carry

Format: **subc** *src1*, *src2*, *dst*  
          reg/lit    reg/lit    reg

Description: Subtracts *src1* from *src2*, then subtracts the opposite of condition code bit 1 (used here as the carry bit) and stores the result in *dst*. If the ordinal subtraction results in a carry, condition code bit 1 is set to 1, otherwise it is set to 0.

This instruction can also be used for integer subtraction. Here, if integer subtraction results in an overflow, condition code bit 0 is set.

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**subc** does not distinguish between ordinals and integers: it sets condition code bits 0 and 1 regardless of data type.

Action:

```
dst = (src2 - src1 -1 + AC.cc[1])[31:0];
AC.cc[2:0] = 0002;
if((src2[31] == src1[31]) && (src2[31] != dst[31]))
    AC.cc[0] = 1;          # Overflow bit.
AC.cc[1] = (src2 - src1 -1 + AC.cc[1])[32];      # Carry out.
```

Faults: STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).

Example:

```
subc g5, g6, g7
# g7 = g6 - g5 - not(condition code bit 1)
```

Opcode: **subc** 5B2H REG

See Also: **addc, addi, addo, subi, subo**

Side Effects: Sets the condition code in the arithmetic controls.

## 6.2.64 SUB<CC> (New 80960 Core Instruction Class)

|           |               |                                      |
|-----------|---------------|--------------------------------------|
| Mnemonic: | <b>subono</b> | Subtract Ordinal if Unordered        |
|           | <b>subog</b>  | Subtract Ordinal if Greater          |
|           | <b>suboe</b>  | Subtract Ordinal if Equal            |
|           | <b>suboge</b> | Subtract Ordinal if Greater or Equal |
|           | <b>subol</b>  | Subtract Ordinal if Less             |
|           | <b>subone</b> | Subtract Ordinal if Not Equal        |
|           | <b>subole</b> | Subtract Ordinal if Less or Equal    |
|           | <b>suboo</b>  | Subtract Ordinal if Ordered          |
|           | <b>subino</b> | Subtract Integer if Unordered        |
|           | <b>subig</b>  | Subtract Integer if Greater          |
|           | <b>subie</b>  | Subtract Integer if Equal            |
|           | <b>subige</b> | Subtract Integer if Greater or Equal |
|           | <b>subil</b>  | Subtract Integer if Less             |
|           | <b>subine</b> | Subtract Integer if Not Equal        |
|           | <b>subile</b> | Subtract Integer if Less or Equal    |
|           | <b>subio</b>  | Subtract Integer if Ordered          |

Format:      **sub\***      *src1*,      *src2*,      *dst*  
                   reg/lit      reg/lit      reg

Description: Subtracts *src1* from *src2* conditionally based on the condition code bits in the arithmetic controls.

If for Unordered the condition code is 0, or if for the other cases the logical AND of the condition code and the mask-part of the opcode is not zero; then *src1* is subtracted from *src2* and the result stored in the destination.

| Instruction      | MASK             | Condition |
|------------------|------------------|-----------|
| subono<br>subino | 000 <sub>2</sub> | Unordered |
| subog<br>subig   | 001 <sub>2</sub> | Greater   |
| suboe<br>subie   | 010 <sub>2</sub> | Equal     |

| Instruction      | MASK    | Condition        |
|------------------|---------|------------------|
| suboge<br>subige | $011_2$ | Greater or equal |
| subol<br>subil   | $100_2$ | Less             |
| subone<br>subine | $101_2$ | Not equal        |
| subole<br>subile | $110_2$ | Less or equal    |
| suboo<br>subio   | $111_2$ | Ordered          |

Action:

**SUBO<cc>:**

```
if ((mask & AC.cc) || (mask == AC.cc))
    dst = (src2 - src1)[31:0];
```

**SUBI<cc>:**

```
if ((mask & AC.cc) || (mask == AC.cc))
    dst = (src2 - src1)[31:0];
if((src2[31] != src1[31]) && (src2[31] != dst[31]))
    {
        if (AC.om == 1)
            AC.of = 1;
        else
            generate_fault (ARITHMETIC.OVERFLOW);
    }
```

Faults:

STANDARD Refer to section 6.1.6, “Faults” (pg. 6-6).  
 ARITHMETIC.OVERFLOW For the **SUBI<cc>** class.

Example:

```
suboge g0,g1,g2      # AC.cc = 0102
                      # g2 = g1 - g0

                      # AC.cc = 0012
subile g0,g1,g2      # g2 not modified
```

## INSTRUCTION SET REFERENCE



|         |               |      |     |
|---------|---------------|------|-----|
| Opcode: | <b>subono</b> | 782H | REG |
|         | <b>subog</b>  | 792H | REG |
|         | <b>suboe</b>  | 7A2H | REG |
|         | <b>suboge</b> | 7B2H | REG |
|         | <b>subol</b>  | 7C2H | REG |
|         | <b>subone</b> | 7D2H | REG |
|         | <b>subole</b> | 7E2H | REG |
|         | <b>suboo</b>  | 7F2H | REG |
|         | <b>subino</b> | 783H | REG |
|         | <b>subig</b>  | 793H | REG |
|         | <b>suble</b>  | 7A3H | REG |
|         | <b>subige</b> | 7B3H | REG |
|         | <b>subil</b>  | 7C3H | REG |
|         | <b>subine</b> | 7D3H | REG |
|         | <b>subile</b> | 7E3H | REG |
|         | <b>subio</b>  | 7F3H | REG |

See Also: **subc, subi, subo, SEL<cc>, test**

Notes: This core instruction is not implemented on Cx, Kx and Sx 80960 processors.

## 6.2.65 subi, subo

|              |   |   |
|--------------|---|---|
| Mnemonic:    | <b>subi</b>   | Subtract Integer  |
|              | <b>subo</b>   | Subtract Ordinal  |
| Format:      | <b>sub*</b>   | <i>src1,</i><br>reg/lit <i>src2,</i><br>reg/lit <i>dst</i><br>reg |
| Description: | Subtracts <i>src1</i> from <i>src2</i> and stores the result in <i>dst</i> . The binary results from these two instructions are identical. The only difference is that <b>subi</b> can signal an integer overflow.                                |   |
| Action:      | <b>subo:</b><br>$dst = (src2 - src1)[31:0];$<br><br><b>subi:</b><br>$dst = (src2 - src1)[31:0];$<br>if((src2[31] != src1[31]) && (src2[31] != dst[31]))<br>{    if(AC.om == 1)<br>AC.of = 1;<br>else<br>generate_fault(ARITHMETIC.OVERFLOW);<br>} |   |
| Faults:      | ARITHMETIC.OVERFLOW for <b>subi</b>   |   |
| Example:     | subi g6, g9, g12 # g12 = g9 - g6  |   |
| Opcode:      | <b>subi</b>   | 593H  |
|              | <b>subo</b>   | 592H  |
| See Also:    | <b>addi, addo, subc, addc</b>   |   |

## 6.2.66 syncf

|              |              |  |
|--------------|--------------|--|
| Mnemonic:    | <b>syncf</b> | Synchronize Faults   |
| Format:      | <b>syncf</b> |  |
| Description: |              | Waits for all faults to be generated that are associated with any prior uncompleted instructions.  |
| Action:      |              | <pre>if(AC.nif == 1)     break; else     wait_until_all_previous_instructions_in_flow_have_completed();     # This also means that all of the faults on these instructions have     # been reported.</pre>                             |
| Faults:      | STANDARD     | Refer to section 6.1.6, "Faults" (pg. 6-6).  |
| Example:     |              | <pre>ld xyz, g6 addi r6, r8, r8 syncf and g6, 0xFFFF, g8 # The syncf instruction ensures that any faults # that may occur during the execution of the # ld and addi instructions occur before the # and instruction is executed.</pre> |
| Opcode:      | <b>syncf</b> | 66FH   |
| See Also:    |              | <b>mark, fmark</b>   |

## 6.2.67 **sysctl**

Mnemonic: **sysctl** System Control

Format: **sysctl** *src1*, *src2*, *src/dst*  
*reg/lit*      *reg/lit*      *reg*

Description: Performs system management and control operations including requesting software interrupts, invalidating the instruction cache, configuring the instruction cache, processor reinitialization, modifying memory-mapped registers, and acquiring breakpoint resource information.

Processor control function specified by the message field of *src1* is executed. The type field of *src1* is interpreted depending upon the command. Remaining *src1* bits are reserved. The *src2* and *src3* operands are also interpreted depending upon the command.

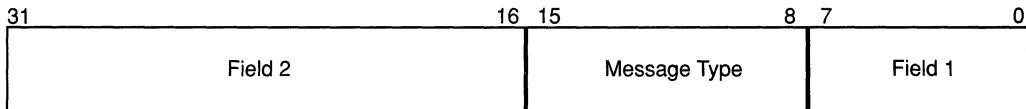


Figure 6-5. Src1 Operand Interpretation

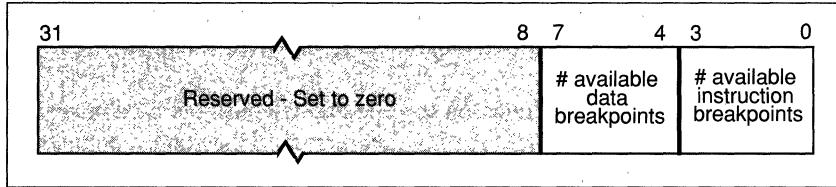
Table 6-14. Sysctl Message Types and Operand Fields

| Message                                     | Src1 |  |                              | Src2               | Src/Dst                           |
|---|------|--|------------------------------|--------------------|-----------------------------------|
|   | Type | Field 1                                      | Field 2                      | Field 3            | Field 4                           |
| Request Interrupt                           | 0x0  | Vector Number                                | N/U                          | N/U                | N/U                               |
| Invalidate Cache                            | 0x1  | N/U  | N/U                          | N/U                | N/U                               |
| Configure Instruction Cache                 | 0x2  | Cache Mode Configuration<br>(See Table 6-15) | N/U                          | Cache load address | N/U                               |
| Reinitialize                                | 0x3  | N/U  | N/U                          | Starting IP        | PRCB Pointer                      |
| Modify Memory-Mapped Control Register (MMR) | 0x5  | N/U  | Lower 2 bytes of MMR address | Value to write     | Mask                              |
| Breakpoint Resource Request                 | 0x6  | N/U  | N/U                          | N/U                | Break-point info (See Figure 6-6) |

Note: Sources and fields that are not used (designated N/U) are ignored.

**Table 6-15. Cache Configuration Modes**

| Mode Field         | Mode Description     | JA      | JF, JD  |
|--------------------|----------------------|---------|---------|
| $000_2$            | Normal cache enabled | 2 Kbyte | 4 Kbyte |
| $XX1_2$            | Full cache disabled  | 2 Kbyte | 4 Kbyte |
| $100_2$ or $110_2$ | Load and lock cache  | 2 Kbyte | 4 Kbyte |

**Figure 6-6. Src/dst Interpretation for Breakpoint Resource Request**

```

Action:
if (PC.em != supervisor)
    generate_fault(TYPE.MISMATCH);
order_wrt(previous_operations);
OPtype = (src1 & 0xff00) >> 8;
switch (OPtype) {
    case 0:      # Signal Software Interrupt
        vector_to_post = 0xff & src1;
        priority_to_post = vector_to_post >> 3;
        pend_ints_addr = interrupt_table_base + 4 + priority_to_post;
        pend_priority = memory_read(interrupt_table_base,atomic_lock);
        # Priority zero just recans Interrupt Table
        if (priority_to_post != 0)
            {pend_ints = memory_read(pend_ints_addr, non-cacheable)
             pend_ints[7 & vector] = 1;
             pend_priority[priority_to_post] = 1;
             memory_write(pend_ints_addr, pend_ints); }
        memory_write(interrupt_table_base,pend_priority,atomic_unlock);
        # Update internal software priority with highest priority interrupt
        # from newly adjusted Pending Priorities word. The current internal
        # software priority is always replaced by the new, computed one. (If
        # there is no bit set in pending_priorities word for the current
        # internal one, then it is discarded by this action.)
        if (pend_priority == 0)
            SW_Int_Priority = 0;
        else { msb_set = scan_bit(pend_priority);
               SW_Int_Priority = msb_set; }
}

```

```
# Make sure change to internal software priority takes full effect
# before next instruction.
order_wrt(subsequent_operations);
break;
case 1:      # Global Invalidate Instruction Cache
    invalidate_instruction_cache( );
    unlock_instruction_cache( );
    break;
case 2:      # Configure Instruction-Cache
    mode = src1 & 0xff;
    if (mode & 1) disable_instruction_cache;
    else switch (mode) {
        case 0:      enable_instruction_cache; break;
        case 4,6:    # Load & Lock code into Instr-Cache
            # All contiguous blocks are locked.
            # Note: block = way on i960 Jx microprocessor.
            # src2 has starting address of code to lock.
            # src2 is aligned to a quadword
            # boundary.
            aligned_addr = src2 & 0xffffffff0;
            invalidate(I-cache); unlock(I-cache);
            for (j = 0; j < number_of_blocks_that_lock; j++)
                {way = block_associated_with_block(j);
                 start = src2 + j*block_size;
                 end = start + block_size;
                 for (i = start; i < end; i=i+4)
                     {set = set_associated_with(i);
                      word = word_associated_with(i);
                      Icache_line[set][way][word] =
                          memory[i];
                      update_tag_n_valid_bits(set,way,word)
                      lock_icache(set,way,word);
                     } } break;
        default:
            generate_operation_invalid_operand_fault;
        } break;
case 3:      # Software Re-init
    disable(I_cache); invalidate(I_cache);
    disable(D_cache); invalidate(D_cache);
    Process_PRCB(dst); # dst has ptr to new PRCB
    IP = src2;
    break;
case 5:      # Modify One Memory-Mapped Control Register (MMR)
    # src1[31:16] has lower 2 bytes of MMR address
```

```

# src2 has value to write; dst has mask.
# After operation, dst has old value of MMR
addr = (0xff00 << 16) | (src1 >> 16);
temp = memory[addr];
memory[addr] = (src2 & dst) | (temp & ~dst);
dst = temp;
break;

case 6: # Breakpoint Resource Request
    acquire_available_instr_breakpoints( );
    dst[3:0] = number_of_available_instr_breakpoints;
    acquire_available_data_breakpoints( );
    dst[7:4] = number_of_available_data_breakpoints;
    dst[31:8] = 0;
    break;

default: # Reserved, fault occurs
    generate_fault(OPERATION.INVALID_OPERAND);
    break;
}

order_wrt(subsequent_operations);

```

**Faults:** STANDARD Refer to section 6.1.6, "Faults" (pg. 6-6).

OPERATION.INVALID\_OPERAND  
TYPE.MISMATCH

**Example:**

|                       |                           |
|-----------------------|---------------------------|
| ldconst 0x100,r6      | # Set up message.         |
| sysctl r6,r7,r8       | # Invalidate instruction  |
|                       | # cache.                  |
|                       | # r7, r8 are not used.    |
| ldconst 0x204, g0     | # Set up message type and |
|                       | # cache configuration     |
|                       | # mode.                   |
|                       | # Lock half cache.        |
| ldconst 0x20000000,g2 | # Starting address of     |
|                       | # code.                   |
| sysctl g0,g2,g2       | # Execute Load and Lock.  |

**Opcode:** **sysctl** 659H REG

**See Also:** **dcctl, icctl**

**Notes:** This instruction is implemented on 80960Jx and 80960Cx processors, and may or may not be implemented on future i960 processors.

## 6.2.68 TEST<cc>

|           |               |                           |
|-----------|---------------|---------------------------|
| Mnemonic: | <b>teste</b>  | Test For Equal            |
|           | <b>testne</b> | Test For Not Equal        |
|           | <b>testl</b>  | Test For Less             |
|           | <b>testle</b> | Test For Less Or Equal    |
|           | <b>testg</b>  | Test For Greater          |
|           | <b>testge</b> | Test For Greater Or Equal |
|           | <b>testo</b>  | Test For Ordered          |
|           | <b>testno</b> | Test For Not Ordered      |
| Format:   | <b>test*</b>  | <i>dst</i>                |
|           |               | <i>reg</i>                |

Description: Stores a true (01H) in *dst* if the logical AND of the condition code and opcode mask-part is not zero. Otherwise, the instruction stores a false (00H) in *dst*. For **testno** (Unordered), a true is stored if the condition code is  $000_2$ , otherwise a false is stored.

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The following table shows the condition-code mask for each instruction. The mask is in bits 0-2 of the opcode.

| Instruction | Mask    | Condition        |
|-------------|---------|------------------|
| testno      | $000_2$ | Unordered        |
| testg       | $001_2$ | Greater          |
| teste       | $010_2$ | Equal            |
| testge      | $011_2$ | Greater or equal |
| testl       | $100_2$ | Less             |
| testne      | $101_2$ | Not equal        |
| testle      | $110_2$ | Less or equal    |
| testo       | $111_2$ | Ordered          |

The optional .t or .f suffix may be appended to the mnemonic. Use .t to speed-up execution when these instructions usually store a true (1) condition in *dst*. Use .f to speed-up execution when these instructions usually store a false (0) condition in *dst*. If a suffix is not provided, the assembler is free to provide one.

Action: For all **TEST<cc>** except **testno**:  
 if((mask & AC.cc) !=  $000_2$ )  
     src1 = 1;     #true value  
 else  
     src1 = 0;     #false value

## INSTRUCTION SET REFERENCE

Action:           **testno:**  
                   if(AC.cc == 000<sub>2</sub>)  
                     src1 = 1;       #true value  
                   else  
                     src1 = 0;     #false value

Faults:           NA

Example:          # Assume AC.cc = 100<sub>2</sub>  
                   testl g9        # g9 = 0x00000001

|         |               |     |      |
|---------|---------------|-----|------|
| Opcode: | <b>teste</b>  | 22H | COBR |
|         | <b>testne</b> | 25H | COBR |
|         | <b>testl</b>  | 24H | COBR |
|         | <b>testle</b> | 26H | COBR |
|         | <b>testg</b>  | 21H | COBR |
|         | <b>testge</b> | 23H | COBR |
|         | <b>testo</b>  | 27H | COBR |
|         | <b>testno</b> | 20H | COBR |

See Also:        **cmpl, cmpdeci, cmpinci**

## 6.2.69 Xnor, XOR

|              |   |                         |                         |                   |
|--------------|---|-------------------------|-------------------------|-------------------|
| Mnemonic:    | <b>xnor</b>   | Exclusive Nor           |                         |                   |
|              | <b>xor</b>  | Exclusive Or            |                         |                   |
| Format:      | <b>xnor</b>   | <i>src1,</i><br>reg/lit | <i>src2,</i><br>reg/lit | <i>dst</i><br>reg |
|              | <b>xor</b>  | <i>src1,</i><br>reg/lit | <i>src2,</i><br>reg/lit | <i>dst</i><br>reg |
| Description: | Performs a bitwise XNOR ( <b>xnor</b> instruction) or XOR ( <b>xor</b> instruction) operation on the <i>src2</i> and <i>src1</i> values and stores the result in <i>dst</i> . |                         |                         |                   |
| Action:      | <b>xnor:</b><br>$dst = \sim(src2 \mid src1) \mid (src2 \And src1);$   |                         |                         |                   |
|              | <b>xor:</b><br>$dst = (src2 \mid src1) \And \sim(src2 \And src1);$  |                         |                         |                   |
| Faults:      | NA  |                         |                         |                   |
| Example:     | <b>xnor r3, r9, r12</b>   | # r12 = r9 XNOR r3      |                         |                   |
|              | <b>xor g1, g7, g4</b>   | # g4 = g7 XOR g1        |                         |                   |
| Opcode:      | <b>xnor</b>   | 589H                    | REG                     |                   |
|              | <b>xor</b>  | 586H                    | REG                     |                   |
| See Also:    | <b>and, andnot, nand, nor, not, notand, notor, or, ornot</b>  |                         |                         |                   |





7

## PROCEDURE CALLS





## CHAPTER 7

# PROCEDURE CALLS

This chapter describes mechanisms for making procedure calls, which include branch-and-link instructions, built-in call and return mechanism, call instructions (**call**, **callx**, **calls**), return instruction (**ret**) and call actions caused by interrupts and faults.

The i960® architecture supports two methods for making procedure calls:

- A RISC-style branch-and-link: a fast call best suited for calling procedures that do not call other procedures.
- An integrated call and return mechanism: a more versatile method for making procedure calls, providing a highly efficient means for managing a large number of registers and the program stack.

On a branch-and-link (**bal**, **balx**), the processor branches and saves a return IP in a register. The called procedure uses the same set of registers and the same stack as the calling procedure. On a call (**call**, **callx**, **calls**) or when an interrupt or fault occurs, the processor also branches to a target instruction and saves a return IP. Additionally, the processor saves the local registers and allocates a new set of local registers and a new stack for the called procedure. The saved context is restored when the return instruction (**ret**) executes.

In many RISC architectures, a branch-and-link instruction is used as the base instruction for coding a procedure call. The user program then handles register and stack management for the call. Since the i960 architecture provides a fully integrated call and return mechanism, coding calls with branch-and-link is not necessary. Additionally, the integrated call is much faster than typical RISC-coded calls.

The branch-and-link instruction in the i960 processor family, therefore, is used primarily for calling leaf procedures. Leaf procedures call no other procedures; they reside at the “leaves” of the call tree.

In the i960 architecture the integrated call and return mechanism is used in two ways:

- explicit calls to procedures in a user’s program
- implicit calls to interrupt and fault handlers

The remainder of this chapter explains the generalized call mechanism used for explicit and implicit calls and call and return instructions.

## PROCEDURE CALLS

The processor performs two call actions:

- local* When a local call is made, execution mode remains unchanged and the stack frame for the called procedure is placed on the *local stack*. The local stack refers to the stack of the calling procedure.
- supervisor* When a supervisor call is made from user mode, execution mode is switched to supervisor and the stack frame for the called procedure is placed on the *supervisor stack*.
- When a supervisor call is issued from supervisor mode, the call degenerates into a local call (i.e., no mode nor stack switch).

Explicit procedure calls can be made using several instructions. Local call instructions **call** and **callx** perform a local call action. With **call** and **callx**, the called procedure's IP is included as an operand in the instruction.

A system call is made with **calls**. This instruction is similar to **call** and **callx**, except that the processor obtains the called procedure's IP from the *system procedure table*. A system call, when executed, is directed to perform either the local or supervisor call action. These calls are referred to as *system-local* and *system-supervisor* calls, respectively. A system-supervisor call is also referred to as a *supervisor call*.

### 7.1 CALL AND RETURN MECHANISM

At any point in a program, the i960 processor has access to the global registers, a local register set and the procedure stack. A subset of the stack allocated to the procedure is called the stack frame.

- When a call executes, a new stack frame is allocated for the called procedure. The processor also saves the current local register set, freeing these registers for use by the newly called procedure. In this way, every procedure has a unique stack and a unique set of local registers.
- When a return executes, the current local register set and current stack frame are deallocated. The previous local register set and previous stack frame are restored.

#### 7.1.1 Local Registers and the Procedure Stack

The processor automatically allocates a set of 16 local registers for each procedure. Since local registers are on-chip, they provide fast access storage for local variables. Of the 16 local registers, 13 are available for general use; r0, r1 and r2 are reserved for linkage information to tie procedures together.

The processor does not always clear or initialize the set of local registers assigned to a new procedure. Therefore, initial register contents are unpredictable. Also, because the processor does not initialize the local register save area in the newly created stack frame for the procedure, its contents are equally unpredictable.

The procedure stack can be located anywhere in the address space and grows from low addresses to high addresses. It consists of contiguous frames, one frame for each active procedure. Local registers for a procedure are assigned a save area in each stack frame (Figure 7-1). The procedure stack, available to the user, begins after this save area.

To increase procedure call speed, the architecture allows an implementation to cache the saved local register sets on-chip. Thus, when a procedure call is made, the contents of the current set of local registers often do not have to be written out to the save area in the stack frame in memory. Refer to section 7.1.4, “Caching of Local Register Sets” (pg. 7-9) and section 7.1.4.1, “Reserving Local Register Sets for High Priority Interrupts” (pg. 7-10) for more about local registers and procedure stack interrelations

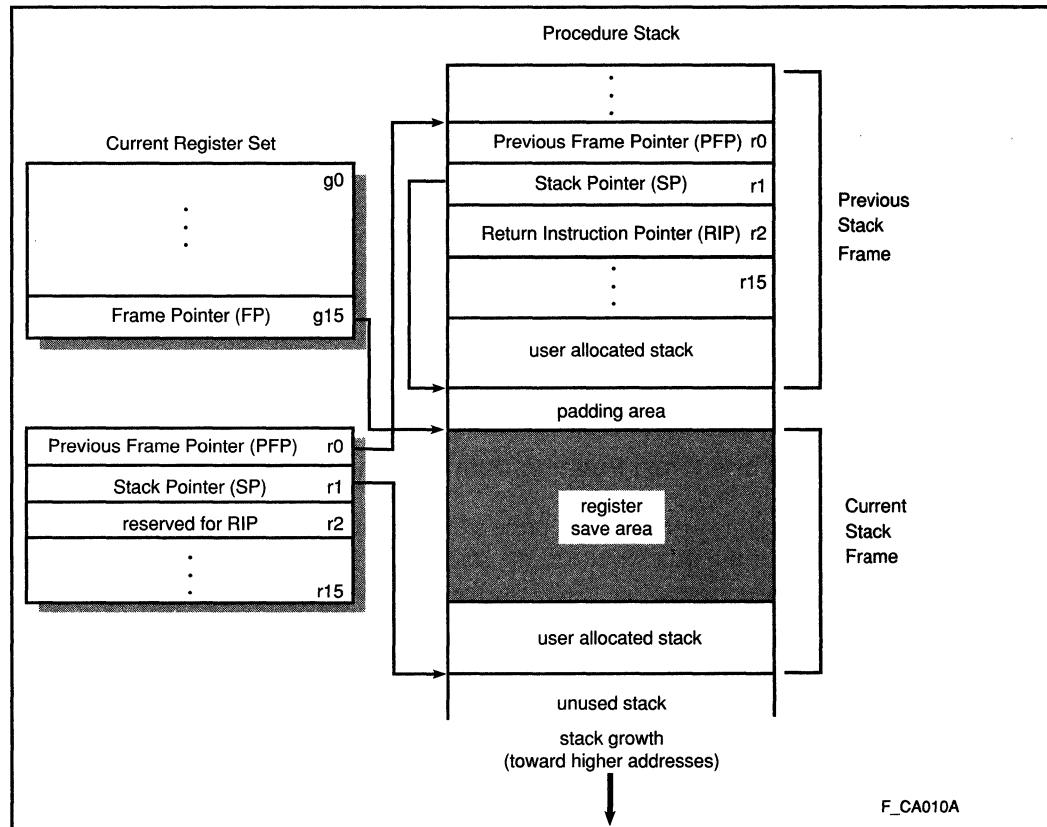


Figure 7-1. Procedure Stack Structure and Local Registers

## PROCEDURE CALLS

### 7.1.2 Local Register and Stack Management

Global register g15 (FP) and local registers r0 (PFP), r1 (SP) and r2 (RIP) contain information to link procedures together and link local registers to the procedure stack (Figure 7-1). The following subsections describe this linkage information.

#### 7.1.2.1 Frame Pointer

The frame pointer is the current stack frame's first byte address. It is stored in global register g15, the frame pointer (FP) register. The FP register is always reserved for the frame pointer; do not use g15 for general storage.

Stack frame alignment is defined for each implementation of the i960 processor family, according to an SALIGN parameter (see section A.2.5, "Data and Data Structure Alignment" (pg. A-3)). In the i960 Jx processors, stacks are aligned on 16-byte boundaries (see Figure 7-1). When the processor needs to create a new frame on a procedure call, it adds a padding area to the stack so that the new frame starts on a 16-byte boundary.

#### 7.1.2.2 Stack Pointer

The stack pointer is the byte-aligned address of the stack frame's next unused byte. The stack pointer value is stored in local register r1, the stack pointer (SP) register. The procedure stack grows upward (i.e., toward higher addresses). When a stack frame is created, the processor automatically adds 64 to the frame pointer value and stores the result in the SP register. This action creates the register save area in the stack frame for the local registers.

The user must modify the SP register value when data is stored or removed from the stack. The i960 architecture does not provide an explicit push or pop instruction to perform this action. This is typically done by adding the size of all pushes to the stack in one operation.

#### 7.1.2.3 Considerations When Pushing Data onto the Stack

Care should be taken in writing to stack in the presence of unforeseen faults and interrupts. In the general case, to ensure that the data written to the stack is not corrupted by a fault or interrupt record, the SP should be incremented first to allocate the space, and then the data should be written to the space so allocated:

```
mov    sp,r4  
addo   24,sp,sp  
st     data,(r4)  
...  
st     data,20(r4)
```

#### 7.1.2.4 Considerations When Popping Data off the Stack

For reasons similar to those discussed in the previous section, care should be taken in reading the stack in the presence of unforeseen faults and interrupts. In the general case, to ensure that data about to be popped off the stack is not corrupted by a fault or interrupt record, the data should be read first and then the sp should be decremented:

```
subo 24,sp,r4  
ld   20(r4),rn  
...  
ld   (r4),rn  
mov r4,sp
```

#### 7.1.2.5 Previous Frame Pointer

The previous frame pointer is the previous stack frame's first byte address. This address' upper 28 bits are stored in local register r0, the previous frame pointer (PFP) register. The four least-significant bits of the PFP are used to store the return-type field.

#### 7.1.2.6 Return Type Field

PFP register bits 0 through 3 contain return type information for the calling procedure. When a procedure call is made — either explicit or implicit — the processor records the call type in the return type field. The processor then uses this information to select the proper return mechanism when returning to the calling procedure. The use of this information is described section 7.8, "RETURNS" (pg. 7-20).

#### 7.1.2.7 Return Instruction Pointer

The actual RIP register (r2) is reserved by the processor to support the call and return mechanism and must not be used by software; the actual value of RIP is unpredictable at all times. For example, an implicit procedure call (fault or interrupt) can occur at any time and modify the RIP. An OPERATION.UNIMPLEMENTED fault is generated when attempting to write the RIP.

The image of the RIP register in the stack frame is used by the processor to determine that frame's return instruction address. When a call is made, the processor saves the address of the instruction after the call in the image of the RIP register in the calling frame.

#### 7.1.3 Call and Return Action

To clarify how procedures are linked and how the local registers and stack are managed, the following sections describe a general call and return operation and the operations performed with the FP, SP, PFP and RIP registers described in the preceding sections.

## PROCEDURE CALLS

The events for call and return operations are given in a logical order of operation. The i960 Jx processors can execute independent operations in parallel; therefore, many of these events execute simultaneously. For example, to improve performance, the processors often begin prefetch of the target instruction for the call or return before the operation is complete.

### 7.1.3.1 Call Operation

When a **call**, **calls** or **callx** instruction is executed or an implicit call is triggered:

1. The processor stores the instruction pointer for the instruction following the call in the current stack's RIP register (r2).
2. The current local registers — including the PFP, SP and RIP registers — are saved, freeing these for use by the called procedure. Because saved local registers are cached on the i960 Jx processors, the registers are always saved in the on-chip local register cache at this time.
3. The frame pointer (g15) for the calling procedure is stored in the current stack's PFP register (r0). The return type field in the PFP register is set according to the call type which is performed. See section 7.8, "RETURNS" (pg. 7-20).
4. For a local or system-local call, new stack frame is allocated by using the stack pointer value saved in step 2. This value is first rounded to the next 16-byte boundary to create a new frame pointer, then stored in the FP register. Next, 64 bytes are added to create the new frame's register save area. This value is stored in the SP register.

For an interrupt call from user mode, the interrupt stack pointer is used instead of the value saved in step 2.

For a system-supervisor call from user mode, the Supervisor Stack Pointer (SSP) is used as a base instead of the value saved in step 2.

5. The instruction pointer is loaded with the address of the first instruction in the called procedure. The processor gets the new instruction pointer from the **call**, the system procedure table, the interrupt table or the fault table, depending on the type of call executed.

Upon completion of these steps, the processor begins executing the called procedure. Sometime before a return or nested call, the local register set is bound to the allocated stack frame.

### 7.1.3.2 Binding of the local register set to the allocated stack frame

The time at which the local register set is actually bound to its save area in the allocated stack frame may vary across implementations. Some implementations may perform the binding at activation time during the call; others may perform the binding only when necessary, such as before processing an explicit/implicit call from the activated procedure itself. This is only a

problem when an activated procedure attempts to change its own FP; in this case it is unpredictable where the register set is actually saved. However, there are only two possibilities for the result: the register set must be saved at the new or at the old address.

The following code illustrates the case:

```
routine1:      # Suppose fp = frameA by definition of the
               # current frame.
               lda     frameB, fp
               call   routine2

routine2:      flushreg
               # Where did the previous local register set get
               # saved? It may have been saved starting at
               # address frameA or frameB depending on the
               # implementation.
```

The stack itself (the stack frame without the register save area) does not encounter this problem, since its binding is immediate. The previous example is modified below to illustrate the point:

```
routine1:      # suppose fp = frameA by definition of the
               # current frame
               # sp = frameA+64
               lda     frameB, fp
               st     data1, sp# place data1 on stack

routine2:      flushreg
               ld     frameA+64, data2
               # data1 = data2 in all cases
```

Modification of FP should be done inside a called procedure, through the use of PFP, as described in section 7.2, “MODIFYING THE PFP REGISTER” (pg. 7-13).

## PROCEDURE CALLS

### 7.1.3.3 Return Operation

A return from any call type — explicit or implicit — is always initiated with a `return (ret)` instruction. On a return, the processor performs these operations:

1. The current stack frame and local registers are deallocated by loading the FP register with the value of the PFP register.
2. The local registers for the return target procedure are retrieved. The registers are usually read from the local register cache; however, in some cases, these registers have been flushed from register cache to memory and must be read directly from the save area in the stack frame.
3. The processor sets the instruction pointer to the value of the RIP register.

Upon completion of these steps, the processor executes the procedure to which it returns. The frames created before the `ret` instruction was executed will be overwritten by later implicit or explicit call operations.

### 7.1.4 Caching of Local Register Sets

Actual implementations of the i960 architecture may cache some number of local register sets within the processor to improve performance. Local registers are typically saved and restored from the local register cache when calls and returns are executed. Other overhead associated with a call or return is performed in parallel with this data movement.

When the number of nested procedures exceeds local register cache size, local register sets must at times be saved to (and restored from) their associated save areas in the procedure stack. Because these operations require access to external memory, this local cache miss impacts call and return performance.

When a call is made and no frames are available in the register cache, a register set in the cache must be saved to external memory to make room for the current set of local registers in the cache (see section 4.2, “LOCAL REGISTER CACHE” (pg. 4-2)). This action is referred to as a frame spill. The oldest set of local registers stored in the cache is spilled to the associated local register save area in the procedure stack. Figure 7-2 illustrates a call operation with and without a frame spill.

Similarly, when a return is made and the local register set for the target procedure is not available in the cache, these local registers must be retrieved from the procedure stack in memory. This operation is referred to as a frame fill. Figure 7-3 illustrates return operations with and without frame fills.

The instruction **flushreg**, described in section 6.2.30, “flushreg” (pg. 6-55), is provided to write all local register sets (except the current one) to their associated stack frames in memory. The register cache is then invalidated, meaning that all flushed register sets are restored from their save areas in memory.

For most programs, the existence of the multiple local register sets and their saving/restoring in the stack frames should be transparent. However, some cases where it may not be apparent follow.

- Without executing **flushreg** first, a store to memory does not necessarily update a local register set.
- Without executing **flushreg** first, reading from memory does not necessarily return the current value of a local register set.
- There is no mechanism, including **flushreg**, to access the current local register set with a read or write to memory.
- **flushreg** must be executed sometime before returning from the current frame if the current procedure modifies the PFP in register r0, or else the behavior of the **ret** instruction is not predictable.
- The values of the local registers r2 to r15 in a new frame are undefined.

**flushreg** is commonly used in debuggers or fault handlers to gain access to all saved local registers. In this way, call history may be traced back through nested procedures.

#### 7.1.4.1 Reserving Local Register Sets for High Priority Interrupts

To decrease interrupt latency for high priority interrupts (interrupted state and process priority greater than or equal to 28), software can limit the number of frames available to all remaining code. This includes code that is either in the executing state (non-interrupted) or code that is in the interrupted state, but, has a process priority less than 28. For the purposes of discussion here, this remaining code will be referred to as *non-critical code*. Specifying a limit for non-critical code, ensures that some number of free frames are available to high-priority interrupt service routines. Software can specify the limit for non-critical code by writing bits 10 through 8 of the register cache configuration word in the PRCB (see Figure 11-6 on page 11-16). The value indicates how many frames within the register cache may be used by non-critical code before a frame needs to be flushed to external memory. The programmed limit is used only when a frame is pushed, which occurs only for an implicit or explicit call.

Allowed values of the programmed limit range from 0 to 7. Setting the value to 7 reserves no frames for high-priority interrupts. Setting the value to 0 causes the register cache to become disabled for non-critical code.

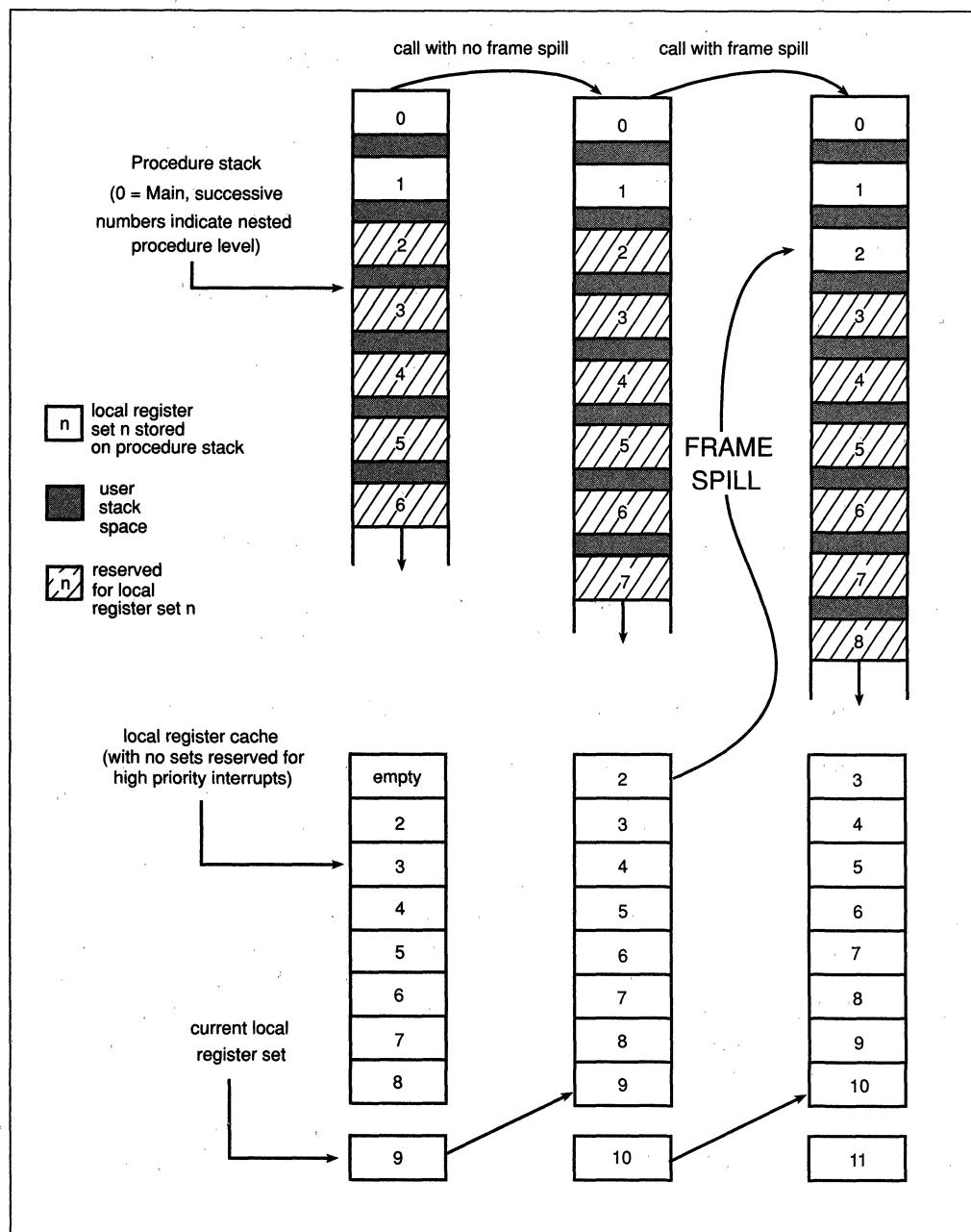


Figure 7-2. Frame Spill

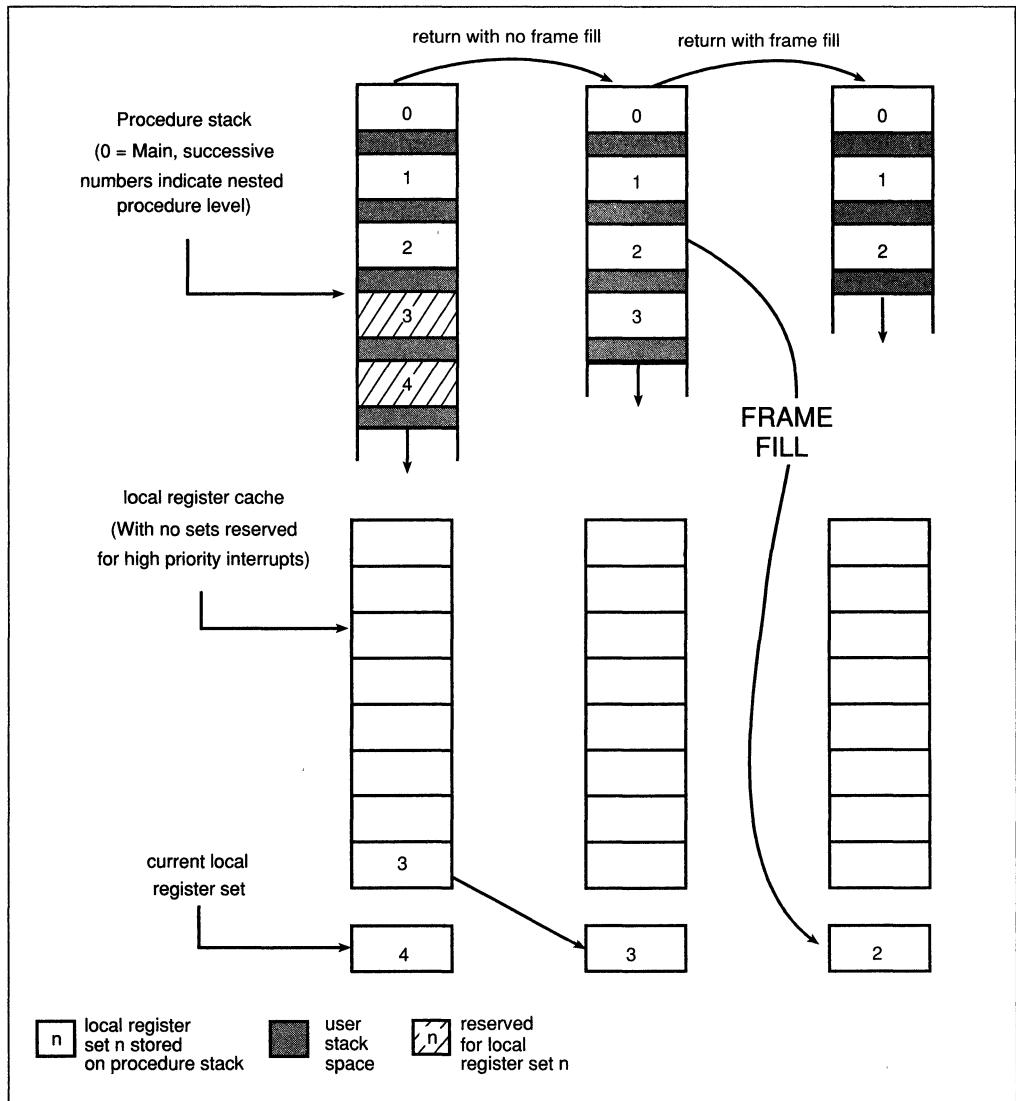


Figure 7-3. Frame Fill

## PROCEDURE CALLS

### 7.2 MODIFYING THE PFP REGISTER

Modification of the PFP is typically for context switches; as part of the switch, the active procedure changes the pointer to the frame that it will return to (previous frame pointer -- PFP). Great care should be taken in modifying the PFP. In the general case, a flushreg must be issued before and after modifying the PFP when the local register cache is enabled. See Example 7-1.

#### Example 7-1. Modifying the PFP

```
# Do a context switch.  
# Assume PFP = 0x5002.  
flushreg          # Flush Frames to correct address.  
lda 0x8002,pfp  
flushreg          # Ensure that "ret" gets updated PFP.  
ret
```

These requirements ensure the correct operation of a context switch on all i960 processors in all situations.

The **flushreg** before the modification is necessary to ensure that the frame of the previous context (mapped to 0x5000 in the example) is “spilled” to the proper external memory address and removed from the local register cache. If the **flushreg** before the modification was omitted, a **flushreg** (or implicit frame spill due to an interrupt) after the modification of PFP would cause the frame of the previous context to be written to the wrong location in external memory.

The **flushreg** after the modification ensures that outstanding results are completely written to the PFP before a subsequent **ret** instruction can be executed. Recall that the **ret** instruction uses the low-order 4-bits of the PFP to select which **ret** function to perform. Requiring the **flushreg** after the PFP modification allows an i960 implementation to implement a simple mechanism that quickly selects the **ret** function at the time the **ret** instruction is issued and provides a faster return operation.

Note the **flushreg** after the modification will execute very quickly because the local register cache has already been flushed by the **flushreg** before; only synchronization of the PFP will be performed. i960 implementations may provide other mechanisms to ensure PFP synchronization in addition to **flushreg**, but, a **flushreg** after a PFP modification is ensured to work on all i960 processors.

### 7.3 PARAMETER PASSING

Parameters are passed between procedures in two ways:

- |                  |   |
|------------------|---|
| <i>value</i>     | Parameters are passed directly to the calling procedure as part of the call and return mechanism. This is the fastest method of passing parameters. |
| <i>reference</i> | Parameters are stored in an argument list in memory and a pointer to the argument list is passed in a global register.                              |

When passing parameters by value, the calling procedure stores the parameters to be passed in global registers. Since the calling procedure and the called procedure share the global registers, the called procedure has direct access to the parameters after the call.

When a procedure needs to pass more parameters than will fit in the global registers, they can be passed by reference. Here, parameters are placed in an argument list and a pointer to the argument list is placed in a global register.

The argument list can be stored anywhere in memory; however, a convenient place to store an argument list is in the stack for a calling procedure. Space for the argument list is created by incrementing the SP register value. If the argument list is stored in the current stack, the argument list is automatically deallocated when no longer needed.

A procedure receives parameters from — and returns values to — other calling procedures. To do this successfully and consistently, all procedures must agree on the use of the global registers.

Parameter registers pass values into a function. Up to 12 parameters can be passed by value using the global registers. If the number of parameters exceeds 12, additional parameters are passed using the calling procedure's stack; a pointer to the argument list is passed in a pre-designated register. Similarly, several registers are set aside for return arguments and a return argument block pointer is defined to point to additional parameters. If the number of return arguments exceeds the available number of return argument registers, the calling procedure passes a pointer to an argument list on its stack where the remaining return values will be placed. Example 7-2 illustrates parameter passing by value and reference.

## PROCEDURE CALLS

Local registers are automatically saved when a call is made. Because of the local register cache, they are saved quickly and with no external bus traffic. The efficiency of the local register mechanism plays an important role in two cases when calls are made:

1. When a procedure is called which contains other calls, global parameter registers should be moved to working local registers at the beginning of the procedure. In this way, parameter registers are freed and nested calls are easily managed. The register move instruction necessary to perform this action is very fast; the working parameters — now in local registers — are saved efficiently when nested calls are made.
2. When other procedures are nested within an interrupt or fault procedure, the procedure must preserve all normally non-preserved parameter registers, such as the global registers. This is necessary because the interrupt or fault occurs at any point in the user's program and a return from an interrupt or fault must restore the exact processor state. The interrupt or fault procedure can move non-preserved global registers to local registers before the nested call.

### Example 7-2. Parameter Passing Code Example

```
# Example of parameter passing . . .
# C-source:    int a,b[10];
#                  a = proc1(a,1,'x',&b[0]);
#                  assembles to ...
#      mov      r3,g0          # value of a
#      ldconst  1,g1          # value of 1
#      ldconst  120,g2         # value of "x"
#      lda     0x40(fp),g3      # reference to b[10]
#      call    _proc1
#      mov      g0,r3          #save return value in "a"
#
#      .
#      .

_proc1:
#      movq    g0,r4          # save parameters
#
#      .
#                  # other instructions in procedure
#                  # and nested calls
#
#      mov      r3,g0          # load return parameter
#      ret
```

## 7.4 LOCAL CALLS

A local call does not cause a stack switch. A local call can be made two ways:

- with the **call** and **callx** instructions; or
- with a system-local call as described in section 7.5, “SYSTEM CALLS” (pg. 7-16).

**call** specifies the address of the called procedures as the IP plus a signed, 24-bit displacement (i.e., - $2^{23}$  to  $2^{23} - 4$ ). **callx** allows any of the addressing modes to be used to specify the procedure address. The IP-with-displacement addressing mode allows full 32-bit IP-relative addressing.

When a local call is made with a **call** or **callx**, the processor performs the same operation as described in section 7.1.3.1, “Call Operation” (pg. 7-7). The target IP for the call is derived from the instruction’s operands and the new stack frame is allocated on the current stack.

## 7.5 SYSTEM CALLS

A system call is a call made via the system procedure table. It can be used to make a system-local call — similar to a local call made with **call** and **callx** in the sense that there is no stack nor mode switch — or a system supervisor call. A system call is initiated with **calls**, which requires a procedure number operand. The procedure number provides an index into the system procedure table, where the processor finds IPs for specific procedures.

Using an i960 processor language assembler, a system procedure is directly declared using the **.sysproc** directive. At link time, the optimized call directive, **callj**, is replaced with a **calls** when a system procedure target is specified. (Refer to current i960 processor assembler documentation for a description of the **.sysproc** and **callj** directives.)

The system call mechanism offers two benefits. First, it supports application software portability. System calls are commonly used to call kernel services. By calling these services with a procedure number rather than a specific IP, applications software does not need to be changed each time the implementation of the kernel services is modified. Only the entries in the system procedure table must be changed. Second, the ability to switch to a different execution mode and stack with a system supervisor call allows kernel procedures and data to be insulated from applications code. This benefit is further described in section 3.7, “USER SUPERVISOR PROTECTION MODEL” (pg. 3-22).

### 7.5.1 System Procedure Table

The system procedure table is a data structure for storing IPs to system procedures. These can be procedures which software can access through (1) a system call or (2) the fault handling mechanism. Using the system procedure table to store IPs for fault handling is described in section 9.1, “FAULT HANDLING FACILITIES OVERVIEW” (pg. 9-1).

Figure 7-4 shows the system procedure table structure. It is 1088 bytes in length and can have up to 260 procedure entries. At initialization, the processor caches a pointer to the system procedure table. This pointer is located in the PRCB. The following subsections describe this table’s fields.

## PROCEDURE CALLS

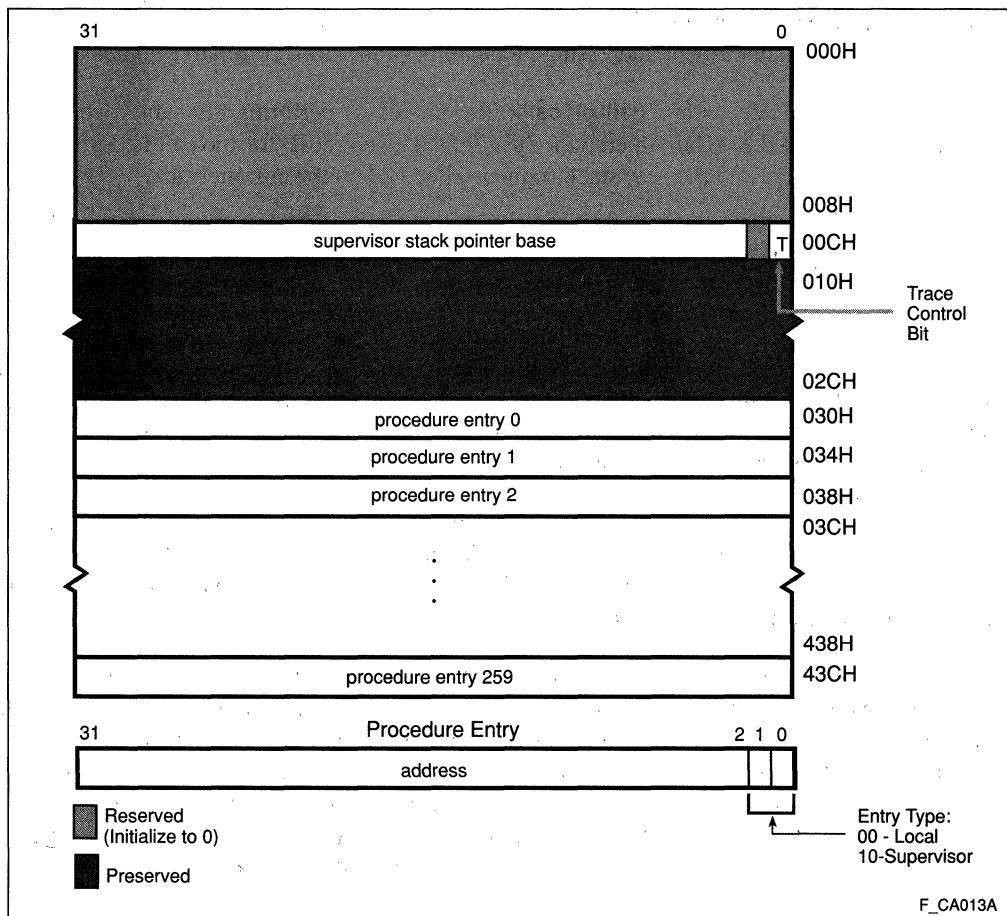


Figure 7-4. System Procedure Table

### 7.5.1.1 Procedure Entries

A procedure entry in the system procedure table specifies a procedure's location and type. Each entry is one word in length and consists of an address (IP) field and a type field. The address field gives the address of the first instruction of the target procedure. Since all instructions are word aligned, only the entry's 30 most significant bits are used for the address. The entry's two least-significant bits specify entry type. The procedure entry type field indicates call type: system-local call or system-supervisor call (Table 7-1). On a system call, the processor performs different actions depending on the type of call selected.

**Table 7-1. Encodings of Entry Type Field in System Procedure Table**

| Encoding  | Call Type              |
|---|------------------------|
| 00  | System-Local Call      |
| 01  | Reserved <sup>1</sup>  |
| 10  | System-Supervisor Call |
| 11  | Reserved <sup>1</sup>  |
| 1. Calls with reserved entry types have unpredictable behavior. |                        |

### 7.5.1.2 Supervisor Stack Pointer

When a system-supervisor call is made, the processor switches to a new stack called the *supervisor stack*, if not already in supervisor mode. The processor gets a pointer to this stack from the supervisor stack pointer field in the system procedure table (Figure 7-4) during the reset initialization sequence and caches the pointer internally. Only the 30 most significant bits of the supervisor stack pointer are given. The processor aligns this value to the next 16 byte boundary to determine the first byte of the new stack frame.

### 7.5.1.3 Trace Control Bit

The trace control bit (byte 12, bit 0) specifies the new value of the trace enable bit in the PC register (PC.te) when a system-supervisor call causes a switch from user mode to supervisor mode. Setting this bit to 1 enables tracing in the supervisor mode; setting it to 0 disables tracing. The use of this bit is described in section 10.1.2, “PC Trace Enable Bit and Trace-Fault-Pending Flag” (pg. 10-3).

### 7.5.2 System Call to a Local Procedure

When a **calls** instruction references an entry in the system procedure table with an entry type of 00, the processor executes a system-local call to the selected procedure. The action that the processor performs is the same as described in section 7.1.3.1, “Call Operation” (pg. 7-7). The call’s target IP is taken from the system procedure table and the new stack frame is allocated on the current stack, and the processor does not switch to supervisor mode. The **calls** algorithm is described in section 6.2.14, “calls” (pg. 6-26).

### 7.5.3 System Call to a Supervisor Procedure

When a **calls** instruction references an entry in the system procedure table with an entry type of 10<sub>2</sub>, the processor executes a system-supervisor call to the selected procedure. The call’s target IP is taken from the system procedure table.

## PROCEDURE CALLS

The processor performs the same action as described in section 7.1.3.1, “Call Operation” (pg. 7-7), with the following exceptions:

- If the processor is in user mode, it switches to supervisor mode.
- If a mode switch occurs, SP is read from the Supervisor Stack Pointer (SSP) base. A new frame for the called procedure is placed at the location pointed to after alignment of SP.
- If no mode switch occurs, the new frame is allocated on the current stack.
- If a mode switch occurs, the state of the trace enable bit in the PC register is saved in the return type field in the PFP register. The trace enable bit is then loaded from the trace control bit in the system procedure table.
- If no mode switch occurs, the value  $000_2$  (**calls** instruction) or  $001_2$  (fault call) is saved in the return type field of the pfp register.

When the processor switches to supervisor mode, it remains in that mode and creates new frames on the supervisor stack until a return is performed from the procedure that caused the original switch to supervisor mode. While in supervisor mode, either the local call instructions (**call** and **callx**) or **calls** can be used to call procedures.

The user-supervisor protection model and its relationship to the supervisor call are described in section 3.7, “USER SUPERVISOR PROTECTION MODEL” (pg. 3-22).

## 7.6 USER AND SUPERVISOR STACKS

When using the user-supervisor protection mechanism, the processor maintains separate stacks in the address space. One of these stacks — the user stack — is for procedures executed in user mode; the other stack — the supervisor stack — is for procedures executed in supervisor mode.

The user and supervisor stacks are identical in structure (Figure 7-1). The base stack pointer for the supervisor stack is automatically read from the system procedure table and cached internally during initialization. Each time a user-to-supervisor mode switch occurs, the cached supervisor stack pointer base is used for the starting point of the new supervisor stack. The base stack pointer for the user stack is usually created in the initialization code. See section 11.2, “INITIALIZATION” (pg. 11-2). The base stack pointers must be aligned to a 16-byte boundary; otherwise, the first frame pointer on the interrupt stack is rounded up to the previous 16-byte boundary.

## 7.7 INTERRUPT AND FAULT CALLS

The architecture defines two types of implicit calls that make use of the call and return mechanism: interrupt handling procedure calls and fault handling procedure calls. A call to an interrupt procedure is similar to a system-supervisor call. Here, the processor obtains pointers to the interrupt procedures through the interrupt table. The processor always switches to supervisor mode on an interrupt procedure call.

A call to a fault procedure is similar to a system call. Fault procedure calls can be local calls or supervisor calls. The processor obtains pointers to fault procedures through the fault table and (optionally) through the system procedure table.

When a fault call or interrupt call is made, a fault record or interrupt record is placed in the newly generated stack frame for the call. These records hold the machine state and information to identify the fault or interrupt. When a return from an interrupt or fault is executed, machine state is restored from these records. See CHAPTER 9, FAULTS for more information on the structure of the fault and interrupt records.

## 7.8 RETURNS

The return (**ret**) instruction provides a generalized return mechanism that can be used to return from any procedure that was entered by **call**, **calls**, **callx**, an interrupt call or a fault call. When **ret** executes, the processor uses the information from the return-type field in the PFP register (Figure 7-5) to determine the type of return action to take.

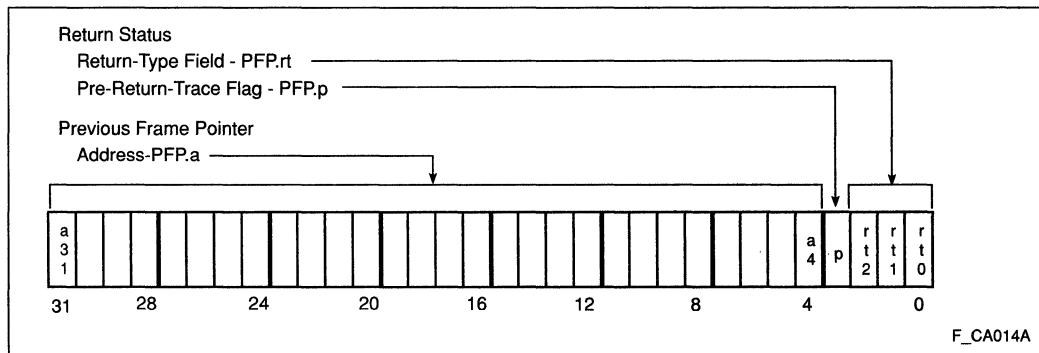


Figure 7-5. Previous Frame Pointer Register (PFP) (r0)

*return-type field* indicates the type of call which was made. Table 7-2 shows the return-type field encoding for the various calls: local, supervisor, interrupt and fault.

## PROCEDURE CALLS



*trace-on-return flag* (PFP.rt0 or bit 0 of the return-type field) stores the trace enable bit value when a system-supervisor call is made from user mode. When the call is made, the PC register trace enable bit is saved as the trace-on-return flag and then replaced by the trace controls bit in the system procedure table. On a return, the trace enable bit's original value is restored. This mechanism allows instruction tracing to be turned on or off when a supervisor mode switch occurs. See section 10.5.2.3, "Tracing on Return from Explicit Call" (pg. 10-14).

*prereturn-trace flag* (PFP.p) is used in conjunction with call-trace and prereturn-trace modes. If call-trace mode is enabled when a call is made, the processor sets the prereturn-trace flag; otherwise it clears the flag. Then, if this flag is set and prereturn-trace mode is enabled, a prereturn trace event is generated on a return, before any actions associated with the return operation are performed. See section 10.2, "TRACE MODES" (pg. 10-3) for a discussion of interaction between call-trace and prereturn-trace modes with the prereturn-trace flag.

**Table 7-2. Encoding of Return Status Field**

| Return Status Field | Call Type   | Return Action   |
|---------------------|---|---|
| 000                 | Local call<br>(system-local call or system-supervisor call made from supervisor mode) | Local return<br>(return to local stack; no mode switch)   |
| 001                 | Fault call  | Fault return  |
| 01t                 | System-supervisor from user mode  | Supervisor return<br>(return to user stack, mode switch to user mode, trace enable bit is replaced with the t bit stored in the PFP register on the call) |
| 100                 | reserved <sup>1</sup>   |   |
| 101                 | reserved <sup>1</sup>   |   |
| 110                 | reserved <sup>1</sup>   |   |
| 111                 | Interrupt call  | Interrupt return  |

**NOTE:** "t" denotes the trace-on-return flag; used only for system supervisor calls which cause a user-to-supervisor mode switch.

1. This return type results in unpredictable behavior.

## 7.9 BRANCH-AND-LINK

A branch-and-link is executed using either the branch-and-link instruction (**bal**) or branch-and-link-extended instruction (**balx**). When either instruction executes, the processor branches to the first instruction of the called procedure (the target instruction), while saving a return IP for the calling procedure in a register. The called procedure uses the same set of local registers and stack frame as the calling procedure:

- For **bal**, the return IP is automatically saved in global register g14
- For **balx**, the return IP instruction is saved in a register specified by one of the instruction's operands

A return from a branch-and-link is generally carried out with a **bx** (branch extended) instruction, where the branch target is the address saved with the branch-and-link instruction. The branch-and-link method of making procedure calls is recommended for calls to leaf procedures. Leaf procedures typically call no other procedures. Branch-and-link is the fastest way to make a call, providing the calling procedure does not require its own registers or stack frame.





8

## INTERRUPTS



# CHAPTER 8

## INTERRUPTS

This chapter describes how a programmer uses the processor's interrupt mechanism, defines data structures used for interrupt handling and describes actions that the processor takes when handling an interrupt.

CHAPTER 13, INTERRUPT CONTROLLER describes the hardware mechanism for signaling and posting interrupts.

### 8.1 OVERVIEW

An interrupt is an event that causes a temporary break in program execution so the processor can handle another chore. Interrupts commonly request I/O services or synchronize the processor with some external hardware activity. For interrupt handler portability across the i960® processor family implementations, the architecture defines a consistent interrupt state and interrupt-priority-handling mechanism. To manage and prioritize interrupt requests in parallel with processor execution, the i960 Jx processor provides an on-chip programmable interrupt controller.

Requests for interrupt service come from many sources. These requests are prioritized so that instruction execution is redirected only if an interrupt request is of higher priority than that of the executing task.

When the processor is redirected to service an interrupt, it uses a vector number that accompanies the interrupt request to locate the vector entry in the interrupt table. From that entry, it gets an address to the first instruction of the selected interrupt procedure. The processor then makes an implicit call to that procedure.

When the interrupt call is made, the processor uses a dedicated interrupt stack. A new frame is created for the interrupt on this stack and a new set of local registers is allocated to the interrupt procedure. The interrupted program's current state is also saved.

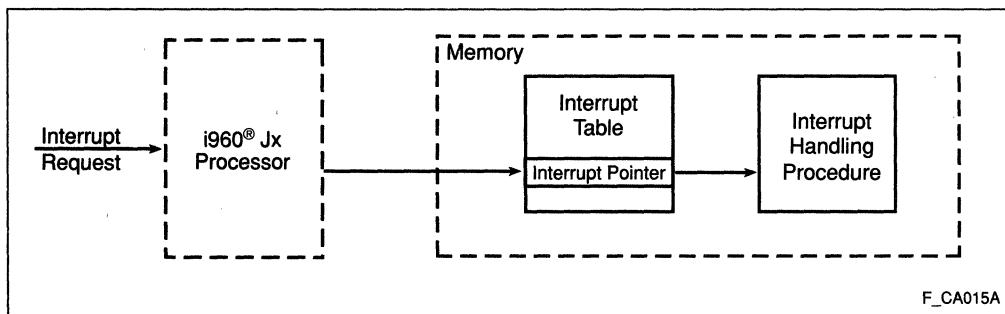
Upon return from the interrupt procedure, the processor restores the interrupted program's state, switches back to the stack that the processor was using prior to the interrupt and resumes program execution.

Since interrupts are handled based on priority, requested interrupts are often saved for later service rather than being handled immediately. The mechanism for saving the interrupt is referred to as interrupt posting. The mechanism the i960 Jx processor uses for posting interrupts is described in section 13.2, "MANAGING INTERRUPT REQUESTS" (pg. 13-2).

## INTERRUPTS

On the i960 Jx processor, interrupt requests may originate from external hardware sources, internal timer unit sources or from software. External interrupts are detected with the chip's 8-bit interrupt port and with a dedicated NMI input. Interrupt requests originate from software by the **sysctl** instruction which signals interrupts. To manage and prioritize all possible interrupts, the processor integrates an on-chip programmable interrupt controller. Integrated interrupt controller configuration and operation is described in CHAPTER 13, INTERRUPT CONTROLLER.

The i960 architecture defines two data structures to support interrupt processing: the interrupt table and interrupt stack (see Figure 8-1). The interrupt table contains 248 vectors for interrupt handling procedures (eight of which are reserved) and an area for posting software requested interrupts. The interrupt stack prevents interrupt handling procedures from overwriting the stack in use by the application program. It also allows the interrupt stack to be located in a different area of memory than the user and supervisor stack (fast SRAM, for example).



**Figure 8-1. Interrupt Handling Data Structures**

## 8.2 SOFTWARE REQUIREMENTS FOR INTERRUPT HANDLING

To use the processor's interrupt handling facilities, user software must provide the following items in memory:

- Interrupt Table
- Interrupt Handler Routines
- Interrupt Stack

These items are established in memory as part of the initialization procedure. Once these items are present in memory and pointers to them have been entered in the appropriate system data structures, the processor handles interrupts automatically and independently from software.

### 8.3 INTERRUPT PRIORITY

Each interrupt procedure pointer is eight bits in length, which allows up to 241 unique procedure pointers to be defined. Each procedure pointer's priority is defined by dividing the procedure pointer number by eight. Thus, at each priority level, there are eight possible procedure pointers (e.g., procedure pointers 8 through 15 have a priority of 1 and procedure pointers 246 through 255 have a priority of 31). Procedure pointers 0 through 7 cannot be used. Since 0 priority is the lowest priority, a priority-0 interrupt will never successfully stop execution of a program of any priority.

The processor compares its current priority with the interrupt request priority to determine whether to service the interrupt immediately or to delay service. The interrupt is serviced immediately if the interrupt request priority is higher than the processor's current priority (the priority of the program or interrupt the processor is executing). If the interrupt priority is less than or equal to the processor's current priority, the processor does not service the request but rather posts it as a pending interrupt. When multiple interrupt requests are pending at the same priority level, the request with the highest vector number is serviced first.

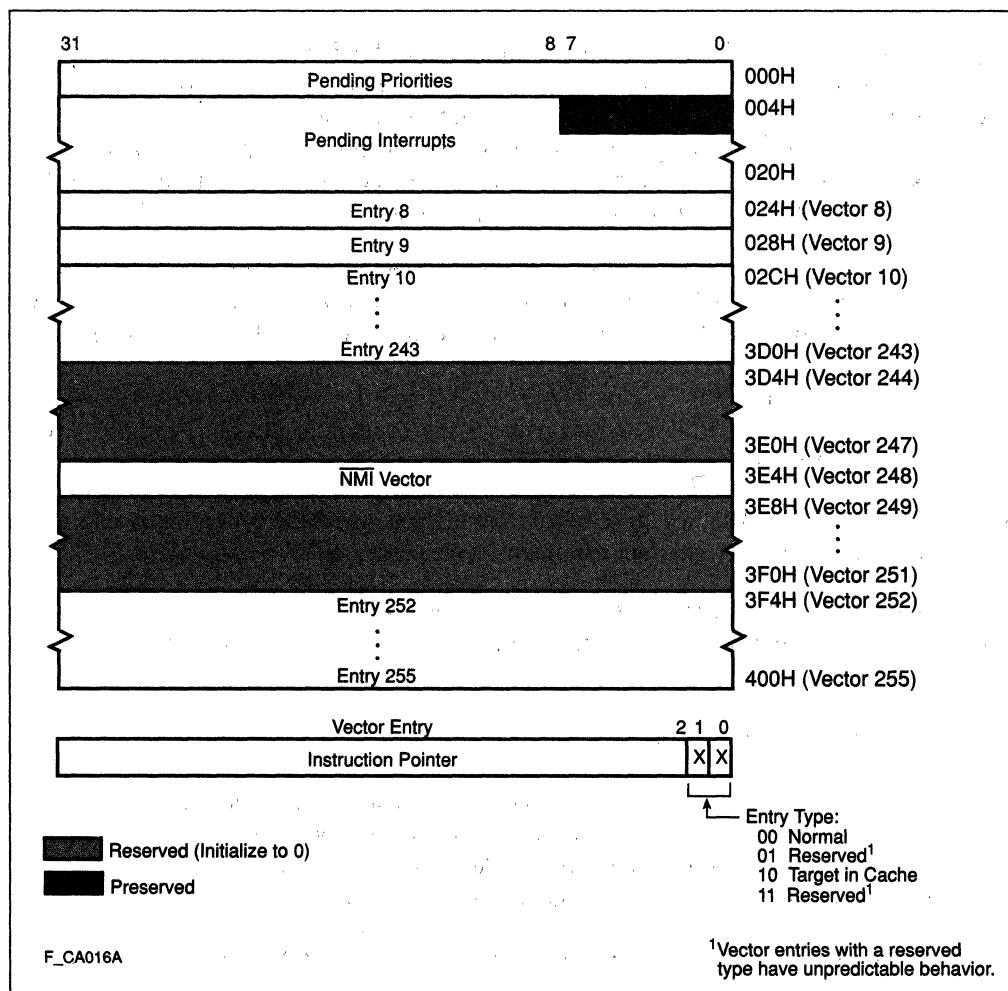
Priority-31 interrupts are handled as a special case. Even when the processor is executing at priority level 31, a priority-31 interrupt will interrupt the processor.

The processor may post requests for later servicing. Interrupts waiting to be serviced — called pending interrupts — are discussed in section 8.4.2, "Pending Interrupts" (pg. 8-5).

### 8.4 INTERRUPT TABLE

The interrupt table (Figure 8-2), 1028 bytes in length, can be located anywhere in the non-reserved address space. It must be aligned on a word boundary. The processor reads a pointer to interrupt table byte 0 during initialization. The interrupt table must be located in RAM since the processor must be able to read and write the table's pending interrupt section.

The interrupt table is divided into two sections: vector entries and pending interrupts. Each are described in the subsections that follow.



**Figure 8-2. Interrupt Table**

## **8.4.1 Vector Entries**

A vector entry contains a specific interrupt handler's address. When an interrupt is serviced, the processor branches to the address specified by the vector entry.

Each interrupt is associated with an 8-bit vector number which points to a vector entry in the interrupt table. The vector entry section contains 248 one-word entries. Vector numbers 8 through 243 and 252 through 255 and their associated vector entries are used for conventional interrupts. Vector number 248 is the NMI vector. Vector numbers 244 - 247 and 249 - 251 are reserved. Vector numbers 0 through 7 cannot be used.

Vector entry structure is given at the bottom of Figure 8-2. Each interrupt procedure must begin on a word boundary, so the processor assumes that the vector's two least significant bits are 0.

#### 8.4.2 Pending Interrupts

The pending interrupts section comprises the interrupt table's first 36 bytes, divided into two fields: pending priorities (byte offset 0 through 3) and pending interrupts (4 through 35).

Each of the 32 bits in the pending priorities field indicate an interrupt priority. When the processor posts a pending interrupt in the interrupt table, the bit corresponding to the interrupt's priority is set. For example, if an interrupt with a priority of 10 is posted in the interrupt table, bit 10 is set.

Each of the pending interrupts field's 256 bits represent an interrupt procedure pointer. Byte offset 5 is for vectors 8 through 15, byte offset 6 is for vectors 16 through 23, and so on. Byte offset 4, the first byte of the pending interrupts field, is reserved. When an interrupt is posted, its corresponding bit in the pending interrupt field is set.

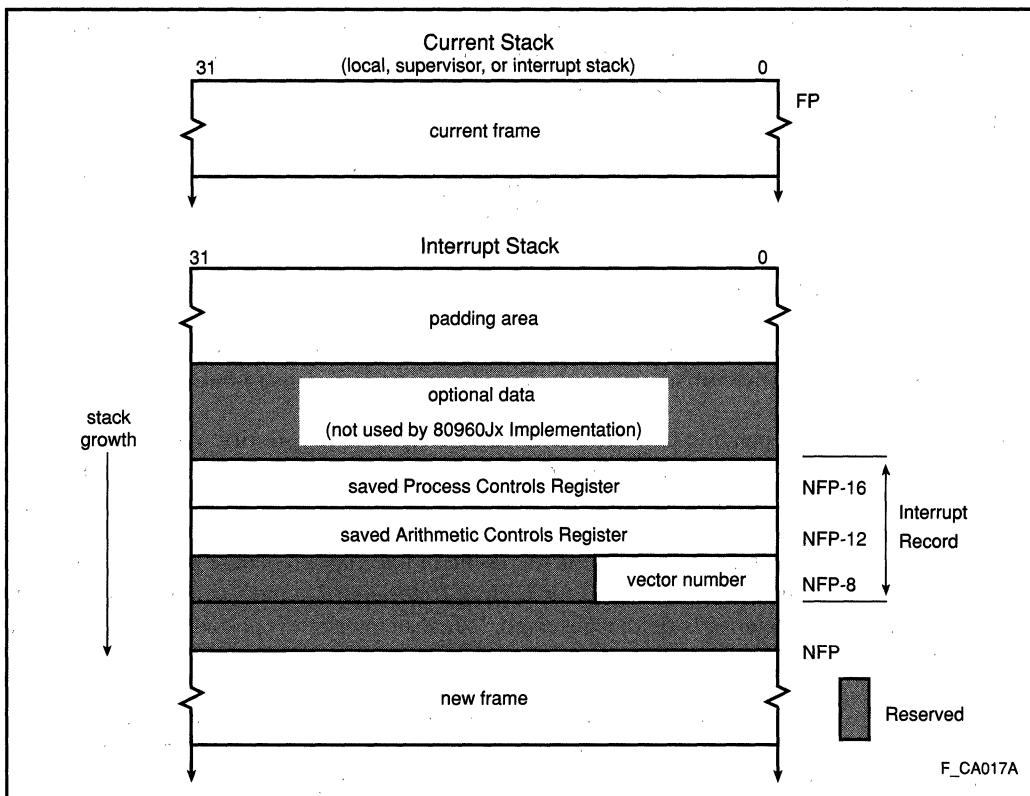
This encoding of the pending priority and pending interrupt fields permits the processor to first check if there are any pending interrupts with a priority greater than the current program and then determine the vector number of the interrupt with the highest priority.

#### 8.5 INTERRUPT STACK AND INTERRUPT RECORD

The interrupt stack can be located anywhere in the non-reserved address space. The processor obtains a pointer to the base of the stack during initialization. The interrupt stack has the same structure as the local procedure stack described in section 7.1.1, "Local Registers and the Procedure Stack" (pg. 7-2). As with the local stack, the interrupt stack grows from lower addresses to higher addresses.

The processor saves the state of an interrupted program — or an interrupted interrupt procedure — in a record on the interrupt stack. Figure 8-3 shows the structure of this interrupt record.

The interrupt record is always stored on the interrupt stack adjacent to the new frame that is created for the interrupt handling procedure. It includes the state of the AC and PC registers at the time the interrupt was received and the interrupt procedure pointer number used. Referenced to the new frame pointer address (designated NFP), the saved AC register is located at address NFP-12; the saved PC register is located at address NFP-16.



**Figure 8-3. Storage of an Interrupt Record on the Interrupt Stack**

## **8.6 INTERRUPT SERVICE ROUTINES**

An interrupt handling procedure performs a specific action that is associated with a particular interrupt procedure pointer. For example, one interrupt handler task might be to initiate a timer unit request. The interrupt handler procedures can be located anywhere in the non-reserved address space. Since instructions in the i960 processor family architecture must be word aligned, each procedure must begin on a word boundary.

When an interrupt handling procedure is called, the processor allocates a new frame on the interrupt stack and a set of local registers for the procedure. If not already in supervisor mode, the processor always switches to supervisor mode while an interrupt is being handled. It also saves the states of the AC and PC registers for the interrupted program.

The interrupt procedure shares the remainder of the execution environment resources (namely the global registers and the address space) with the interrupted program. Thus, interrupt procedures must preserve and restore the state of any resources shared with a non-cooperating program. Interrupt procedures must preserve and restore the state of any resources shared with a non-cooperating program.

For example, an interrupt procedure which uses a global register which is not permanently allocated to it should save the register's contents before it uses the register and restore the contents before returning from the interrupt handler.

To reduce interrupt latency to critical interrupt routines, interrupt handlers may be locked into the instruction cache. See section 13.5.2.2, "Caching Interrupt Routines and Reserving Register Frames" (pg. 13-23) for a complete description.

## 8.7 INTERRUPT CONTEXT SWITCH

When the processor services an interrupt, it automatically saves the interrupted program state or interrupt procedure and calls the interrupt handling procedure associated with the new interrupt request. When the interrupt handler completes, the processor automatically restores the interrupted program state.

The method that the processor uses to service an interrupt depends on the processor state when the interrupt is received. If the processor is executing a background task when an interrupt request is to be serviced, the interrupt context switch must change stacks to the interrupt stack. This is called an executing-state interrupt. If the processor is already executing an interrupt handler, no stack switch is required since the interrupt stack will already be in use. This is called an interrupted-state interrupt.

The following subsections describe interrupt handling actions for executing-state and interrupted-state interrupts. In both cases, it is assumed that the interrupt priority is higher than that of the processor and thus is serviced immediately when the processor receives it.

## INTERRUPTS

### 8.7.1 Executing-State Interrupt

When the processor receives an interrupt while in the executing state (i.e., executing a program), it performs the following actions to service the interrupt. This procedure is the same regardless of whether the processor is in user or supervisor mode when the interrupt occurs. The processor:

1. switches to the interrupt stack (as shown in Figure 8-3). The interrupt stack pointer becomes the new stack pointer for the processor.
2. saves the current state of process controls and arithmetic controls in an interrupt record on the interrupt stack. The processor also saves the interrupt procedure pointer number.
3. allocates a new frame on the interrupt stack and loads the new frame pointer (NFP) in global register g15.
4. switches to the interrupted state.
5. sets the state flag in its internal process controls to interrupted, its execution mode to supervisor and its priority to the priority of the interrupt. Setting the processor's priority to that of the interrupt ensures that lower priority interrupts cannot interrupt the servicing of the current interrupt.
6. clears the trace-enable flag in its internal process controls. Clearing these flags allows the interrupt to be handled without trace faults being raised.
7. sets the frame return status field (associated with the PFP in register r0) to  $111_2$ .
8. performs a call operation as described in CHAPTER 7, PROCEDURE CALLS. The address for the called procedure is specified in the interrupt table for the specified interrupt procedure pointer.

Once the processor completes the interrupt procedure, it performs the following return actions:

1. copies the arithmetic controls field and the process controls field from the interrupt record into the arithmetic controls register and process controls, respectively. It also returns the trace-enable bit to its value before the interrupt occurred.
2. deallocates the current stack frame and interrupt record from the interrupt stack and switches to the local or supervisor stack (the one it was using when it was interrupted).
3. performs a return operation as described in CHAPTER 7, PROCEDURE CALLS. This causes the processor to switch back to the local or supervisor stack (whichever it was using before the interrupt).
4. switches to the executing state and resumes work on the program, if there are no pending interrupts to be serviced or trace faults to be handled.

### 8.7.2 Interrupted-State Interrupt

If the processor receives an interrupt while it is servicing another interrupt, and the new interrupt has a higher priority than the interrupt currently being serviced, the current interrupt-handler routine is interrupted. Here, the processor performs the same interrupt-servicing action as is described in section 8.7.1, “Executing-State Interrupt” (pg. 8-8) to save the state of the interrupted interrupt-handler routine. The interrupt record is saved on the top of the interrupt stack prior to the new frame that is created for use in servicing the new interrupt.

On the return from the current interrupt handler to the previous interrupt handler, the processor de-allocates the current stack frame and interrupt record, and stays on the interrupt stack.





9

## FAULTS



# CHAPTER 9

## FAULTS

This chapter describes the i960® Jx processor's fault handling facilities. Subjects covered include the fault handling data structures and fault handling mechanism. See section 9.11, "FAULT REFERENCE" (pg. 9-21) for detailed information on each fault type.

### 9.1 FAULT HANDLING FACILITIES OVERVIEW

The i960 processor architecture defines various conditions in code and/or the processor's internal state that could cause the processor to deliver incorrect or inappropriate results or that could cause it to choose an undesirable control path. These are called *fault conditions*. For example the architecture defines faults for divide-by-zero and overflow conditions on integer calculations with an inappropriate operand value.

As shown in Figure 9-1, the architecture defines a fault table, a system procedure table, a set of fault handling procedures and stacks (user stack, supervisor stack, interrupt stack) to handle processor-generated faults.

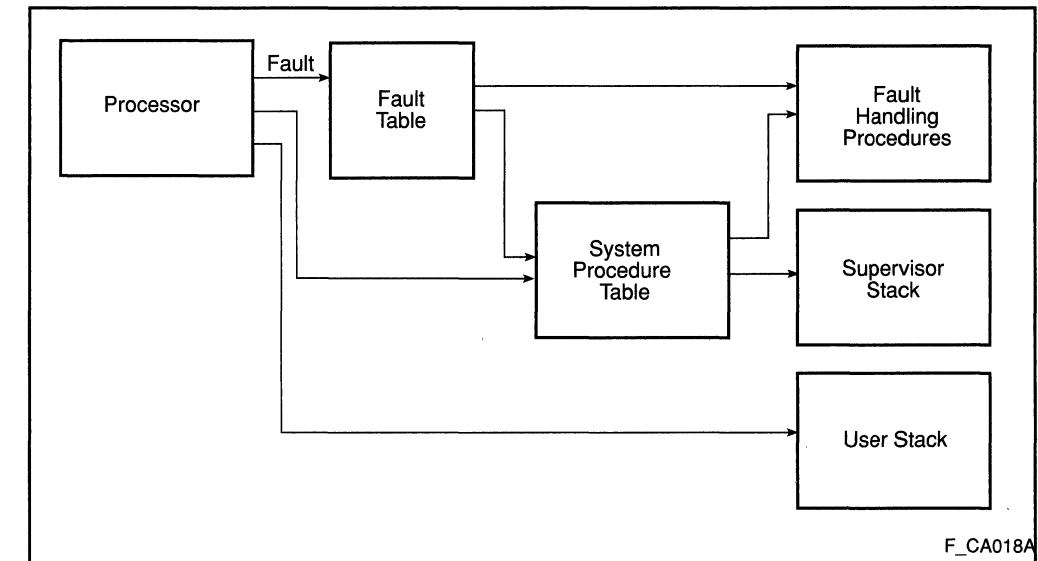


Figure 9-1. Fault-Handling Data Structures

## FAULTS

The fault table contains pointers to fault handling procedures. The system procedure table optionally provides an interface to any fault handling procedure and allows faults to be handled in supervisor mode. Stack frames for fault handling procedures are created on either the user or supervisor stack, depending on the mode in which the fault is handled. While servicing an interrupt, the processor uses the interrupt stack.

Once these data structures and the code for the fault procedures are established in memory, the processor handles faults automatically and independently from application software.

The processor can detect a fault at any time while executing instructions, whether from a program, interrupt handling procedure or fault handling procedure. When a fault occurs, the processor determines the fault type and selects a corresponding fault handling procedure from the fault table. It then invokes the fault handling procedure by means of an implicit call. As described later in this chapter, the fault handler call can be:

- A local call (call-extended operation)
- A system-local call (local call through the system procedure table)
- A system-supervisor call (supervisor call through the system procedure table)

As part of the implicit call to the fault handling procedure, the processor creates a fault record on the stack that the fault handling procedure is using. This record includes information on the fault and the processor's state when the fault was generated.

After the fault record is created, the processor executes the selected fault handling procedure. If a fault is recoverable (i.e., the program can be resumed after handling the fault) the Return Instruction Pointer (RIP) is defined for the fault being serviced (see section 9.11, "FAULT REFERENCE" (pg. 9-21), the processor will resume execution at the RIP upon return from the fault handler. If the RIP is undefined, the fault handling procedure can create one by using the **flushreg** instruction followed by a modification of the RIP in the previous frame. The fault handler can also call a debug monitor or reset the processor instead of resuming prior execution.

This procedure call mechanism also handles faults that occur:

- While the processor is servicing an interrupt
- While the processor is working on another fault handling procedure

## 9.2 FAULT TYPES

The i960 architecture defines a basic set of faults that are categorized by type and subtype. Each fault has a unique type and subtype number. When the processor detects a fault, it records the fault type and subtype numbers in a fault record. It then uses the type number to select a fault handling procedure.

The fault handling procedure can optionally use the subtype number to select a specific fault handling action. The i960 Jx processor recognizes i960 architecture-defined faults and a new fault subtype for detecting unaligned memory accesses. Table 9-1 lists all faults that the i960 Jx processor detects, arranged by type and subtype. Text that follows the table gives column definitions.

**Table 9-1. i960® Jx Processor Fault Types and Subtypes**

| Fault Type |            | Fault Subtype          |                  | Fault Record                                       |
|------------|------------|------------------------|------------------|--|
| Number     | Name       | Number or Bit Position | Name             |  |
| 0H         | OVERRIDE   | NA                     | NA               | See section 9.10.1,<br>"Overrides" (pg. 9-21)      |
| 0H         | PARALLEL   | NA                     | NA               | see section 9.6.4, "Parallel<br>Faults" (pg. 9-11) |
| 1H         | TRACE      | Bit 1                  | INSTRUCTION      | XX01 XX02H   |
|            |            | Bit 2                  | BRANCH           | XX01 XX04H   |
|            |            | Bit 3                  | CALL             | XX01 XX08H   |
|            |            | Bit 4                  | RETURN           | XX01 XX10H   |
|            |            | Bit 5                  | PRERETURN        | XX01 XX20H   |
|            |            | Bit 6                  | SUPERVISOR       | XX01 XX40H   |
|            |            | Bit 7                  | MARK             | XX01 XX80H   |
| 2H         | OPERATION  | 1H                     | INVALID_OPCODE   | XX02 XX01H   |
|            |            | 2H                     | UNIMPLEMENTED    | XX02 XX02H   |
|            |            | 3H                     | UNALIGNED        | XX02 XX03H   |
|            |            | 4H                     | INVALID_OPERAND  | XX02 XX04H   |
| 3H         | ARITHMETIC | 1H                     | INTEGER_OVERFLOW | XX03 XX01H   |
|            |            | 2H                     | ZERO-DIVIDE      | XX03 XX02H   |
| 4H         | Reserved   |                        |                  |  |
| 5H         | CONSTRAINT | 1H                     | RANGE            | XX05 XX01H   |
| 6H         | Reserved   |                        |                  |  |
| 7H         | PROTECTION | Bit 1                  | LENGTH           | XX07 XX01H   |
| 8H - 9H    | Reserved   |                        |                  |  |
| AH         | TYPE       | 1H                     | MISMATCH         | XX0A XX01H   |
| BH - FH    | Reserved   |                        |                  |  |

In Table 9-1:

- The first (left-most) column contains the fault type numbers in hexadecimal.
- The second column shows the fault type name.

## FAULTS

- The third column gives the fault subtype number as either: (1) a hexadecimal number or (2) as a bit position in the fault record's 8-bit fault subtype field. The bit position method of indicating a fault subtype is used for certain faults (such as trace faults) in which two or more fault subtypes may occur simultaneously.
- The fourth column gives the fault subtype name. For convenience, individual faults are referred to in this manual by their fault-subtype name. Thus an OPERATION.INVALID\_OPERAND fault is referred to as simply an INVALID\_OPERAND fault; an ARITHMETIC.INTEGER\_OVERFLOW fault is referred to as an INTEGER\_OVERFLOW fault.
- The fifth column shows the encoding of the word in the fault record that contains the fault type and fault subtype numbers.

Other i960 processor family members may provide extensions that recognize additional fault conditions. Fault type and subtype encoding allows all faults to be included in the fault table: those that are common to all i960 processors and those that are specific to one or more family members. The fault types are used consistently for all family members. For example, Fault Type 4 is reserved for floating point faults. Any i960 processor with floating point operations uses Entry 4 to store the pointer to the floating point fault handling procedure.

### 9.3 FAULT TABLE

The fault table (Figure 9-2) is the processor's pathway to the fault handling procedures. It can be located anywhere in the address space. The processor obtains a pointer to the fault table during initialization.

The fault table contains one entry for each fault type. When a fault occurs, the processor uses the fault type to select an entry in the fault table. From this entry, the processor obtains a pointer to the fault handling procedure for the type of fault that occurred. Once called, a fault handling procedure has the option of reading the fault subtype or subtypes from the fault record when determining the appropriate fault recovery action.

| Fault Table       |                                 |                |
|-------------------|---------------------------------|----------------|
| 31                | Override/Parallel Fault Entry   | 0              |
|                   | Trace Fault Entry               | 00H            |
|                   | Operation Fault Entry           | 08H            |
|                   | Arithmetic Fault Entry          | 10H            |
|                   |                                 | 18H            |
|                   |                                 | 20H            |
|                   | Constraint Fault Entry          | 28H            |
|                   |                                 | 30H            |
|                   | Protection Fault Entry          | 38H            |
|                   |                                 | 40H            |
|                   |                                 | 48H            |
|                   | Type Fault Entry                | 50H            |
|                   |                                 |                |
|                   |                                 | FCH            |
| Local-Call Entry  |                                 |                |
| 31                | Fault-Handler Procedure Address | 2 1 0<br>0 0 n |
|                   |                                 | n+4            |
| System-Call Entry |                                 |                |
| 31                | Fault-Handler Procedure Number  | 2 1 0<br>1 0 n |
|                   | 0000 027FH                      | n+4            |
|                   | Reserved (Initialize to 0)      |                |
|                   |                                 | F_C0A19A       |

Figure 9-2. Fault Table and Fault Table Entries

## FAULTS

As indicated in Figure 9-2, two fault table entry types are allowed: local-call entry and system-call entry. Each is two words in length. The entry type field (bits 0 and 1 of the entry's first word) and the value in the entry's second word determine the entry type.

- |  |  |
|--|--|
| <i>local-call entry</i><br>(type $00_2$ )  | Provides an instruction pointer for the fault handling procedure. The processor uses this entry to invoke the specified procedure by means of an implicit local-call operation. The second word of a local procedure entry is reserved. It must be set to zero when the fault table is created and not accessed after that.  |
| <i>system-call entry</i><br>(type $10_2$ ) | Provides a procedure number in the system procedure table. This entry must have an entry type of $10_2$ and a value in the second word of $0000\ 027FH$ . Using this entry, the processor invokes the specified fault handling procedure by means of an implicit call-system operation similar to that performed for the <b>calls</b> instruction. A fault handling procedure in the system procedure table can be called with a system-local call or a system-supervisor call, depending on the entry type in the system-procedure table. |

Other entry types ( $01_2$  and  $11_2$ ) are reserved and have unpredictable behavior. To summarize, a fault handling procedure can be invoked through the fault table in any of three ways: a local call, a system-local call or a system-supervisor call.

### 9.4 STACK USED IN FAULT HANDLING

The architecture does not define a dedicated fault handling stack. Instead, to handle a fault, the processor uses either the user, interrupt or supervisor stack, whichever is active when the fault is generated. There is however, one exception: if the user stack is active when a fault is generated and the fault handling procedure is called with an implicit system supervisor call, the processor switches to the supervisor stack to handle the fault.

### 9.5 FAULT RECORD

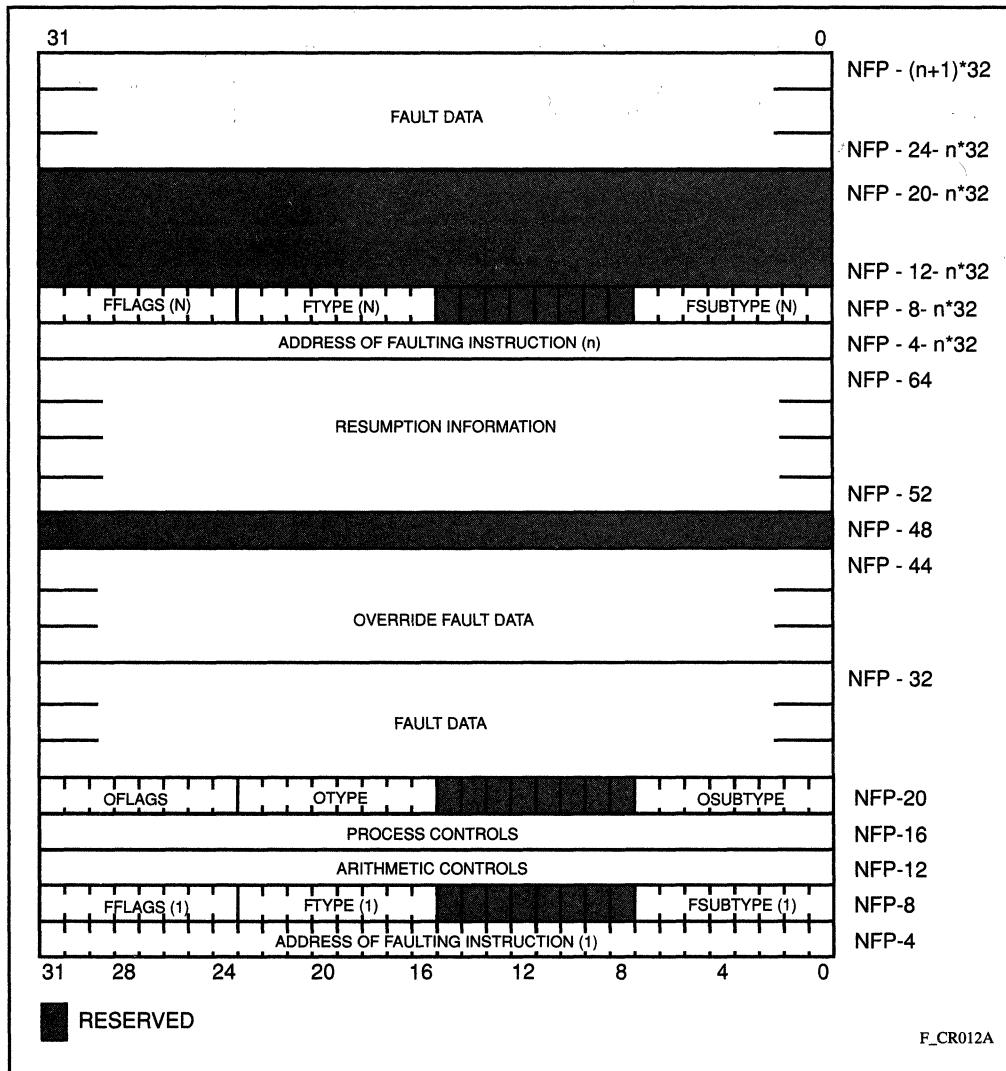
When a fault occurs, the processor records information about the fault in a fault record in memory. The fault handling procedure uses the information in the fault record to correct or recover from the fault condition and, if possible, resume program execution. The fault record is stored on the stack that the fault handling procedure will use to handle the fault.

### 9.5.1 Fault Record Description

Figure 9-3 shows the fault record's structure. In this record, the fault's type number is stored in the fault type field and the fault's subtype number (or bit positions for multiple subtypes) is stored in the fault subtype field. The address-of-faulting-instruction field contains the IP of the instruction that caused the processor to fault.

When a fault is generated, the existing PC and AC register contents are stored in their respective fault record fields. The processor uses this information to resume program execution after the fault is handled.

## FAULTS



**Figure 9-3. Fault Record**

The Override fault data field is used to store optional data for the override fault condition. Refer to section 9.10.1, “Overrides” (pg. 9-21) for more information. The OType and OSubtype fields are used to describe PARALLEL and OVERRIDE faults. For single faults, the 80960Jx places the number of faults (one) in the OSubtype field, as it does for parallel faults (greater than one). The Optional Data field is defined for certain faults. This field contains additional information about

the faulting conditions, usually to assist resumption. Refer to section 9.11, “FAULT REFERENCE” (pg. 9-21) for more details on the faults that use this field. All unused bytes in the fault record are reserved.

### 9.5.2 Fault Record Location

The fault record is stored on the stack that the processor uses to execute the fault handling procedure. As shown in Figure 9-4, this stack can be the user stack, supervisor stack or interrupt stack. The fault record begins at byte address NFP-1. NFP refers to the new frame pointer that is computed by adding the memory size allocated for padding and the fault record to the new stack pointer (NSP). The processor rounds the FP to the next 16-byte boundary and then allocates 80 bytes for the fault record. The size and alignment of the fault record is implementation-dependent.

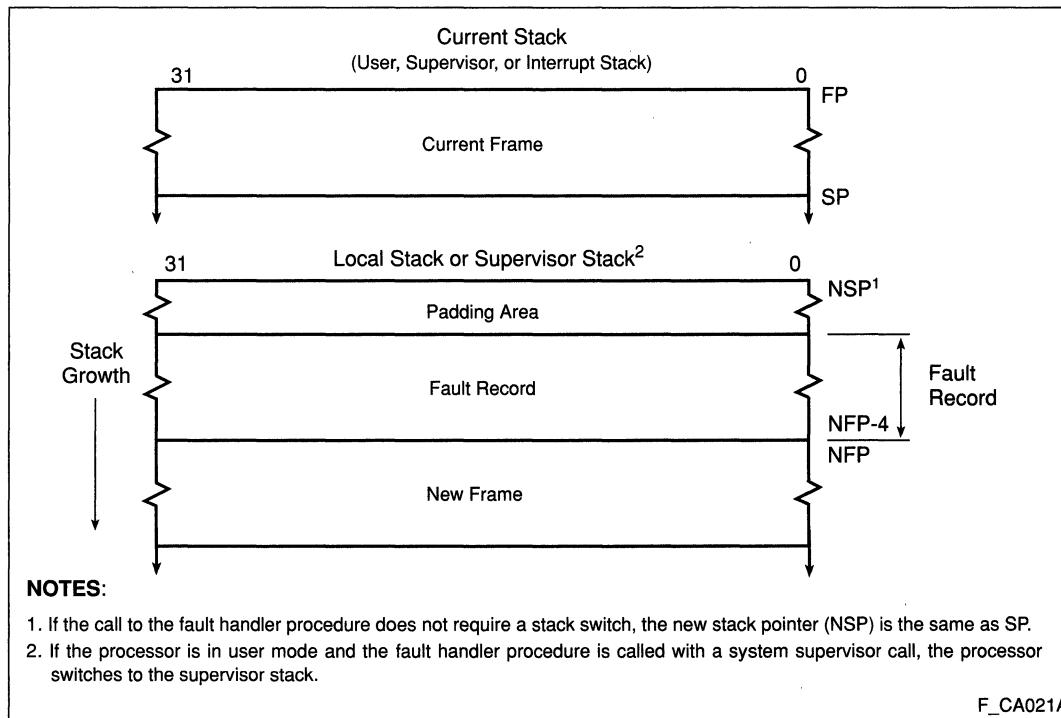


Figure 9-4. Storage of the Fault Record on the Stack

## 9.6 MULTIPLE AND PARALLEL FAULTS

Multiple fault conditions can occur during a single instruction execution and during multiple instruction execution when the instructions are executed by different units within the processor. The following sections describe how faults are handled under these conditions.

### 9.6.1 Multiple Non-Trace Faults on the Same Instruction

Multiple fault conditions can occur during a single instruction execution. For example, an instruction can have an invalid operand and unaligned address. When this situation occurs, the processor is required to recognize and generate at least one of the fault conditions. The processor may not detect all fault conditions and may not report all detected faults on a single instruction.

In a multiple fault situation, the reported fault condition is left to the implementation. On the Jx processor, all non-trace fault conditions present in one instruction are prioritized. Only the non-trace fault of highest priority is reported in the fault record. The faults by order of decreasing priority are:

- OPERATION.UNIMPLEMENTED (Attempt to execute from on-chip RAM or a memory-mapped region only.)
- OPERATION.INVALID\_OPCODE
- OPERATION.INVALID\_OPERAND
- TYPE.MISMATCH
- OPERATION.UNIMPLEMENTED (All other faults related to unimplemented operations)
- ARITHMETIC.ZERO\_DIVIDE
- ARITHMETIC.INTEGER\_OVERFLOW
- CONSTRAINT.RANGE
- PROTECTION.LENGTH

### 9.6.2 Multiple Trace and Fault Conditions on the Same Instruction

Trace faults on different instructions cannot happen concurrently, because trace faults are precise. Multiple trace fault conditions on the same instruction are reported in a single trace fault record (with the exception of prereturn trace, which always happens alone). To support this multiple fault reporting, the trace fault uses bit positions in the fault-subtype field to indicate occurrences of multiple faults of the same type (Table 9-1).

### 9.6.3 Multiple Trace and Non-Trace Fault Conditions on the Same Instruction

The execution of a single instruction can create one or more trace fault conditions in addition to multiple non-trace fault conditions. When this occurs, the processor generates at least two faults: a non-trace fault and a trace fault.

The non-trace fault is handled first and the trace fault is triggered immediately after executing the return instruction (**ret**) at the end of the non-trace fault handler.

### 9.6.4 Parallel Faults

The i960 Jx processor exploits the architecture's tolerance of out-of-order instruction execution by issuing instructions to independent execution units on the chip. The following subsections describe how the processor handles faults in this environment.

### 9.6.5 Faults on Multiple Instructions Executed in Parallel

If AC.nif = 0, imprecise faults relative to different instructions executing in parallel may be reported in a single parallel fault record and the processor calls a unique fault handler, the PARALLEL fault handler (see section 9.9.4, "No Imprecise Faults (AC.nif) Bit" (pg. 9-20)). This mechanism allows instructions that can fault to be executed in parallel with other instructions or out of order.

In parallel fault situations, the processor saves the fault type and subtype of the second and subsequent faults detected in the optional section of the fault record. The fault handling procedure for parallel faults can then analyze the fault record and handle the faults. The fault record for parallel faults is described in the next section.

If the RIP is undefined for at least one of the faults found in the parallel fault record, then the RIP of the parallel fault handler is undefined. In this case, the parallel fault handling procedure can either create a RIP and return to it or call a debug monitor to analyze the faults.

If the RIP is defined for all faults found in the fault record, then it will point to the next instruction not yet executed. The parallel fault handler can simply return to the next instruction not yet executed with a **ret** instruction.

Consider the following code example, where the **muli** and the **addi** instructions both have overflow conditions. AC.om = 0, AC.nif = 0, and both instructions are in the instruction cache at the time of their execution. The **addi** and **muli** are allowed to execute in parallel because AC.nif = 0 and because the faults that these instructions can potentially take (ARITHMETIC) are imprecise.

```
muli g2, g4, g6;  
addi g8, g9, g10;      # results in integer overflow
```

## FAULTS

The fault on the **addi** is detected before the fault on the **muli** because the **muli** takes longer to execute. The fault call synchronizes faults on the way to the overflow fault handler for the **addi** instruction (see section 9.9.5, “Controlling Fault Precision” (pg. 9-20)) which is when the **muli** fault is detected. The processor builds a parallel fault record with information relative to both faults and calls the parallel fault handler. In the fault handler, ARITHMETIC faults may be recovered by storing the desired result of the instruction in the proper destination register and setting the AC.of flag(optional) to indicate an overflow occurred. Then a **ret** at the end of the parallel fault handler routine will return to the next instruction not yet executed in the program flow.

On the i960 Jx processor, the **muli** overflow fault is the only fault that can happen with a delay. Therefore, parallel fault records can report a maximum of 2 faults, one of which must be a **muli** ARITHMETIC.INTEGER\_OVERFLOW fault.

A parallel fault handler must be accessed through a system-supervisor call. Local and system-local parallel fault handlers are not supported by the architecture and have an unpredictable behavior. Tracing is disabled upon entry into the parallel fault handler (PC.te is cleared). It is restored upon return from the handler. The parallel fault handler should not set PC.te to prevent infinite internal loops.

### 9.6.6 Fault Record for Parallel Faults

Figure 9-3 shows the structure of the fault record for parallel faults.

To calculate byte offsets, “n” indicates the fault number. Thus, for the second fault recorded (n=2), the relationship (NFP - 8 - (n \* 32)) reduces to NFP-72. For the i960 Jx processor, a maximum of two faults are reported in the parallel fault record, and one of them must be the ARITHMETIC.INTEGER\_OVERFLOW fault on a **muli** instruction.

When multiple parallel faults occur, the processor selects one of the faults and records it in the first 16 bytes of the fault record as described in section 9.5.1, “Fault Record Description” (pg. 9-7). The remaining parallel faults are written to the fault record’s optional section and the fault handling procedure for parallel faults is invoked.

The OType/OSubtype word at NFP - 20 contains information about the parallel faults. The byte at offset NFP-18 contains 00H (encoding for the PARALLEL fault type); the byte at NFP-20 contains the number of parallel faults. The optional section also contains a 32-byte parallel fault record for each additional fault. These parallel fault records are stored incrementally in the fault record starting at byte offset NFP-65. The fault record for each additional fault contains only the fault type, fault subtype, address-of-faulting-instruction, and the optional fault section. (For example, if two parallel faults occur, the fault record for the second fault is located from NFP - 96 to NFP - 65.)

## 9.7 FAULT HANDLING PROCEDURES

The fault handling procedures can be located anywhere in the address space. Each procedure must begin on a word boundary. The processor can execute the procedure in user mode or supervisor mode, depending on the type of fault table entry.

### 9.7.1 Possible Fault Handling Procedure Actions

The processor allows easy recovery from many faults that occur. When fault recovery is possible, the processor's fault handling mechanism allows the processor to automatically resume work on the program or interrupt pending when the fault occurred. Resumption is initiated with a `ret` instruction in the fault handling procedure.

If recovery from the fault is not possible or not desirable, the fault handling procedure can take one of the following actions, depending on the nature and severity of the fault condition (or conditions, in the case of multiple faults):

- Return to a point in the program or interrupt code other than the point of the fault.
- Call a debug monitor.
- Explicitly write the processor state and fault record into memory and perform processor or system shutdown.
- Perform processor or system shutdown without explicitly saving the processor state or fault information.

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When working with the processor at the development level, a common fault handling procedure action is to save the fault and processor state information and make a call to a debugging device such as a debugging monitor. This device can then be used to analyze the fault information.

### 9.7.2 Program Resumption Following a Fault

Because of the wide variety of faults, they can occur at different times with respect to the faulting instruction:

- Before execution of the faulting instruction (e.g. fetch from on-chip RAM)
- During instruction execution (e.g. integer overflow)
- Immediately following execution (e.g. trace)

When the fault occurs before the faulting instruction is executed, the faulting instruction may be re-executed upon return from the fault handling procedure.

## FAULTS

When a fault occurs during or after execution of the faulting instruction, the fault may be accompanied by a program state change such that program execution cannot be resumed after the fault is handled. For example, when an integer overflow fault occurs, the overflow value is stored in the destination. If the destination register is the same as one of the source registers, the source value is lost, making it impossible to re-execute the faulting instruction.

In general, resumption of program execution with no changes in the program's control flow is possible with the following fault types or subtypes:

- All OPERATION Subtypes
- All CONSTRAINT Subtypes
- PROTECTION.LENGTH
- ARITHMETIC.ZERO\_DIVIDE
- All TRACE Subtypes

Resumption of the program may or may not be possible with the following fault subtype:

- ARITHMETIC.INTEGER\_OVERFLOW

The effect of specific fault types on a program is defined in section 9.11, “FAULT REFERENCE” (pg. 9-21) under the heading *Program State Changes*.

### 9.7.3 Return Instruction Pointer (RIP)

When a fault handling procedure is called, a Return Instruction Pointer (RIP) is saved in the image of the RIP in the faulting frame. The RIP can be accessed at address pfp+8 while executing the fault handler after a **flushreg**. The RIP in the previous frame points to an instruction where program execution can be resumed with no break in the program's control flow. It generally points to the faulting instruction or to the next instruction to be executed. In some instances, however, the RIP is undefined. RIP content for each fault is described in section 9.11, “FAULT REFERENCE” (pg. 9-21).

### 9.7.4 Returning to the Point in the Program Where the Fault Occurred

As described in section 9.7.2, “Program Resumption Following a Fault” (pg. 9-13), most faults can be handled such that program control flow is not affected. In this case, the processor allows a program to be resumed at the point where the fault occurred, following a return from a fault handling procedure (initiated with a **ret** instruction). The resumption mechanism used here is similar to that provided for returning from an interrupt handler.

The fault handling procedure should be executed in supervisor mode (either by using a supervisor call or by running the program in supervisor mode) for the PC register to be restored from the fault record upon return from the fault handler. (See the pseudocode in section 6.2.54, “ret” (pg. 6-91)).

### 9.7.5 Returning to a Point in the Program Other Than Where the Fault Occurred

A fault handling procedure can also return to a point in the program other than where the fault occurred. To do this, the fault procedure must alter the RIP.

To perform a return from a fault handling procedure to an alternate point in the program predictably, the fault handling procedure should perform the following steps:

1. Flush the local register sets to the stack with a **flushreg** instruction.
2. Modify the RIP in the previous frame.
3. Clear the trace-fault-pending flag in the fault record's process controls field before the return (optional).
4. Execute a return with the **ret** instruction.

Use this technique carefully and only in situations where the fault handling procedure is closely coupled with the application program.

### 9.7.6 Fault Controls

For certain fault types and subtypes the processor employs register mask bits or flags that determine whether or not a fault is generated when a fault condition occurs. Table 9-2 summarizes these flags and masks, the data structures in which they are located, and the fault subtypes they affect.

The integer overflow mask bit inhibits the generation of integer overflow faults. The use of this mask is discussed in section 9.11, “FAULT REFERENCE” (pg. 9-21).

The no imprecise faults (NIF) bit controls the synchronizing of faults for a category of faults called imprecise faults. The function of this bit is described in section 9.9, “PRECISE AND IMPRECISE FAULTS” (pg. 9-19).

## FAULTS

TC register trace mode bits and the PC register trace enable bit support trace faults. Trace mode bits enable trace modes; the trace enable bit enables trace fault generation. The use of these bits is described in the trace faults description in section 9.11, “FAULT REFERENCE” (pg. 9-21). Further discussion of these flags is provided in CHAPTER 10, TRACING AND DEBUGGING.

**Table 9-2. Fault Flags or Masks**

| Flag or Mask Name         | Location                          | Faults Affected  |
|---------------------------|-----------------------------------|--|
| Integer Overflow Mask Bit | Arithmetic Controls (AC) Register | INTEGER_OVERFLOW   |
| No Imprecise Faults Bit   | Arithmetic Controls (AC) Register | All Imprecise Faults   |
| Trace Enable Bit          | Process Controls (PC) Register    | All TRACE Faults   |
| Trace Mode                | Trace Controls (TC) Register      | All TRACE Faults except hardware breakpoint traces and fmark |
| Unaligned Fault Mask      | Process Control Block (PRCB)      | UNALIGNED Fault  |

The unaligned fault mask bit is located in the process control block (PRCB), which is read during initialization. It controls whether unaligned memory accesses generate a fault. See section 15.2.5, “Data Alignment” (pg. 15-22).

## 9.8 FAULT HANDLING ACTION

Once a fault occurs, the processor saves the program state, calls the fault handling procedure and — when the fault recovery action completes — restores the program state (if possible). No software other than the fault handling procedures is required to support this activity.

Three types of implicit procedure calls can be used to invoke the fault handling procedure according to the information in the selected fault table entry: a local call, a system-local call and a system-supervisor call.

The following subsections describe actions the processor takes while handling faults. It is not necessary to read these sections to use the fault handling mechanism or to write a fault handling procedure. This discussion is provided for those readers who wish to know the details of the fault handling mechanism.

### 9.8.1 Local Fault Call

When the selected fault handler entry in the fault table is an entry type  $00_2$  (local procedure), the processor operates as described in section 7.1.3.1, “Call Operation” (pg. 7-7), with the following exceptions:

- A new frame is created on the stack that the processor is currently using. The stack can be the user stack, supervisor stack or interrupt stack.
- The fault record is copied into the area allocated for it in the stack, beginning at NFP-1. (See Figure 9-4.)
- The processor gets the IP for the first instruction in the called fault handling procedure from the fault table.
- The processor stores the fault return code ( $001_2$ ) in the PFP return type field.

If the fault handling procedure is not able to perform a recovery action, it performs one of the actions described in section 9.7.2, “Program Resumption Following a Fault” (pg. 9-13).

If the handler action results in recovery from the fault, a **ret** instruction in the fault handling procedure allows processor control to return to the program that was pending when the fault occurred. Upon return, the processor performs the action described in section 7.1.3.3, “Return Operation” (pg. 7-8), except that the arithmetic controls field from the fault record is copied into the AC register. If the processor is in user mode before execution of the return, the process controls field from the fault record is not copied back to the PC register.

### 9.8.2 System-Local Fault Call

When the fault handler selects an entry for a local procedure in the system procedure table (entry type  $10_2$ ), the processor performs the same action as is described in the previous section for a local fault call or return. The only difference is that the processor gets the fault handling procedure's address from the system procedure table rather than from the fault table.

### 9.8.3 System-Supervisor Fault Call

When the fault handler selects an entry for a supervisor procedure in the system procedure table, the processor performs the same action described in section 7.1.3.1, “Call Operation” (pg. 7-7), with the following exceptions:

- If the fault occurs while in user mode, the processor switches to supervisor mode, reads the supervisor stack pointer from the system procedure table and switches to the supervisor stack. A new frame is then created on the supervisor stack.

## FAULTS

- If the fault occurs while in supervisor mode, the processor creates a new frame on the current stack. If the processor is executing a supervisor procedure when the fault occurred, the current stack is the supervisor stack; if it is executing an interrupt handler procedure, the current stack is the interrupt stack. (The processor switches to supervisor mode when handling interrupts.)
- The fault record is copied into the area allocated for it in the new stack frame, beginning at NFP-1. (See Figure 9-4.)
- The processor gets the IP for the first instruction of the fault handling procedure from the system procedure table (using the index provided in the fault table entry).
- The processor stores the fault return code ( $001_2$ ) in the PFP register return type field. If the fault is not a trace, parallel or override fault, it copies the state of the system procedure table trace control flag (byte 12, bit 0) into the PC register trace enable bit. If the fault is a trace, parallel or override fault, the trace enable bit is cleared.

On a return from the fault handling procedure, the processor performs the action described in section 7.1.3.3, "Return Operation" (pg. 7-8) with the addition of the following:

- The fault record arithmetic controls field is copied into the AC register.
- If the processor is in supervisor mode prior to the return from the fault handling procedure (which it should be), the fault record process controls field is copied into the PC register. The mode is then switched back to user, if it was in user mode before the call.
- The processor switches back to the stack it was using when the fault occurred. (If the processor was in user mode when the fault occurred, this operation causes a switch from the supervisor stack to the user stack.)
- If the trace-fault-pending flag and trace enable bit are set in the PC field of the fault record, the trace fault on the instruction at the origin of the supervisor fault call is handled at this time.

PC register restoration causes any changes to the process controls caused by the fault handling procedure to be lost.

### 9.8.4      Faults and Interrupts

If an interrupt occurs during:

- An instruction that will fault; or
- An instruction that has already faulted; or
- Fault handling procedure selection

The processor handles the interrupt in the following way: It completes the selection of the fault handling procedure, creates the fault record and then services the interrupt just prior to executing the first instruction of the fault handling procedure. The fault is handled upon return from the interrupt. Handling the interrupt before the fault reduces interrupt latency.

## 9.9 PRECISE AND IMPRECISE FAULTS

As described in section 9.11.5, “PARALLEL Faults” (pg. 9-29), the i960 architecture — to support parallel and out-of-order instruction execution — allows some faults to be generated together.

The processor provides two mechanisms for controlling the circumstances under which faults are generated: the AC register no-imprecise-faults bit (AC.nif bit) and the instructions that synchronize faults. See section 9.9.5, “Controlling Fault Precision” (pg. 9-20) for more information. Faults are categorized as precise, imprecise and asynchronous. The following subsections describe each.

### 9.9.1 Precise Faults

A fault is precise if it meets all of the following conditions:

- The faulting instruction is the earliest instruction in instruction issue order to generate a fault.
- All instructions before the faulting instruction, in instruction issue order, have completed successfully with no unreported faults.
- All instructions after the faulting instruction, in instruction issue order, are ensured not to have executed.

The faults that are always precise are:

- TRACE
- PROTECTION

### 9.9.2 Imprecise Faults

Faults that do not meet all of the requirements for precise faults are considered imprecise. For imprecise faults, the state of execution of instructions surrounding the faulting instruction may be unpredictable. When instructions are executed out-of-order and an imprecise fault occurs, it may not be possible to access the source operands of the instruction. This is because they may have been modified by subsequent instructions executed out-of-order. However, the RIP of some imprecise faults (e.g. ARITHMETIC) points to the next instruction that has not yet executed and guarantees the return from the fault handler to the original flow of execution. Faults that the architecture allows to be imprecise are:

- OPERATION
- CONSTRAINT
- ARITHMETIC
- TYPE

## FAULTS

### 9.9.3 Asynchronous Faults

Asynchronous faults are those whose occurrence has no direct relationship to the instruction pointer. This group includes MACHINE faults, which are not implemented on the 80960Jx.

### 9.9.4 No Imprecise Faults (AC.nif) Bit

The AC.nif bit controls imprecise fault generation. If AC.nif is set, all faults generated are precise. If AC.nif is clear, several imprecise faults may be reported together in a parallel fault record. Precise faults can never be found in parallel fault records, thus only more than one imprecise fault occurring concurrently with AC.nif = 0 can produce a parallel fault.

Compiled code should execute with the AC.nif bit clear, using **syncf** where necessary to ensure that faults occur in order. In this mode, imprecise faults are considered to be catastrophic errors from which recovery is not needed. This also allows the processor to take advantage of internal pipelining which can speed up processing time. When only precise faults are allowed, the processor must restrict the use of pipelining to prevent imprecise faults.

The NIF bit should be set if recovery from one or more imprecise faults is required. For example, the NIF bit should be set if a program needs to handle — and recover from — unmasked integer-overflow faults and the fault handling procedure cannot be closely coupled with the application to perform imprecise fault recovery.

### 9.9.5 Controlling Fault Precision

The **syncf** instruction forces the processor to complete execution of all instructions that occur prior to **syncf** and to generate all faults before it begins work on instructions that occur after **syncf**. This instruction has two uses:

- It forces faults to be precise when the NIF bit is clear.
- It ensures that all instructions are complete and all faults are generated in one block of code before executing another block of code.

In addition to the **syncf** instruction, an implicit fault synchronization is performed at the beginning of the following instructions or operations:

- Call and Return Operations including **call**, **callx**, **calls**, and **ret** instructions, plus the implicit interrupt and fault call operations.
- Atomic Operations including **atadd** and **atmod**.

## 9.10 FAULTS WITHIN A FAULT HANDLER

The architecture provides for graceful degradation in situations where faults occur while attempting to perform the action defined for a previous fault (i.e., from the time the first fault was detected until the time that the call to its fault handler completes). The first such successive fault is called an override, and results in a different fault handler being selected. The second such successive fault is called a system error.

### 9.10.1 Overrides

If a second fault occurs while storing a fault record for a previous fault or in invoking the fault handler, and the previous fault is not for an override or parallel fault condition, an override is said to occur.

This is similar to normal fault-handler invocation, with the following exceptions. The fault record describes the first fault as described previously. Field OType contains the fault type of the second fault, field OSubtype contains the fault subtype of the second fault and field override-fault-data contains what would normally be the fault data field for the second fault type. Rather than selecting the fault handler corresponding to the first or second fault types, the override fault handler is selected.

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When an override condition does not occur, these fields in the fault record have no defined value, except for the OType/OSubtype fields (see section 9.5.1, “Fault Record Description” (pg. 9-7)).

An override fault handler must be accessed through a system-supervisor call. Local and system-local override fault handlers are not supported by the architecture and have an unpredictable behavior. Tracing is disabled upon entry into the override fault handler (PC.te is cleared). It is restored upon return from the handler. To prevent infinite internal loops, the override fault handler should set PC.te.

### 9.10.2 System Error

A system error occurs when a fault condition is detected while servicing an override or a parallel fault. This type of error causes the processor to enter a system error state. In this state, the processor indefinitely sends an error message on the address bus, while asserting the FAIL pin. Refer to section 11.2.2.3, “The Fail Pin (FAIL)” (pg. 11-7) for more information on system error conditions.

## 9.11 FAULT REFERENCE

This section describes each fault type and subtype and gives detailed information about what is stored in the various fields of the fault record. The section is organized alphabetically by fault type. The following paragraphs describe the information that is provided for each fault type.

## FAULTS

|                        |  |
|------------------------|--|
| Fault Type:            | Gives the number that appears in the fault record fault-type field when the fault is generated.  |
| Fault Subtype:         | Lists the fault subtypes and the number associated with each fault subtype.  |
| Function:              | Describes the purpose and handling of the fault type and each subtype. The error message take the form of the dummy address 0xFFFFFFF68.   |
| RIP:                   | Describes the value saved in the image of the RIP register in the stack frame that the processor was using when the fault occurred. In the RIP definitions, “next instruction” refers to the instruction directly after the faulting instruction or to an instruction to which the processor can logically return when resuming program execution.<br><br>Note that the discussions of many fault types specify that the RIP contains the address of the instruction that would have executed next had the fault not occurred. Since some implementations may choose to execute instructions out of order when this can be done transparently, the RIP need not necessarily point to the instruction immediately following (in an execution-order sense); it may point elsewhere in the instruction stream. However, it must point to a spot at which execution can be resumed correctly if one wants to resume execution after the fault, and thus the implementation cannot execute out-of-order any instructions subsequent to the faulting instruction that are dependant on any result of the faulting instruction. |
| Fault IP:              | Describes the contents of the fault record’s fault instruction pointer field, typically the faulting instruction’s IP.   |
| Fault Data:            | Describes any values stored in the fault record’s fault data field.  |
| Class:                 | Indicates if a fault is precise or imprecise.  |
| Program State Changes: | Describes the process state changes that would prevent re-executing the faulting instruction if applicable.  |
| Trace Reporting:       | Relates whether a trace fault (other than PRERET) can be detected on the faulting instruction, also if and when the fault is serviced.   |
| Notes:                 | Additional information specific to particular implementations of the i960 architecture.  |

### 9.11.1 ARITHMETIC Faults

Fault Type: 3H

| Fault Subtype: | Number           | Name |
|----------------|------------------|------|
| 0H             | Reserved         |      |
| 1H             | INTEGER_OVERFLOW |      |
| 2H             | ZERO_DIVIDE      |      |
| 3H-FH          | Reserved         |      |

Function: Indicates a problem with an operand or the result of an arithmetic instruction. An INTEGER\_OVERFLOW fault is generated when the result of an integer instruction overflows its destination and the AC register integer overflow mask is cleared. Here, the result's *n* least significant bits are stored in the destination, where *n* is destination size. Instructions that generate this fault are:

|      |      |          |
|------|------|----------|
| addi | subi | stis     |
| stib | shli | ADDI<cc> |
| muli | divi | SUBI<cc> |

An ARITHMETIC.ZERO\_DIVIDE fault is generated when the divisor operand of an ordinal- or integer-divide instruction is zero. Instructions that generate this fault are:

|      |      |
|------|------|
| divo | divi |
| ediv | remi |
| remo | modi |

RIP: IP of the instruction that would have executed next if the fault had not occurred.

Fault IP: IP of the faulting instruction.

Class: Imprecise.

Program State Changes: Faults may be imprecise when executing with the NIF bit cleared. An INTEGER\_OVERFLOW and ZERO\_DIVIDE faults may not be recoverable because the result is stored in the destination before the fault is generated; (e.g., the faulting instruction cannot be re-executed if the destination register was also a source register for the instruction).

Trace Reporting: The trace is reported upon return from the Arithmetic fault handler.

## FAULTS

### 9.11.2 CONSTRAINT Faults

|                        |   |          |
|------------------------|---|----------|
| Fault Type:            | 5H  |          |
| Fault Subtype:         | Number  | Name     |
|                        | 0H  | Reserved |
|                        | 1H  | RANGE    |
|                        | 2H-FH   | Reserved |
| Function:              | Indicates the program or procedure violated an architectural constraint.  |          |
|                        | A CONSTRAINT.RANGE fault is generated when a <b>FAULT&lt;cc&gt;</b> instruction is executed and the AC register condition code field matches the condition required by the instruction.   |          |
| RIP:                   | No defined value.   |          |
| Fault IP:              | Faulting Instruction.   |          |
| Class:                 | Imprecise.  |          |
| Program State Changes: | These faults may be imprecise when executing with the NIF bit cleared. No changes in the program's control flow accompany these faults. A CONSTRAINT.RANGE fault is generated after the fault-if instruction executes. The program state is not affected. |          |
| Trace Reporting:       | Serviced upon return from the Constraint fault handler.   |          |

### 9.11.3 OPERATION Faults

Fault Type: 2H

| Fault Subtype: | Number  | Name            |
|----------------|---------|-----------------|
|                | 0H      | Reserved        |
|                | 1H      | INVALID_OPCODE  |
|                | 2H      | UNIMPLEMENTED   |
|                | 3H      | UNALIGNED       |
|                | 4H      | INVALID_OPERAND |
|                | 5H - FH | Reserved        |

Function: Indicates the processor cannot execute the current instruction because of invalid instruction syntax or operand semantics.

An INVALID\_OPCODE fault is generated when the processor attempts to execute an instruction containing an undefined opcode or addressing mode.

An UNIMPLEMENTED fault is generated when the processor attempts to execute an instruction fetched from on-chip data RAM, or when a non-word or unaligned access to a memory-mapped region is performed, or when attempting to write memory-mapped region 0xFF0084XX when not granted.

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An UNALIGNED fault is generated when the following conditions are present: (1) the processor attempts to access an unaligned word or group of words in non-MMR memory; and (2) the fault is enabled by the unaligned-fault mask bit in the PRCB fault configuration word.

An INVALID\_OPERAND fault is generated when the processor attempts to execute an instruction that has one or more operands having special requirements that are not satisfied. This fault is generated when specifying a non-defined **sysctl**, **icctl**, **dcctl** or **intctl** command, or referencing an unaligned long-, triple- or quad-register group, or by referencing an undefined register, or by writing to the RIP register(r2).

RIP: No defined value.

Fault IP: Address of the faulting instruction.

Fault Data: When an UNALIGNED fault is signaled, the effective address of the unaligned access is placed in the fault record's optional data section, beginning at address NFP-24. This address is useful to debug a program that is making unintentional unaligned accesses.

Class: Imprecise.

## FAULTS

- Program State Changes:** For the INVALID\_OPCODE and UNIMPLEMENTED (case: store to MMR), the destination of the faulting instruction is not modified. (For the UNALIGNED fault, the memory operation completes correctly before the fault is reported.) In all other cases, the destination is undefined.
- Trace Reporting:** The trace event is lost.
- Notes:** OPERATION.UNALIGNED fault is not implemented on i960 Kx and Sx CPUs.

#### 9.11.4 OVERRIDE Faults

|                  |   |
|------------------|---|
| Fault Type:      | Fault table entry = 0H<br>Fault type in fault record = fault type of the program instruction that faulted.  |
| Fault Subtype:   | Fault subtype of the program instruction that faulted.  |
| Fault OType:     | Fault type of the additional fault detected while attempting to deliver the program fault.  |
| Fault OSubtype:  | Fault Subtype of the additional fault detected while attempting to deliver the program fault.   |
| Function:        | The override fault handler must be accessed through a system-supervisor call. Local and system-local override fault handlers are not supported by the architecture and have an unpredictable behavior. Tracing is disabled upon entry into the override fault handler (PC.te is cleared). It is restored upon return from the handler. To prevent infinite internal loops, the override fault handler should not set PC.te. |
| Trace Reporting: | Same behavior as if the override condition had not existed. Refer to the description of the original program fault.   |

## FAULTS

### 9.11.5 PARALLEL Faults

|                 |  |
|-----------------|--|
| Fault Type:     | Fault table entry = 0H<br>Fault type in fault record = fault type of one of the parallel faults.   |
| Fault Subtype:  | Fault subtype of one of the parallel faults.   |
| Fault OType:    | 0H   |
| Fault OSubtype: | Number of parallel faults.   |
| Function:       | See section 9.6.4, "Parallel Faults" (pg. 9-11) for a complete description of parallel faults. When the AC.nif bit in the arithmetic controls is zero, the architecture permits the implementation to execute instructions in parallel and out-of-order by different execution units. When an imprecise fault occurs in any of these units, it is not possible to stop the execution of those instructions after the faulting instruction. It is also possible that more than one fault is detected from different instructions almost at the same time. |

When there is more than one outstanding fault at the point when all execution units terminate, a parallel fault situation arises. The fault record of parallel faults contains the fault information of all the faults that occurred in parallel. The size of the fault record is variable and depends on the number of parallel faults. The maximum size of the fault record is implementation dependent and depends on the number of parallel and pipeline execution units in the specific implementation.

The parallel fault handler must be accessed through a system-supervisor call. Local and system-local parallel fault handlers are not supported by the architecture and have an unpredictable behavior. Tracing is disabled upon entry into the parallel fault handler (PC.te is cleared). It is restored upon return from the handler. The parallel fault handler should not set PC.te to prevent infinite internal loops.

|                        |  |
|------------------------|--|
| RIP:                   | If all of the parallel fault types allow a RIP to be defined, the RIP is the next instruction in the flow of execution, otherwise it is undefined. |
| Fault IP:              | IP of one of the faulting instructions.  |
| Class:                 | Imprecise.   |
| Program State Changes: | State changes associated with all the parallel faults.   |
| Trace Reporting:       | Same behavior as if the override condition had not existed. Refer to the description of the original program fault.                                |

### 9.11.6 PROTECTION Faults

|             |               |             |
|-------------|---------------|-------------|
| Fault Type: | 7H            |             |
| Function:   | <b>Number</b> | <b>Name</b> |
|             | Bit 0         | Reserved    |
|             | Bit 1         | LENGTH      |
|             | Bits 2-7      | Reserved    |

Indicates that a program or procedure is attempting to perform an illegal operation that the architecture protects against.

A PROTECTION.LENGTH fault is generated when the index operand used in a **calls** instruction points to an entry beyond the extent of the system procedure table.

|                        |   |
|------------------------|---|
| RIP:                   | IP of the faulting instruction.         |
| Fault IP:              | IP of the faulting instruction.         |
| Class:                 | Precise.                                |
| Program State Changes: | None. The instruction does not execute. |
| Trace Reporting:       | The trace event is lost.                |

## FAULTS

### 9.11.7 TRACE Faults

|                |  |             |
|----------------|--|-------------|
| Fault Type:    | 1H   |             |
| Fault Subtype: | <b>Number</b>  | <b>Name</b> |
|                | Bit 0  | Reserved    |
|                | Bit 1  | INSTRUCTION |
|                | Bit 2  | BRANCH      |
|                | Bit 3  | CALL        |
|                | Bit 4  | RETURN      |
|                | Bit 5  | PRERETURN   |
|                | Bit 6  | SUPERVISOR  |
|                | Bit 7  | MARK        |
| Function:      | Indicates the processor detected one or more trace events. The event tracing mechanism is described in CHAPTER 10, TRACING AND DEBUGGING.  |             |
|                | <p>A trace event is the occurrence of a particular instruction or instruction type in the instruction stream. The processor recognizes seven different trace events: instruction, branch, call, return, prereturn, supervisor, mark. It detects these events only if the TC register mode bit is set for the event. If the PC register trace enable bit is also set, the processor generates a fault when a trace event is detected.</p> <p>A TRACE fault is generated following the instruction that causes a trace event (or prior to the instruction for the prereturn trace event). The following trace modes are available:</p> <ul style="list-style-type: none"> <li>INSTRUCTION Generates a trace event following every instruction.</li> <li>BRANCH Generates a trace event following any branch instruction when the branch is taken (a branch trace event does not occur on branch-and-link or call instructions).</li> <li>CALL Generates a trace event following any call or branch-and-link instruction or an implicit fault call.</li> <li>RETURN Generates a trace event following a <b>ret</b>.</li> <li>PRERETURN Generates a trace event prior to any <b>ret</b> instruction, providing the PFP register prereturn trace flag is set (the processor sets the flag automatically when a call trace is serviced.) A prereturn trace fault is always generated alone.</li> </ul> |             |

**SUPERVISOR** Generates a trace event following any **calls** instruction that references a supervisor procedure entry in the system procedure table and on a return from a supervisor procedure where the return status type in the PFP register is  $010_2$  or  $011_2$ .

**MARK** Generates a trace event following the **mark** instruction. The MARK fault subtype bit, however, is used to indicate a match of the instruction-address breakpoint register or the data-address breakpoint register as well as the **fmark** and **mark** instructions.

TRACE fault subtype bit is associated with each mode. Multiple fault subtypes can occur simultaneously; all trace fault conditions detected on one instruction (except prereturn) are reported in one single trace fault, with the fault subtype bit set for each subtype that occurs. The prereturn trace is always reported alone.

When a fault type other than a TRACE fault is generated during execution of an instruction that causes a trace event, the non-trace fault is handled before the trace fault. An exception is the prereturn-trace fault, which occurs before the processor detects a non-trace fault and is handled first.

Similarly, if an interrupt occurs during an instruction that causes a trace event, the interrupt is serviced before the TRACE fault is handled. Again, the TRACE.PRERETURN fault is an exception. Since it is generated before the instruction, it is handled before any interrupt that occurs during instruction execution.

A trace fault handler must be accessed through a system-supervisor call (it must be a supervisor procedure in the system procedure table). Local and system-local trace fault handlers are not supported by the architecture and may have unpredictable behavior. Tracing is automatically disabled when entering the trace fault handler and is restored upon return from the trace fault handler. The trace fault handler should not modify PC.te.

**RIP:** Instruction immediately following the instruction traced, in instruction issue order, except for PRERETURN. For PRERETURN, the RIP is the return instruction traced.

**Fault IP:** IP of the faulting instruction for all except prereturn trace and call trace (on implicit fault calls), for which the fault IP field is undefined.

## FAULTS

Class: Precise.

Program State Changes: All trace faults except PRERETURN are serviced after the execution of the faulting instruction. The processor returns to the instruction immediately following the instruction traced, in instruction issue order. For PRERETURN, the return is traced before it executes. The processor re-executes the return instruction after completion of the PRERETURN trace fault handler.

### 9.11.8 TYPE Faults

Fault Type: AH

| Fault Subtype: | Number | Name     |
|----------------|--------|----------|
|                | 0H     | Reserved |
|                | 1H     | MISMATCH |
|                | 2H-FH  | Reserved |

Function: Indicates a program or procedure attempted to perform an illegal operation on an architecture-defined data type or a typed data structure.

A TYPE.MISMATCH fault is generated when attempts are made to:

- Execute a privileged (supervisor-mode only) instruction while the processor is in user mode. Privileged instructions on the i960 Jx processor are:

|        |        |
|--------|--------|
| modpc  | dcctl  |
| halt   | intctl |
| sysctl | inten  |
| icctl  | intdis |

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- Write to on-chip data RAM while the processor is in supervisor-only write mode and BCON.ipr is set. See Figure 12-3.
- Write to the first 64 bytes of on-chip data RAM while the processor is in either user or supervisor mode and BCON.sirp is set. See Figure 12-3.
- Write to memory-mapped registers in supervisor space from user mode.
- Write to timer registers while in user mode, when timer registers are protected against user-mode writes.

RIP: No defined value.

Fault IP: IP of the faulting instruction.

Class: Imprecise.

Program State Changes: The fault happens before execution of the instruction. The machine state is not changed.

Trace Reporting: The trace event is lost.





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## TRACING AND DEBUGGING



# CHAPTER 10

## TRACING AND DEBUGGING

This chapter describes the i960® Jx processor's facilities for runtime activity monitoring. The i960 architecture provides facilities for monitoring processor activity through trace event generation. A trace event indicates a condition where the processor has just completed executing a particular instruction or a type of instruction or where the processor is about to execute a particular instruction. When the processor detects a trace event, it generates a trace fault and makes an implicit call to the fault handling procedure for trace faults. This procedure can, in turn, call debugging software to display or analyze the processor state when the trace event occurred. This analysis can be used to locate software or hardware bugs or for general system monitoring during program development.

Tracing is enabled by the process controls (PC) register trace enable bit and a set of trace mode bits in the trace controls (TC) register. Alternatively, the **mark** and **fmark** instructions can be used to generate trace events explicitly in the instruction stream.

The i960 Jx processor also provides four hardware breakpoint registers that generate trace events and trace faults. Two registers are dedicated to trapping on instruction execution addresses, while the remaining two registers can trap on the addresses of various types of data accesses.

### 10.1 TRACE CONTROLS

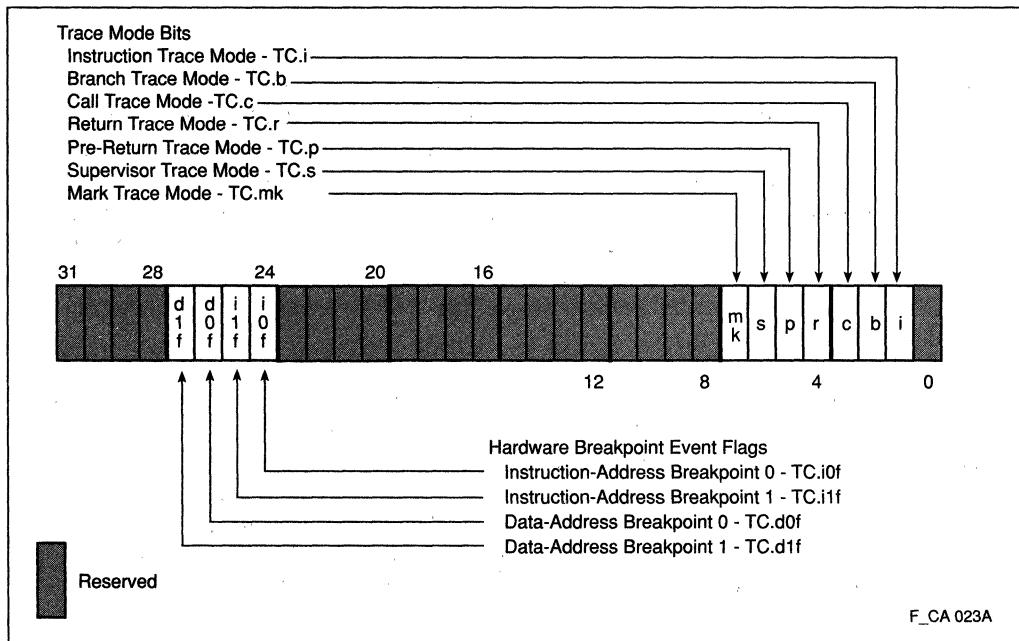
To use the architecture's tracing facilities, software must provide trace fault handling procedures, perhaps interfaced with a debugging monitor. Software must also manipulate the following registers and control bits to enable the various tracing modes and enable or disable tracing in general.

- TC register mode bits
- DAB0-DAB1 registers' address field and enable bit (in the control table)
- System procedure table supervisor-stack-pointer field trace control bit
- IPB0-IPB1 registers' address field (in the control table)
- PC register trace enable bit
- PFP register return status field prereturn trace flag (bit 3)
- BPCON register breakpoint mode bits and enable bits (in the control table)

These controls are described in the following subsections.

### 10.1.1 Trace Controls (TC) Register

The TC register (Figure 10-1) allows software to define conditions that generate trace events.



**Figure 10-1. Trace Controls (TC) Register**

The TC register contains mode bits and event flags. Mode bits define a set of tracing conditions that the processor can detect. For example, when the call-trace mode bit is set, the processor generates a trace event when a call or branch-and-link operation executes. See section 10.2 (pg. 10-3). The processor uses event flags to monitor which breakpoint trace events are generated.

A special instruction, modify-trace-controls (**modtc**), allows software to modify the TC register. On initialization, the TC register is read from the Control Table. **modtc** can then be used to set or clear trace mode bits as required. Updating TC mode bits may take up to four non-branching instructions to take effect. Software can access the breakpoint event flags using **modtc**. The processor automatically sets and clears these flags as part of its trace handling mechanism: the breakpoint event corresponding to the trace being serviced is set in the TC while servicing a breakpoint trace fault; the TC event flags are cleared upon return from the trace fault handler. When not in a trace fault handler, or when the trace is not for breakpoints, the TC event bits are clear. TC register bits 0, 8 through 23 and 28 through 31 are reserved. Software must initialize these bits to zero and cannot modify them afterwards.

### 10.1.2 PC Trace Enable Bit and Trace-Fault-Pending Flag

The PC register trace enable bit and the trace-fault-pending flag in the PC field of the fault record control tracing. The trace enable bit enables the processor's tracing facilities; when set, the processor generates trace faults on all trace events.

Typically, software selects the trace modes to be used through the TC register. It then sets the trace enable bit to begin tracing. This bit is also altered as part of some call and return operations that the processor performs as described in section 10.5.2, "Tracing on Calls and Returns" (pg. 10-12).

The update of PC.te through **modpc** may take up to four non-branching instructions to take effect. The update of PC.te through call and return operations is immediate.

The trace-fault-pending flag, in the PC field of the fault record, allows the processor to remember to service a trace fault when a trace event is detected at the same time as another event (e.g., non-trace fault, interrupt). The non-trace fault event is serviced before the trace fault, and depending on the event type and execution mode, the trace fault pending flag in the PC field of the fault record may be used to generate a fault upon return from the non-trace fault event (see section 10.5.2.4, "Tracing on Return from Implicit Call: Fault Case" (pg. 10-14)).

## 10.2 TRACE MODES

This section defines trace modes enabled through the TC register. These modes can be enabled individually or several modes can be enabled at once. Some modes overlap, such as call-trace mode and supervisor-trace mode.

- Instruction trace
- Branch trace
- Mark trace
- Prereturn trace
- Call trace
- Return trace
- Supervisor trace

See section 10.4, "HANDLING MULTIPLE TRACE EVENTS" (pg. 10-11) for a description of processor function when multiple trace events occur.

### 10.2.1 Instruction Trace

When the instruction-trace mode is enabled in TC (TC.i = 1) and tracing is enabled in PC (PC.te = 1), the processor generates an instruction-trace fault immediately after an instruction is executed. A debug monitor can use this mode (TC.i = 1, PC.te = 1) to single-step the processor.

### 10.2.2 Branch Trace

When the branch-trace mode is enabled in TC (TC.b = 1) and PC.te is set, the processor generates a branch-trace fault immediately after a branch instruction executes, if the branch is taken. A branch-trace event is not generated for conditional-branch instructions that do not branch, branch-and-link instructions, and call-and-return instructions.

### 10.2.3 Call Trace

When the call-trace mode is enabled in TC (TC.c = 1) and PC.te is set after the call, the processor generates a call-trace fault when a call instruction (**call**, **callx** or **calls**) or a branch-and-link instruction (**bal** or **balx**) executes. See section 10.5.2.1, “Tracing on Explicit Call” (pg. 10-12) for a detailed description of call tracing on explicit instructions. Interrupt calls are never traced.

An implicit call to a fault handler also generates a call trace if TC.c and PC.te are set after the call. Refer to section 10.5.2.2, “Tracing on Implicit Call” (pg. 10-13) for a complete description of this case.

When the processor services a trace fault, it sets the prereturn-trace flag (PFP register bit 3) in the new frame created by the call operation or in the current frame if a branch-and-link operation was performed. The processor uses this flag to determine whether or not to signal a prereturn-trace event on a **ret** instruction.

### 10.2.4 Return Trace

When the return-trace mode is enabled in TC and PC.te is set after the return instruction, the processor generates a return-trace fault for a return from explicit call (PFP.rrr = 000 or PFP.rrr = 01x). See section 10.5.2.3, “Tracing on Return from Explicit Call” (pg. 10-14).

A return from fault may be traced and a return from interrupt is not. See section 10.5.2.4, “Tracing on Return from Implicit Call: Fault Case” (pg. 10-14) and section 10.5.2.5, “Tracing on Return from Implicit Call: Interrupt Case” (pg. 10-15) for details.

### 10.2.5 Prereturn Trace

When the TC prereturn-trace mode, the PC.te, and the PFP prereturn-trace flag (PFP.p) are set, the processor generates a prereturn-trace fault prior to executing a **ret** execution. The dependence on PFP.p implies that prereturn tracing cannot be used without enabling call tracing. The processor sets PFP.p whenever it services a call-trace fault (as described above) for call-trace mode.

If another trace event occurs at the same time as the prereturn-trace event, the processor generates a fault on the non-prereturn-trace event first. Then, on a return from that fault handler, it generates a fault on the prereturn-trace event. The prereturn trace is the only trace event that can cause two successive trace faults to be generated between instruction boundaries.

### 10.2.6 Supervisor Trace

When supervisor-trace mode is enabled in TC and PC.te is set, the processor generates a supervisor-trace fault after both of the following:

- A call-system instruction (**calls**) executes from user mode and the procedure table entry is for a system-supervisor call.
- A **ret** instruction executes from supervisor mode and the return-type field is set to  $010_2$  or  $011_2$  (i.e., return from **calls**).

This trace mode allows a debugging program to determine kernel-procedure call boundaries within the instruction stream.

### 10.2.7 Mark Trace

Mark trace mode allows trace faults to be generated at places other than those specified with the other trace modes, using the **mark** instruction. It should be noted that the MARK fault subtype bit in the fault record is used to indicate a match of the instruction-address breakpoint registers or the data-address breakpoint registers as well as the **fmark** and **mark** instructions.

#### 10.2.7.1 Software Breakpoints

**mark** and **fmark** allow breakpoint trace faults to be generated at specific points in the instruction stream. When mark trace mode is enabled and PC.te is set, the processor generates a mark trace fault any time it encounters a **mark** instruction. **fmark** causes the processor to generate a mark trace fault regardless of whether or not mark trace mode is enabled, provided PC.te is set. If PC.te is clear, **mark** and **fmark** behave like no-ops.

#### 10.2.7.2 Hardware Breakpoints

The hardware breakpoint registers are provided to enable generation of trace faults on instruction execution and data access.

The i960 Jx microprocessor implements two instruction and two data address breakpoint registers, denoted IBP0, IBP1, DAB0, and DAB1. The instruction and data address breakpoint registers are 32-bit registers. The instruction breakpoint registers cause a break *after* execution of the target instruction. The DABx registers cause a break *after* the memory access has been issued to the bus controller.

## TRACING AND DEBUGGING

Hardware breakpoint registers may be armed or disarmed. When armed, hardware breakpoints can generate an architectural trace fault. When the registers are disarmed, no action occurs, and execution continues normally. Since instructions are always word aligned, the two low-order bits of the IBPx registers act as control bits. Control bits for the DABx registers reside in the Breakpoint Control (BPCON) register. BPCON enables the data address breakpoint registers, and sets the specific modes of these registers. Hardware breakpoints are globally enabled by the process controls trace enable bit (PC.te).

The IBPx, DABx, and BPCON registers may be accessed using normal load and store instructions (except for loads from IBPx register). The application must be in supervisor mode for a legal access to occur. See Section 3.3, MEMORY-MAPPED CONTROL REGISTERS (pg. 3-5) for more information on the address for each register.

Well behaved applications must request modification rights to the hardware breakpoint resources, before attempting to modify these resources. Rights are requested by executing the **sysctl** instruction, as described in the following section.

### 10.2.7.3 Requesting Modification Rights to Hardware Breakpoint Resources

Application code must always first request and acquire modification rights to the hardware breakpoint resources before any attempt is made to modify them. This mechanism is employed to eliminate simultaneous usage of breakpoint resources by emulation tools and application code. An emulation tool exercises supervisor control over breakpoint resource allocation. If the emulator retains control of breakpoint resources, none are available for application code. If an emulation tool is not being used in conjunction with the device, modification rights to breakpoint resources will be granted to the application. The emulation tool may relinquish control of breakpoint resources to the application.

If the application attempts to modify the breakpoint or breakpoint control (BPCON) registers without first obtaining rights, an OPERATION.unimplemented fault will be generated. In this case, the breakpoint resource will not be modified, whether accessed through a **sysctl** instruction or as a memory-mapped register.

Application code requests modification rights by executing the **sysctl** instruction and issuing the Breakpoint Resource Request message (*src1.Message\_Type* = 06H). In response, the current available breakpoint resources will be returned as the *src/dest* parameter (*src/dest* must be a register). The *src2* parameter is not used. Results returned in the *src/dest* parameter must be interpreted as shown in Table 10-1.

**Table 10-1. SRC/DEST Encoding**

| SRC/DEST 7:4  | SRC/DEST 3:0                                |
|---|---|
| Number of Available Data Address Breakpoints                | Number of Available Instruction Breakpoints |
| Note: SRC3 31:8 are reserved and will always return zeroes. |   |

The following code sample illustrates the execution of the breakpoint resource request.

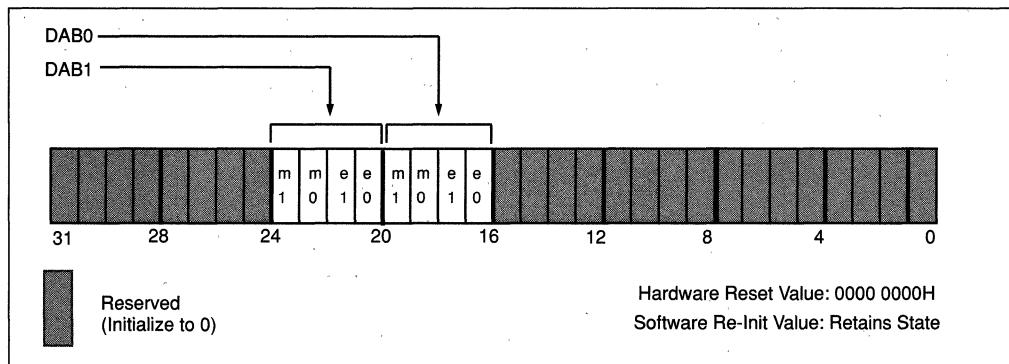
```
ldconst 0x600, r4      # Load the Breakpoint Resource
                        # Request message type into r4.
sysctl r4, r4, r4      # Issue the request.
```

Assume in this example that after execution of the **sysctl** instruction, the value of r4 is 0000.0022H. This indicates that the application has gained modification rights to both instruction and both data address breakpoint registers. If the value returned is zero, the application has not gained the rights to the breakpoint resources.

Because the i960 Jx processor does not initialize the breakpoint registers from the control table during initialization (as i960 Cx processors do), the application must explicitly initialize the breakpoint registers in order to use them once modification rights have been granted by the **sysctl** instruction.

#### 10.2.7.4 Breakpoint Control Register

The format of the BPCON register is shown in Figure 10-2. Each breakpoint has four control bits associated with it: two mode and two enable bits. The enable bits (DABx.e0, DABx.e1) in BPCON act to enable or disable the data address breakpoints, while the mode bits (DABx.m0, DABx.m1) dictate which type of access will generate a break event.

**Figure 10-2. Breakpoint Control Register (BPCON)**

Programming the BPCON register is summarized in Table 10-2.

**Table 10-2. Configuring the Data Address Breakpoint Registers**

| <b>PC.te</b> | <b>DABx.e1</b> | <b>DABx.e0</b> | <b>Description</b>  |
|--------------|----------------|----------------|---|
| 0            | X              | X              | No action. With PC.te clear, breakpoints are globally disabled. |
| X            | 0              | 0              | No action. DABx is disabled.                                    |
| 1            | 0              | 1              | Reserved.   |
| 1            | 1              | 0              | Reserved.   |
| 1            | 1              | 1              | Generate a Trace Fault.   |

Note: "X" = don't care. Reserved combinations must not be used.

The mode bits of BPCON control what type of access generates a fault, trace message, or break event, as summarized in Table 10-3.

**Table 10-3. Programming the Data Address Breakpoint Modes**

| <b>DABx.m1</b> | <b>DABx.m0</b> | <b>Mode</b>                              |
|----------------|----------------|--|
| 0              | 0              | Break on Data Write Access Only.         |
| 0              | 1              | Break on Data Read or Data Write Access. |
| 1              | 0              | Break on Data Read Access.               |
| 1              | 1              | Any access.                              |

### 10.2.7.5 Data Address Breakpoint Registers

The format for the Data Address Breakpoint (DAB) registers is shown in Figure 10-3. Data Address Breakpoint Register Format. Each of the two breakpoint registers contains a 32-bit address of a byte to match on.

A breakpoint is triggered when both a data access's type and address matches that specified by BPCON and the appropriate DAB register. The mode bits for each DAB register, which are contained in BPCON (see section 10.2.7.4), qualify the access types that DAB will match. An access-type match selects that DAB register to perform address checking. An address match occurs when the byte address of any of the bytes referenced by the data access matches the byte address contained within a selected DAB.

Consider the following example. DAB0 is enabled to break on any data read access and has a value of 100FH. Any of the following instructions will cause the DAB0 breakpoint to be triggered:

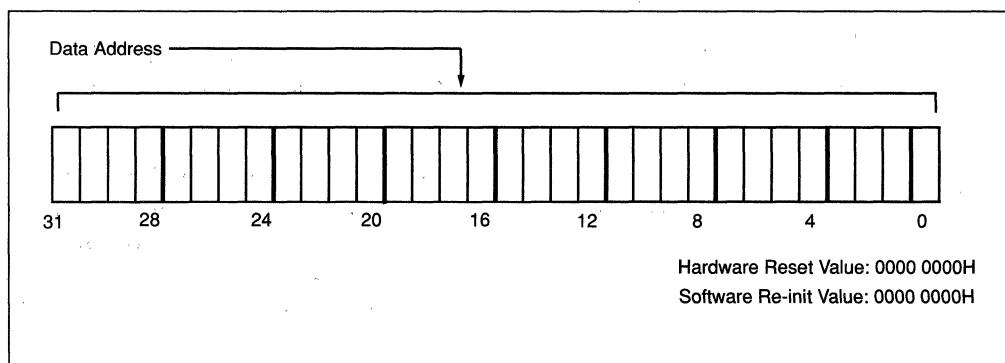
```
ldob  0x100f,r8  
ldos  0x100e,r8  
ld    0x100c,r8  
ld    0x100d,r8    /* even unaligned accesses */  
ldl   0x1008,r8  
ldq   0x1000,r8
```

Note that "Idt 0x1000,r8" will not cause the breakpoint to be triggered because byte 100FH is not referenced by the triple word access.

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Data address breakpoints can be set to break on any data read, any data write, or any data read or data write access. All accesses qualify for checking. These include explicit load and store instructions, and implicit data accesses performed by other instructions and normal processor operations.

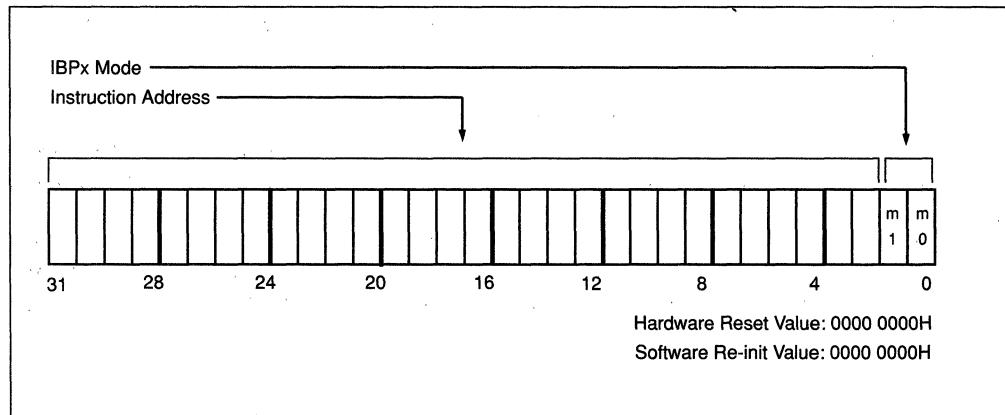
For data accesses to the memory-mapped control register space, it is unpredictable whether breakpoint traces are generated when the access matches the breakpoints and also results in an OPERATION fault or TYPE.MISMATCH fault. The OPERATION or TYPE.MISMATCH fault will always be reported in this case.



**Figure 10-3. Data Address Breakpoint Register Format**

#### 10.2.7.6 Instruction Breakpoint Registers

The format for the instruction breakpoint registers is given in Figure 10-4. Instruction Breakpoint Register Format. The upper thirty bits of the IBPx register contains the word-aligned, instruction address to break on. The two low-order bits indicate the action to take upon an address match.



**Figure 10-4. Instruction Breakpoint Register Format**

Programming the instruction breakpoint register modes is shown in Table 10-4.

On the i960 Jx microprocessor, the instruction breakpoint memory-mapped registers can be read by using the **sysctl** instruction only. They can be modified by **sysctl** or by a word-length store instruction.

**Table 10-4. Instruction Breakpoint Modes**

| PC.te | IBPx.m1 | IBPx.m0 | Action                        |
|-------|---------|---------|-------------------------------|
| 0     | X       | X       | No action. Globally disabled. |
| X     | 0       | 0       | No action. IBPx disabled.     |
| 1     | 0       | 1       | Reserved.                     |
| 1     | 1       | 0       | Reserved.                     |
| 1     | 1       | 1       | Generate a Trace Fault.       |

Note: "X" = don't care. Reserved combinations must not be used.

### 10.3 GENERATING A TRACE FAULT

To summarize the information presented in the previous sections, the processor services a trace fault when PC.te is set and the processor detects any of the following conditions:

- An instruction included in a trace mode group executes or is about to execute (in the case of a prereturn trace event) and the trace mode for that instruction is enabled.
- A fault call operation executes and the call-trace mode is enabled.
- A **mark** instruction executes and the breakpoint-trace mode is enabled.
- An **fmark** instruction executes.
- The processor executes an instruction at an IP matching an enabled instruction address breakpoint register.
- The processor issues a memory access matching the conditions of an enabled data address breakpoint register.

### 10.4 HANDLING MULTIPLE TRACE EVENTS

With the exception of a prereturn trace event, which is always reported alone, it is possible for a combination of trace events to be reported in the same fault record. The processor may not report all events; however, it will always report a supervisor event and it will always signal at least one event.

If the processor reports prereturn trace and other trace types at the same time, it reports the other trace types in a single trace fault record first, and then services the prereturn trace fault upon return from the other trace fault.

## 10.5 TRACE FAULT HANDLING PROCEDURE

The processor calls the trace fault handling procedure when it detects a trace event. See section 9.7, "FAULT HANDLING PROCEDURES" (pg. 9-13) for general requirements for fault handling procedures.

The trace fault handling procedure is involved in a specific way and is handled differently than other faults. A trace fault handler must be invoked with an implicit system-supervisor call. When the call is made, the PC register trace enable bit is cleared. This disables trace faults in the trace fault handler. Recall that, for all other implicit or explicit system-supervisor calls, the trace enable bit is replaced with the system procedure table trace control bit. The exceptional handling of trace enable for trace faults ensures that tracing is turned off when a trace fault handling procedure is being executed. This is necessary to prevent an endless loop of trace fault handling calls.

### 10.5.1 Tracing and Interrupt Procedures

When the processor invokes an interrupt handling procedure to service an interrupt, it disables tracing. It does this by saving the PC register's current state in the interrupt record, then clearing the PC register trace enable bit.

On returning from the interrupt handling procedure, the processor restores the PC register to the state it was in prior to handling the interrupt, which restores the trace enable bit. See section 10.5.2.2, "Tracing on Implicit Call" (pg. 10-13) and section 10.5.2.5, "Tracing on Return from Implicit Call: Interrupt Case" (pg. 10-15) for a detailed description of tracing on calls and returns from interrupts.

### 10.5.2 Tracing on Calls and Returns

During call and return operations, the trace enable flag (PC.te) may be altered. This section discusses how tracing is handled on explicit and implicit calls and returns.

Since all trace faults (except prereturn) are serviced after execution of the traced instruction, tracing on calls and returns is controlled by the PC.te in effect after the call or the return.

#### 10.5.2.1 Tracing on Explicit Call

Tracing an explicit call happens before execution of the first instruction of the procedure called.

Tracing is not modified by using a **call** or **callx** instruction. Further, tracing is not modified by using a **calls** instruction from supervisor mode. When **calls** is issued from user mode, PC.te is read from the supervisor stack pointer trace enable bit (SSP.te) of the system procedure table, which is cached on chip during initialization. The trace enable bit in effect before the **calls** is

stored in the new PFP[0] bit and is restored upon return from the routine (see section 10.5.2.3, “Tracing on Return from Explicit Call” (pg. 10-14)). The **calls** instruction and all instructions of the procedure called are traced according to the new PC.te.

Table 10-5 summarizes all cases; a and x are bit variables.

**Table 10-5. Tracing on Explicit Call**

| Call Type   | Source PC.te | Source PC.em | PFP.rrr | Target PC.te | Trace Enable Used for Traces on Call |
|-------------|--------------|--------------|---------|--------------|--------------------------------------|
| call, callx | a            | x            | 000     | a            | a                                    |
| calls       | a            | super        | 000     | a            | a                                    |
| calls       | a            | user         | 01a     | SSP.te       | SSP.te                               |

### 10.5.2.2 Tracing on Implicit Call

Tracing on an implicit call happens before execution of the first instruction of the non-trace fault handler called. Table 10-6 summarizes all cases of tracing on implicit call. In the table, a is a bit variable that symbolizes the trace enable bit in PC.

**Table 10-6. Tracing on Implicit Call**

| Call Type                                | SPT entry | rrr                               | Source PC.te | Target PC.te | TE Used for Traces on Implicit Call |
|--|-----------|-----------------------------------|--------------|--------------|-------------------------------------|
| 00-Flt*                                  | N.A.      | 001                               | a            | a            | a                                   |
| 10-Flt*                                  | 00        | 001                               | a            | a            | a                                   |
| 10-Flt*                                  | 10        | 001                               | a            | SSP.te       | SSP.te                              |
| 00-Parallel/Override Flt<br>00-Trace Flt | x         | Type of trace fault not supported |              |              |                                     |
| 10-Parallel/Override Flt<br>10-Trace Flt | 00        | Type of trace fault not supported |              |              |                                     |
| 10-Parallel/Override Flt<br>10-Trace Flt | 10        | 001                               | a            | 0            | 0                                   |
| Interrupt                                | N.A.      | 111                               | a            | 0            | 0                                   |

\* All faults except parallel/override and trace faults

Tracing is not altered on the way to a local or a system-local fault handler, so the call is traced if PC.te and TC.call are set before the call. For an implicit system-supervisor call, PC.te is read from SSP.te. The trace on the call is serviced before execution of the first instruction of the non-trace fault handler (tracing is disabled on the way to a trace fault handler).

The only type of parallel/override fault handler supported is the system-supervisor type. Tracing is disabled on the way to the parallel/override fault handler.

The only type of trace fault handler supported is the system-supervisor type. Tracing is disabled on the way to the trace fault handler.

Tracing is disabled by the processor on the way to an interrupt handler, so an interrupt call is never traced.

Note that the Fault IP field of the fault record is not defined when tracing a fault call, because there is no instruction pointer associated to an implicit call.

#### **10.5.2.3 Tracing on Return from Explicit Call**

Table 10-7 shows all cases.

**Table 10-7. Tracing on Return From Explicit Call**

| PFP.rrr | PC.em | PC.te | Trace Enable Used for Trace on Return |
|---------|-------|-------|---------------------------------------|
| 000     | x     | w     | w                                     |
| 01a     | user  | w     | w                                     |
| 01a     | super | w     | a                                     |

For a return from local call (return type 000), tracing is not modified. For a return from system call (return type 01a, with PC.te equal to “a” before the call), tracing of the return and subsequent instructions is controlled by “a”, which is restored in the PC.te during execution of the return.

#### **10.5.2.4 Tracing on Return from Implicit Call: Fault Case**

When the processor detects several fault conditions on the same instruction (referred as the “target”), the non-trace fault is serviced first. Upon return from the non-trace fault handler, the processor services a trace fault on the target if in supervisor mode before the return and if the trace enable and trace fault pending flags are set in the PC field of the non-trace fault record (at FP-16).

If the processor is in user mode before the return, tracing is not altered. The pending trace on the target instruction is lost, and the return is traced according to the current PC.te. Table 10-8 summarizes the two cases:

**Table 10-8. Tracing on Return from Fault**

| PFP.rrr | PC.em<br>Before<br>Return | PC.te<br>Before<br>Return | Target PC.te<br>After Return | Pending Trace on<br>Target When | Trace on<br>Return When |
|---------|---------------------------|---------------------------|------------------------------|---------------------------------|-------------------------|
| 001     | user                      | w                         | w                            | Pending Trace is Lost           | w & TC.event            |
| 001     | super                     | w                         | (FP-16).te                   | (FP-16).te &<br>(FP-16).tfp     | Not Traced              |

#### 10.5.2.5 Tracing on Return from Implicit Call: Interrupt Case

When an interrupt and a trace fault are reported on the same instruction, the instruction completes and then the interrupt is serviced. Upon return from the interrupt, the trace fault is serviced, if the interrupt handler did not switch to user mode. On the i960 Jx processor, the interrupt handler returns directly to the trace fault handler.

If the interrupt return is executed from user mode, the PC register is not restored and tracing of the return occurs according to the PC.te and TC.modes bit fields.

Table 10-9 summarizes the user and supervisor cases:

**Table 10-9. Tracing on Return from Interrupt**

| rrr | PC.em | PC.te | Tgt PC.te  | Pending Trace on Target When | Trace on Return When |
|-----|-------|-------|------------|------------------------------|----------------------|
| 111 | user  | w     | w          | Pending Trace is Lost        | w & TC.ev            |
| 111 | super | w     | (FP-16).TE | RIP points to trace handler  | Not Traced*          |

\* Assume the interrupt handler does not turn tracing on. If it does, it is unpredictable whether the return is traced or not.





11

## INITIALIZATION AND SYSTEM REQUIREMENTS



# CHAPTER 11

## INITIALIZATION AND SYSTEM REQUIREMENTS

This chapter describes the steps that the i960<sup>®</sup> Jx processor performs during initialization. Discussed are the **RESET** pin, the reset state and built-in self test (BIST) features. This chapter also describes the processor's basic system requirements — including power, ground and clock — and concludes with some general guidelines for high-speed circuit board design.

### 11.1 OVERVIEW

During the time that the **RESET** pin is held asserted, the processor is in a quiescent reset state. All external pins are inactive and the internal processor state is forced to a known condition. The processor begins initialization when the **RESET** pin is deasserted.

When initialization begins, the processor uses an Initial Memory Image (IMI) to establish its state. The IMI includes:

- Initialization Boot Record (IBR) – contains the addresses of the first instruction of the user's code and the PRCB.
- Process Control Block (PRCB) – contains pointers to system data structures; also contains information used to configure the processor at initialization.
- System data structures – the processor caches several data structure pointers internally at initialization.

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Software can reinitialize the processor. When a reinitialization takes place, a new PRCB and reinitialization instruction pointer are specified. Reinitialization is useful for relocating data structures from ROM to RAM after initialization.

The i960 Jx processor supports several facilities to assist in system testing and startup diagnostics. ONCE mode electrically removes the processor from a system. This feature is useful for system-level testing where a remote tester exercises the processor system. The i960 Jx processor also supports JTAG boundary scan (see Chapter 17, TEST FEATURES). During initialization, the processor performs an internal functional self test and external bus self test. These features are useful for system diagnostics to ensure basic CPU and system bus functionality.

The processor is designed to minimize the requirements of its external system. It requires an input clock (CLKIN) and clean power and ground connections ( $V_{SS}$  and  $V_{CC}$ ). Since the processor can operate at a high frequency, the external system must be designed with considerations to reduce induced noise on signals, power and ground.

## INITIALIZATION AND SYSTEM REQUIREMENTS

### 11.2 INITIALIZATION

Initialization describes the mechanism that the processor uses to establish its initial state and begin instruction execution. Initialization begins when the **RESET** pin is deasserted. At this time, the processor automatically configures itself with information specified in the IMI and performs its built-in self test based on the sampling of the **STEST** pin. The processor then branches to the first instruction of user code. See Figure 11-1 for a flow chart of i960 Jx processor initialization.

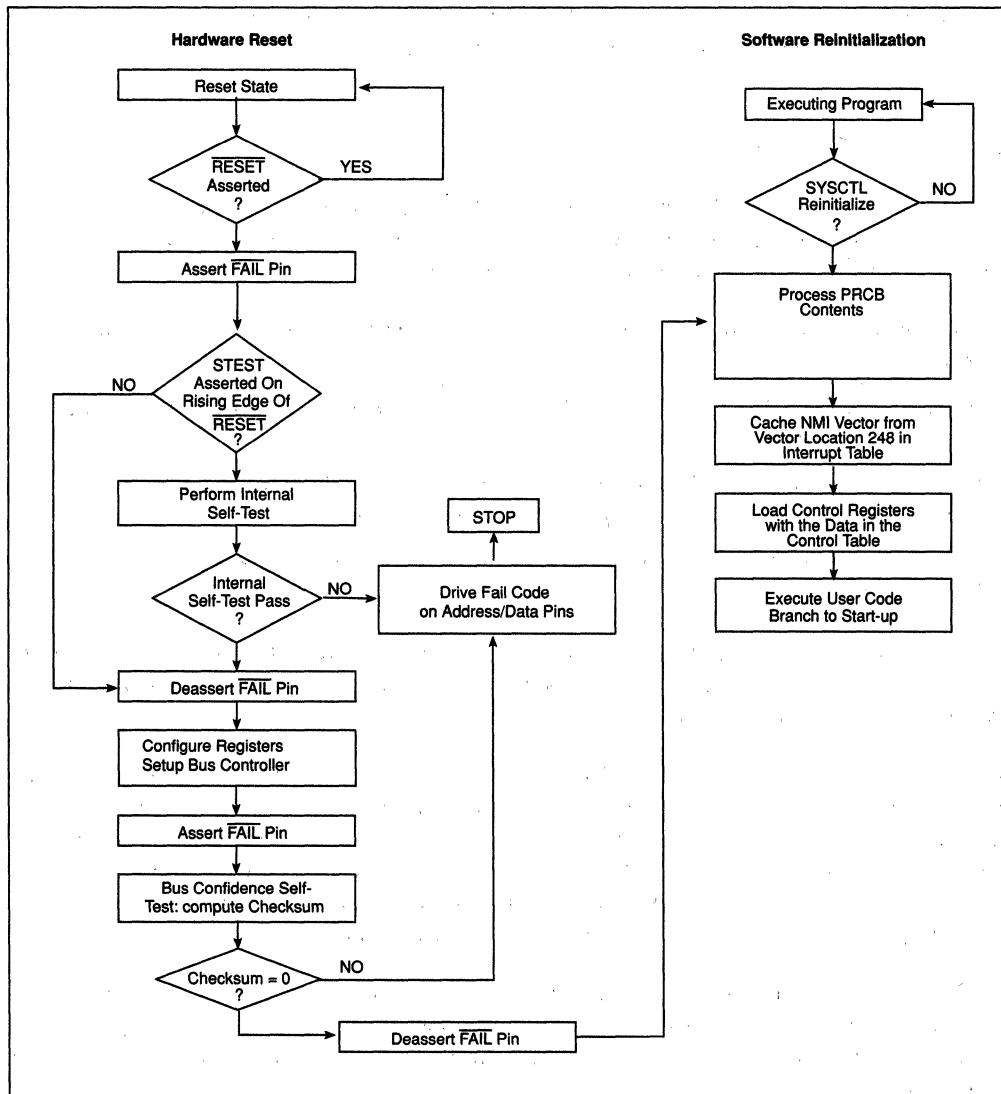


Figure 11-1. Processor Initialization Flow

The objective of the initialization sequence is to provide a complete, working initial state when the first user instruction executes. The user's startup code needs only to perform several basic functions to place the processor in a configuration for executing application code.

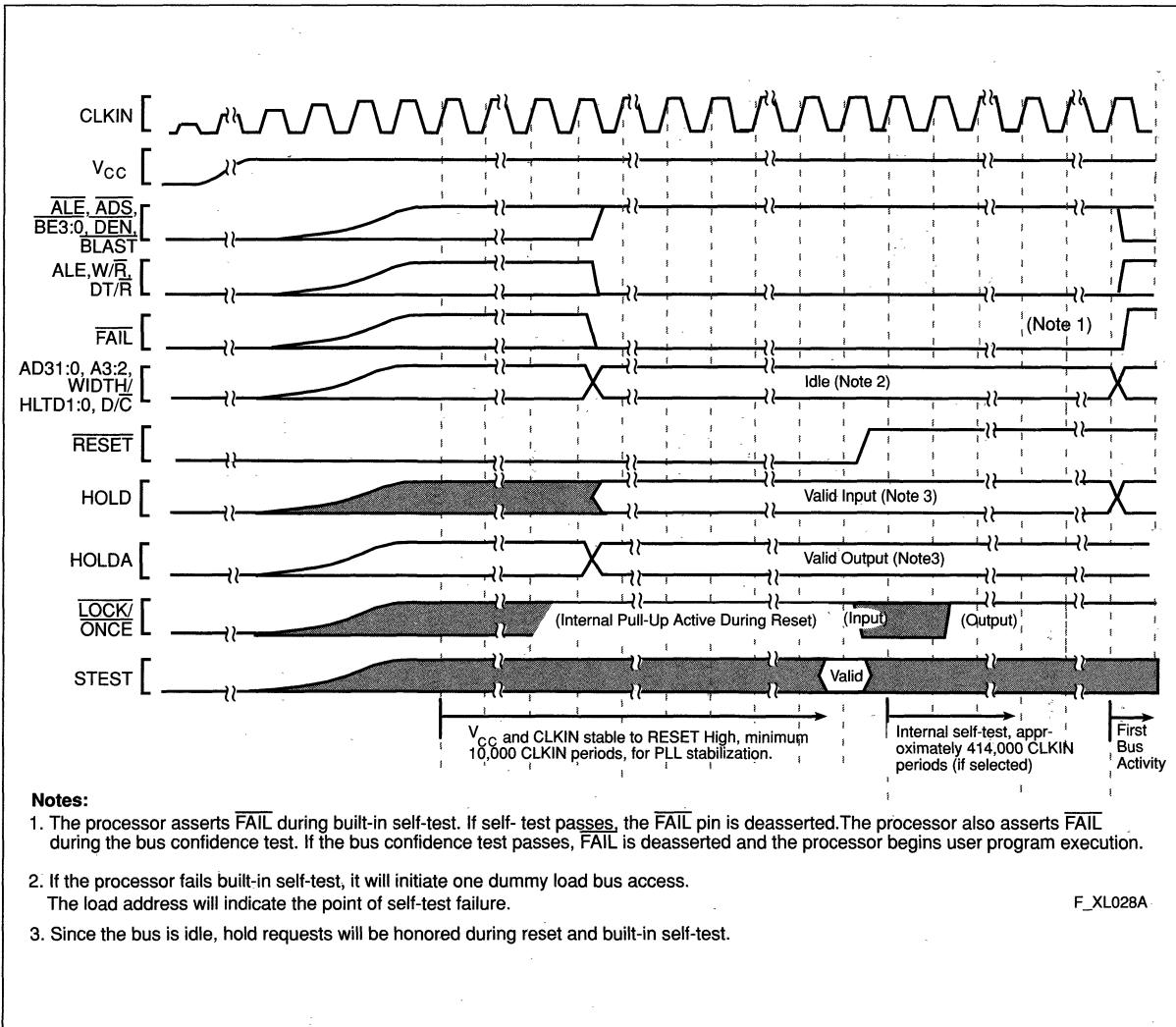
### 11.2.1 Reset State Operation

The **RESET** pin, when asserted (active low), causes the processor to enter the reset state. All external signals go to a defined state (Table 11-1), internal logic is initialized, and certain registers are set to defined values (Table 11-2). When the **RESET** pin is deasserted, the processor initializes as described in section 11.5, "Startup Code Example" (pg. 11-23). **RESET** is a level-sensitive, asynchronous input. If HOLD is asserted while the processor is in reset, the processor will acknowledge the request. All external pins will assume their usual Th states while the bus is in the hold state.

The **RESET** pin must be asserted when power is applied to the processor. The processor then stabilizes in the reset state. This power-up reset is referred to as *cold reset*. To ensure that all internal logic has stabilized in the reset state, a valid input clock (CLKIN) and V<sub>CC</sub> must be present and stable for a specified time before **RESET** can be deasserted.

The processor may also be cycled through the reset state after execution has started. This is referred to as *warm reset*. For a warm reset, the **RESET** pin must be asserted for a minimum number of clock cycles. If a warm reset is asserted during a bus hold, the processor continues to drive HOLDA until HOLD is deasserted. However, the processor will begin the internal initialization process. Specifications for a cold and warm reset can be found in the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* or the *80960JD Embedded 32-bit Microprocessor Data Sheet*.

While the processor's **RESET** pin is asserted, output pins are driven to the states as indicated in Table 11-1. The reset state cannot be entered under direct control from user code. No reset instruction — or other condition that forces a reset — exists on the i960 Jx processors. The **RESET** pin must be asserted to enter the reset state. The processor does, however, provide a means to re-enter the initialization process. See section 11.4.1, "Reinitializing and Relocating Data Structures" (pg. 11-22).

**Figure 11-2. Cold Reset Waveform**

**Table 11-1. Pin Reset State**

| Pins          | Reset State     | Pins       | Reset State     |
|---------------|-----------------|------------|-----------------|
| AD31:0        | Floating        | W/R        | Low (read)      |
| ALE           | Low (inactive)  | DT/R       | Low (receive)   |
| ALE           | High (inactive) | DEN        | High (inactive) |
| ADS           | High (inactive) | BLAST      | High (inactive) |
| A3:2          | Floating        | LOCK/ ONCE | High (inactive) |
| BE3:0         | High (inactive) | HOLDA      | Valid Output    |
| WIDTH/HLTD1:0 | Floating        | FAIL       | Low (Active)    |
| D/C           | Floating        | TDO        | Valid Output    |

**Table 11-2. Register Values After Reset (Sheet 1 of 2)**

| Register | Value After Cold Reset   | Value After Software Re-Init               |
|----------|--|--|
| AC       | AC initial image in PRCB   | AC initial image in PRCB                   |
| PC       | 001F2002H  | 001F2002H                                  |
| TC       | initial image in Control Table, offset 68H                               | initial image in Control Table, offset 68H |
| FP (g15) | interrupt stack base   | interrupt stack base                       |
| PFP (r0) | undefined  | value before software re-init              |
| SP (r1)  | interrupt stack base+64  | interrupt stack base+64                    |
| RIP (r2) | undefined  | undefined                                  |
| IPND     | undefined  | value before software re-init              |
| IMSK     | 00H  | 00H  |
| LMAR0-1  | undefined  | value before software re-init              |
| LMMR0-1  | bit 0 = 0; bits 1 -31 = undefined  | value before software re-init              |
| DLMCON   | bit 0 = bit 7 of byte at FEFF FF3CH<br>bit 1 = 0; bits 2 -31 = undefined | value before software re-init              |
| TRR0-1   | undefined  | value before software re-init              |
| TCR0-1   | undefined  | value before software re-init              |
| TMR0-1   | bits 1-6 = 0; bits 0, 7-31 = undefined                                   | bits 1-6 = 0; bits 0, 7-31 = undefined     |
| IPB0     | 0000.0000H   | 0000.0000H                                 |
| IPB1     | 0000.0000H   | 0000.0000H                                 |
| DAB0     | 0000.0000H   | 0000.0000H                                 |
| DAB1     | 0000.0000H   | 0000.0000H                                 |
| IMAP0    | initial image in Control Table, offset 10H                               | initial image in Control Table, offset 10H |
| IMAP1    | initial image in Control Table, offset 14H                               | initial image in Control Table, offset 14H |

**Table 11-2. Register Values After Reset (Sheet 2 of 2)**

| Register   | Value After Cold Reset                     | Value After Software Re-Init               |
|------------|--|--|
| IMAP2      | initial image in Control Table, offset 18H | initial image in Control Table, offset 18H |
| ICON       | initial image in Control Table, offset 1CH | initial image in Control Table, offset 1CH |
| PMCON0_1   | initial image in Control Table, offset 20H | initial image in Control Table, offset 20H |
| PMCON2_3   | initial image in Control Table, offset 28H | initial image in Control Table, offset 28H |
| PMCON4_5   | initial image in Control Table, offset 30H | initial image in Control Table, offset 30H |
| PMCON6_7   | initial image in Control Table, offset 38H | initial image in Control Table, offset 38H |
| PMCON8_9   | initial image in Control Table, offset 40H | initial image in Control Table, offset 40H |
| PMCON10_11 | initial image in Control Table, offset 48H | initial image in Control Table, offset 48H |
| PMCON12_13 | initial image in Control Table, offset 50H | initial image in Control Table, offset 50H |
| PMCON14_15 | initial image in Control Table, offset 58H | initial image in Control Table, offset 58H |
| BPCON      | 0000.0000H                                 | Value before software re-init.             |
| BCON       | initial image in Control Table, offset 6CH | initial image in Control Table, offset 6CH |
| DEVICEID   | initialized by reset process               | initialized by reset process               |

### 11.2.2 Self Test Function (STEST, FAIL)

As part of initialization, the i960 Jx processor executes a bus confidence self test, an alignment check for data structures within the initial memory image (IMI), and optionally, an built-in self test program. The self test (STEST) pin enables or disables built-in self test. The FAIL pin indicates that the self tests passed or failed by asserting FAIL. During normal operations the FAIL pin can be asserted if a System Error is detected. The following subsections further describe these pin functions.

Internal self test checks basic functionality of internal data paths, registers and memory arrays on-chip. Internal self test is not intended to be a full validation of processor functionality; it is intended to detect catastrophic internal failures and complement a user's system diagnostics by ensuring a confidence level in the processor before any system diagnostics are executed.

#### 11.2.2.1 The STEST Pin

The STEST pin enables and disables Built-In Self Test (BIST). BIST can be disabled if the initialization time needs to be minimized or if diagnostics are simply not necessary. The STEST pin is sampled on the rising edge of the RESET input:

- If STEST is asserted (high), the processor executes the built-in self test.
- If STEST is deasserted, the processor bypasses built-in self test.

### 11.2.2.2 External Bus Confidence Test

The external bus confidence test is always performed regardless of STEST pin value.

The external bus confidence test checks external bus functionality; it reads eight words from the Initialization Boot Record (IBR) and performs a checksum on the words and the constant FFFF FFFFH. The test passes only when the processor calculates a sum of zero (0). The external bus confidence test can detect catastrophic bus failures such as external address, data or control lines that are stuck, shorted or open.

### 11.2.2.3 The Fail Pin (FAIL)

The FAIL pin signals errors in either the built-in self test or bus confidence self test. FAIL is asserted (low) for each self test (Figure 11-3):

- When any test fails, the FAIL pin remains asserted, a fail code message is driven onto the address bus, and the processor stops execution at the point of failure.
- When a system error occurs, FAIL is also asserted. See section 11.2.2.4, “IMI Alignment Check and System Error” (pg. 11-8) for details.
- When the test passes, FAIL is deasserted.

If FAIL stays asserted, the only way to resume normal operation is to perform a reset operation. When the STEST pin is used to disable the built-in self test, the test does not execute; however, FAIL still asserts at the point where the built-in self test would occur. FAIL is deasserted after the bus confidence test passes. In Figure 11-3, all transitions on the FAIL pin are relative to CLKIN as described in the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet*.

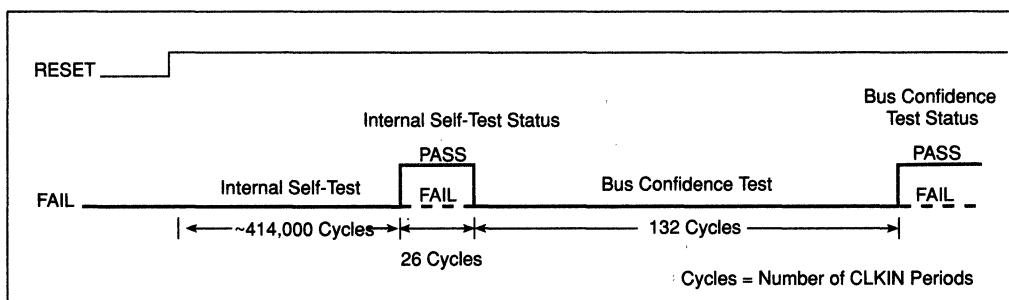


Figure 11-3. FAIL Timing (80960JA/JF Case)

#### 11.2.2.4 IMI Alignment Check and System Error

The alignment check during initialization for data structures within the IMI ensures that the PRCB, control table, interrupt table, system-procedure table, and fault table are aligned to word boundaries. Normal processor operation is not possible without the alignment of these key data structures. The alignment check is one case where a System Error could occur.

The other case of System Error can occur during regular operation when generation of an override fault incurs a fault. The sequence of events leading up to this case is quite uncommon.

When a System Error is detected, the FAIL pin is asserted, a fail code message is driven onto the address bus, and the processor stops execution at the point of failure. The only way to resume normal operation of the processor is to perform a reset operation. Because System Error generation can occur sometime after the BUS confidence test and even after initialization during normal processor operation, the FAIL pin will be at a logic one before the detection of a System Error.

#### 11.2.2.5 FAIL Code

The processor uses only one read bus transaction to signal the fail code message; the address of the bus transaction is the fail code itself. The fail code is of the form: **0xfeffffnn**; bits 6 to 0 contain a mask recording the possible failures. Bit 7, when one, indicates the mask contains failures from Built-In Self-Test (BIST); when zero, the mask indicates other failures. The fail codes are shown in Table 11-3 and Table 11-4.

**Table 11-3. Fail Codes For BIST (bit 7 = 1)**

| Bit | When set:  |
|-----|--|
| 6   | On-chip Data-RAM failure detected by BIST  |
| 5   | Internal Microcode ROM failure detected by BIST                                    |
| 4   | I-cache failure detected by BIST   |
| 3   | D-cache failure detected by BIST   |
| 2   | Local-register cache or processor core (RF, EU, MDU, PSQ) failure detected by BIST |
| 1   | Always Zero.   |
| 0   | Always Zero.   |

**Table 11-4. Remaining Fail Codes (bit 7 = 0)**

| Bit | When set:  |
|-----|--|
| 6   | Always One; this bit does not indicate a failure.                  |
| 5   | Always One; this bit does not indicate a failure.                  |
| 4   | A data structure within the IMI is not aligned to a word boundary. |
| 3   | A System Error during normal operation has occurred.               |
| 2   | The Bus Confidence test has failed.                                |
| 1   | Always Zero.   |
| 0   | Always Zero.   |

## 11.3 ARCHITECTURALLY RESERVED MEMORY SPACE

The i960 Jx microprocessor contains  $2^{32}$  bytes of address space. Portions of this address space are architecturally reserved and must not be used by customers. Figure 3-2. Memory Address Space (pg. 3-13) shows the reserved address space. The i960 Jx suppresses all external bus cycles from 0 to 3FFH and from FF00 0000H to FFFF FFFFH.

Addresses FEFF FF60H through FFFF FFFFH are reserved for implementation-specific functions. This address range is termed “reserved” since i960 architecture implementations may use these addresses for functions such as memory-mapped registers or data structures. Therefore, to ensure complete object level compatibility, portable code must not access or depend on values in this region.

The i960 Jx microprocessor uses the reserved address range 0000 0000H through 0000 03FFH for internal data RAM. This internal data RAM is used for storage of interrupt vectors plus general purpose storage available for application software variable allocation or data structures. Loads and stores directed to these addresses access internal memory; instruction fetches from these addresses are not allowed for the i960 Jx microprocessor. See Chapter 4, CACHE AND ON-CHIP DATA RAM, for more details.

### 11.3.1 Initial Memory Image (IMI)

The IMI comprises the minimum set of data structures that the processor needs to initialize its system. As shown in Figure 11-4, these structures are: the initialization boot record (IBR), process control block (PRCB) and system data structures. The IBR is located at a fixed address in memory. The other components are referenced directly or indirectly by pointers in the IBR and the PRCB.

## INITIALIZATION AND SYSTEM REQUIREMENTS

The IMI performs three functions for the processor:

- Provides initial configuration information for the core and integrated peripherals.
- Provides pointers to the system data structures and the first instruction to be executed after processor initialization.
- Provides checksum words that the processor uses in its self test routine at startup.

Several data structures are typically included as part of the IMI because values in these data structures are accessed by the processor during initialization. These data structures are usually programmed in the system's boot ROM, located in memory region 14\_15 of the address space. The required data structures are:

- PRCB
- IBR
- System procedure table
- Control table
- Interrupt table
- Fault table

To ensure proper processor operation, the PRCB, system procedure table, control table, interrupt table, and fault table must not be located in architecturally reserved memory -- addresses reserved for on-chip Data RAM and addresses at and above FEFF FF60H. In addition, each of these structures must start at a word-aligned address; a System Error occurs if any of these structures are not word-aligned (see section 11.2.2.3).

At initialization, the processor loads the Supervisor Stack Pointer (SSP) from the system procedure table, aligns it to a 16-byte boundary, and caches the pointer in the SSP memory-mapped control register (see section 3.3, "MEMORY-MAPPED CONTROL REGISTERS" (pg. 3-5)). Recall that the supervisor stack pointer is located in the preamble of the system procedure table at byte offset 12 from the base address. The system procedure table base address is programmed in the PRCB. Consult section 7.5.1, "System Procedure Table" (pg. 7-16) for the format of the system procedure table.

At initialization, the NMI vector is loaded from the interrupt table and saved at location 0000 0000H of the internal data RAM. The interrupt table is typically programmed in the boot ROM and then relocated to internal RAM by reinitializing the processor.

The fault table is typically located in boot ROM. If it is necessary to locate the fault table in RAM, the processor must be reinitialized.

The remaining data structures that an application may need are the user stack, supervisor stack and interrupt stack. These stacks must be located in a system's RAM.

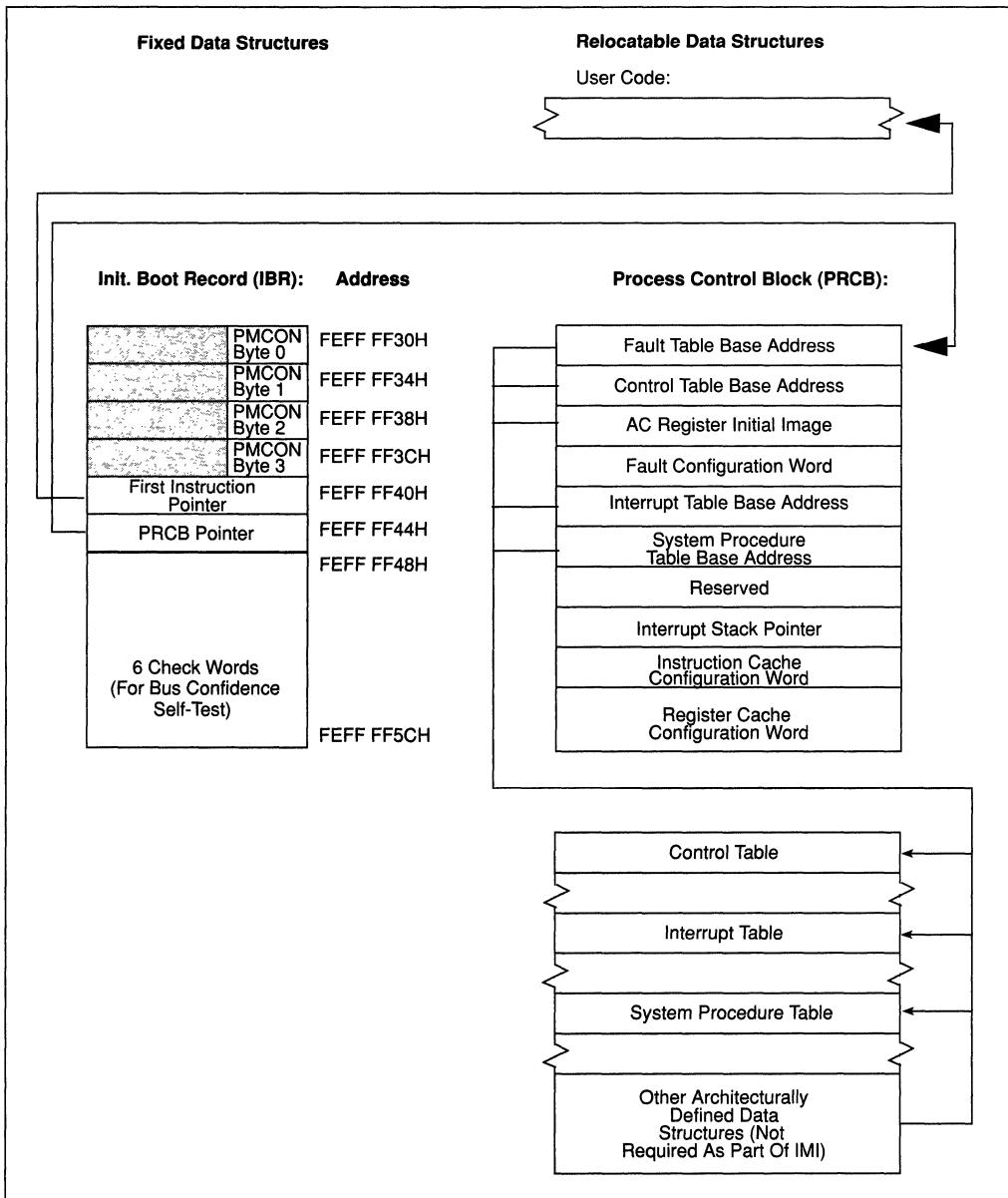


Figure 11-4. Initial Memory Image (IMI) and Process Control Block (PRCB)

### 11.3.1.1 Initialization Boot Record (IBR)

The initialization boot record (IBR) is the primary data structure required to initialize the i960 Jx processor. The IBR is a 12-word structure which must be located at address FEFF FF30H (see Table 11-5). The IBR is made up of four components: the initial bus configuration data, the first instruction pointer, the PRCB pointer and the bus confidence test checksum data.

**Table 11-5. Initialization Boot Record**

| Byte Physical Address  | Description                           |
|------------------------|---------------------------------------|
| FEFF FF30H             | PMCON14_15, byte 0                    |
| FEFF FF31 to FEFF FF33 | <i>Reserved</i>                       |
| FEFF FF34H             | PMCON14_15, byte 1                    |
| FEFF FF35 to FEFF FF37 | <i>Reserved</i>                       |
| FEFF FF38H             | PMCON14_15, byte 2                    |
| FEFF FF39 to FEFF FF3B | <i>Reserved</i>                       |
| FEFF FF3CH             | PMCON14_15, byte 3                    |
| FEFF FF3D to FEFF FF3F | <i>Reserved</i>                       |
| FEFF FF40 to FEFF FF43 | First Instruction Pointer             |
| FEFF FF44 to FEFF FF47 | PRCB Pointer                          |
| FEFF FF48 to FEFF FF4B | Bus Confidence Self-Test Check Word 0 |
| FEFF FF4C to FEFF FF4F | Bus Confidence Self-Test Check Word 1 |
| FEFF FF50 to FEFF FF53 | Bus Confidence Self-Test Check Word 2 |
| FEFF FF54 to FEFF FF57 | Bus Confidence Self-Test Check Word 3 |
| FEFF FF58 to FEFF FF5B | Bus Confidence Self-Test Check Word 4 |
| FEFF FF5C to FEFF FF5F | Bus Confidence Self-Test Check Word 5 |

When the processor reads the IMI during initialization, it must know the bus characteristics of external memory where the IMI is located. Specifically, it must know the bus width and endianism for the remainder of the IMI. At initialization, the processor sets the PMCON register to an 8-bit bus width. The processor then needs to form the initial DLMCON and PMCON14\_15 registers so that the memory containing the IBR can be accessed correctly. The lowest-order byte of each of the IBR's first 4 words are used to form the register values. On the i960 Jx processor, the bytes at FEFF FF30 and FEFF FF34 are not needed, so the processor starts fetching at address FEFF FF38. The loading of these registers is shown in the pseudo-code flow in Example 11-1.

**Example 11-1. Processor Initialization Flow**

```
Processor_Initialization_flow()
{
    FAIL_pin = true;
    restore_full_cache_mode; disable(I_cache); invalidate(I_cache);
    disable(D_cache); invalidate(D_cache);
    BCON.ctv = 0; /* Selects PMCON14_15 to control all accesses */
    PMCON14_15 = 0; /* Selects 8-bit bus width */

    /** Exit Reset State & Start_Init **/
    if (STEST_ON_RISING_EDGE_OF_RESET)
        status = BIST(); /* BIST does not return if it fails */
    FAIL_pin = false;
    PC = 0x001f2002;           /* PC.Priority = 31, PC.em = Supervisor, */
                               /* PC.te = 0; PC.State = Interrupted */
    ibr_ptr = 0xfffffff30;     /* ibr_ptr used to fetch IBR words */

    /** Read PMCON14_15 image in IBR **/
    FAIL_pin = true;          IMSK      = 0;
    DLMCON.dcen = 0;          LMMR0.lmte = 0;   LMMR1.lmte = 0;
    DLMCON.be = (memory[ibr_ptr + 0xc] >> 7);
    PMCON14_15[byte2] = 0xc0 & memory[ibr_ptr + 8];

    /** Compute CheckSum on Boot Record **/
    carry = 0; CheckSum = 0xffffffff;
    for (i=0; i<6; i++) /* carry is carry out from previous add*/
        CheckSum = memory[ibr_ptr + 16 + i*4] + CheckSum + carry;
    if (CheckSum != 0)
        { fail_msg = 0xfffffff64; /* Fail BUS Confidence Test */
          dummy = memory[fail_msg]; /* Do load with address = fail_msg */
          for (;;) ;
        }                         /* loop forever with FAIL pin true */
    else FAIL_pin = false;

    /** Process PRCB and Control Table **/
    prcb_ptr = memory[ibr_ptr+0x14];
    ctrl_table = memory[prcb_ptr+4];
    Process_PRCB(prcb_ptr); /* See Process PRCB Section for Details */
    IP = memory[ibr_ptr+0x10];
    g0 = DEVICE_ID;
    return; /* Execute First Instruction */
}
```

Bit 31 of the assembled PMCON word loaded from the IBR is written to DLMCON.be to establish the initial endianism of memory; the processor initializes the DLMCON.dcen bit to 0 to disable data caching. The remainder of the assembled word is used to initialize PMCON14\_15. In conjunction with this step, the processor clears the bus control table valid bit (BCON.ctv), to ensure for the remainder of initialization that every bus request issued takes configuration information from the PMCON14\_15 register, regardless of the memory region associated with the request. At a later point in initialization, the processor loads the remainder of the memory region

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configuration table from the external control table. The Bus Configuration (BCON) register is also loaded at this time. The control table valid (BCON.ctv) bit is then set in the control table to validate the PMCON registers after they are loaded. In this way, the bus controller is completely configured during initialization. (See Chapter 15, EXTERNAL BUS for a complete discussion of memory regions and configuring the bus controller.)

After the bus configuration data is loaded and the new bus configuration is in place, the processor loads the remainder of the IBR which consists of the first instruction pointer, the PRCB pointer and six checksum words. The PRCB pointer and the first instruction pointer are internally cached. The six checksum words — along with the PRCB pointer and the first instruction pointer — are used in a checksum calculation which implements a confidence test of the external bus. The checksum calculation is shown in the pseudo-code flow in Example 11-1. If the checksum calculation equals zero, then the confidence test of the external bus passes.

Figure 11-4 further describe the IBR organization.

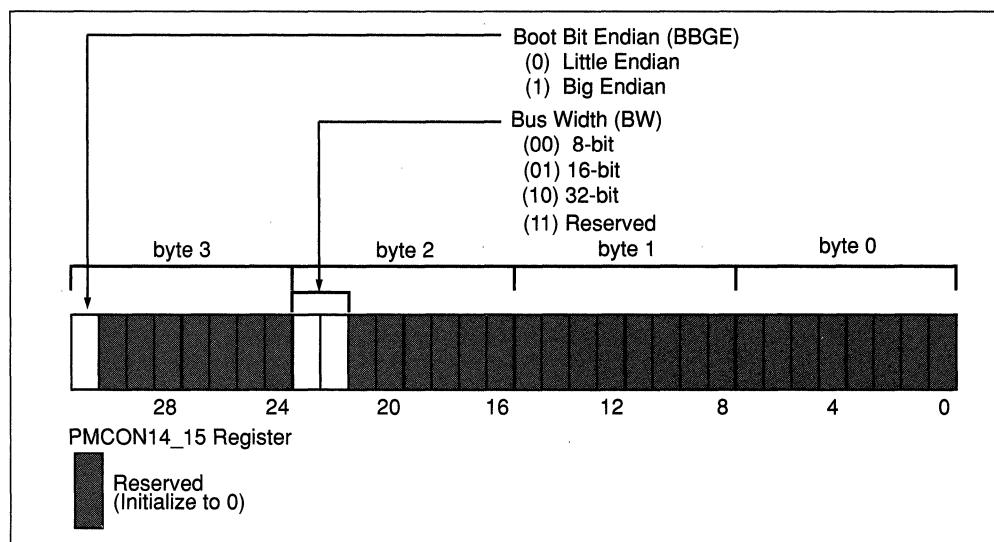


Figure 11-5. PMCON14\_15 Register Bit Description in IBR

### 11.3.1.2 Process Control Block (PRCB)

The PRCB contains base addresses for system data structures and initial configuration information for the core and integrated peripherals. The base addresses are accessed from these internal registers. The registers are accessible to the users through the memory mapped interface. Upon reset or reinitialization, the registers are initialized. The PRCB format is shown in Table 11-6.

**Table 11-6. PRCB Configuration**

| Physical Address   | Description                          |
|--------------------|--------------------------------------|
| PRCB POINTER + 00H | Fault Table Base Address             |
| PRCB POINTER + 04H | Control Table Base Address           |
| PRCB POINTER + 08H | AC Register Initial Image            |
| PRCB POINTER + 0CH | Fault Configuration Word             |
| PRCB POINTER + 10H | Interrupt Table Base Address         |
| PRCB POINTER + 14H | System Procedure Table Base Address  |
| PRCB POINTER + 18H | Reserved                             |
| PRCB POINTER + 1CH | Interrupt Stack Pointer              |
| PRCB POINTER + 20H | Instruction Cache Configuration Word |
| PRCB POINTER + 24H | Register Cache Configuration Word    |

The initial configuration information is programmed in the arithmetic controls (AC) initial image, the fault configuration word, the instruction cache configuration word, and the register cache configuration word. Figure 11-6 shows these configuration words.

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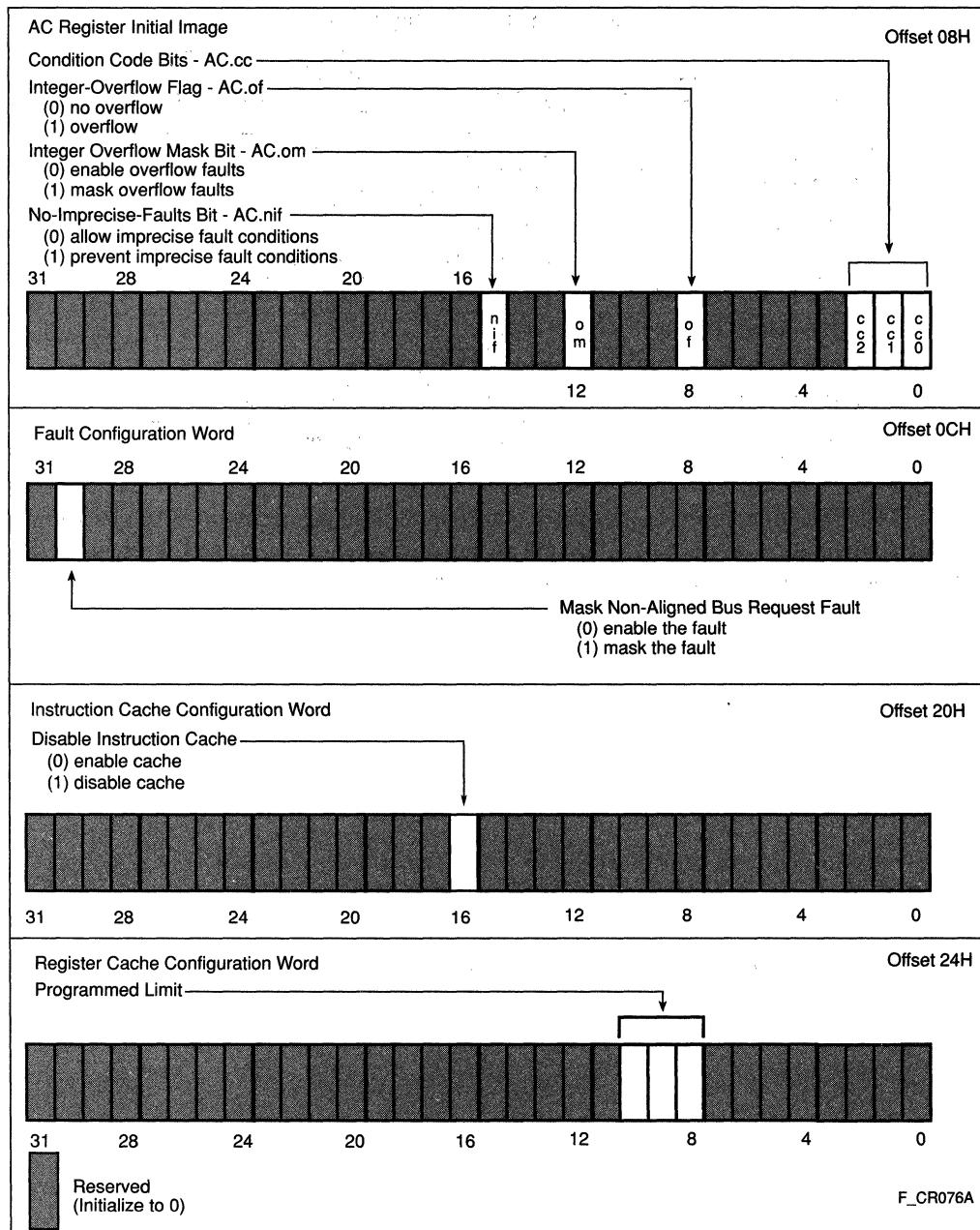


Figure 11-6. Process Control Block Configuration Words

### 11.3.2 Process PRCB Flow

The following pseudo-code flow illustrates the processing of the PRCB. Note that this flow is used for both initialization and reinitialization (through **sysctl**).

**Example 11-2. Process PRCB Flow**

```
Process_PRCB(prcb_ptr)
{
    PRCB_mmr = prcb_ptr;
    reset_state(data_ram); /* It is unpredictable whether the */
                           /* Data RAM keeps its prior contents */
    fault_table = memory[PRCB_mmr];
    ctrl_table = memory[PRCB_mmr+0x4];
    AC = memory[PRCB_mmr+0x8];
    fault_config = memory[PRCB_mmr+0xc];
    if (1 & (fault_config >> 30)) generate_fault_on_unaligned_access = false;
    else                               generate_fault_on_unaligned_access = true;

    /** Load Interrupt Table and Cache NMI Vector Entry in Data RAM**/
    Reset_block_NMI;
    interrupt_table = memory[PRCB_mmr+0x10];
    memory[0] = memory[interrupt_table + (248*4) + 4];

    /** Process System Procedure Table **/
    sysproc = memory[PRCB_mmr+0x14];
    temp = memory[sysproc+0xc];
    SSP_mmr = (~0x3) & temp;
    SSP.te = 1 & temp;

    /** Initialize ISP, FP, SP, and PFP **/
    ISP_mmr = memory[PRCB_mmr+0x1c];
    FP = ISP_mmr;
    SP = FP + 64;
    PFP = FP;

    /** Initialize Instruction Cache **/
    ICCW = memory[PRCB_mmr+0x20];
    if (1 & (ICCW >> 16) ) enable(I_cache);

    /** Configure Local Register Cache **/
    programmed_limit = (7 & (memory[PRCB_mmr+0x24] >> 8) );
    config_reg_cache( programmed_limit );

    /** Load_control_table. Note breakpoints and BPCON are excluded here **/
    load_control_table(ctrl_table+0x10 , ctrl_table+0x58);
    load_control_table(ctrl_table+0x68 , ctrl_table+0x6c);
    IBP0 = 0x0; IBP1 = 0x0; DAB0 = 0x0; DAB1 = 0x0;
    /** Initialize Timers **/
    TMR0.tc = 0; TMR1.tc = 0; TMR0.enable = 0; TMR1.enable = 0;
    TMR0.sup = 0; TMR1.sup = 0; TMR0.reload = 0; TMR1.reload = 0;
    TMR0.csel = 0; TMR1.csel = 0;
    return;
}
```

### **11.3.2.1 AC Initial Image**

The AC initial image is loaded into the on-chip AC register during initialization. The AC initial image allows the initial value of the overflow mask, no imprecise faults bit and condition code bits to be selected at initialization.

The AC initial image condition code bits can be used to specify the source of an initialization or reinitialization when a single instruction entry point to the user startup code is desirable. This is accomplished by programming the condition code in the AC initial image to a different value for each different entry point. The user startup code can detect the condition code values — and thus the source of the reinitialization — by using the compare or compare-and-branch instructions.

### **11.3.2.2 Fault Configuration Word**

The fault configuration word allows the operation-unaligned fault to be masked when an unaligned memory request is issued. (See section 15.2.5, “Data Alignment” (pg. 15-22) for a description of unaligned memory requests.) Whenever an unaligned access is encountered, the processor *always* performs the access. After performing the access, the processor determines whether it should generate a fault. If bit 30 in the fault configuration word is set, a fault is not generated after an unaligned memory request is performed. If bit 30 is clear, a fault is generated after an unaligned memory request is performed.

### **11.3.2.3 Instruction Cache Configuration Word**

The instruction cache configuration word allows the instruction cache to be enabled or disabled at initialization. If bit 16 in the instruction cache configuration word is set, the instruction cache is disabled and all instruction fetches are directed to external memory. Disabling the instruction cache is useful for tracing execution in a software debug environment. The instruction cache remains disabled until one of two operations is performed:

- The processor is reinitialized with a new value in the instruction cache configuration word
- `icctl` is issued with the enable instruction cache operation
- `sysctl` is issued with the configure instruction cache message type and a cache configuration mode other than disable cache

### **11.3.2.4 Register Cache Configuration Word**

The register cache configuration word specifies the number of free frames in the local register cache that can be used by non-critical code — code that is either in the executing state (non-interrupted) or code which is in the interrupted state, but, has a process priority less than 28 — must reserve for critical code (interrupted state and process priority greater than or equal to 28).

The register cache and the configuration word are explained further in section 4.2, “LOCAL REGISTER CACHE” (pg. 4-2).

### 11.3.3 Control Table

The control table is the data structure that contains the on-chip control registers values. It is automatically loaded during initialization and must be completely constructed in the IMI. Figure 11-7 shows the Control Table format.

For register bit definitions of the on-chip control table registers, see the following:

- IMAP — Figure 13-7. Interrupt Mapping (IMAP0-IMAP2) Registers (pg. 13-15)
- ICON — Figure 13-6. Interrupt Control (ICON) Register (pg. 13-13)
- PMCON — Figure 12-2. PMCON Register Bit Description (pg. 12-6)
- TC — Figure 10-1. Trace Controls (TC) Register (pg. 10-2)
- BCON — Figure 12-3. Bus Control Register (BCON) (pg. 12-7)

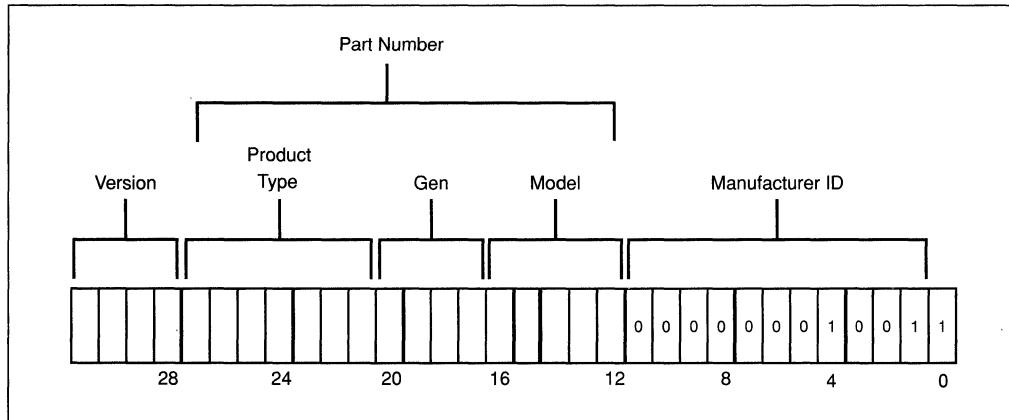
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| 31 | 0   |
|----|---|
|    | Reserved (Initialize to 0)                              |
|    | 00H   |
|    | Reserved (Initialize to 0)                              |
|    | 04H   |
|    | Reserved (Initialize to 0)                              |
|    | 08H   |
|    | Reserved (Initialize to 0)                              |
|    | 0CH   |
|    | Interrupt Map 0 (IMAP0)                                 |
|    | 10H   |
|    | Interrupt Map 1 (IMAP1)                                 |
|    | 14H   |
|    | Interrupt Map 2 (IMAP2)                                 |
|    | 18H   |
|    | Interrupt Configuration (ICON)                          |
|    | 1CH   |
|    | Physical Memory Region 0:1 Configuration (PMCON0_1)     |
|    | 20H   |
|    | Reserved (Initialize to 0)                              |
|    | 24H   |
|    | Physical Memory Region 2:3 Configuration (PMCON2_3)     |
|    | 28H   |
|    | Reserved (Initialize to 0)                              |
|    | 2CH   |
|    | Physical Memory Region 4:5 Configuration (PMCON4_5)     |
|    | 30H   |
|    | Reserved (Initialize to 0)                              |
|    | 34H   |
|    | Physical Memory Region 6:7 Configuration (PMCON6_7)     |
|    | 38H   |
|    | Reserved (Initialize to 0)                              |
|    | 3CH   |
|    | Physical Memory Region 8:9 Configuration (PMCON8_9)     |
|    | 40H   |
|    | Reserved (Initialize to 0)                              |
|    | 44H   |
|    | Physical Memory Region 10:11 Configuration (PMCON10_11) |
|    | 48H   |
|    | Reserved (Initialize to 0)                              |
|    | 4CH   |
|    | Physical Memory Region 12:13 Configuration (PMCON12_13) |
|    | 50H   |
|    | Reserved (Initialize to 0)                              |
|    | 54H   |
|    | Physical Memory Region 14:15 Configuration (PMCON14_15) |
|    | 58H   |
|    | Reserved (Initialize to 0)                              |
|    | 5CH   |
|    | Reserved (Initialize to 0)                              |
|    | 60H   |
|    | Reserved (Initialize to 0)                              |
|    | 64H   |
|    | Trace Controls (TC)                                     |
|    | 68H   |
|    | Bus Configuration Control (BCON)                        |
|    | 6CH   |

**Figure 11-7. Control Table**

## 11.4 DEVICE IDENTIFICATION ON RESET

A number characterizing the microprocessor type and stepping is programmed during manufacture into the DEVICEID memory-mapped register. During initialization, the value is also placed in g0.



**Figure 11-8. IEEE 1149.1 Device Identification Register**

The value for device identification is compliant with the IEEE 1149.1 specification and Intel standards. Table 11-7 describes the fields of the device ID. The Version field corresponds to silicon stepping: for example, 0000 refers to the A-0 stepping.

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**Table 11-7. i960 Jx Processor Device Identification Register Settings by Model**

|   | Part Number         |              |            |              | <b>Manufacturer</b> | <b>1</b> |
|---|---------------------|--------------|------------|--------------|---------------------|----------|
|   | <b>Version</b>      | <b>XType</b> | <b>Gen</b> | <b>Model</b> |                     |          |
| <b>80L960JA,</b><br>3.3V<br>2K Instruction Cache<br>1K Data Cache | xxxx                | 0000 100     | 0 001      | 0 0001       | 0000 0001 001       | 1        |
|   | <b>0x0082 1013</b>  |              |            |              |                     |          |
| <b>80960JF</b><br>5V<br>4K Instruction Cache<br>2K Data Cache     | xxxx                | 1000 100     | 0 001      | 0 0000       | 0000 0001 001       | 1        |
|   | <b>0x0882 0013*</b> |              |            |              |                     |          |
| <b>80L960JF</b><br>3.3V<br>4K Instruction Cache<br>2K Data Cache  | xxxx                | 0000 100     | 0 001      | 0 0000       | 0000 0001 001       | 1        |
|   | <b>0x0082 0013</b>  |              |            |              |                     |          |
| <b>80960JD</b><br>5V<br>4K Instruction Cache<br>2K Data Cache     | xxxx                | 1000 100     | 0 001      | 0 0000       | 0000 0001 001       | 1        |
|   | <b>0x0882 0013*</b> |              |            |              |                     |          |

\*The 80960JF and 80960JD part numbers are the same.

### 11.4.1 Reinitializing and Relocating Data Structures

Reinitialization can reconfigure the processor and change pointers to data structures. The processor is reinitialized by issuing the **sysctl** instruction with the reinitialize processor message type. (See section 6.2.67, “**sysctl**” (pg. 6-114) for a description of **sysctl**.) The reinitialization instruction pointer and a new PRCB pointer are specified as operands to the **sysctl** instruction. When the processor is reinitialized, the fields in the newly specified PRCB are loaded as described in section 11.3.1.2, “Process Control Block (PRCB)” (pg. 11-14).

Reinitialization is useful for relocating data structures to RAM after initialization. The interrupt table must be located in RAM: to post software-generated interrupts, the processor writes to the pending priorities and pending interrupts fields in this table. It may also be necessary to relocate the control table to RAM: it must be in RAM if the control register values are to be changed by user code. In some systems, it is necessary to relocate other data structures (fault table and system procedure table) to RAM because of unsatisfactory load performance from ROM.

After initialization, the software is responsible for copying data structures from ROM into RAM. The processor is then reinitialized with a new PRCB which contains the base addresses of the new data structures in RAM.

Reinitialization is required to relocate any of the data structures listed below, since the processor caches the pointers to the structures.

The processor caches the following pointers during its initialization. To modify these data structures, a software re-initialization is needed.

- Interrupt Table Address
- Fault Table Address
- System Procedure Table Address
- Control Table Address

## 11.5 STARTUP CODE EXAMPLE

After initialization is complete, user startup code typically copies initialized data structures from ROM to RAM, reinitializes the processor, sets up the first stack frame, changes the execution state to non-interrupted and calls the `_main` routine. This section presents an example startup routine and associated header file. This simplified startup file can be used as a basis for more complete initialization routines.

The examples in this section are useful for creating and evaluating startup code. The following lists the example's number, name and page.

- Example 11-3. Initialization Header File (`init.h`) (pg. 11-23)
- Example 11-4., Startup Routine (`init.s`) (pg. 11-24)
- Example 11-5., High-Level Startup Code (`initmain.c`) (pg. 11-28)
- Example 11-6., Control Table (`ctltbl.c`) (pg. 11-29)
- Example 11-7., Initialization Boot Record File (`rom_ibr.c`) (pg. 11-30)
- Example 11-8., Linker Directive File (`init.ld`) (pg. 11-31)
- Example 11-9., Makefile (pg. 11-33)

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### Example 11-3. Initialization Header File (init.h)

```

/*
 *-----*
 * init.h
 *-----*/
 */

#define BYTE_N(n,data)  (((unsigned)(data) >> (n*8)) & 0xFF)

typedef struct

{
    unsigned char bus_byte_0;
    unsigned char reserved_0[3];
    unsigned char bus_byte_1;
    unsigned char reserved_1[3];
    unsigned char bus_byte_2;
    unsigned char reserved_2[3];
    unsigned char bus_byte_3;
    unsigned char reserved_3[3];
    void (*first_inst)();
    unsigned *prcb_ptr;
    int check_sum[6];
} IBR;

/* PMCON Bus Width can be 8,16 or 32, default to 8
 * PMCON14_15 BOOT_BIG_ENDIAN 0=little endian, 1=big endian
 */
#define BUS_WIDTH(bw) ((bw==16)?(1<<22):(0)) | ((bw==32)?(2<<22):(0))
#define BOOT_BIG_ENDIAN (on) ((on)?(1<<31:0))

/* Bus configuration */
#define DEFAULT (BUS_WIDTH(8) | BOOT_BIG_ENDIAN(0))
#define I_O     (BUS_WIDTH(8) | BOOT_BIG_ENDIAN(0))
#define DRAM   (BUS_WIDTH(32) | BOOT_BIG_ENDIAN(0))
#define ROM    (BUS_WIDTH(8) | BOOT_BIG_ENDIAN(0))

```

**Example 11-4. Startup Routine (init.s) (Sheet 1 of 4)**

```
/*-----*/
/* init.s */
/*-----*/
/* initial PRCB */

.globl _rom_prcb
.align 4 /* or .align 2 */
_rom_prcb:
.word boot_flt_table      # 0 - Fault Table
.word _boot_control_table # 4 - Control Table
.word 0x00001000          # 8 - AC reg mask overflow fault
.word 0x40000000          # 12 - Flt CFG
.word boot_intr_table     # 16 - Interrupt Table
.word rom_sys_proc_table # 20 - System Procedure Table
.word 0                   # 24 - Reserved
.word _intr_stack         # 28 - Interrupt Stack Pointer
.word 0x00000000          # 32 - Inst. Cache - enable cache
.word 0x00000200          # 36 - Register Cache Configuration

/* ROM system procedure table */

.equ supervisor_proc, 2
.text
.align 6 /* or .align 2 or .align 4 */
rom_sys_proc_table:
.space 12             # Reserved
.word _supervisor_stack # Supervisor stack pointer
.space 32             # Preserved
.word _default_sysproc # sysproc 0
.word _default_sysproc # sysproc 1
.word _default_sysproc # sysproc 2
.word _default_sysproc # sysproc 3
.word _default_sysproc # sysproc 4
.word _default_sysproc # sysproc 5
.word _default_sysproc # sysproc 6
.word _fault_handler + supervisor_proc # sysproc 7
.word _default_sysproc # sysproc 8
.space 251*4           # sysproc 9-259

/* Fault Table */
.equ syscall, 2
.equ fault_proc, 7
.text
.align 4
boot_flt_table:
.word (fault_proc<<2) + syscall    # 0-Parallel Fault
.word 0x27f
.word (fault_proc<<2) + syscall    # 1-Trace Fault
.word 0x27f
.word (fault_proc<<2) + syscall    # 2-Operation Fault
.word 0x27f
```

## Example 11-4. Startup Routine (init.s) (Sheet 2 of 4)

```

.word  (fault_proc<<2) + syscall    # 3-Arithmetic Fault
.word  0x27f
.word  0                                # 4-Reserved
.word  0
.word  (fault_proc<<2) + syscall    # 5-Constraint Fault
.word  0x27f
.word  0                                # 6-Reserved
.word  0
.word  (fault_proc<<2) + syscall    # 7-Protection Fault
.word  0x27f
.word  0                                # 8-Reserved
.word  0
.word  0                                # 9-Reserved
.word  0
.word  (fault_proc<<2) + syscall    # 0xa-Type Fault
.word  0x27f
.space 21*8                            # reserved

/* Boot Interrupt Table */

.text
boot_intr_table:
.word  0                                # Pending Priorities
.word  0, 0, 0, 0, 0, 0, 0    # Pending Interrupts      Vectors
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 8
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 10
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 18
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 20
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 28
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 30
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 38
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 40
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 48
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 50
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 58
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 60
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 68
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 70
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 78
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 80
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 88
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 90
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # 98
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # a0
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # a8
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # b0
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # b8
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # c0
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # c8
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # d0
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # d8
.word  _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # e0

```

**Example 11-4. Startup Routine (init.s) (Sheet 3 of 4)**

```
.word    _intx, _intx, _intx, _intx, _intx, _intx, _intx, _intx # e8
.word    _intx, _intx, _intx, _intx, 0, 0, 0, 0 # f0
.word    _nmi, 0, 0, 0, _intx, _intx, _intx, _intx # f8

/* START */
/* Processor starts execution here after reset. */
.text
.globl _start_ip
.globl _reinit
_start_ip:
    mov    0, g14           /* g14 must be 0 for ic960 C compiler */
/* MON960 requires copying the .data area into RAM. If a user application
* does not require this it is not necessary.
* Copy the .data into RAM. The .data has been packed in the ROM after the
* code area. If the copy is not needed (RAM-based monitor), the symbol
* rom_data can be defined as 0 in the linker directives file.
*/
    lda    rom_data, g1      # load source of copy
    cmpobe 0, g1, 1f
    lda    __Bdata, g2       # load destination
    lda    __Edata, g3
init_data:
    ldq    (g1), r4
    addo   16, g1, g1
    stq    r4, (g2)
    addo   16, g2, g2
    cmpobl g2, g3, init_data
1:
/* Initialize the BSS area of RAM. */
    lda    __Bbss, g2        # start of bss
    lda    __Ebss, g3        # end of bss
    movq   0,r4
bss_fill:
    stq    r4, (g2)
    addo   16, g2, g2
    cmpobl g2, g3, bss_fill

_reinit:
    ldconst 0x300, r4        # reinitialize sys control
    lda    1f, r5
    lda    _ram_prcb, r6
    sysctl r4, r5, r6
1:
    lda    _user_stack, pfp
    lda    64(pfp), sp
    mov    pfpf, fp           /* new pfp */
    flushreg

    ldconst 0x001f2403, r3    /* PC mask */
    ldconst 0x000f0003, r4    /* PC value */
    modpc r3, r3, r4          /* Lower interrupt priority */
```

**Example 11-4. Startup Routine (init.s) (Sheet 4 of 4)**

```

/* Clear the IPND register */
lda    0xffff008500, g0
mov    0, g1
st     g1, (g0)
callx _main                      #to main routine

.globl _intr_stack
.globl _user_stack
.globl _supervisor_stack
.bss   _user_stack, 0x0200, 6      # default application stack
.bss   _intr_stack, 0x0200, 6       # interrupt stack
.bss   _supervisor_stack, 0x0600, 6 # fault (supervisor) stack

.text
_fault_handler:
ldconst 'F', g0
call   _co
ret

_default_sysproc:
ret

_intx:
ldconst 'I', g0
call   _co
ret

```

**Example 11-5. High-Level Startup Code (initmain.c)**

```

unsigned componentid = 0;

main()
{
    /* system- or board-specific code goes here */
}    /* this code is called by init.s           */
co()
{
    /* system or board-specific output routine goes here */
}

```

**Example 11-6. Control Table (ctltbl.c)**

```
/*-----*/
/*  ctltbl.c
/*-----*/
#include "init.h"

typedef struct
{
    unsigned control_reg[28];
}CONTROL_TABLE;
const CONTROL_TABLE boot_control_table = {
    /* Reserved */
    0, 0, 0, 0,
    /* Interrupt Map Registers */
    0, 0, 0,/* Interrupt Map Regs (set by code as needed) */
    0x43bc, /* ICON
               *
               *          - dedicated mode,
               *          - enabled
               * system_init 0 - falling edge activated,
               * system_init 1 - falling edge activated,
               * system_init 2 - falling edge activated,
               * system_init 3 - falling edge activated,
               * system_init 4 - level-low activated,
               * system_init 5 - falling edge activated,
               * system_init 6 - falling edge activated,
               * system_init 7 - falling edge activated,
               *
               *          - mask unchanged,
               *          - not cached,
               *          - fast,
               */
    /* Physical Memory Configuration Registers */

    DEFAULT, 0, /* Region 0_1 */
    DEFAULT, 0, /* Region 2_3 */
    DEFAULT, 0, /* Region 4_5 */
    I_O, 0, /* Region 6_7 */
    DEFAULT, 0, /* Region 8_9 */
    DEFAULT, 0, /* Region 10_11 */
    DRAM, 0, /* Region 12_13 */
    ROM, 0, /* Region 14_15 */

    /* Bus Control Register */
    0, /* Reserved */
    0, /* Reserved */
    1 /* BCON Register (Region config. valid) */
};
```

**Example 11-7. Initialization Boot Record File (rom\_ibr.c) (Sheet 1 of 2)**

```
#include "init.h"

/*
 * NOTE: The ibr must be located at 0xFFFFFFF30. Use the linker to
 * locate this structure.
 *
 * The boot configuration is always region 14_15, since the IBR
 * must be located there
 */

extern void start_ip();
extern unsigned rom_prcb;
extern unsigned checksum;

#define CS_6 (int) &checksum /* value calculated in linker */
#define BOOT_CONFIG ROM

const IBR init_boot_record =
{
    BYTE_N(0,BOOT_CONFIG),      /* PMCON14_15 byte 1 */
    0,0,0,                      /* reserved set to 0 */
    BYTE_N(1,BOOT_CONFIG),      /* PMCON14_15 byte 2 */
    0,0,0,                      /* reserved set to 0 */
    BYTE_N(2,BOOT_CONFIG),      /* PMCON14_15 byte 3 */
    0,0,0,                      /* reserved set to 0 */
```

**Example 11-7. Initialization Boot Record File (rom\_ibr.c) (Sheet 2 of 2)**

```
BYTE_N(3,BOOT_CONFIG),      /* PMCON14_15 byte 4 */  
0,0,0,                      /* reserved set to 0 */  
  
start_ip,  
&rom_prcb,  
  
-2,  
  
0,  
  
0,  
  
0,  
  
CS_6  
};
```

**Example 11-8. Linker Directive File (init.ld) (Sheet 1 of 2)**

```
/*-----*/  
/* init.ld */  
/*-----*/  
  
MEMORY  
{  
    /*  
        Enough space must be reserved in ROM after the text  
        section to hold the initial values of the data section.  
    */  
    rom:      o=0xfefefe0000,l=0x1fc00  
    rom_dat: o=0xfeffffc00,l=0x0300    /* placeholder for .data image */  
  
    ibr:      o=0xfffffff30,l=0x0030  
    data:     o=0xa0000000,l=0x0300  
    bss:      o=0xa0000300,l=0x7d00  
}
```

**INITIALIZATION AND SYSTEM REQUIREMENTS****Example 11-8. Linker Directive File (init.ld) (Sheet 2 of 2)**

```
SECTIONS
{
    .ibr :
    {
        rom_ibr.o
    } > ibr

    .text :
    {
    } > rom

    .data :
    {
    } > data

    .bss :
    {
    } > data
}

rom_data = __Etext; /* used in init.s as source of .data
                      section initial values. ROM960
                      "move" command places the .data
                      section right after the .text section
*/
                      /*

_checksum = -(_rom_prcb + _start_ip);

HLL()

/*Rommer script embedded here: the following creates a ROM image
#*move $0 .text 0
#*move $0
#*move $0 .ibr 0x1ff30
##mkimage $0 $0.ima
##ihex $0.ima $0.hex model16
##map $0
##quit
*/
```

**Example 11-9. Makefile**

```
/*-----*/  
/*  makefile */  
/*-----*/  
  
LDFILE = init  
FINALOBJ = init  
OBJS = init.o ctltbl.o initmain.o  
IBR = rom_ibr.o  
LDFLAGS = -AJF -Fcoff -T$(LDFILE) -m  
ASFLAGS = -AJF -V  
CCFLAGS = -AJF -Fcoff -V -c  
  
init.ima: $(FINALOBJ)  
        rom960 $(LDFILE) $(FINALOBJ)  
  
init: $(OBJS) $(IBR)  
        gld960 $(LDFLAGS) -o $< $(OBJS)  
  
.S.O:  
        gas960c $(ASFLAGS) $<  
  
.C.O:  
        gcc960 $(CCFLAGS) $<
```

## 11.6 SYSTEM REQUIREMENTS

The following sections discuss generic hardware requirements for a system built around the i960 Jx processor. This section describes electrical characteristics of the processor's interface to the external circuit. The CLKIN, RESET, STEST, FAIL, ONCE, V<sub>SS</sub> and V<sub>CC</sub> pins are described in detail. Specific signal functions for the external bus signals and interrupt inputs are discussed in their respective sections in this manual.

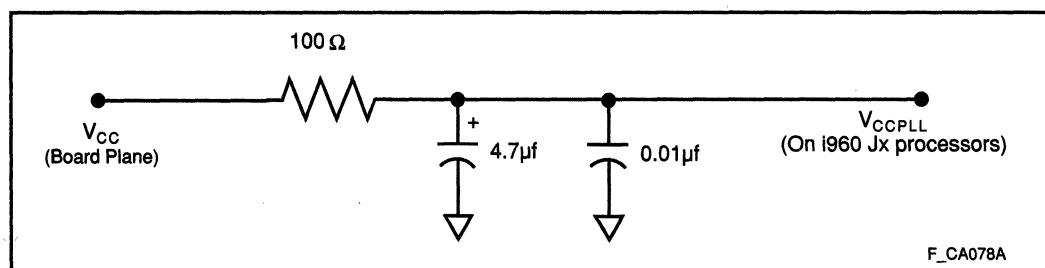
### 11.6.1 Input Clock (CLKIN)

The clock input (CLKIN) determines processor execution rate and timing. It is designed to be driven by most common TTL crystal clock oscillators. The clock input must be free of noise and conform with the specifications listed in the data sheet. CLKIN input capacitance is minimal; for this reason, it may be necessary to terminate the CLKIN circuit board trace at the processor to reduce overshoot and undershoot.

### 11.6.2 Power and Ground Requirements ( $V_{CC}$ , $V_{SS}$ )

The large number of  $V_{SS}$  and  $V_{CC}$  pins effectively reduces the impedance of power and ground connections to the chip and reduces transient noise induced by current surges. The i960 Jx processor is implemented in CHMOS IV technology. Unlike NMOS processes, power dissipation in the CHMOS process is due to capacitive charging and discharging on-chip and in the processor's output buffers; there is almost no DC power component. The nature of this power consumption results in current surges when capacitors charge and discharge. The processor's power consumption depends mostly on frequency. It also depends on voltage and capacitive bus load (see the *80960JF Embedded 32-bit Processor Data Sheet*).

To reduce clock skew on the i960 Jx processor, the  $V_{CCPLL}$  pin for the Phase Lock Loop (PLL) circuit is isolated on the pinout. The lowpass filter, as shown in Figure 11-9, reduces noise induced clock jitter and its effects on timing relationships in system designs. The 4.7 $\mu$ f capacitor must be (low ESR solid tantalum), the 4.7  $\mu$ f capacitor must be of the type X7R and the node connecting  $V_{CCPLL}$  must be as short as possible.



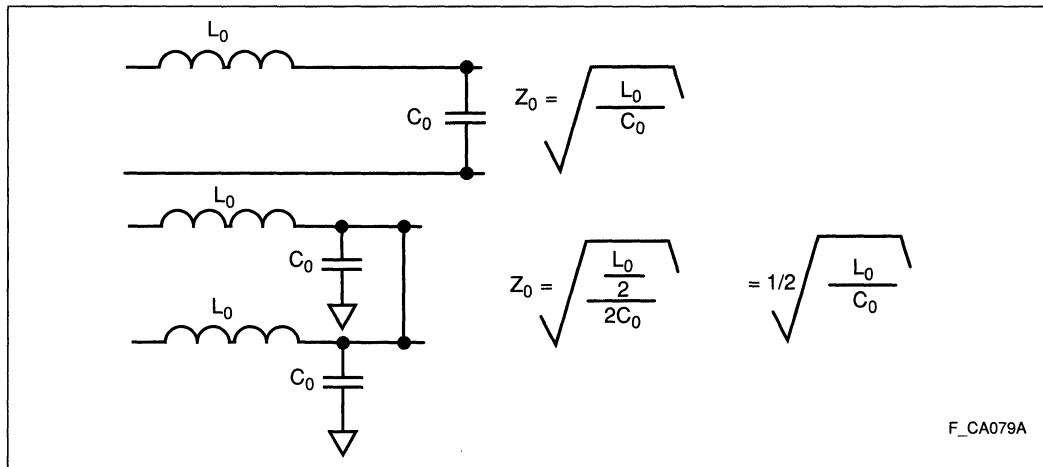
**Figure 11-9.  $V_{CCPLL}$  Lowpass Filter**

### 11.6.3 Power and Ground Planes

Power and ground planes must be used in i960 Jx processor systems to minimize noise. Justification for these power and ground planes is the same as for multiple  $V_{SS}$  and  $V_{CC}$  pins. Power and ground lines have inherent inductance and capacitance; therefore, an impedance  $Z=(L/C)^{1/2}$ .

Total characteristic impedance for the power supply can be reduced by adding more lines. This effect is illustrated in Figure 11-10, which shows that two lines in parallel have half the impedance of one. Ideally, a plane — an infinite number of parallel lines — results in the lowest impedance. Fabricate power and ground planes with a 1 oz. copper for outer layers and 0.5 oz. copper for inner layers.

All power and ground pins must be connected to the planes. Ideally, the i960 Jx processor should be located at the center of the board to take full advantage of these planes, simplify layout and reduce noise.



**Figure 11-10. Reducing Characteristic Impedance**

#### 11.6.4 Decoupling Capacitors

Decoupling capacitors placed across the processor between  $V_{CC}$  and  $V_{SS}$  reduce voltage spikes by supplying the extra current needed during switching. Place these capacitors close to the device because connection line inductance negates their effect. Also, for this reason, the capacitors should be low inductance. Chip capacitors (surface mount) exhibit lower inductance.

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#### 11.6.5 I/O Pin Characteristics

The i960 Jx processor interfaces to its system through its pins. This section describes the general characteristics of the input and output pins.

##### 11.6.5.1 Output Pins

All output pins on the i960 Jx processor are three-state outputs. Each output can drive a logic 1 (low impedance to  $V_{CC}$ ); a logic 0 (low impedance to  $V_{SS}$ ); or float (present a high impedance to  $V_{CC}$  and  $V_{SS}$ ). Each pin can drive an appreciable external load. The *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet* describe each pin's drive capability and provide timing and derating information to calculate output delays based on pin loading.

### 11.6.5.2 Input Pins

All i960 Jx processor inputs are designed to detect TTL thresholds, providing compatibility with the vast amount of available random logic and peripheral devices that use TTL outputs.

Most i960 Jx processor inputs are synchronous inputs (Table 11-8). A synchronous input pin must have a valid level (TTL logic 0 or 1) when the value is used by internal logic. If the value is not valid, it is possible for a metastable condition to be produced internally resulting in undeterminate behavior. The *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet* specify input valid setup and hold times relative to CLKIN for the synchronized inputs.

**Table 11-8. Input Pins**

| Synchronous Inputs<br>(sampled by CLKIN)      | Asynchronous Inputs<br>(sampled by CLKIN)    | Asynchronous Inputs<br>(sampled by RESET) |
|---|--|---|
| AD31:0<br><u>RDYRCV</u><br>HOLD<br>TDI<br>TMS | <u>RESET</u><br><u>XINT7:0</u><br><u>NMI</u> | STEST<br><u>LOCK</u> <u>ONCE</u>          |

i960 Jx processor inputs which are considered asynchronous are internally synchronized to the rising edge of CLKIN. Since they are internally synchronized, the pins only need to be held long enough for proper internal detection. In some cases, it is useful to know if an asynchronous input will be recognized on a particular CLKIN cycle or held off until a following cycle. The i960 Jx microprocessor data sheet provides setup and hold requirements relative to CLKIN which ensure recognition of an asynchronous input. The data sheets also supply hold times required for detection of asynchronous inputs.

The ONCE and STEST inputs are asynchronous inputs. These signals are sampled and latched on the rising edge of the RESET input instead of CLKIN.

### 11.6.6 High Frequency Design Considerations

At high signal frequencies and/or with fast edge rates, the transmission line properties of signal paths in a circuit must be considered. Transmission line effects and crosstalk become significant in comparison to the signals. These errors can be transient and therefore difficult to debug. In this section, some high-frequency design issues are discussed; for more information, consult a reference on high-frequency design.

### 11.6.7 Line Termination

Input voltage level violations are usually due to voltage spikes that raise input voltage levels above the maximum limit (overshoot) and below the minimum limit (undershoot). These voltage levels can cause excess current on input gates, resulting in permanent damage to the device. Even if no damage occurs, many devices are not guaranteed to function as specified if input voltage levels are exceeded.

Signal lines are terminated to minimize signal reflections and prevent overshoot and undershoot. Terminate the line if the round-trip signal path delay is greater than signal rise or fall time. If the line is not terminated, the signal reaches its high or low level before reflections have time to dissipate and overshoot or undershoot occurs.

For the i960 Jx processor, two termination methods are attractive: AC and series. An AC termination matches the impedance of the trace, thereby eliminating reflections due to the impedance mismatch.

Series termination decreases current flow in the signal path by adding a series resistor as shown in Figure 11-11. The resistor increases signal rise and fall times so that the change in current occurs over a longer period of time. Because the amount of voltage overshoot and undershoot depends on the change in current over time ( $V = L \frac{di}{dt}$ ), the increased time reduces overshoot and undershoot. Place the series resistor as close as possible to the signal source. AC termination is effective in reducing signal reflection (ringing). This termination is accomplished by adding an RC combination at the signal's farthest destination (Figure 11-12). While the termination provides no DC load, the RC combination damps signal transients.

Selection of termination methods and values is dependent upon many variables, such as output buffer impedance, board trace impedance and input impedance.

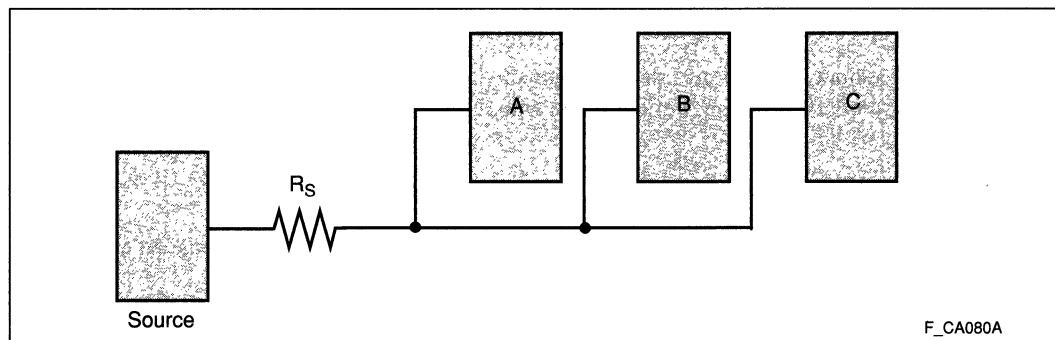
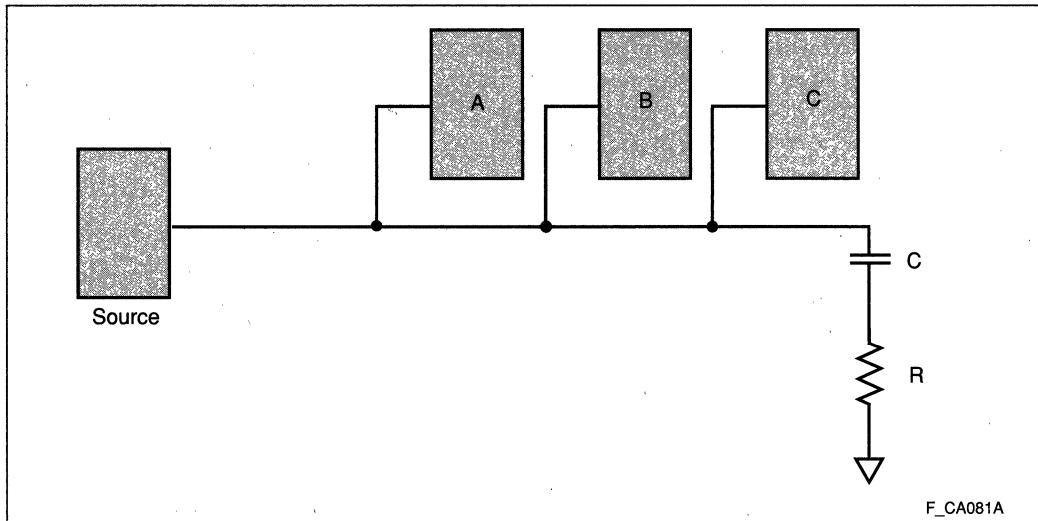


Figure 11-11. Series Termination



**Figure 11-12. AC Termination**

### 11.6.8 Latchup

Latchup is a condition in a CMOS circuit in which  $V_{CC}$  becomes shorted to  $V_{SS}$ . Intel's CMOS IV processes are immune to latchup under normal operation conditions. Latchup can be triggered when the voltage limits on I/O pins are exceeded, causing internal PN junctions to become forward biased. The following guidelines help prevent latchup:

- Observe the maximum rating for input voltage on I/O pins.
- Never apply power to an i960 Jx processor pin or a device connected to an i960 Jx processor pin before applying power to the i960 Jx processor itself.
- Prevent overshoot and undershoot on I/O pins by adding line termination and by designing to reduce noise and reflection on signal lines.

### 11.6.9 Interference

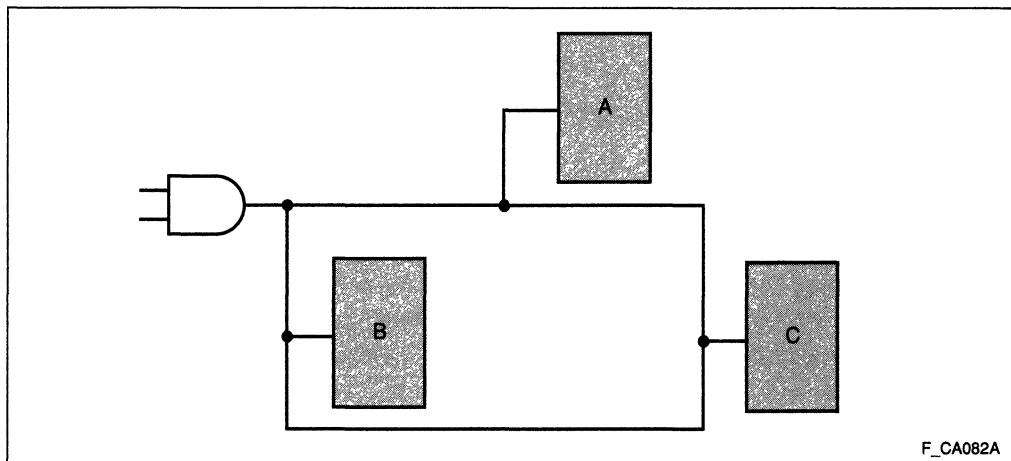
Interference is the result of electrical activity in one conductor that causes transient voltages to appear in another conductor. Interference increases with the following factors:

- Frequency Interference is the result of changing currents and voltages. The more frequent the changes, the greater the interference.
- Closeness-of-conductors Interference is due to electromagnetic and electrostatic fields whose effects are weaker further from the source.

Two types of interference must be considered in high frequency circuits: electromagnetic interference (EMI) and electrostatic interference (ESI).

EMI is caused by the magnetic field that exists around any current-carrying conductor. The magnetic flux from one conductor can induce current in another conductor, resulting in transient voltage. Several precautions can minimize EMI:

- Run ground lines between two adjacent lines wherever they traverse a long section of the circuit board. The ground line should be grounded at both ends.
- Run ground lines between the lines of an address bus or a data bus if either of the following conditions exist:
  - The bus is on an external layer of the board.
  - The bus is on an internal layer but not sandwiched between power and ground planes that are at most 10 mils away.



**Figure 11-13. Avoid Closed-Loop Signal Paths**

ESI is caused by the capacitive coupling of two adjacent conductors. The conductors act as the plates of a capacitor; a charge built up on one induces the opposite charge on the other.

The following steps reduce ESI:

- Separate signal lines so that capacitive coupling becomes negligible.
- Run a ground line between two lines to cancel the electrostatic fields.





12

## MEMORY CONFIGURATION



# CHAPTER 12

## MEMORY CONFIGURATION

The Bus Control Unit (BCU) includes logic to control many common types of memory subsystems directly. Every bus access is “formatted” according to the BCU programming. The i960 Jx processor’s BCU programming model differs from schemes used in other i960 processors.

### 12.1 Memory Attributes

Every location in memory has associated physical and logical attributes. For example, a specific location may have the following attributes:

- **Physical:** Memory is an 8-bit wide ROM
- **Logical:** Memory is ordered big-endian and data is non-cacheable

In the example above, physical attributes correspond to those parameters that indicate *how to physically access the data*. The BCU uses physical attributes to determine the bus protocol and signal pins to use when controlling the memory subsystem. The logical attributes tell the BCU how to interpret, format and control interaction of on-chip data caches. The physical and logical attributes for an individual location are independently programmable.

#### 12.1.1 Physical Memory Attributes

The only programmable physical memory attribute for the i960 Jx microprocessor is the bus width, which can be 8-, 16- or 32-bits wide.

For the purposes of assigning memory attributes, the physical address space is partitioned into 8, fixed 512 Mbyte regions determined by the upper three address bits. The regions are numbered as 8 paired sections for consistency with other i960 processor implementations. Region 0\_1 maps to addresses 0000 0000H to 1FFF FFFFH and region 14\_15 maps to addresses E000 0000H to FFFF FFFFH. The physical memory attributes for each region are programmable through the PMCON registers. The PMCON registers are loaded from the Control Table. The i960 Jx microprocessor provides one PMCON register for each region. The descriptions of the PMCON registers and instructions on programming them are found in Section 12.3.

### 12.1.2 Logical Memory Attributes

The i960 Jx provides a mechanism for defining two *logical memory templates* (LMTs). An LMT may be used to specify the logical memory attributes for a section (or subset) of a physical memory subsystem connected to the BCU (e.g., DRAM, SRAM). The logical memory attributes defined by the i960 Jx are byte ordering and whether the information is cacheable or non-cacheable in the on-chip data cache.

There are typically several different LMTs defined within a single memory subsystem. For example, data within one area of DRAM may be non-cacheable while data in another area is cacheable. Figure 12-1 shows the use of the Control Table (PMCON registers) with logical memory templates for a single DRAM region in a typical application.

Each logical memory template is defined by programming Logical Memory Configuration (LMCON) registers. An LMCON Register pair defines a data template for areas of memory that have common logical attributes. The Jx microprocessor has two pairs of LMCON registers — defining two separate templates. The extent of each data template is described by an address (on 4 Kbyte boundaries) and an address mask. The address is programmed in the Logical Memory Address register (LMADR). The mask is programmed in the Logical Memory Mask register (LMMSK). These two registers constitute the LMCON register pair.

The *Default Logical Memory Configuration* register is used to provide configuration data for areas of memory that do not fall within one of the two logical data templates. The DLMCON also specifies byte-ordering (little endian/big endian) for all data accesses in memory, including on-chip data RAM.

The LMCON registers and their programming are described in section 12.6.

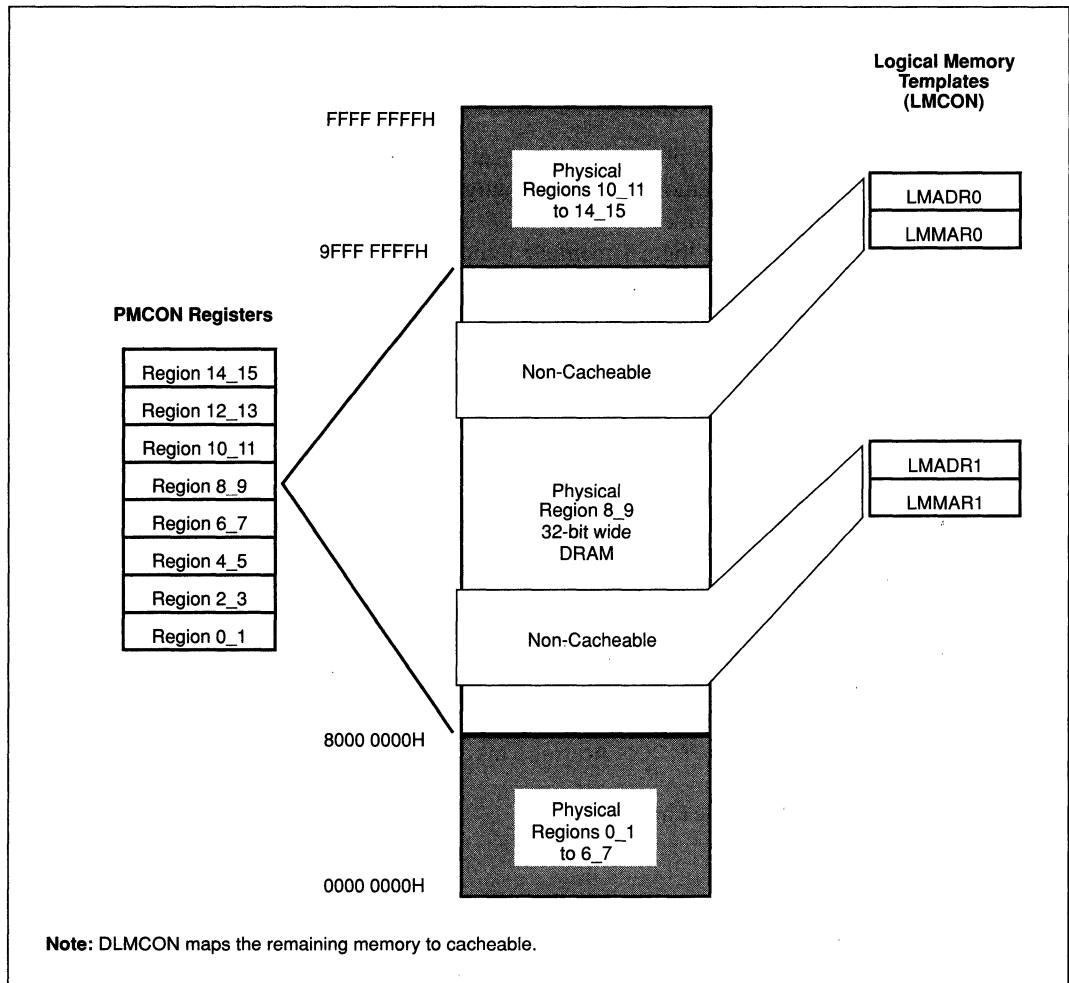


Figure 12-1. PMCON and LMCON Example

## MEMORY CONFIGURATION

### 12.2 Differences With Previous i960 Processors

The mechanism described in this chapter is not implemented on the i960 Kx or Sx processors. Although the i960 Cx processor has a memory configuration mechanism, it is different from the 80960Jx's in the following ways:

- For the purposes of assigning physical and logical memory attributes, the i960 Cx processor evenly divides physical memory into 16 contiguous regions. When assigning physical memory attributes, the Jx divides memory into 8 contiguous, 512 Mbyte regions starting on 512 Mbyte boundaries. The logical memory templates of the i960 Jx processor provide a programmable association of logical memory addresses, whereas the i960 Cx processor assigns these attributes to the physical memory regions.
- The i960 Cx processor provides per-region programming of wait states, address pipelining and bursting. No such mechanisms exist on the 80960Jx. Bus wait states must be generated using external logic.

### 12.3 Programming the Physical Memory Attributes (PMCON Registers)

The layout of the Physical Memory Configuration registers, PMCON0\_1 to PMCON14\_15, is shown in Figure 12-2, which gives the descriptions of the individual bits. The PMCON registers reside within memory-mapped control register space. Each PMCON register controls one 512-Mbyte region of memory according to the mapping shown in Table 12-1

**Table 12-1. PMCON Address Mapping (Sheet 1 of 2)**

| Register (Control Table Entry) | Region Controlled   |
|--------------------------------|---|
| PMCON0_1                       | 0000.0000H to 0FFF.FFFFH<br>and<br>1000.0000H to 1FFF.FFFFH |
| PMCON2_3                       | 2000.0000H to 2FFF.FFFFH<br>and<br>3000.0000H to 3FFF.FFFFH |
| PMCON4_5                       | 4000.0000H to 4FFF.FFFFH<br>and<br>5000.0000H to 5FFF.FFFFH |

**Table 12-1. PMCON Address Mapping (Sheet 2 of 2)**

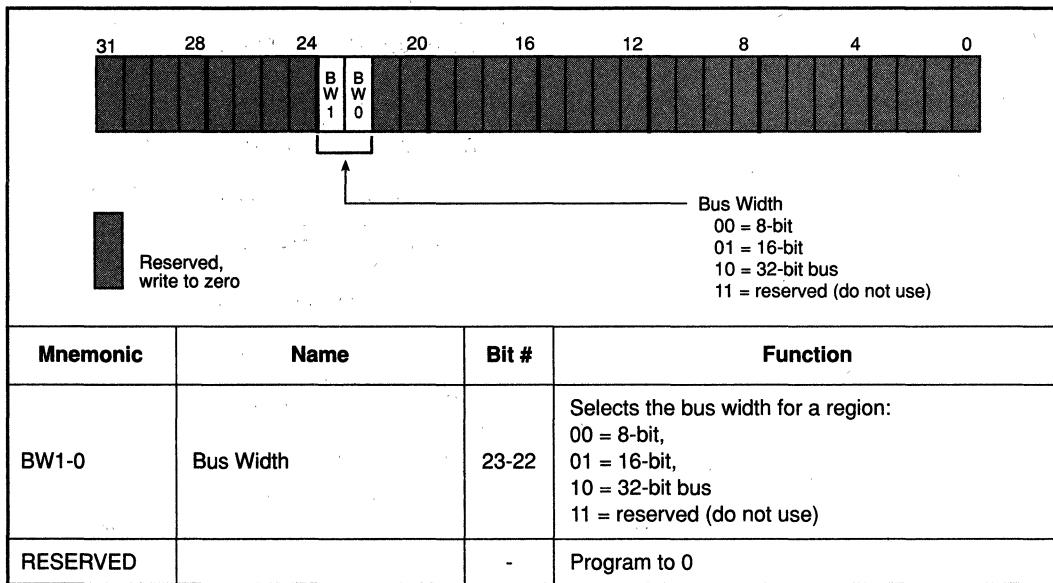
|            |   |
|------------|---|
| PMCON6_7   | 6000.0000H to 6FFF.FFFFH<br>and<br>7000.0000H to 7FFF.FFFFH |
| PMCON8_9   | 8000.0000H to 8FFF.FFFFH<br>and<br>9000.0000H to 9FFF.FFFFH |
| PMCON10_11 | A000.0000H to AFFF.FFFFH<br>and<br>B000.0000H to BFFF.FFFFH |
| PMCON12_13 | C000.0000H to CFFF.FFFFH<br>and<br>D000.0000H to DFFF.FFFFH |
| PMCON14_15 | E000.0000H to EFFF.FFFFH<br>and<br>F000.0000H to FFFF.FFFFH |

### 12.3.1 Bus Width

The bus width for a region is controlled by the BW1:0 bits in the PMCON register. The operation of the i960 Jx processor with different bus width programming options is described in section 15.2.3.1, “Bus Width” (pg. 15-7).

The bit combination “11” is reserved for the BW1:0 field and can result in unpredictable operation.

## MEMORY CONFIGURATION



**Figure 12-2. PMCON Register Bit Description**

## 12.4 Physical Memory Attributes at Initialization

All eight PMCON registers are loaded automatically during system initialization. The initial values are stored in the Control Table in the Initialization Boot Record (see section 11.3.1, “Initial Memory Image (IMI)” (pg. 11-9)).

### 12.4.1 Bus Control (BCON) Register

Immediately after a hardware reset, the PMCON register contents are marked invalid in the Bus Control (BCON) register. Figure 12-3 shows the BCON register and Control Table Valid (CTV) bit. Whenever the PMCON entries are marked invalid in BCON, the BCU uses the parameters in PMCON14\_15 for *all* regions. On a hardware reset, PMCON14\_15 is automatically cleared. This operation configures all regions to an 8-bit bus width. Subsequently, the processor loads all PMCON registers from the Control Table. The processor then loads BCON from the Control Table. If BCON.ctv is clear, then PMCON14\_15 will remain in use for all bus accesses. If BCON.ctv is set, the region table is valid and the BCU uses the programmed PMCON values for each region.

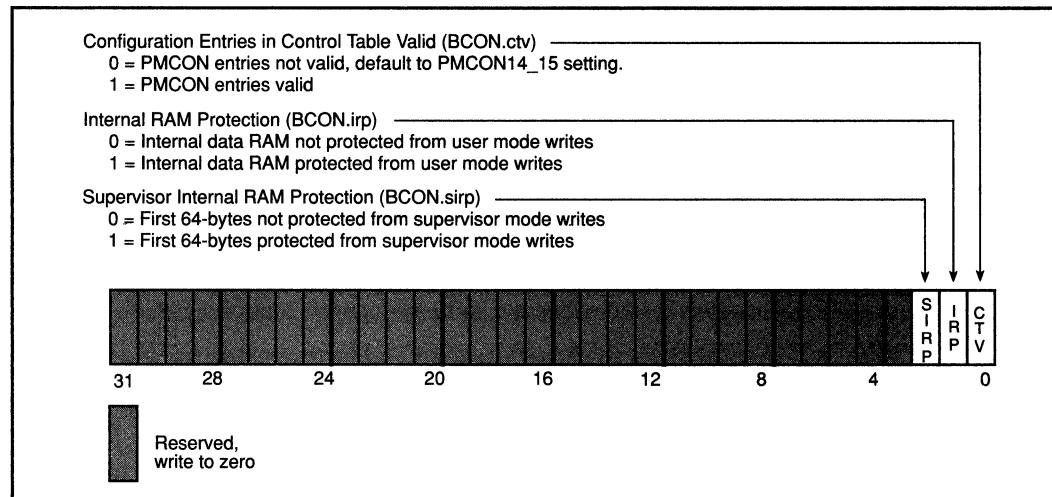


Figure 12-3. Bus Control Register (BCON)

## 12.5 Boundary Conditions for Physical Memory Regions

The following sections describe the operation of the PMCON registers during conditions other than “normal” accesses.

### 12.5.1 Internal Memory Locations

The PMCON registers are ignored during accesses to internal memory or memory-mapped registers. The processor performs those accesses over 32-bit buses, except for local register cache accesses. The register bus is 128 bits wide.

### 12.5.2 Bus Transactions Across Region Boundaries

An unaligned bus request that spans region boundaries uses the PMCON settings of both regions. Accesses that lie in the first region use that region’s PMCON parameters, and the remaining accesses use the second region’s PMCON parameters.

For example, an unaligned quad word load/store beginning at address 1FFF FFFEH would cross boundaries from region 0\_1 to 2\_3. The physical parameters for region 0\_1 would be used for the first 2-byte access and the physical parameters for region 2\_3 would be used for the remaining access.

## MEMORY CONFIGURATION

### 12.5.3 Modifying the PMCON Registers

An application can modify the value of a PMCON register by using the **st** or **sysctl** instruction. If a **st** or **sysctl** instruction is issued when an access is in progress, the current access is completed before the modification takes effect.

### 12.6 Programming the Logical Memory Attributes

The bit/bit field definitions for the LMADR1:0 and LMMR1:0 registers are shown in Figure 12-4 and Figure 12-5. LMCN registers reside within the memory-mapped control register space.

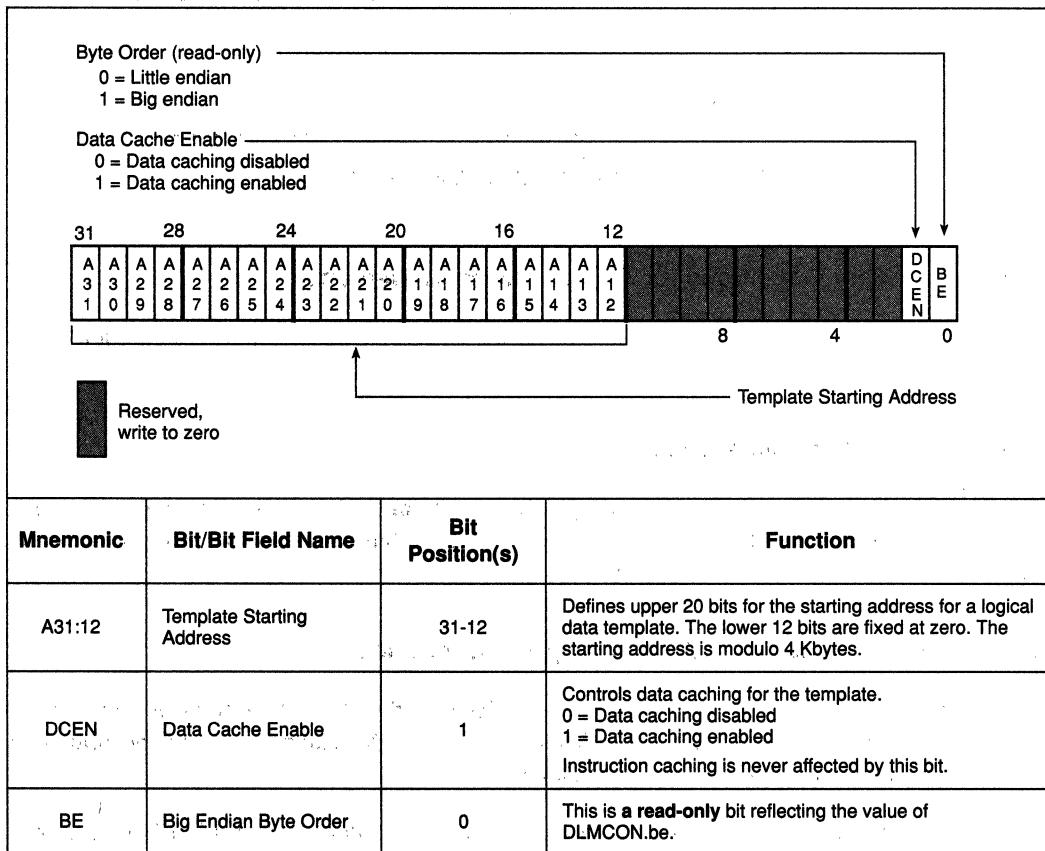
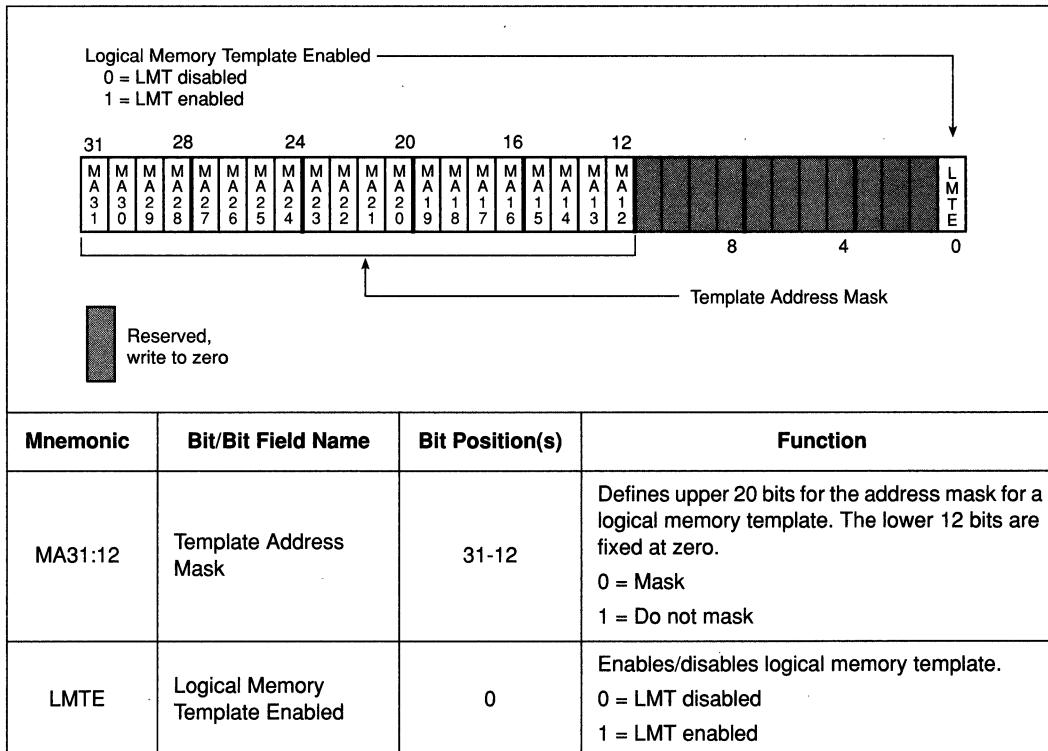


Figure 12-4. Logical Memory Template Starting Address Registers (LMADR0-1)

The Default Logical Memory Configuration (DLMCON) register is shown in Figure 12-6. The BCU uses the parameters in the DLMCON register when the current access does not fall within one of the two logical memory templates (LMTs). Notice the byte ordering is controlled for the entire address space by programming the DLMCON register.



**Figure 12-5. Logical Memory Template Mask Registers (LMMR0-1)**

## MEMORY CONFIGURATION

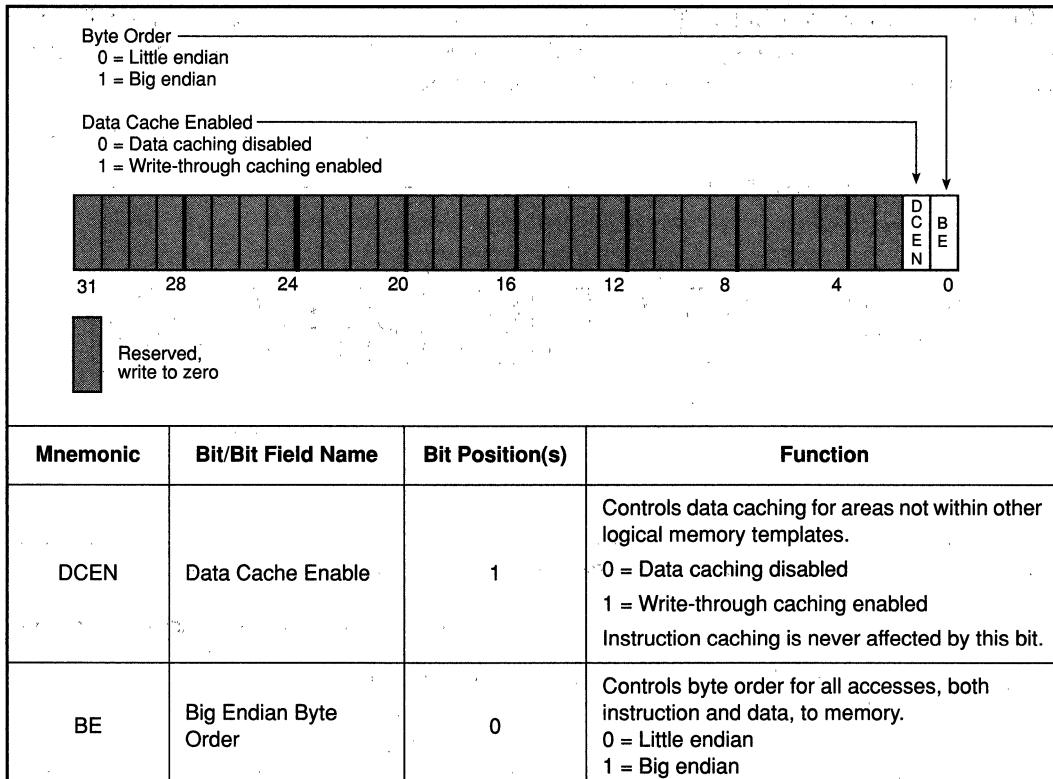


Figure 12-6. Default Logical Memory Configuration Register (DLMCON)

### 12.6.1 Defining the Effective Range of a Logical Data Template

For each logical data template, an LMADR register sets the base address using the A31:12 field. The LMMR register sets the address mask using the MA31:12 field. The effective address range for a logical data template is defined using the A31:12 field in an LMADRx register and the MA31:12 field in an LMMRx register. For each access, the upper 20 address bits (A31:12) are compared against A31:12 in the LMADRx register. Address bits for are compared with corresponding MA bits set are compared. Address bits with corresponding MA bits cleared (0) are automatically considered a “match”. The processor will only use the logical data template when all compared address bits match. Two examples help clarify the operation of the address comparators.

- Create a template 64 Kbytes in length beginning at address 0010 0000H and ending at address 0010 FFFFH. Determine the form of the candidate address to match and then program the LMADR and LMMR registers:

Candidate Address is of form: 0010 XXXX

LMADR <31:12> should be: 0010 0...

LMMR <31:12> should be: FFFF 0...

- Multiple data templates can be created from a single LMADR/LMMR register pair by aliasing effective addresses. For example, to create sixteen 64 Kbyte templates, each beginning on modulo 1 Mbyte boundaries starting at 0000 0000H and ending with 00F0 0000H, the registers are programmed as follows:

Candidate Address is of form: 00X0 XXXX

LMADR <31:12> should be: 0000 0...

LMMR <31:12> should be: FF0F 0...

### 12.6.2 Selecting the Byte Order

The BCU can automatically convert aligned big endian data in memory into little endian data for the processor core. The conversion is done transparently in hardware, with no performance penalty. The BE bit in the DLMCON register controls the default byte ordering for address regions of the system including internal data RAM but excluding memory-mapped registers. Instruction fetches and data accesses are automatically converted to little endian format when they are fetched from external memory and the programmed default byte-order (DLMCON.be) is big-endian.

The recommended, portable way to determine the byte-ordering associated with a logical memory template is to read the appropriate LMADR. The i960 Jx microprocessor supports this method by always ensuring that the DLMCON.be bit is reflected in bit zero of LMADR0 and LMADR1 (also labelled as LMADR.be) when they are read. Any attempts to write bit zero of an LMADR are ignored.

Great care should be exercised when dynamically changing the processor's homogenous byte order. See section 12.6.8, "Dynamic Byte Order Changing" (pg. 12-13) for an instruction code example.

Byte-ordering is not applicable to memory-mapped registers since they are always accessed as words.

## MEMORY CONFIGURATION

### 12.6.3 Data Caching Enable

Enabling and disabling data caching for an LMT is controlled via the DCEN bit in the LMADR register. Likewise, the DCEN bit in DLMCON enables and disables data-caching for regions of memory that are not covered by the LMCON registers. The DCEN bit has no effect on the instruction cache.

### 12.6.4 Enabling the Logical Memory Template

The LMTE bit activates the logical data template in the LMMR register for the programmed range.

### 12.6.5 Initialization

Immediately following a hardware reset, all LMTs are disabled. The LMTE bit in each of the LMMR registers is cleared (0) and all other bits are undefined. Immediately after a hardware reset the Default Logical Memory Control register (DLMCON) has the values shown in Table 12-2.

**Table 12-2. DLMCON Values at Reset**

| DLMCON Bit                 | Value Upon Reset Microcode                      |
|----------------------------|---|
| DCEN (Data Caching Enable) | 0 (Data Caching Disabled)                       |
| BE (Big-Endian)            | Initialized from PMCON14_15 image in IBR bit 31 |

Application software may initialize and enable the logical memory template after hardware reset. The registers are not modified by software initialization.

### 12.6.6 Boundary Conditions for Logical Memory Templates

The following sections describe the operation of the LMT registers during conditions other than “normal” accesses. See Chapter 4, CACHE AND ON-CHIP DATA RAM for a treatment of data cache coherency when modifying an LMT.

#### 12.6.6.1 Internal Memory Locations

The LMT registers are not used during accesses to memory-mapped registers. Internal data RAM locations are never cached; LMT bits controlling caching are ignored for data RAM accesses. However, the byte-ordering of the internal data RAM is controlled by DLMCON.be.

### 12.6.6.2 Overlapping Logical Data Template Ranges

Logical data templates that specify overlapping ranges are not allowed. When an access is attempted that matches more than one enabled LMT range, the operation of the access becomes undefined.

To establish different logical memory attributes for the same address range, program non-overlapping logical ranges, then use partial physical address decoding.

### 12.6.6.3 Accesses Across LMT Boundaries

Accesses that cross LMT boundaries should be avoided. These accesses are unaligned and broken into a number of smaller aligned accesses, which reside in one or the other LMT, but not both. Each smaller access is completed using the parameters of the MPT in which it resides.

## 12.6.7 Modifying the LMT Registers

An LMT register can be modified using **st** or **sysctl** instructions. Both instructions ensure data cache coherency and order the modification with previous and subsequent data accesses.

## 12.6.8 Dynamic Byte Order Changing

Programmed byte order changes take effect immediately. The next instruction fetch will use the new byte order setting. This byte-swapping usually results in errors because the current instruction stream uses the previous byte order setting.

Dynamically changing the byte order to perform limited operations is possible if the code sequence is locked in the instruction cache. The application must ensure that code executes from within the locked region (including faults and interrupts) while the opposite byte order is in effect. The following example illustrates this method:

```
safe_addr:    lda      safe_addr,r4
              mov      1,r5
              icctl   0x3,r4,r5      # Lock code in cache.
              ld      DLMCON_MM,r6
              notbit  0,r6,r7
              st      r7,DLMCON_MM    # Toggle byte order.

              . . .

              <Short code sequence>

              . . .
```

## MEMORY CONFIGURATION

```
        st      r6,DLMCON_MM    # Restore byte order.  
        icctl  2,0,r6          # Invalidate cache  
                           # to unlock code.
```

In most cases, it is safer to retain the original byte order and use the **bswap** instruction to convert data between little-endian and big-endian byte order.



13

## INTERRUPT CONTROLLER



# CHAPTER 13

## INTERRUPT CONTROLLER

This chapter contains interrupt controller information that is of particular importance to the system implementor. The method for handling interrupt requests from user code is described in CHAPTER 8, INTERRUPTS. Specifically, this chapter describes the i960® Jx processor's facilities for requesting and posting interrupts, the programmer's interface to the on-chip interrupt controller, implementation, latency and how to optimize interrupt performance.

### 13.1 OVERVIEW

The interrupt controller's primary functions are to provide a flexible, low-latency means for requesting and posting interrupts and to minimize the core's interrupt handling burden. The interrupt controller handles the posting of interrupts requested by hardware and software sources. The interrupt controller, acting independently from the core, compares the priorities of posted interrupts with the current process priority, off-loading this task from the core.

The interrupt controller provides the following features for managing hardware-requested interrupts:

- Low latency, high throughput handling.
- Support of up to 240 external sources.
- Eight external interrupt pins, one non-maskable interrupt pin, two internal timer units (TU) sources for detection of hardware-requested interrupts.
- Edge or level detection on external interrupt pins.
- Debounce option on external interrupt pins.

The user program interfaces to the interrupt controller with six memory-mapped control registers. The interrupt control register (ICON) and interrupt map control registers (IMAP0-IMAP2) provide configuration information. The interrupt pending (IPND) register posts hardware-requested interrupts. The interrupt mask (IMSK) register selectively masks hardware-requested interrupts.

## 13.2 MANAGING INTERRUPT REQUESTS

The i960 processor architecture provides a consistent interrupt model, as required for interrupt handler compatibility between various implementations of the i960 processor family. The architecture, however, leaves the interrupt request management strategy to the specific i960 processor family implementations. In the i960 Jx processors, the programmable on-chip interrupt controller transparently manages all interrupt requests (Figure 13-1). These requests originate from:

- Eight-bit external interrupt pins  $\overline{\text{XINT7:0}}$
- Two internal timer unit interrupts (TINT1:0)
- Non-maskable interrupt pin  $\overline{\text{NMI}}$
- **sysctl** instruction execution (software-initiated interrupts)

### 13.2.1 External Interrupt

External interrupt pins can be programmed to operate in three modes:

1. Dedicated mode: the pins may be individually mapped to interrupt vectors.
2. Expanded mode: the pins may be interpreted as a bit field which can request any of the 240 possible external interrupts that the i960 processor family supports.
3. Mixed mode: five pins operate in expanded mode and can request thirty-two different interrupts, and three pins operate in dedicated mode.

Dedicated-mode requests are posted in the Interrupt Pending Register (IPND). The processor's ICU does not post expanded-mode requests.

### 13.2.2 Timer Interrupt

Each of the two timer units has an associated interrupt to allow the application to accept or post the interrupt request. Timer unit interrupt requests are always handled as dedicated-mode interrupt requests.

### 13.2.3 Non-Maskable Interrupt ( $\overline{\text{NMI}}$ )

The  $\overline{\text{NMI}}$  pin generates an interrupt for implementation of critical interrupt routines.  $\overline{\text{NMI}}$  provides an interrupt that cannot be masked and that has a priority of 31. The interrupt vector for  $\overline{\text{NMI}}$  resides in the interrupt table as vector number 248. During initialization, the core caches the vector for  $\overline{\text{NMI}}$  on-chip, to reduce  $\overline{\text{NMI}}$  latency. The  $\overline{\text{NMI}}$  vector is cached in location 0H of internal data RAM.

The core immediately services NMI requests. While servicing an NMI, the core does not respond to any other interrupt requests — even another NMI request. The processor remains in this non-interruptible state until any return-from-interrupt (in supervisor mode) occurs. An interrupt request on the NMI pin is always falling-edge detected. (Note that a return-from-interrupt in user mode does not unblock NMI events and should be avoided by software.)

### 13.2.4 Software Interrupt

The application program may use the **sysctl** instruction to request interrupt service. The vector that **sysctl** requests is serviced immediately or posted in the interrupt table's pending interrupts section, depending upon the current processor priority and the request's priority. The interrupt controller caches the priority of the highest priority interrupt posted in the interrupt table.

The processor cannot request vector 248 (NMI) as a software interrupt.

### 13.2.5 Interrupt Prioritization Model

The interrupt controller continuously compares the processor's priority to the priorities of the highest-posted software interrupt and the highest-pending hardware interrupt. The core is interrupted when a pending interrupt request is higher than the processor priority or has a priority of 31. (Note that a priority-31 interrupt handler can be interrupted by another priority-31 interrupt.) Note that there are no priority-0 interrupts, since such an interrupt would never have a priority higher than the current process, and would therefore never be serviced.

In the event that both hardware- and software-requested interrupts are posted at the same level, the hardware interrupt is delivered first while the software interrupt is left pending. As a result, if both priority-31 hardware- and software-requested interrupts are pending, control will first be transferred to the interrupt handler for the hardware-requested interrupt, however, before the first instruction of that handler can be executed, the pending software-requested interrupt will be delivered and cause control to be transferred to the corresponding interrupt handler.

#### Example 13-1. Interrupt Resolution

```
/* Model used to resolve interrupts between execution of all macro instructions */
if (NMI_pending && !block_NMI)
{ block_NMI = true; /* Reset on return from NMI INTR handler */
  vecnum = 248; vector_addr = 0;
  PC.priority = 31;
  push_local_register_set();
  goto common_interrupt_process; }

if (ICON.gie == enabled) {
  expand_HW_int();
  temp = max(HW_Int_Priority, SW_Int_Priority);
  if (temp == 31 || temp > PC.priority)
    { PC.priority = temp;
      if (SW_Int_Priority > HW_Int_Priority) goto Deliver_SW_Int;
      else{ vecnum = HW_vecnum; goto Deliver_HW_Int; }
    }
}
```

## INTERRUPT CONTROLLER

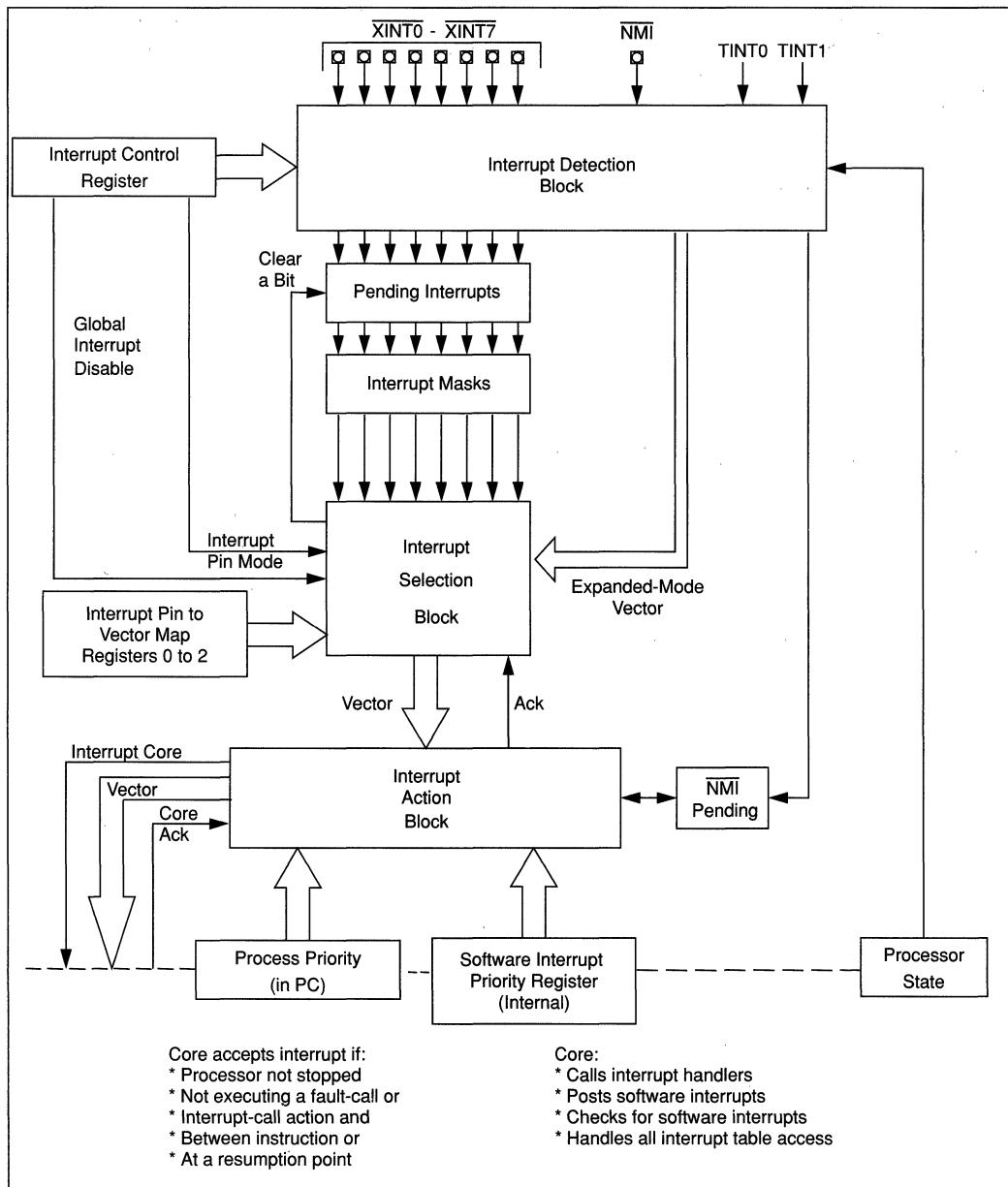


Figure 13-1. Interrupt Controller

### 13.2.6 Interrupt Controller Modes

The eight external interrupt pins can be configured for one of three modes: expanded, dedicated or mixed. Each mode is described in the subsections that follow.

#### 13.2.6.1 Dedicated Mode

In dedicated mode, each external interrupt pin is assigned a vector number. Vector numbers that may be assigned to a pin are those with the encoding PPPP 0010<sub>2</sub> (Figure 13-2), where bits marked P are programmed with bits in the interrupt map (IMAP) registers. This encoding of programmable bits and preset bits can designate 15 unique vector numbers, each with a unique, even-numbered priority. (Vector 0000 0010<sub>2</sub> is undefined; it has a priority of 0.)

Dedicated-mode interrupts are posted in the interrupt pending (IPND) register. Single bits in the IPND register correspond to each of the eight dedicated external interrupt inputs, plus the two timer unit inputs to the interrupt controller. The interrupt mask (IMSK) register selectively masks each of the dedicated-mode interrupts. The IMSK register can optionally be saved and cleared when a dedicated interrupt is serviced. This allows other hardware-generated interrupts to be locked out until the mask is restored. See section 13.3.3, “Programmer’s Interface” (pg. 13-11) for a further description of the IMSK, IPND and IMAP registers.

Interrupt vectors are assigned to timer unit inputs in the same way external pins are assigned dedicated-mode vectors. The timer unit interrupts are always dedicated-mode interrupts.

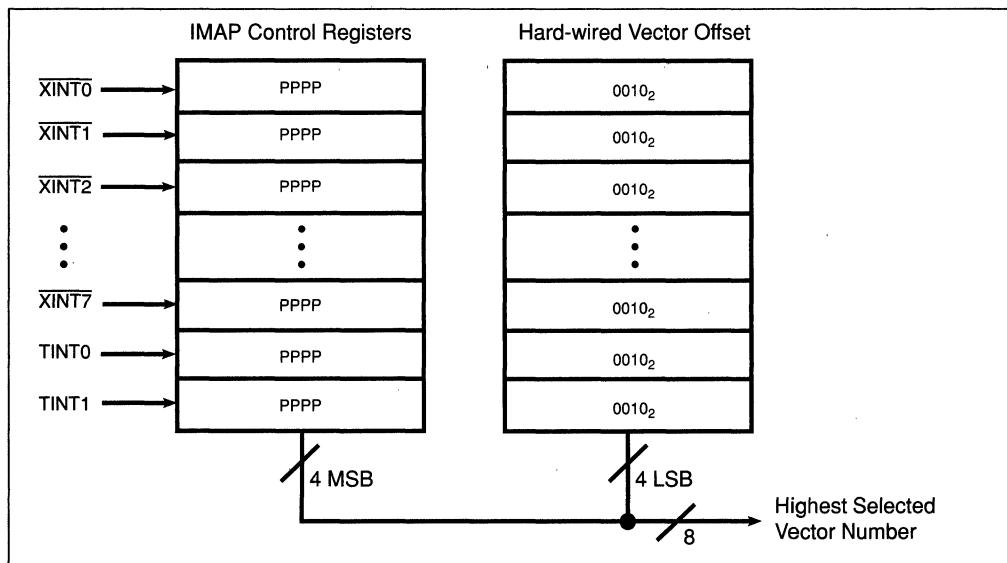


Figure 13-2. Dedicated Mode

## INTERRUPT CONTROLLER

### 13.2.6.2 Expanded Mode

In expanded mode, up to 240 interrupts can be requested from external sources. Multiple external sources are externally encoded into the 8-bit interrupt vector number. This vector number is then applied to the external interrupt pins (Figure 13-3), with the  $\overline{\text{XINT}0}$  pin representing the least-significant bit and  $\overline{\text{XINT}7}$  the most significant bit of the number. Note that external interrupt pins are active low; therefore, the inverse of the vector number is actually applied to the pins.

In expanded mode, external logic is responsible for posting and prioritizing external sources. Typically, this scheme is implemented with a simple configuration of external priority encoders. The interrupt source must remain asserted until the processor services the interrupt and explicitly clears the source. As shown in Figure 13-4, simple, combinational logic can handle prioritization of the external sources when more than one expanded mode interrupt is pending.

An expanded mode interrupt source must remain asserted until the processor services the interrupt and explicitly clears the source. External-interrupt pins in expanded mode are always active low and level-detect. The interrupt controller ignores vector numbers 0 through 7. The output of the external priority encoders in Figure 13-4 can use the 0 vector to indicate that no external interrupts are pending.

The low-order four bits of  $\text{IMAP}0$  are used to internally buffer the expanded-mode interrupt.  $\overline{\text{XINT}7:4}$  are placed in  $\text{IMAP}0[3:0]$ ;  $\overline{\text{XINT}3:0}$  are latched in a special register for use in further arbitrating the interrupt and in selecting the interrupt handler.

$\text{IMSK}$  register bit 0 provides a global mask for all expanded interrupts. The remaining bits (1-7) must be set to 0 in expanded mode. The mask bit can optionally be saved and cleared when an expanded mode interrupt is serviced. This allows other hardware-requested interrupts to be locked out until the mask is restored.  $\text{IPND}$  register bits 0-7 have no function in expanded mode, since external logic is responsible for posting interrupts.

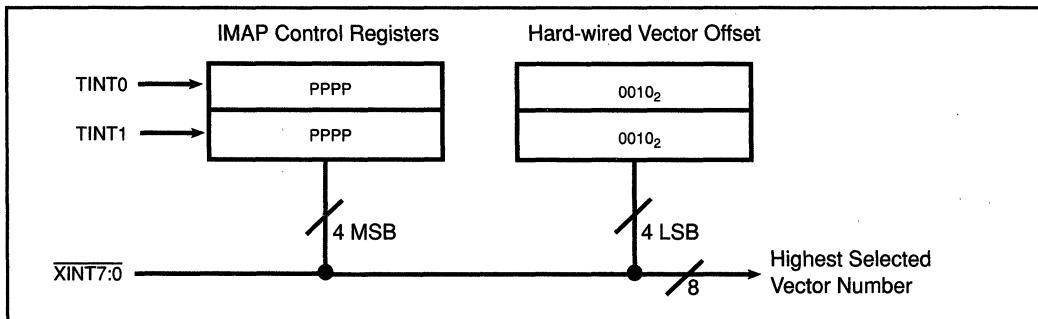


Figure 13-3. Expanded Mode

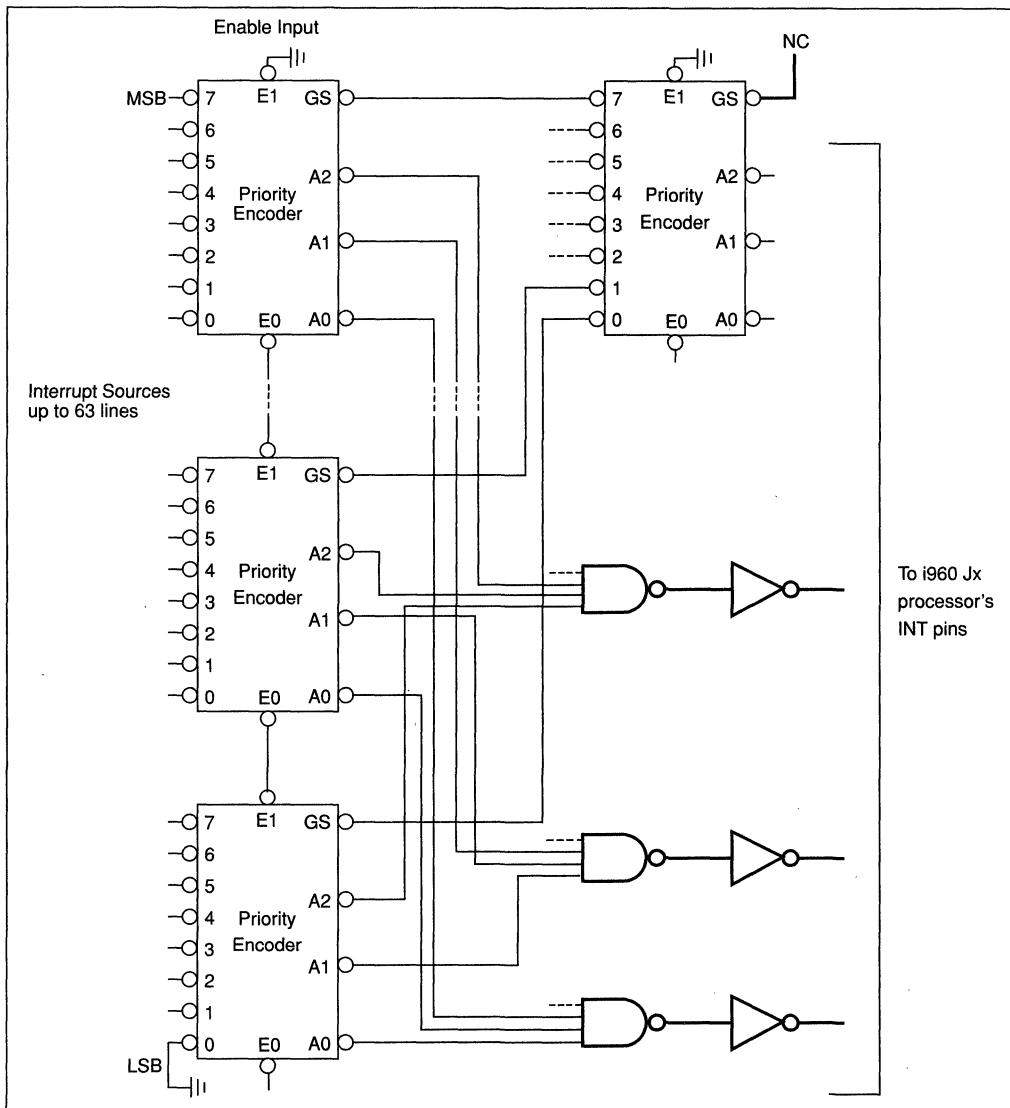


Figure 13-4. Implementation of Expanded Mode Sources

## INTERRUPT CONTROLLER

### 13.2.6.3 Mixed Mode

In mixed mode, pins  $\overline{XINT0}$  through  $\overline{XINT4}$  are configured for expanded mode. These pins are encoded for the five most-significant bits of an expanded-mode vector number; the three least-significant bits of the vector number are set internally to  $010_2$ . Pins  $\overline{XINT5}$  through  $\overline{XINT7}$  are configured for dedicated mode.

The low-order four bits of IMAPO are used to buffer the expanded-mode interrupt internally.  $XINT4:1$  are placed in IMAPO[3:0];  $\overline{XINT0}$  is latched in a special register for use in further arbitrating the interrupt and in selecting the interrupt handler.

IMSK register bit 0 is a global mask for the expanded-mode interrupts; bits 5 through 7 mask the dedicated interrupts from pins  $\overline{XINT5}$  through  $\overline{XINT7}$ , respectively. IMSK register bits 1-4 must be set to 0 in mixed mode. The IPND register posts interrupts from the dedicated-mode pins  $XINT7:5$ . IPND register bits that correspond to expanded-mode inputs are not used.

### 13.2.7 Saving the Interrupt Mask

Whenever an interrupt requested by  $\overline{XINT7:0}$  or by the internal timers is serviced, the IMSK register is automatically saved in register r3 of the new local register set allocated for the interrupt handler. After the mask is saved, the IMSK register is optionally cleared. This allows all interrupts except NMIs to be masked while an interrupt is being serviced. Since the IMSK register value is saved, the interrupt procedure can restore the value before returning. The option of clearing the mask is selected by programming the ICON register as described in section 13.3.4, “Interrupt Control Register (ICON)” (pg. 13-12). Several options are provided for interrupt mask handling:

1. Mask is unchanged.
2. Clear for dedicated-mode sources only.
3. Clear for expanded-mode sources only.
4. Clear for all hardware-requested interrupts (dedicated and expanded mode).

Options 2 and 3 are used in mixed mode, where both dedicated-mode and expanded-mode inputs are allowed. Timer unit interrupts are always dedicated-mode interrupts.

Note that if the same interrupt is requested simultaneously by a dedicated- and an expanded-mode source, the interrupt is considered an expanded-mode interrupt and the IMSK register is handled accordingly.

The IMSK register must be saved and cleared when expanded mode inputs request a priority-31 interrupt. Priority-31 interrupts are interrupted by other priority-31 interrupts. In expanded mode, the interrupt pins are level-activated. For level-activated interrupt inputs, instructions within the interrupt handler are typically responsible for causing the source to deactivate. If these priority-31 interrupts are not masked, another priority-31 interrupt will be signaled and serviced before the handler is able to deactivate the source. The first instruction of the interrupt handling procedure is never reached, unless the option is selected to clear the IMSK register on entry to the interrupt.

Another use of the mask is to lock out other interrupts when executing time-critical portions of an interrupt handling procedure. All hardware-generated interrupts are masked until software explicitly replaces the mask.

The processor does not restore r3 to the IMSK register when the interrupt return is executed. If the IMSK register is cleared, the interrupt handler must restore the IMSK register to enable interrupts after return from the handler.

### 13.3 EXTERNAL INTERFACE DESCRIPTION

This section describes the physical characteristics of the interrupt inputs. The i960 Jx processors provide eight external interrupt pins and one non-maskable interrupt pin for detecting external interrupt requests. The eight external pins can be configured as dedicated inputs, where each pin is capable of requesting a single interrupt. The external pins can also be configured in an expanded mode, where the value asserted on the external pins represents an interrupt vector number. In this mode, up to 240 values can be directly requested with the interrupt pins. The external interrupt pins can be configured in mixed mode. In this mode, some pins are dedicated inputs and the remaining pins are used in expanded mode.

#### 13.3.1 Pin Descriptions

The interrupt controller provides nine interrupt pins:

- |                         |   |
|-------------------------|---|
| XINT7:0                 | External Interrupt (input) - These eight pins cause interrupts to be requested. Pins are software configurable for three modes: dedicated, expanded, mixed. Each pin can be programmed as an edge- or level-detect input. Also, a debounce sampling mode for these pins can be selected under program control.  |
| $\overline{\text{NMI}}$ | Non-Maskable Interrupt (input) - This edge-activated pin causes a non-maskable interrupt event to occur. $\overline{\text{NMI}}$ is the highest priority interrupt recognized. A debounce sampling mode for $\overline{\text{NMI}}$ can be selected under program control. This pin is internally synchronized. |

External interrupt pin functions  $\overline{\text{XINT7:0}}$  depend on the operation mode (expanded, dedicated or mixed) and on several other options selected by setting ICON register bits.

## INTERRUPT CONTROLLER

### 13.3.2 Interrupt Detection Options

The XINT7:0 pins can be programmed for level-low or falling-edge detection when used as dedicated inputs. All dedicated inputs plus the NMI pin are programmed (globally) for fast sampling or debounce sampling. Expanded-mode inputs are always sampled in debounce mode. Pin detection and sampling options are selected by programming the ICON register.

When falling-edge detection is enabled and a high-to-low transition is detected, the processor sets the corresponding pending bit in the IPND register. The processor clears the IPND bit upon entry into the interrupt handler.

When a pin is programmed for low-level detection, the pin's bit in the IPND register remains set as long as the pin is asserted (low). The processor attempts to clear the IPND bit on entry into the interrupt handler; however, if the active level on the pin is not removed at this time, the bit in the IPND register remains set until the source of the interrupt is deactivated and the IPND bit is explicitly cleared by software. Software may attempt to clear an interrupt pending bit before the active level on the corresponding pin is removed. In this case, the active level on the interrupt pin causes the pending bit to remain asserted.

After the interrupt signal is deasserted, the handler then clears the interrupt pending bit for that source before return from handler is executed. If the pending bit is not cleared, the interrupt is re-entered after the return is executed.

Example 13-2 demonstrates how a level detect interrupt is typically handled. The example assumes that the **ld** from address “timer\_0,” deactivates the interrupt input.

#### Example 13-2. Return from a Level-detect Interrupt

```
# Clear level-detect interrupts before return from handler
    lda    IPND_MM, g1
    ld     timer_0, g0 # Get timer value and clear TMRO
    lda    0x1000, g2
wait:
    mov    0, g3
    atmod g1, g2, g3
    bbs    0xC, g3, wait
    ret        # Return from handler
```

The debounce sampling mode provides a built-in filter for noisy or slow-falling inputs. The debounce sampling mode requires that a low level is stable for seven consecutive samples before the expanded mode vector is resolved internally. Expanded mode interrupts are always sampled using the debounce sampling mode. This mode provides time for interrupts to trickle through external priority encoders.

Figure 13-5 shows how a signal is sampled in each mode. The debounce-sampling option adds several clocks to an interrupt's latency due to the multiple clocks of sampling. Inputs are sampled once every two CLKIN cycles (external bus clock).

Interrupt pins are asynchronous inputs. Setup or hold times relative to CLKIN are not needed to ensure proper pin detection. Note in Figure 13-5. that interrupt inputs are sampled once every two CLKIN cycles. For practical purposes, this means that asynchronous interrupting devices must generate an interrupt signal that is asserted for at least three CLKIN cycles for the fast sampling mode or seven CLKIN cycles for the debounce sampling mode. See the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* or the *80960JD Embedded 32-bit Microprocessor Data Sheet* for setup and hold specifications that guarantee detection of the interrupt on particular edges of CLKIN. These specification are useful in designs that use synchronous logic to generate interrupt signals to the processor. These specification must also be used to calculate the minimum signal width, as shown in Figure 13-5.

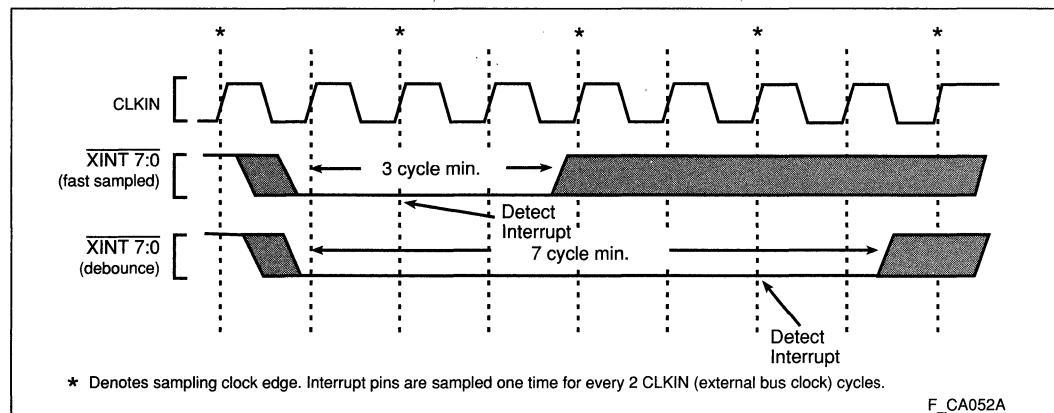


Figure 13-5. Interrupt Sampling

### 13.3.3 Programmer's Interface

The programmer's interface to the interrupt controller is through six memory-mapped control registers: ICON control register, IMAP0-IMAP2 control registers, IMSK register and IPND control registers. Table 13-1 describes the ICU registers.

**Table 13-1. Interrupt Control Registers Memory-Mapped Addresses**

| Register Name | Description                | Address    |
|---------------|----------------------------|------------|
| IMAP0         | Interrupt Map Register 0   | FF00 8520H |
| IMAP1         | Interrupt Map Register 1   | FF00 8524H |
| IMAP2         | Interrupt Map Register 2   | FF00 8528H |
| ICON          | Interrupt Control Register | FF00 8510H |
| IPND          | Interrupt Pending Register | FF00 8500H |
| IMSK          | Interrupt Mask Register    | FF00 8504H |

#### 13.3.4      **Interrupt Control Register (ICON)**

The ICON register (see Figure 13-6) is a 32-bit memory-mapped control register, that sets up the interrupt controller. Software can manipulate this register using the load/store type instructions. The ICON register is also automatically loaded at initialization from the control table in external memory. Figure 13-6 shows the layout of the ICON register.

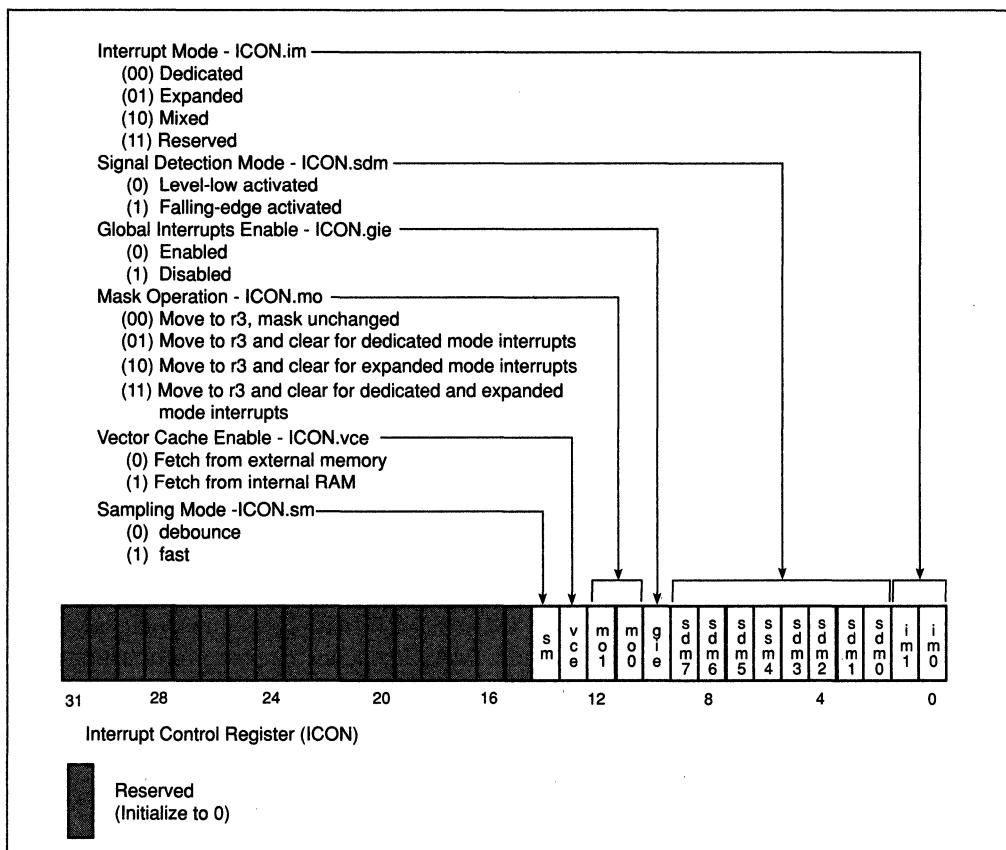


Figure 13-6. Interrupt Control (ICON) Register

13

The *interrupt mode field* (bits 0 and 1) determines the operation mode for the external interrupt pins ( $\overline{XINT7:0}$ ) — dedicated, expanded or mixed.

The *signal detection mode bits* (bits 2 - 9) determine whether the signals on the individual external interrupt pins ( $\overline{XINT7:0}$ ) are level-low activated or falling-edge activated. Expanded-mode inputs are always level-detected; the  $\overline{NMI}$  input is always edge-detected — regardless of the bit's value.

The *global interrupts enable bit* (bit 10) globally enables or disables the external interrupt pins and timer unit inputs. It does not affect the  $\overline{NMI}$  pin. This bit performs the same function as clearing the mask register. The global interrupts enable bit is also changed indirectly by the use of the following instructions: **inten**, **intdis**, **intctl**.

## INTERRUPT CONTROLLER

The *mask-operation field* (bits 11, 12) determines the operation the core performs on the mask register when a hardware-generated interrupt is serviced. On an interrupt, the IMSK register is either unchanged; cleared for dedicated-mode interrupts; cleared for expanded-mode interrupts; or cleared for both dedicated- and expanded-mode interrupts. IMSK is never cleared for NMI or software interrupts.

The *vector cache enable bit* (bit 13) determines whether interrupt table vector entries are fetched from the interrupt table or from internal data RAM. Only vectors with the four least-significant bits equal to  $0010_2$  may be cached in internal data RAM.

The *sampling-mode bit* (bit 14) determines whether dedicated inputs and  $\overline{\text{NMI}}$  pin are sampled using debounce sampling or fast sampling. Expanded-mode inputs are always detected using debounce mode.

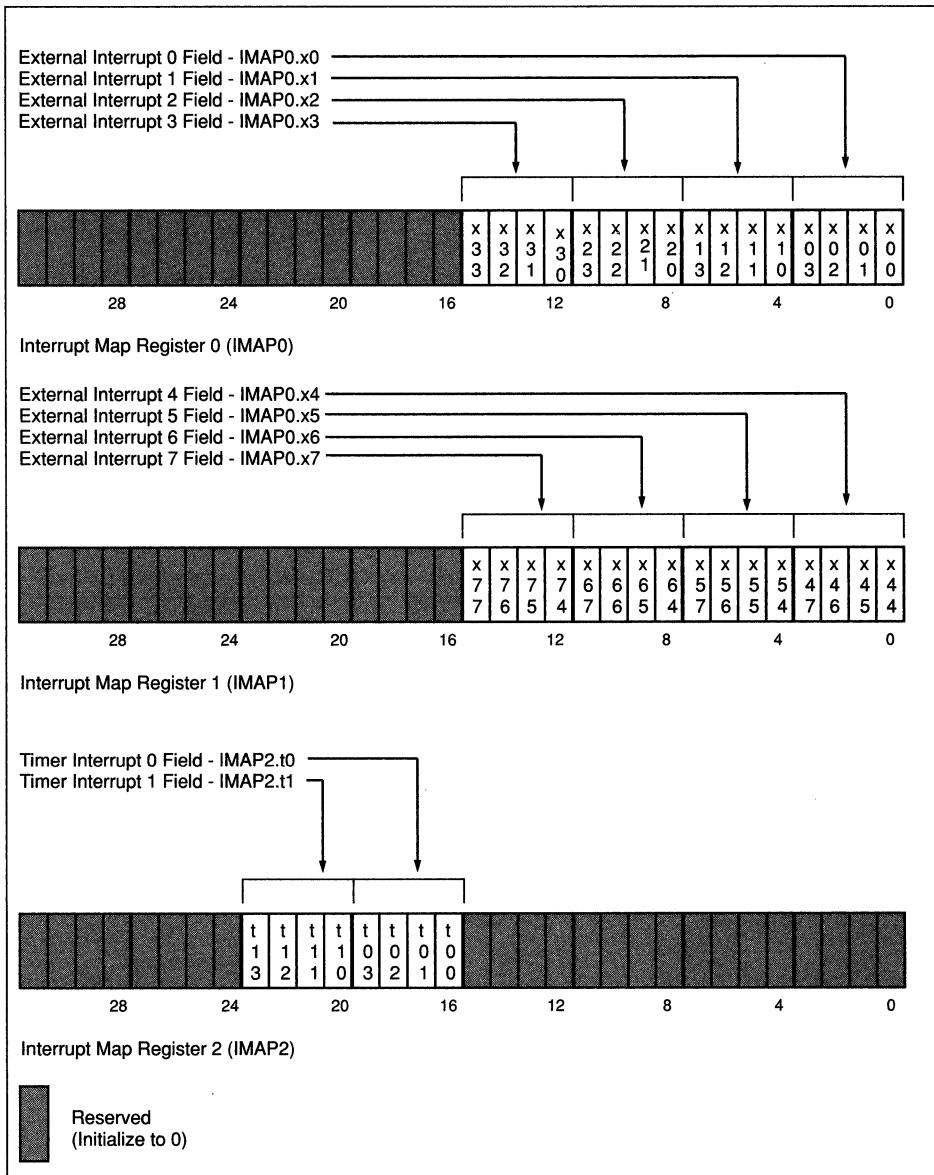
Bits 15 through 31 are reserved and must be set to 0 at initialization.

### 13.3.5 Interrupt Mapping Registers (IMAP0-IMAP2)

The IMAP registers (Figure 13-7) are three 32-bit registers (IMAP0 through IMAP2). These register's bits are used to program the vector number associated with the interrupt source when the source is connected to a dedicated-mode input. IMAP0 and IMAP1 contain mapping information for the external interrupt pins (four bits per pin). IMAP2 contains mapping information for the timer-interrupt inputs (four bits per interrupt).

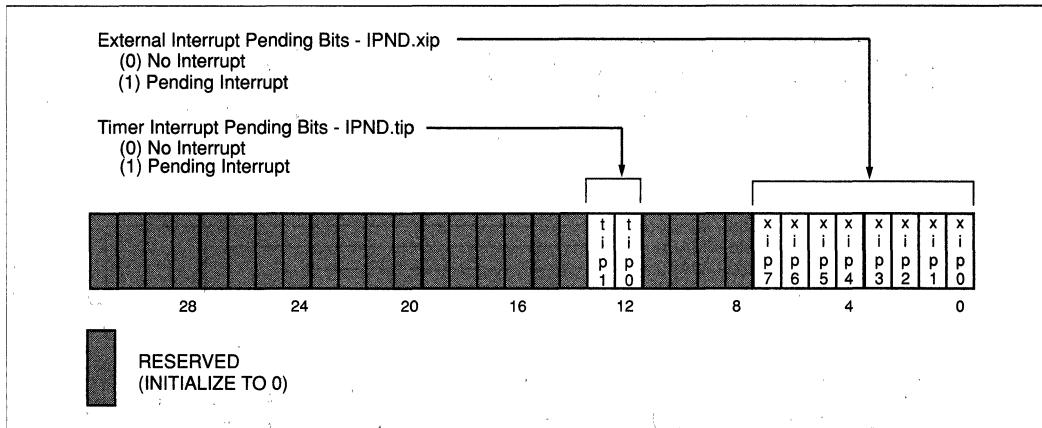
Each set of four bits contains a vector number's four most-significant bits; the four least-significant bits are always  $0010_2$ . In other words, each source can be programmed for a vector number of PPPP  $0010_2$ , where "P" indicates a programmable bit. For example, IMAP0 bits 4 through 7 contain mapping information for the  $\overline{\text{XINT1}}$  pin. If these bits are set to  $0110_2$ , the pin is mapped to vector number  $0110\ 0010_2$  (or vector number 98).

Software can access the mapping registers using load/store type instructions. The mapping registers are also automatically loaded at initialization from the control table in external memory. Note that bits 16 through 31 of IMAP0 and IMAP1 are reserved and should be set to 0 at initialization. Bits 0-15 and 24-31 of IMAP2 are also reserved and should be set to 0.



### 13.3.5.1 Interrupt Mask (IMSK) and Interrupt Pending (IPND) Registers

The IMSK and IPND registers (see Figure 13-9) are both memory-mapped registers. Bits 0 through 7 of these registers are associated with the external interrupt pins ( $\overline{XINT0}$  through  $\overline{XINT7}$ ) and bits 12 and 13 are associated with the timer-interrupt inputs (TMR0 and TMR1). All other bits are reserved and should be set to 0 at initialization.



**Figure 13-8. Interrupt Pending (IPND) Register**

The IPND register posts dedicated-mode interrupts originating from the eight external dedicated sources (when configured in dedicated mode) and the two timer sources. Asserting one of these inputs causes a 1 to be latched into its associated bit in the IPND register. In expanded mode, bits 0 through 7 of this register are not used and should not be modified; in mixed mode, bits 0 through 4 are not used and should not be modified.

The mask register provides a mechanism for masking individual bits in the IPND register. An interrupt source is disabled if its associated mask bit is set to 0.

Mask register bit 0 has two functions: it masks interrupt pin  $\overline{XINT0}$  in dedicated mode and it masks all expanded-mode interrupts globally in expanded and mixed modes. In expanded mode, bits 1 through 7 are not used and should contain zeros only; in mixed mode, bits 1 through 4 are not used and should contain zeros only.

When delivering a hardware interrupt, the interrupt controller conditionally clears IMSK based on the value of the ICON.mo bit. Note that IMSK is never cleared for NMI or software interrupt.

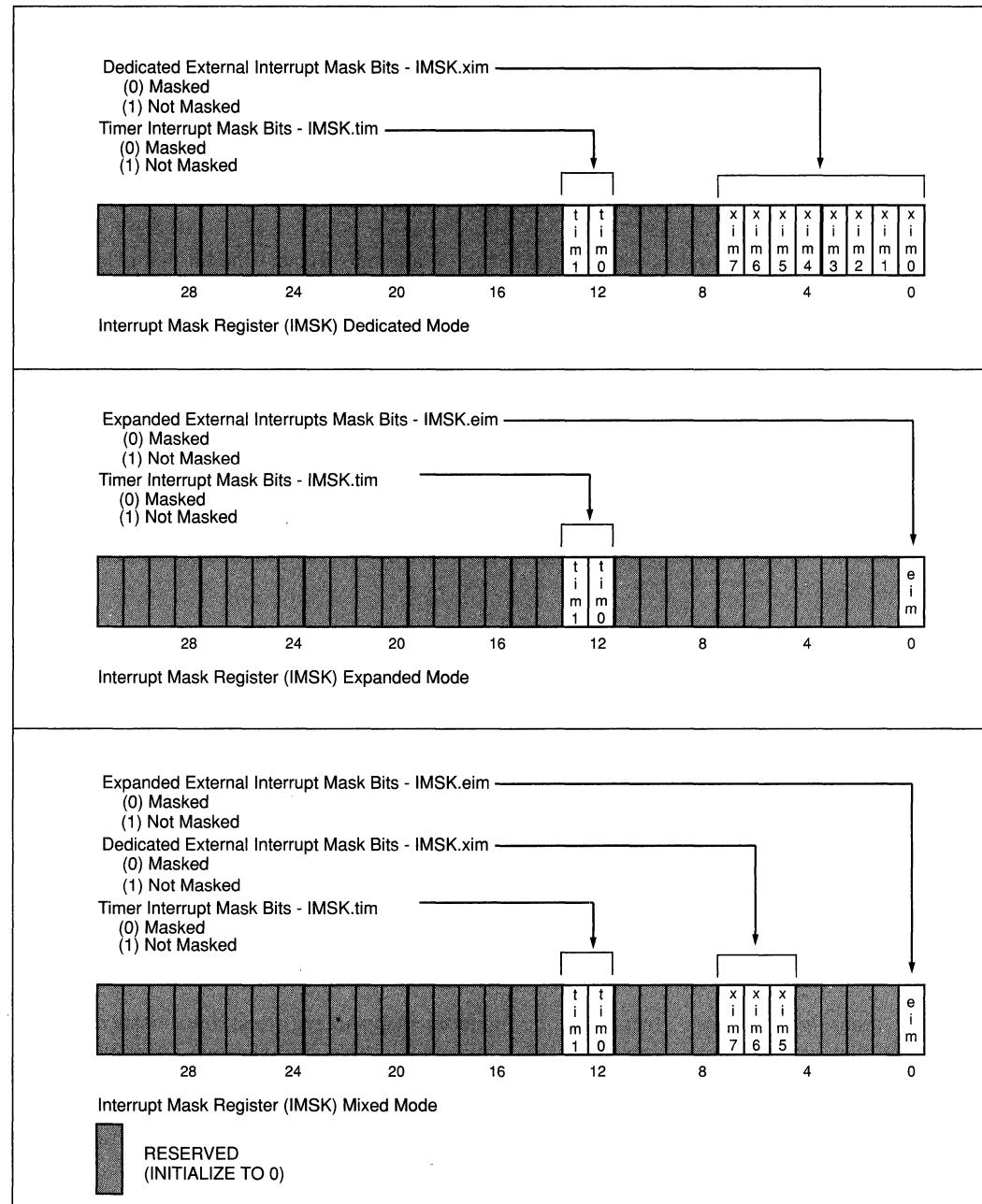


Figure 13-9. Interrupt Mask (IMSK) Registers

Although software can read and write IPND and IMSK using any memory-format instruction, a read-modify-write operation on these registers must be performed using the atomic-modify instruction (ATMOD). Executing an ATMOD on one of these registers causes the interrupt controller to perform regular interrupt processing (including using or automatically updating IPND and IMSK) either before or after, but, not during the read-modify-write operation on that register. This requirement ensures that modifications to IPND and IMSK take effect cleanly, completely, and at a well-defined point. Note that the processor does not assert the **LOCK** pin externally when executing an atomic instruction to IPND and IMSK.

When the processor core handles a pending interrupt, it attempts to clear the bit that is latched for that interrupt in the IPND register before it begins servicing the interrupt. If that bit is associated with an interrupt source that is programmed for level detection and the true level is still present, the bit remains set. Because of this, the interrupt routine for a level-detected interrupt should clear the external interrupt source and explicitly clear the IPND bit before return from the handler is executed.

An alternative method of posting interrupts in the IPND register, other than through the external interrupt pins, is to set bits in the register directly using an ATMOD instruction. This operation has the same effect as requesting an interrupt through the external interrupt pins. The bit set in the IPND register must be associated with an interrupt source that is programmed for dedicated-mode operation.

### **13.3.5.2 Default and Reset Register Values**

The ICON and IMAP2:0 control registers are loaded from the control table in external memory when the processor is initialized or reinitialized. The control table is described in section 11.3.3, "Control Table" (pg. 11-19). The IMSK register is set to 0 when the processor is initialized (**RESET** is deasserted). The IPND register value is undefined after a power-up initialization (cold reset). The application is responsible for clearing this register before any mask register bits are set; otherwise, unwanted interrupts may be triggered. For a reset while power is on (warm reset), the pending register value is retained.

### **13.3.6 Interrupt Controller Register Access Requirements**

Like all other load accesses from internal memory-mapped registers, once issued, a load instruction that accesses an interrupt register has a latency of one internal processor cycle.

A store access to an interrupt register is synchronous with respect to the next instruction; that is, the operation completes fully and all state changes take effect before the next instruction begins execution.

Interrupts can be enabled and disabled quickly by the new **intdis** and **inten** instructions, which take four cycles each. **intctl** takes a few cycles longer because it returns the previous interrupt enable value.

### 13.4 INTERRUPT OPERATION SEQUENCE

The interrupt controller, microcode and core resources handle all stages of interrupt service. Interrupt service is handled in the following stages:

**Request Interrupt** — In the i960® Jx microprocessor, the programmable on-chip interrupt controller transparently manages all interrupt requests. Interrupts are generated by hardware (external events) or software (the application program). Hardware requests are signaled on the 8-bit external interrupt port ( $\overline{\text{XINT7:0}}$ ), the non-maskable interrupt pin ( $\overline{\text{NMI}}$ ) or the two timer channels. Software interrupts are signaled with the sysctl instruction with post-interrupt message type.

**Posting Interrupts** — When an interrupt is requested, the interrupt is either serviced immediately or saved for later service, depending on the interrupt's priority. Saving the interrupt for later service is referred to as posting. Once posted, an interrupt becomes a pending interrupt. Hardware and software interrupts are posted differently:

- Hardware interrupts are posted by setting the interrupt's assigned bit in the interrupt pending (IPND) memory mapped register
- Software interrupts are posted by setting the interrupt's assigned bit in the interrupt table's pending priorities and pending interrupts fields

**Check Pending Interrupts** — The Interrupt Control Unit (ICU) compares each pending interrupt's priority with the current process priority. If process priority changes, posted interrupts of higher priority are then serviced. Comparing the process priority to posted interrupt priority is handled differently for hardware and software interrupts. Each hardware interrupt is assigned a specific priority when the processor is configured. The priority of all posted hardware interrupts is continually compared to the current process priority. Software interrupts are posted in the interrupt table in external memory. The highest priority posted in this table is also saved in an on-chip software priority register; this register is continually compared to the current process priority.

**Servicing Interrupts** — If the process priority falls below that of any posted interrupt, the interrupt is serviced. The comparator signals the core to begin a microcode sequence to perform the interrupt context switch and branch to the first instruction of the interrupt routine.

Figure 13-1 illustrates interrupt controller function. For best performance, the interrupt flow for hardware interrupt sources is implemented entirely in hardware.

The comparator only signals the core when a posted interrupt is a higher priority than the process priority. Because the comparator function is implemented in hardware, microcode cycles are never consumed unless an interrupt is serviced.

## INTERRUPT CONTROLLER

### 13.4.1 Setting Up the Interrupt Controller

This section provides an example of setting up the interrupt controller. The following example describes how the interrupt controller can be dynamically configured after initialization.

Example 13-3 sets up the interrupt controller for expanded-mode operation. Initially the IMSK register is masked to allow for setup. A value which selects expanded-mode operation is loaded into the ICON register and the IMSK is unmasked.

#### Example 13-3. Programming the Interrupt Controller for Expanded Mode

```
# Example expanded mode setup . . .
mov    0, g0
mov    1, g1
st     g0,IMSK           # mask, IMSK MMR at 0XFF008504
st     g1,ICON
st     g1,IMSK           # unmask expanded interrupts
```

## 13.5 OPTIMIZING INTERRUPT PERFORMANCE

Figure 13-10 depicts the path from interrupt source to interrupt service routine. This section discusses interrupt performance in general and suggests techniques the application can use to get the best interrupt performance.

### 13.5.1 Interrupt Service Latency

The established measure of interrupt performance is the time required to perform an interrupt task switch, which is known as *interrupt service latency*. Latency is the time measured between activation of an interrupt source and execution of the first instruction for the accompanying interrupt-handling procedure.

Interrupt latency depends on interrupt controller configuration and the instruction being executed at the time of the interrupt. The processor also has a number of cache options which reduce interrupt latency. In the discussion that follows, interrupt latency is expressed as a number of bus clock cycles, and reflects differences between the 80960JA/JF and the 80960JD due to the 80960JD processor's clock-doubled core.

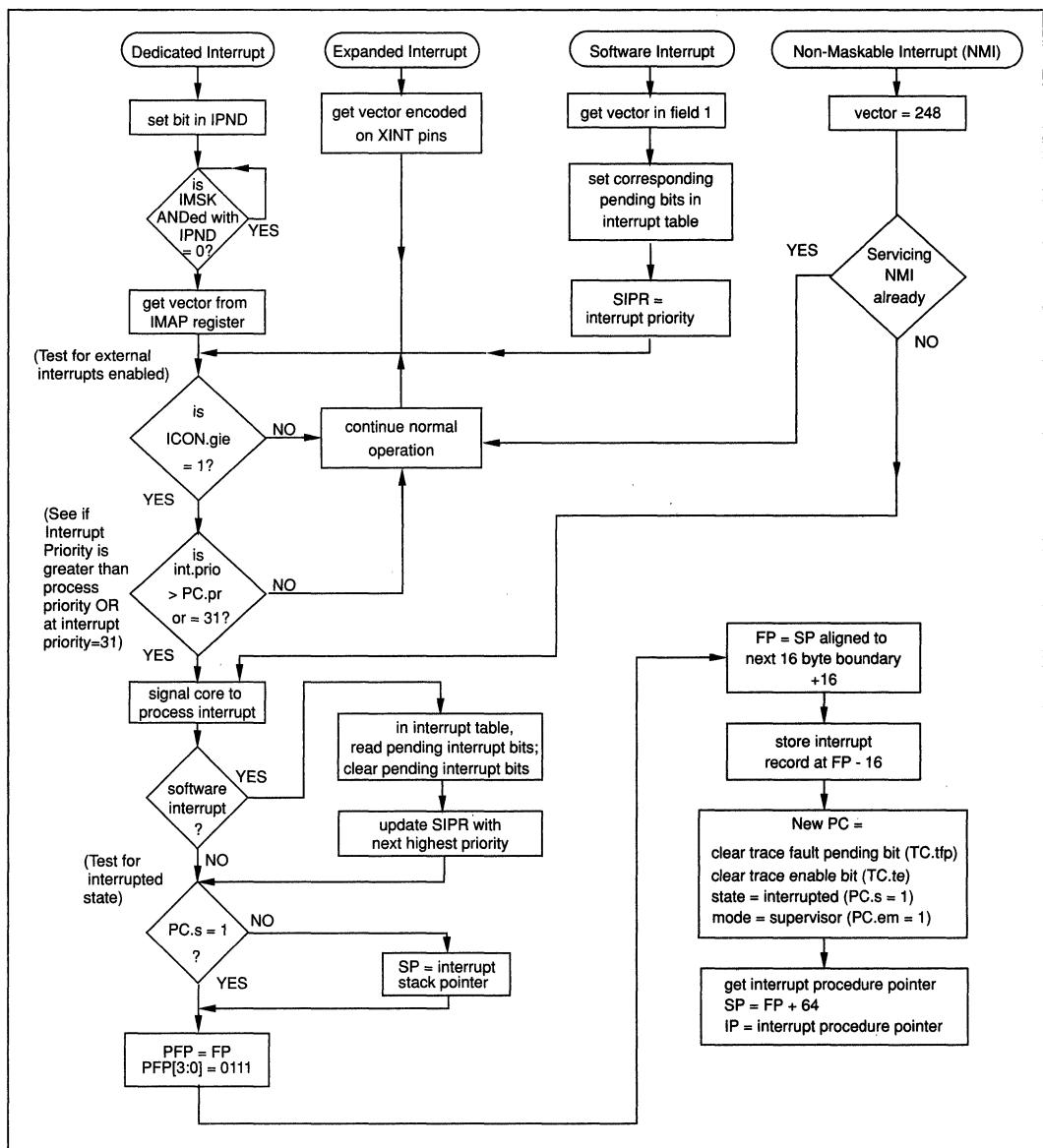


Figure 13-10. Interrupt Service Flowchart

## INTERRUPT CONTROLLER

### 13.5.2 Features to Improve Interrupt Performance

The i960 Jx processor implementation employs four methods to specifically reduce interrupt latency:

- Caching interrupt vectors on-chip
- Caching of interrupt handling procedure code
- Reserving register frames in the local register cache
- Caching the interrupt stack in the data cache

#### 13.5.2.1 Vector Caching Option

To reduce interrupt latency, the i960 Jx processors allow some interrupt table vector entries to be cached in internal data RAM. When the vector cache option is enabled and an interrupt request that has a cached vector to be serviced, the controller fetches the associated vector from internal RAM rather than from the interrupt table in memory.

Interrupts with a vector number with the four least-significant bits equal to  $0010_2$  can be cached. The vectors that can be cached coincide with the vector numbers that are selected with the mapping registers and assigned to dedicated-mode inputs. The vector caching option is selected when programming the ICON register; software must explicitly store the vector entries in internal RAM.

Since the internal RAM is mapped directly to the address space, this operation can be performed using the core's store instructions. Table 13-2 shows the required vector mapping to specific locations in internal RAM. For example, the vector entry for vector number 18 must be stored at RAM location 04H, and so on.

The NMI vector is also shown in Table 13-2. This vector is always cached in internal data RAM at location 0000H. The processor automatically loads this location at initialization with the value of vector number 248 in the interrupt table.

**Table 13-2. Location of Cached Vectors in Internal RAM**

| <b>Vector Number (Binary)</b> | <b>Vector Number (Decimal)</b> | <b>Internal RAM Address</b> |
|-------------------------------|--------------------------------|-----------------------------|
| (NMI)                         | 248                            | 0000H                       |
| 0001 0010 <sub>2</sub>        | 18                             | 0004H                       |
| 0010 0010 <sub>2</sub>        | 34                             | 0008H                       |
| 0011 0010 <sub>2</sub>        | 50                             | 000CH                       |
| 0100 0010 <sub>2</sub>        | 66                             | 0010H                       |
| 0101 0010 <sub>2</sub>        | 82                             | 0014H                       |
| 0110 0010 <sub>2</sub>        | 98                             | 0018H                       |
| 0111 0010 <sub>2</sub>        | 114                            | 001CH                       |
| 1000 0010 <sub>2</sub>        | 130                            | 0020H                       |
| 1001 0010 <sub>2</sub>        | 146                            | 0024H                       |
| 1010 0010 <sub>2</sub>        | 162                            | 0028H                       |
| 1011 0010 <sub>2</sub>        | 178                            | 002CH                       |
| 1100 0010 <sub>2</sub>        | 194                            | 0030H                       |
| 1101 0010 <sub>2</sub>        | 210                            | 0034H                       |
| 1110 0010 <sub>2</sub>        | 226                            | 0038H                       |
| 1111 0010 <sub>2</sub>        | 242                            | 003CH                       |

### 13.5.2.2 Caching Interrupt Routines and Reserving Register Frames

The time required to fetch the first instructions of an interrupt-handling procedure affects interrupt response time and throughput. The controller allows this fetch time to be reduced by caching interrupt procedures or portions of procedures in the i960 Jx microprocessor's instruction cache. See section 4.4, "INSTRUCTION CACHE" (pg. 4-4) for information on the instruction cache.

To decrease interrupt latency for high priority interrupts (priority 28 and above), software can limit the number of frames in the local register cache available to code running at a lower priority (priority 27 and below). This ensures that some number of free frames are available to high-priority interrupt service routines. See section 4.2, "LOCAL REGISTER CACHE" (pg. 4-2), for more details.

### 13.5.2.3 Caching the Interrupt Stack

By locating the interrupt stack in memory that can be cached by the data cache, the performance of interrupt returns can be improved. This is because potentially accesses to the interrupt record by the interrupt return can be satisfied by the data cache. See section 12.6, “Programming the Logical Memory Attributes” (pg. 12-8) for details on how to enable data caching for portions of memory.

### 13.5.3 Base Interrupt Latency

In many applications, the processor’s instruction mix and cache configuration are known sufficiently well to use typical interrupt latency in calculations of overall system performance. For example, a timer interrupt may frequently trigger a task switch in a multi-tasking kernel. Base interrupt latency assumes the following:

- Single-cycle RISC instruction is interrupted.
- Frame flush does not occur.
- Bus queue is empty.
- Cached interrupt handler.
- No interaction of faults and interrupts (i.e., a stable system).

Table 13-3 shows the base latencies for all interrupt types, with varying pin sampling and vector caching options. Note that the 80960JD interrupt latency is approximately 50% less than the 80960JA/JF interrupt latency due to its core clock operating at twice the speed of CLKIN.

Table 13-3. Base Interrupt Latency

| Interrupt Type   | Detection Option | Vector Caching Enabled | Typical 80960JA/JF Latency (Bus Clocks) | Typical 80960JD Latency (Bus Clocks) |
|--|------------------|------------------------|---|--------------------------------------|
| <u>NMI</u>   | Fast             | Yes                    | 29                                      | 149                                  |
|  | Debounced        | Yes                    | 32                                      | 15.5                                 |
| <u>Dedicated Mode XINT7:0, TINT1:0</u>   | Fast             | Yes                    | 34                                      | 17.5                                 |
|  |                  | No                     | 40+a                                    | 21+b                                 |
|  | Debounced        | Yes                    | 37                                      | 21.5                                 |
|  |                  | No                     | 45+a                                    | 26+b                                 |
| <u>Expanded Mode XINT7:0, TINT1:0</u>  | Debounced        | Yes                    | 37                                      | 22                                   |
|  |                  | No                     | 45+a                                    | 26+b                                 |
| <u>Software</u>  | NA               | Yes                    | 68                                      | 35                                   |
|  |                  | No                     | 69+a                                    | 36.5+b                               |
| Notes:<br>a = MAX (0,N - 7)<br>b = MAX (0,N - 3.5)<br>where "N" is the number of bus cycles needed to perform a word load. |                  |                        |   |                                      |

### 13.5.4 Maximum Interrupt Latency

In real-time applications, worst-case interrupt latency must be considered for critical handling of external events. For example, an interrupt from a mechanical subsystem may need service to calculate servo loop parameters to maintain directional control. Determining worst-case latency depends on knowledge of the processor's instruction mix and operating environment as well as the interrupt controller configuration. Excluding certain very long, uninterruptable instructions from critical sections of code will effectively reduce worst-case interrupt latency to levels approaching the base latency.

## INTERRUPT CONTROLLER

Tables 13-3 through 13-3 present worst case interrupt latencies based on possible execution of **divo** (r15 destination), **divo** (r3 destination), **calls** or **flushreg** instructions or software interrupt detection. The assumptions for these tables are the same as for Table 13-3, except for instruction execution.

**Table 13-4. Worst-Case Interrupt Latency Controlled by divo to Destination r15**

| Interrupt Type  | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |
|---|------------------|------------------------|---------------------------------------|------------------------------------|
| <b>NMI</b>  | Fast             | Yes                    | 42                                    | 23.5                               |
|   | Debounced        | Yes                    | 46                                    | 26                                 |
| <b>Dedicated Mode XINT7:0, TINT1:0</b>  | Fast             | Yes                    | 45                                    | 23.5                               |
|   |                  | No                     | 45+a                                  | 23.5+b                             |
|   | Debounced        | Yes                    | 49                                    | 27.5                               |
|   |                  | No                     | 51+a                                  | 27.5+b                             |
| <b>Expanded Mode XINT7:0, TINT1:0</b>   | Debounced        | Yes                    | 50                                    | 27.5                               |
|   |                  | No                     | 51+a                                  | 27.5+b                             |
| Notes:<br>a = MAX (0,N - 11)<br>b = MAX (0,N - 5)<br>where "N" is the number of bus cycles needed to perform a word load. |                  |                        |                                       |                                    |

Table 13-5. Worst-Case Interrupt Latency Controlled by divo to Destination r3

| Interrupt Type   | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |
|--|------------------|------------------------|---------------------------------------|------------------------------------|
| <b>NMI</b>   | Fast             | Yes                    | 59                                    | 30.5                               |
|  | Debounced        | Yes                    | 64                                    | 34.5                               |
| Dedicated Mode<br>XINT7:0, TINT1:0   | Fast             | Yes                    | 65                                    | 33.5                               |
|  |                  | No                     | 72+a                                  | 37.5+b                             |
|  | Debounced        | Yes                    | 69                                    | 37                                 |
|  |                  | No                     | 76+a                                  | 42+b                               |
| Expanded Mode<br>XINT7:0, TINT1:0  | Debounced        | Yes                    | 70                                    | 37.5                               |
|  |                  | No                     | 76+a                                  | 42+b                               |
| Notes:<br>a = MAX (0,N - 7)<br>b = MAX (0,N - 3.5)<br>where "N" is the number of bus cycles needed to perform a word load. |                  |                        |                                       |                                    |

Table 13-6. Worst-Case Interrupt Latency Controlled by calls (Sheet 1 of 2)

| Interrupt Type   | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |
|--|------------------|------------------------|---------------------------------------|------------------------------------|
| <b>NMI</b>   | Fast             | Yes                    | 53+a                                  | 27+c                               |
|  | Debounced        | Yes                    | 56+a                                  | 32+c                               |
| Dedicated Mode<br>XINT7:0, TINT1:0   | Fast             | Yes                    | 58+a                                  | 29.5+c                             |
|  |                  | No                     | 66+a+b                                | 33.5+c+d                           |
|  | Debounced        | Yes                    | 62+a                                  | 33+c                               |
|  |                  | No                     | 69+a+b                                | 38+b+c                             |
| Notes:<br>a = MAX (0,N - 4)<br>b = MAX (0,N - 7)<br>c= MAX (0,N - 2.5)<br>d= MAX (0,N - 3.5)<br>where "N" is the number of bus cycles needed to perform a word load. |                  |                        |                                       |                                    |

## INTERRUPT CONTROLLER

**Table 13-6. Worst-Case Interrupt Latency Controlled by calls (Sheet 2 of 2)**

| Interrupt Type                    | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |
|-----------------------------------|------------------|------------------------|---------------------------------------|------------------------------------|
| Expanded Mode<br>XINT7:0, TINT1:0 | Debounced        | Yes                    | 63+a                                  | 32.5+c                             |
|                                   |                  | No                     | 70+a+b                                | 38+c+d                             |

Notes:  
 a = MAX (0,N - 4)  
 b = MAX (0,N - 7)  
 c= MAX (0,N - 2.5)  
 d= MAX (0,N - 3.5)  
 where "N" is the number of bus cycles needed to perform a word load.

**Table 13-7. Worst-Case Interrupt Latency When Delivering a Software Interrupt**

| Interrupt Type                     | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |
|------------------------------------|------------------|------------------------|---------------------------------------|------------------------------------|
| NMI                                | Fast             | Yes                    | 96                                    | 47                                 |
|                                    | Debounced        | Yes                    | 97                                    | 47                                 |
| Dedicated Mode<br>XINT7:0, TINT1:0 | Fast             | Yes                    | 99                                    | 48                                 |
|                                    |                  | No                     | 107+a                                 | 53+b                               |
|                                    | Debounced        | Yes                    | 100                                   | 48                                 |
|                                    |                  | No                     | 107+a                                 | 53+b                               |
| Expanded Mode<br>XINT7:0, TINT1:0  | Debounced        | Yes                    | 96                                    | 48                                 |
|                                    |                  | No                     | 105+a                                 | 53+b                               |

Notes:  
 a = MAX (0,N - 7)  
 b = MAX (0,N - 3.5)  
 where "N" is the number of bus cycles needed to perform a word load.

**Table 13-8. Worst-Case Interrupt Latency Controlled by flushreg of One Stack Frame**

| Interrupt Type  | Detection Option | Vector Caching Enabled | Worst 80960JA/JF Latency (Bus Clocks) | Worst 80960JD Latency (Bus Clocks) |  |
|---|------------------|------------------------|---------------------------------------|------------------------------------|--|
| <b>NMI</b>  | Fast             | Yes                    | $77+a+b$                              | $41+d+e$                           |  |
|   | Debounced        | Yes                    | $81+a+b$                              | $43+d+e$                           |  |
| <b>Dedicated Mode<br/>XINT7:0, TINT1:0</b>  | Flat             | Yes                    | $82+a+b$                              | $43+d+e$                           |  |
|   |                  | No                     | $89+a+b+c$                            | $47.5+d+e+f$                       |  |
|   | Debounced        | Yes                    | $86+a+b$                              | $47+d+e$                           |  |
|   |                  | No                     | $93+a+b+c$                            | $51+d+e+f$                         |  |
| <b>Expanded Mode<br/>XINT7:0, TINT1:0</b>   | Debounced        | Yes                    | $88+a+b$                              | $47.5+d+e$                         |  |
|   |                  | No                     | $93+a+b+c$                            | $52+d+e+f$                         |  |
| <b>Notes:</b>   |                  |                        |                                       |                                    |  |
| a = MAX (0, M - 15)   |                  | d = MAX (0, M - 7.5)   |                                       |                                    |  |
| b = MAX (0, M - 28)   |                  | e = MAX (0, M - 15)    |                                       |                                    |  |
| c = MAX (0, N - 7)  |                  | f = MAX (0, n - 3.5)   |                                       |                                    |  |
| where "M" is the number of bus cycles needed to perform a quad word store and "N" is the number of bus cycles needed to perform a word load. Interrupt latency increases rapidly as the number of flushed stack frames increases. |                  |                        |                                       |                                    |  |

#### 13.5.4.1 Avoiding Certain Destinations for MDU Operations

Typically, when delivering an interrupt, the processor attempts to push the first four local registers (pfp, sp, rip, and R3) onto the local register cache as early as possible. Because of register-interlock, this operation is stalled until previous instructions return their results to these registers. In most cases, this is not a problem; however, in the case of instructions performed by the Multiply/Divide Unit (**divo**, **divi**, **ediv**, **modi**, **remo**, and **remi**), the processor could be stalled for many cycles waiting for the result and unable to proceed to the next step of interrupt delivery.

Interrupt latency can be improved by avoiding the first four local registers as the destination for a Multiply/Divide Unit operation. (Registers pfp, sp, and rip should be avoided anyway for general operations as these are used for procedure linking.)

### 13.5.4.2 Masking Integer Overflow Faults for **syncf**

The i960 core architecture requires an implicit **syncf** before delivering an interrupt so that a fault handler can be dispatched first, if necessary. The **syncf** can require a number of cycles to complete if a multi-cycle multiply or divide instruction was issued previously and integer-overflow faults are unmasked (allowed to occur). Interrupt latency can be improved by masking integer-overflow faults, which allows the implicit **syncf** to complete in much shorter time.



14

## TIMERS





## CHAPTER 14 TIMERS

A key enhancement of the i960® Jx processor — not available on previous i960 processor family members — are the two identical, fully independent 32-bit timers. Each is programmed by use of the timer registers. These registers are memory-mapped within the processor, addressable on 32-bit boundaries. The timers have a single shot mode and auto-reload capabilities for continuous operation. Each timer has an independent interrupt request to the processor's interrupt controller. A timer can generate a fault when unauthorized writes from user mode are detected. Figure 14-1 shows a diagram of the timer functions. Figure 14-5 shows the Timer Unit state diagram

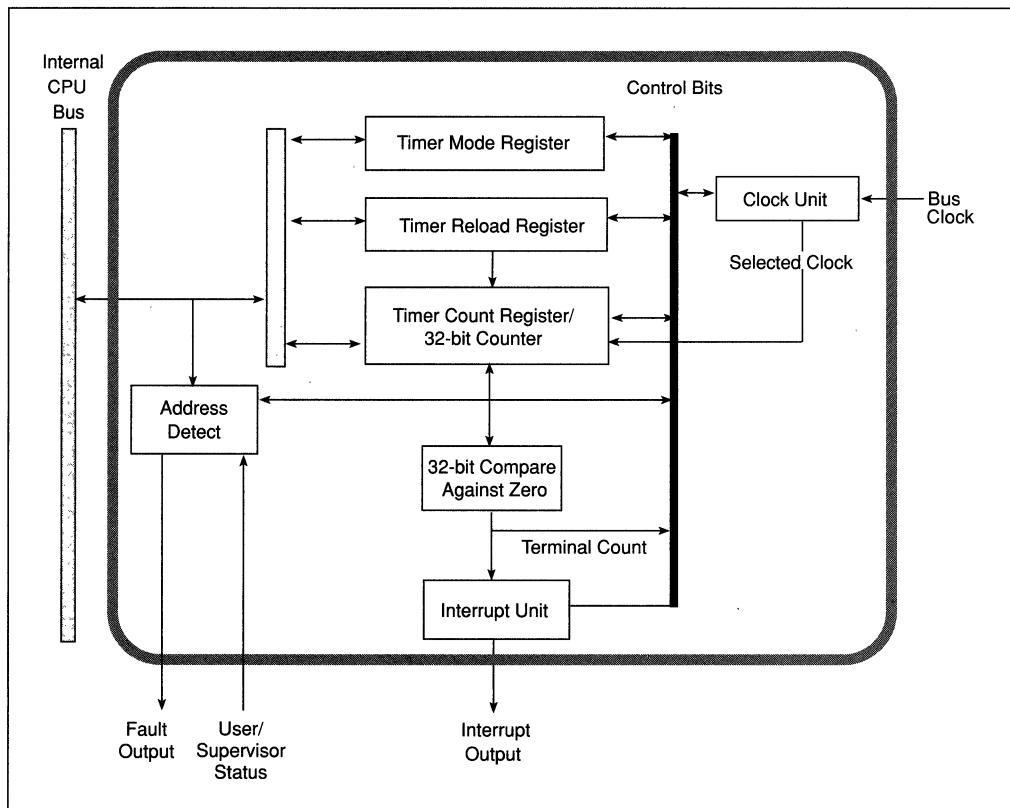


Figure 14-1. Integrated Timer Functional Diagram

**TIMERS****14.1 TIMER REGISTERS**

Each timer can contain a user-defined count value. When enabled, this count value decrements with each Timer Clock (TCLOCK) cycle. The timers can be configured to either stop when the user-defined count value reaches zero (“single-shot”) or run continuously (“auto-reload”). Each timer is clocked internally to decrement at a rate equal to the Bus Clock frequency, Bus Clock /2, Bus Clock /4, or Bus Clock /8.

As shown in Table 14-1, each memory-mapped timer has three registers:

- Timer Reload register - contains the timer’s reload count; described in section 14.1.3, “Timer Reload Register (TRR0, TRR1)” (pg. 14-7).
- Timer Count register - contains the timer’s current count; described in section 14.1.2, “Timer Count Register (TCR0, TCR1)” (pg. 14-6).
- Timer Mode register - programs the specific mode of operation or indicates the current programmed status of the timer. This register is described in section 14.1.1, “Timer Mode Register (TMR0, TMR1)” (pg. 14-2).

**Table 14-1. Timer Registers**

| Timer   | Register Acronym | Register Name           |
|---------|------------------|-------------------------|
| Timer 0 | TRR0             | Timer Reload register 0 |
|         | TCR0             | Timer Count register 0  |
|         | TMR0             | Timer Mode register 0   |
| Timer 1 | TRR1             | Timer Reload register 1 |
|         | TCR1             | Timer Count register 1  |
|         | TMR1             | Timer Mode register 1   |

**14.1.1 Timer Mode Register (TMR0, TMR1)**

The Timer Mode register (TMRx; see Figure 14-2) programs the specific mode of operation or indicates the current programmed status for the specified timer. TMRx bits are described in the subsections following Figure 14-2 and summarized in Table 14-2.

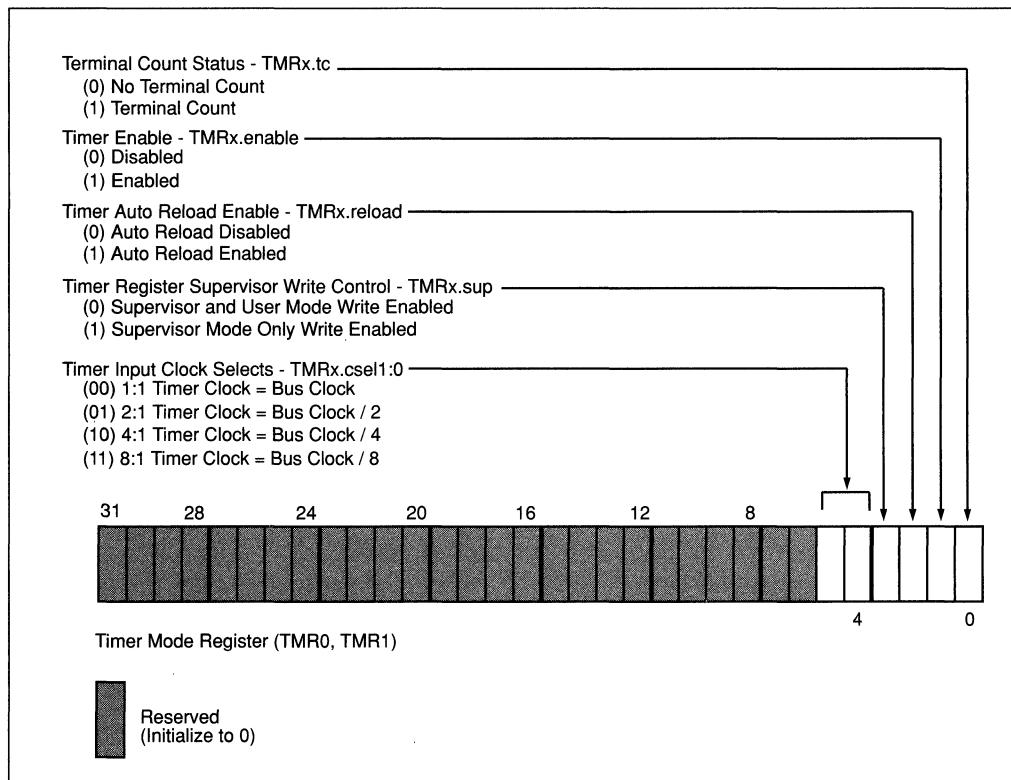


Figure 14-2. Timer Mode Register (TMR0, TMR1)

#### 14.1.1.1 Bit 0 - Terminal Count Status Bit (TMRx.tc)

When the auto-reload (bit 2) is not selected for a timer, the Terminal Count (TC) bit is set when the Timer Count Register (TCR) reaches the zero count value. The TC bit gives the application the ability to monitor timer status through software instead of through interrupts. The TC bit will remain set until software accesses (reads or writes) the TMR. The access clears the TC bit. A value specified for TMRx.tc is ignored in the case of a write.

When auto-reload is selected for a timer and the timer is enabled, the TC bit is unpredictable. Software should avoid relying on the value of the TC bit when auto-reload is enabled.

#### 14.1.1.2 Bit 1 - Timer Enable (TMRx.enable)

The Timer Enable bit allows user software to control the timer's RUN/STOP status. When:

- TMRx.enable = 1      The Timer Count register decrements every Timer Clock (TCLOCK) cycle. TCLOCK is determined by the Timer Input Clock Select (TMRx.csell:0 bits, refer to section 14.1.1.5). TMRx.enable is automatically cleared when the count reaches zero if reload=0. If Reload=1, the bit remains set.
- TMRx.enable = 0      The timer is disabled and all input transitions are ignored.

User software sets this bit. Once set, the timer continues to run, regardless of other processor activity (for example, the timer runs while the processor is in Halt mode) until:

- User software explicitly clears this bit (TMRx.enable = 0).
- TCRx value reaches terminal count (= 0) and the Timer Auto Reload Enable (TMRx.reload) bit = 0.
- Reset (hardware/software reset or powerup). Refer to section 11.2, "INITIALIZATION" (pg. 11-2)

#### 14.1.1.3 Bit 2 - Timer Auto Reload Enable (TMRx.reload)

Bit 2 (TMRx.reload) determines whether the timer runs continuously or in single-shot mode. When TCRx = 0 and TMRx.enable = 1 and:

- TMRx.reload = 1      Allows the timer to run continuously. The processor:
  - Automatically loads TCRx with the value in the Timer Reload register (TRRx), when TCR.x value is zero.
  - TCRx decrements until TCRx = 0 again.

This process repeats until software clears bits 1 or 2.

- TMRx.reload = 0      Timer runs until the Timer Count Register = 0. TRRx has no effect on the timer.

This bit is set and cleared by user software. It is also cleared upon powerup (hardware reset) or software reset. Refer to section 11.2, "INITIALIZATION" (pg. 11-2).

#### 14.1.1.4 Bit 3 - Timer Register Supervisor Read/Write Control (TMRx.sup)

This bit determines whether user mode writes are permitted to the Timer registers (TMRx, TCRx, TRRx). Supervisor mode writes are allowed regardless of this bit's condition. These registers can be read from either mode.

**Table 14-2. Timer Mode Register Control Bit Summary**

| Bit 3<br>(TMRx.sup) | TRRx | TCRx | Bit 2<br>(TMRx.reload) | Bit 1<br>(TMRx.enable) | Action   |
|---------------------|------|------|------------------------|------------------------|--|
| X                   | X    | X    | X                      | 0                      | Timer disabled.  |
| X                   | X    | N    | 0                      | 1                      | Timer enabled, TMRx.enable will be cleared when TCRx decrements to zero.                                     |
| X                   | N    | N    | 1                      | 1                      | Timer and auto reload enabled, TMRx.enable remains set when TCRx=0. When TCRx=0, TCRx equals the TRRx value. |
| 0                   | X    | X    | X                      | X                      | No faults for user mode writes will be generated.  |
| 1                   | X    | X    | X                      | X                      | TYPE.MISMATCH fault generated on user mode write.  |

**Notes:** X = don't care  
N = a number between 1H and FFFF FFFFH

When:

TMRx.sup = 1      A TYPE.MISMATCH fault is generated when a user mode task attempts a write to any of the timer registers; however, supervisor mode writes are allowed.

TMRx.sup = 0      The timer registers can be written from either supervisor mode or user mode.

This bit has no effect on reading the timer registers from user or supervisor mode. This bit can always be written in supervisor mode.

When the processor is in supervisor mode, user software can set or clear this bit. It is also cleared upon power-up (hardware reset) or software reset. Refer to section 11.2, "INITIALIZATION" (pg. 11-2).

#### 14.1.1.5 Bits 4, 5 - Timer Input Clock Selects (TMRx.csel1:0)

Software programs these bits to select the Timer Clock (TCLOCK; see Table 14.3). As shown in Figure 14-1, the bus clock is an input to the Timer Clock Unit. These bits allow the application to specify whether TCLOCK runs at or slower than the Bus Clock frequency.

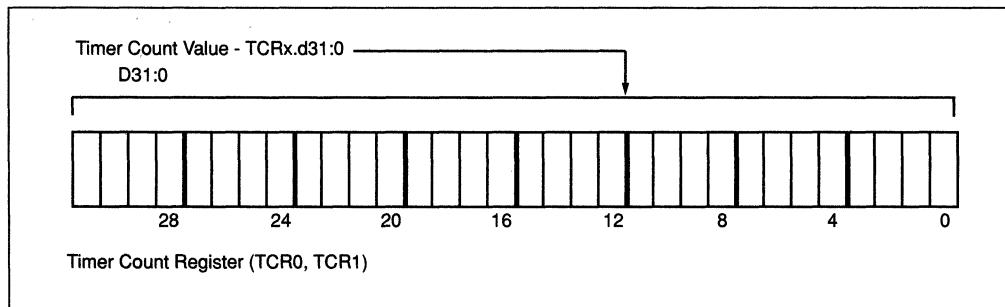
These bits are only set by software. Upon powerup (hardware reset) or software reset, these bits are cleared (TCLOCK = Bus Clock).

**Table 14.3. Timer Input Clock (TCLOCK) Frequency Selection**

| Bit 5<br>TMRx.csel1 | Bit 4<br>TMRx.csel0 | Timer Clock (TCLOCK)        |
|---------------------|---------------------|-----------------------------|
| 0                   | 0                   | Timer Clock = Bus Clock     |
| 0                   | 1                   | Timer Clock = Bus Clock / 2 |
| 1                   | 0                   | Timer Clock = Bus Clock / 4 |
| 1                   | 1                   | Timer Clock = Bus Clock / 8 |

#### 14.1.2 Timer Count Register (TCR0, TCR1)

The timer count register ('TCR') is a 32-bit register which contains the timer's current count. This register can be read or written when the timer is running or stopped. The register value will be decremented for each timer clock tick. When this register value is decremented to a zero value (terminal count), a timer interrupt will be generated; if auto-reload is not selected for the timer, the TC status bit in the timer mode register (TMR, Bit 0) will be set and remain set until the TMRx register is accessed. Figure 14-3 shows the timer count register.

**Figure 14-3. Timer Count Register (TCR0, TCR1)**

The maximum programmable value is FFFF FFFFH; the minimum value is 1H. Programming a value of 0 should be avoided and will have different results. See section 14.5, “Uncommon TCRx and TRRx Conditions” (pg. 14-11) for more information.

User software can access (read or write) the TCRx whether the timer is running or stopped. Bit 3 of the TMRx register determines read/write control (see section 14.1.1.4 for read/write control). TCRx register value is undefined after powerup or reset.

### 14.1.3 Timer Reload Register (TRR0, TRR1)

The Timer Reload register (TRRx; Figure 14-4) is a 32-bit register that the user programs to contain the timer's reload count. The reload count value is only loaded into TCRx when TMRx.reload is set (1), TMRx.enable is set (1) and TCRx equals zero.

The maximum programmable value of the Timer Reload register is FFFF FFFFH, and the minimum value is 1H. Programming a value of 0 should be avoided, as it may cause TINTx to not be asserted continuously. See section 14.5, “Uncommon TCRx and TRRx Conditions” (pg. 14-11) for more information on results of setting TRRx to zero.

User software can access the TRRx whether the timer is running or stopped. Bit 3 of the TMRx register determines read/write control (see section 14.1.1.4 for read/write control). TRRx register value is undefined after powerup or reset.

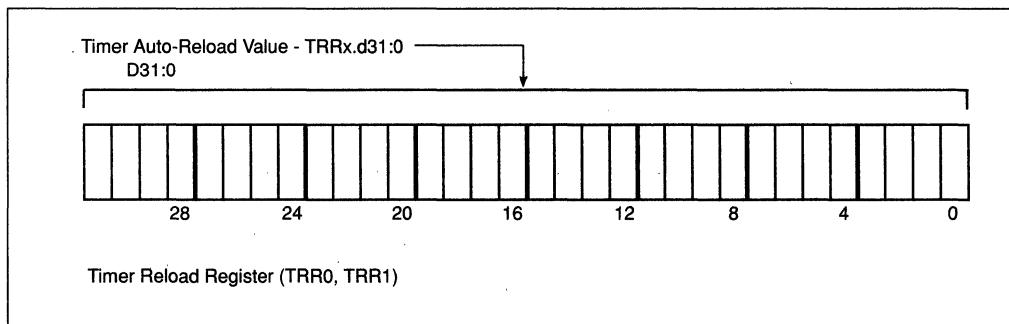


Figure 14-4. Timer Reload Register (TRR0, TRR1)

### 14.1.4 Timer Responses to Bit Settings

Table 14-4 summarizes the timer access timing and maximum times for the timer to respond when registers are accessed. Refer also to the individual register descriptions for details.

## 14.2 TIMER FUNCTIONS

The following sections describe enabling and disabling the Timer Counters and the associated latency.

Table 14-4. Timer Responses to Register Bit Settings

| Name   | Status | Action   |
|--|--------|--|
| (TMRx.tc)<br>Terminal Count<br>Bit 0                                 | READ   | Bit is cleared when user software accesses TMRx. It can be set 1 bus clock later. The timer sets this bit within 1 bus clock of TCRx reaching zero if TMR.reload=0.  |
|  | WRITE  | Bit is cleared within 1 bus clock after the software accesses TMRx.  |
| (TMRx.enable)<br>Timer Enable<br>Bit 1                               | READ   | Bit is available 1 bus clock after executing a read instruction from TMRx.   |
|  | WRITE  | Writing a '1' enables the bus clock to decrement TCRx within 1 bus clock after executing a store instruction to TMRx.  |
| (TMRx.reload)<br>Timer Auto<br>Reload Enable<br>Bit 2                | READ   | Bit is available 1 bus clock after executing a read instruction from TMRx.   |
|  | WRITE  | Writing a '1' enables the reload capability within 1 bus clock after the store instruction to TMRx has executed. This allows TRRx data to be loaded into TCRx and decremented on the next bus clock cycle.   |
| (TMRx.sup)<br>Timer Register<br>Supervisor<br>Write Control<br>Bit 3 | READ   | Bit is available 1 bus clock after executing a read instruction from TMRx.   |
|  | WRITE  | Writing a '1' locks out user mode writes within 1 bus clock after the store instruction executes to TMRx. The timer prevents user mode writes. Upon detecting a user mode write the timer generates a fault condition.   |
| (TMRx.csel1:0)<br>Timer Input<br>Clock Select<br>Bits 4-5            | READ   | Bits are available 1 bus clock after executing a read instruction from TMRx.csel1:0 bit(s).  |
|  | WRITE  | The timer re-synchronizes the clock cycle used to decrement TCRx within one bus clock cycle after executing a store instruction to TMRx.csel1:0 bit(s).  |
| TCRx.d31:0<br>Timer Count<br>Register                                | READ   | The current TCRx count value is available within 1 bus clock cycle after executing a read instruction from TCRx. If the count is to be decremented, the pre-decremented value is returned as the current count value.  |
|  | WRITE  | The value written to TCRx becomes the active TCRx value to be decremented within 1 bus clock cycle. If TCRx is decremented, the value written becomes the active TCRx value to be decremented in the current clock cycle.  |
| TRRx.d31:0<br>Timer Reload<br>Register                               | READ   | The current TRRx count value is available within 1 bus clock after executing a read instruction from TRRx. If the TRRx count is being transferred into TCRx in the current count cycle, the new TCRx count value will be returned to the executing read instruction. |
|  | WRITE  | The value written to TRRx becomes the active value stored in TRRx within 1 bus clock cycle. If the TRRx value is being transferred into the TCRx, data written to TRRx is also transferred into TCRx).   |

### 14.2.1 Enabling/Disabling Counters

Each timer has an Enable bit in its Control register (TMRx.enable) to allow or prevent the timer from counting. The supervisor (SUP) bit controls write accesses to the Enable bit. User software can set or clear the Enable bit. If the timer is not programmed for continuous operation (Auto Reload), the Enable bit automatically clears at the end of a counting sequence.

As with all other load accesses from internal memory-mapped registers, a load instruction that accesses a timer register has a latency of one internal processor cycle. With one exception, a store access to a timer register is synchronous with respect to the next instruction; that is, the operation completes fully and all state changes take effect before the next instruction begins execution. The exception to this is when disabling a timer. Latency associated with the disabling action is such that a timer interrupt may be posted immediately after the store to TMRx to disable it completes. This is because the timer is potentially near zero as the storing of the TMRx MMR occurs. In this case, the timer interrupt is guaranteed to be posted immediately after the store to the TMRx MMR completes and before the next instruction can execute.

Note that the processor may delay the actual issuing of the load or store operation due to previous instruction activity and resource availability of processor functional units.

Lastly, the processor ensures that the TC bit will be cleared within 1 bus clock after a load or store instruction accesses the TMR register.

### 14.2.2 Programming Considerations

Since timer registers can be read or written whether the timer is operating or not, and processor accesses to timer registers are synchronized with counter element accesses, the processor cannot read a partially modified register.

## 14.3 TIMER INTERRUPTS

Each timer is the source for one interrupt. When a timer detects a zero count in its TCR, the timer will force the generation of an internal edge-detected Timer Interrupt signal (TINTx) to the interrupt controller, and the interrupt-pending (IPND.tipx) will be set in the interrupt controller. Each timer interrupt can be selectively masked in the Interrupt Mask (IMSK) register or handled as a dedicated hardware-requested interrupt. Refer to CHAPTER 13, INTERRUPT CONTROLLER for a description of hardware-requested interrupts.

If the interrupt is disabled after a request has been generated, but before a pending interrupt is serviced, the interrupt request is still active (the Interrupt Controller latches the request). If a timer generates a second interrupt request before the CPU services the first interrupt request, the second request may be lost.

**TIMERS**

When auto-reload is enabled for a timer, the timer will continue to decrement the contents in the TCR even after entry into the timer interrupt handler.

An interrupt is generated when:

- the Timer Count Register reaches 0 and
- the auto reload is not selected (TMRx.reload=0). See section 14.1.1.1, “Bit 0 - Terminal Count Status Bit (TMRx.tc)” (pg. 14-3)

#### **14.4 POWERUP/RESET INITIALIZATION**

Upon power up, external hardware reset or software reset (**sysctl**), the Timer Mode register is initialized to the value shown in Table 14-5.

**Table 14-5. Timer Powerup Mode Settings**

| Mode/Control Bit | Notes                                    |
|------------------|--|
| TMRx.tc = 0      | Read only                                |
| TMRx.enable = 0  | Prevents counting and assertion of TINTx |
| TMRx.reload = 0  | Single terminal count mode               |
| TMRx.sup = 0     | Supervisor or User Mode access           |
| TMRx.csel1:0 = 0 | Timer Clock = Bus Clock                  |
| TCRx.d31:0 = 0   | undefined                                |
| TRRx.d31:0 = 0   | undefined                                |
| TINTx output     | deasserted                               |

## 14.5 UNCOMMON TCRX AND TRRX CONDITIONS

Under certain conditions it may be useful to set the Timer Count register or the Timer Reload counter to zero before enabling the timer counter unit. Table 14-6 details the conditions and results when these conditions are set.

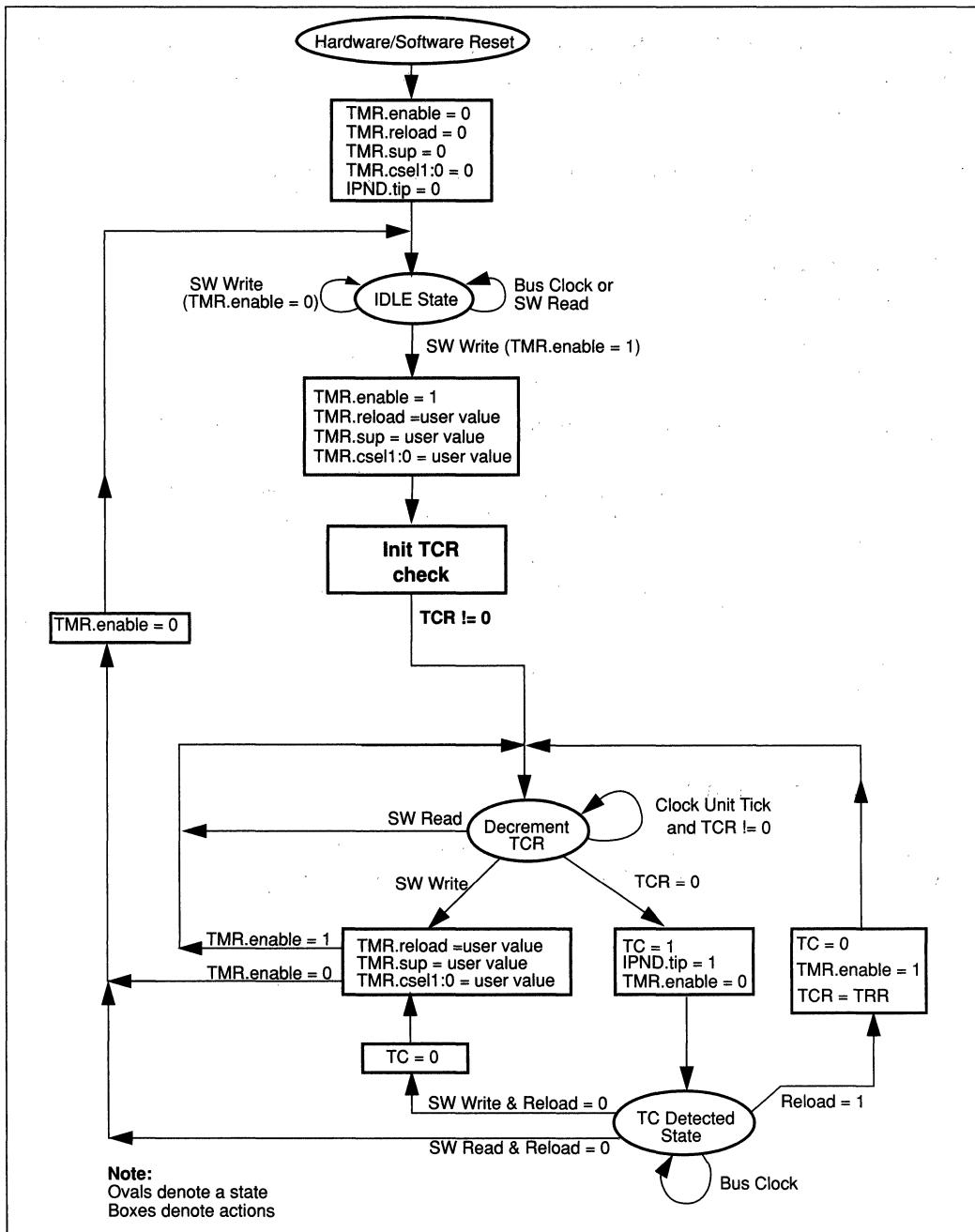
**Table 14-6. Uncommon TMRx Control Bit Settings**

| TRRx | TCRx | Bit 2<br>(TMRx.reload) | Bit 1<br>(TMRx.enable) | Action  |
|------|------|------------------------|------------------------|---|
| X    | 0    | 0                      | 1                      | TMRx.tc and TINTx will be set, TMR.enable will be cleared   |
| 0    | 0    | 1                      | 1                      | Timer and auto reload enabled, TINTx will not be generated and timer enable remains set.  |
| 0    | N    | 1                      | 1                      | Timer and auto reload enabled. TINT.x will be set when TCRx=0. The timer will stay enabled but further TINTx's will not be generated.   |
| N    | 0    | 1                      | 1                      | Timer and auto reload enabled, TINTx will not be set initially, TCRx = TRRx, TINTx will be set when TCRx has completely decremented the value it loaded from TRRx. TMRx.enable remains set. |

**NOTE:** X = don't care  
N = a number between 1H and FFFF FFFFH

## 14.6 TIMER STATE DIAGRAM

The Figure 14-5 shows the common states of the Timer Unit. For uncommon conditions see section 14.5, “Uncommon TCRx and TRRx Conditions” (pg. 14-11)



**Figure 14-5. Timer Unit State Diagram**



15

## EXTERNAL BUS





# CHAPTER 15

## EXTERNAL BUS

This chapter describes the bus interface of the i960® Jx processor. It explains the following:

- Bus states and their relationship to each other
- Bus signals, which consist of address/data, control/status
- Read, write, burst and atomic bus transactions
- Related bus functions such as arbitration

This chapter also serves as a starting point for the hardware designer when interfacing typical memory and peripheral devices to the i960 Jx processor's address/data bus.

For information on programmable bus configuration, refer to CHAPTER 12, MEMORY CONFIGURATION.

### 15.1 OVERVIEW

The bus is the data communication path between the various components of an i960 Jx microprocessor hardware system, allowing the processor to fetch instructions, manipulate data and interact with its I/O environment. To perform these tasks at high bandwidth, the processor features a burst transfer capability, allowing up to four successive 32-bit data transfers at a maximum rate of one word every clock cycle.

The address/data path is multiplexed for economy and bus width is programmable to 8-, 16- and 32-bit widths. The processor has dedicated control signals for external address latches, buffers and data transceivers. In addition, the processor uses other signals to communicate with alternate bus masters. All bus transactions are synchronized with the processor's clock input (CLKIN); therefore, the memory system control logic can be implemented as state machines.

### 15.2 BUS OPERATION

Knowing definitions of the terms *request*, *access* and *transfer* is essential to understand descriptions of bus operations.

## EXTERNAL BUS

The processor's bus control unit is designed to decouple bus activity from instruction execution in the core as much as possible. When a load or store instruction or instruction prefetch is issued, a *bus request* is generated in the bus control unit. The bus control unit independently processes the request and retrieves data from memory for load instructions and instruction prefetches. The bus control unit delivers data to memory for store instructions.

The i960 architecture defines byte, short word, word, double word, triple word and quad word data lengths for load and store instructions. When a load or store instruction is encountered, the processor issues a bus request of the appropriate data length: for example, **ldq** requests that four words of data be retrieved from memory; **stob** requests that a single byte be delivered to memory. The processor always fetches instructions using double or quad word bus requests.

A bus *access* is defined as a bus transaction bounded by the assertion of **ADS** (address/data status) and de-assertion of **BLAST** (burst last) signals, which are outputs from the processor. A bus access consists of one to four data *transfers*. During each transfer, the processor either reads data or drives data on the bus. The number of transfers per access and the number of accesses per request is governed by the requested data length, the programmed width of the bus and the alignment of the address.

### 15.2.1 Basic Bus States

The bus has five basic bus states: idle (Ti), address (Ta), wait/data (Tw/Td), recovery (Tr), and hold (Th). During system operation, the processor continuously enters and exits different bus states.

The bus occupies the idle (Ti) state when no address/data transactions are in progress and when **RESET** is asserted. When the processor needs to initiate a bus access, it enters the Ta state to transmit the address.

Following a Ta state, the bus enters the Tw/Td state to transmit or receive data on the address/data lines. Assertion of the **RDYRCV** input signal indicates completion of each transfer. When data is not ready, the processor can wait as long as necessary for the memory or I/O device to respond.

After the data transfer, the bus exits the Tw/Td state and enters the recovery (Tr) state. In the case of a burst transaction, the bus exits the Td state and re-enters the Td/Tw state to transfer the next data word. The processor asserts the **BLAST** signal during the last Tw/Td states of an access. Once all data words transfer in a burst access (up to four), the bus enters the Tr state to allow devices on the bus to recover.

The processor remains in the Tr state until **RDYRCV** is deasserted. When the recovery state completes, the bus enters the Ti state if no new accesses are required. If an access is pending, the bus enters the Ta state to transmit the new address.

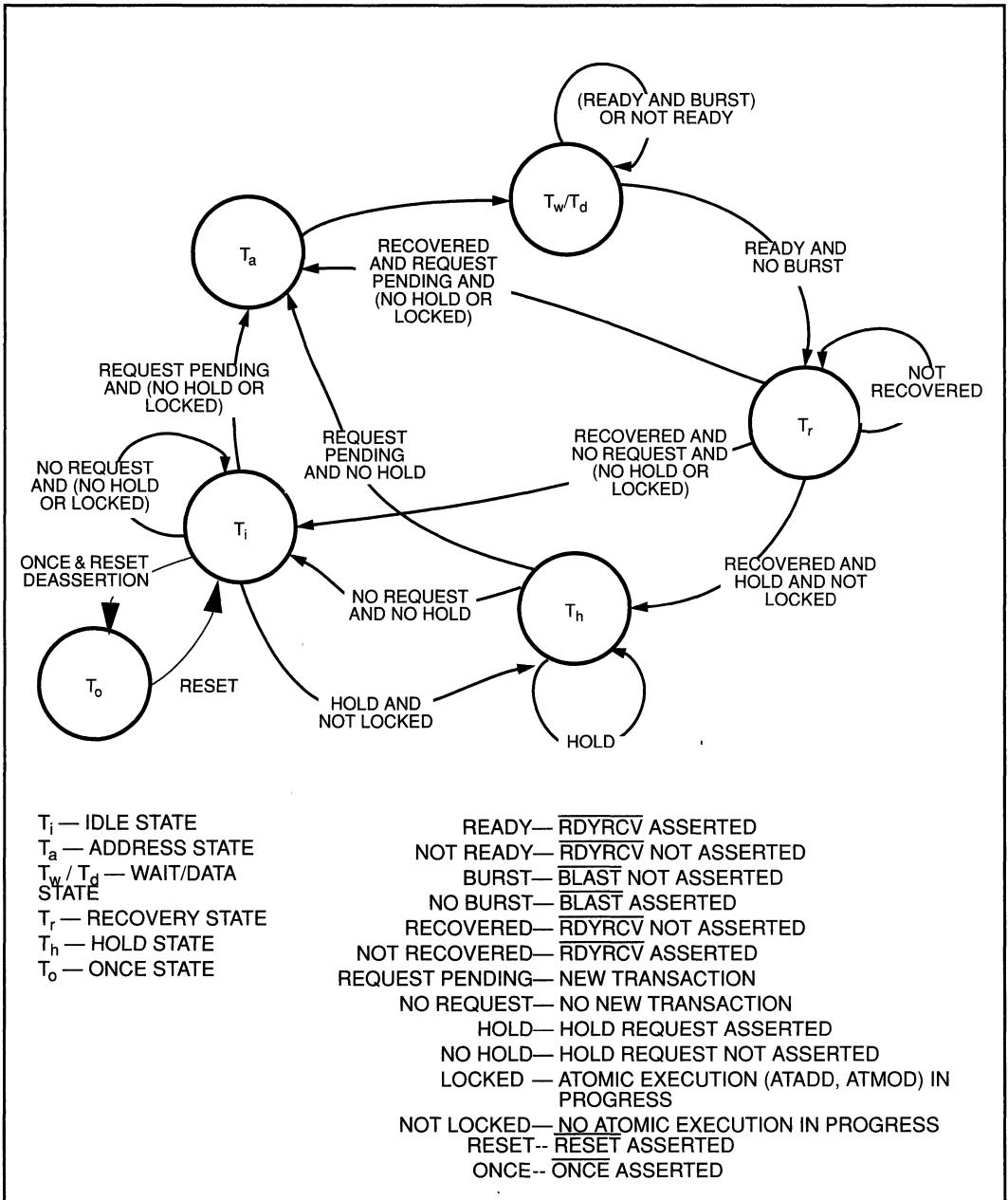


Figure 15.1. Bus States with Arbitration

## EXTERNAL BUS

### 15.2.2 Bus Signal Types

Bus signals consist of three groups: address/data, control/status and bus arbitration. They are listed in Table 15.1. A detailed description of all signals can be found in the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet*.

#### 15.2.2.1 Clock Signal

The CLKIN input signal is the reference for all i960 Jx microprocessor signal timing relationships. Note that this is true even for the i960 JD processor, even though the CPU core runs at twice the CLKIN rate. Transitions on the AD31:2, AD1:0, A3:2,  $\overline{AD\$}$ , BE3:0, WIDTH/HLTD1:0, D/C, W/R, DEN, BLAST, RDYRCV, LOCK/ONCE, HOLD/HOLDA and BSTAT bus signal pins are always measured directly from the rising edge of CLKIN. The processor asserts ALE and ALE directly from the rising CLKIN edge at the beginning of a Ta state but deasserts them approximately half way through the state instead of the next rising CLKIN edge. All transitions on DT/R are also referenced to a point halfway through the Ta state instead of rising CLKIN edges.

#### 15.2.2.2 Address/Data Signal Definitions

The address/data signal group consists of 34 lines. 32 of these signals multiplex within the processor to serve a dual purpose. During Ta, the processor drives AD31:2 with the address of the bus access. At all other times, these lines are defined to contain data. A3:2 are demultiplexed address pins providing incrementing word addresses during burst cycles. AD1:0 denote burst size during Ta and data during other states.

The processor routinely performs data transfers less than 32 bits wide. If the programmed bus width is 32 bits and transfers are 16- or 8-bit, then during write cycles the processor will replicate the data that is being driven on the unused address/data pins. If the programmed bus width is 16 or 8 bits, then during write cycles the processor will continue driving address on any unused address/data pins.

Whenever the programmed bus width is less than 32 bits, additional demultiplexed address bits are available on unused byte enable pins (See section 15.2.3.1, "Bus Width" (pg. 15-7)). These signals increment during burst accesses in similar fashion to the A3:2 pins.

#### 15.2.2.3 Control/Status Signal Definitions

The control/status signal group consists of 15 signals. These signals control data buffers and address latches or furnish information useful to external chip-select generation logic. All output control/status signals are three-state.

Table 15-1. Summary of i960 Jx Processor Bus Signals

| Signal Symbol          | Name (Direction)   | Signal Function  |
|------------------------|--|--|
| AD31:2                 | Address/Data 31:2 (I/O)  | Word address, driven during Ta. Read or write data, driven or sampled during Tw/Td.  |
| AD1:0                  | Address/Data 1:0 and Size 1:0 (I/O)                                | Number of transfers, driven during Ta. Read or write data, driven or sampled during Tw/Td.   |
| A3:2                   | Address 3:2 (O)  | Incrementing burst address bits, driven during Ta and Tw/Td.   |
| ALE                    | Address Latch Enable (O)   | Driven during Ta for demultiplexing AD bus.  |
| $\overline{ALE}$       | Address Latch Enable (Inverted) (O)                                | Driven during Ta for demultiplexing AD bus.  |
| $\overline{ADS}$       | Address/Data Status (O)  | Valid address indicator, driven during Ta.   |
| $\overline{BE3:0}$     | Byte Enables 3:0 and Byte High Enable/Byte Low Enable and A1:0 (O) | Enable selected data bytes on bus. (16-bit bus) $\overline{BE3}$ and $\overline{BE0}$ enable high and low bytes. (8-bit bus) $\overline{BE1:0}$ are incrementing burst address bits. Driven during Ta and Tw/Td. |
| WIDTH/HLTD 1:0         | Width and Processor Halted (O)                                     | Physical bus size, driven during Ta and Tw/Td. Can denote Halt Mode.   |
| D/ $\overline{C}$      | Data/Code (O)  | Data access or instruction access, driven during Ta and Tw/Td.   |
| W/ $\overline{R}$      | Write/Read (O)   | Indication of data direction, driven during Ta and Tw/Td.  |
| DT/ $\overline{R}$     | Data Transmit/Receive (O)  | Delayed indication of data direction, driven during Ta and Tw/Td.  |
| $\overline{DEN}$       | Data Enable (O)  | Enables data on bus, driven during Tw/Td.  |
| $\overline{BLAST}$     | Burst Last (O)   | Last transfer of a bus access, driven during Tw/Td.  |
| $\overline{RDYRCV}$    | Ready/Recover (I)  | Data transfer edge when sampled low during Tw/Td. Bus recovered when sampled high during Tr.   |
| $\overline{LOCK/ONCE}$ | Lock/On-Circuit Emulation (I/O)                                    | Atomic operation, driven during Ta and Tw/Td. ONCE floats all pins when sampled at reset.  |
| HOLD                   | Hold (I)   | Acquisition request from external bus master, sampled any clock.   |
| HOLDA                  | Hold Acknowledge (O)   | Bus control granted to external bus master, driven during Th.  |
| BSTAT                  | Bus Status (O)   | Processor may stall unless it can acquire bus, driven any clock.   |

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Bus accesses begin with the assertion of  $\overline{\text{ADS}}$  (address/data status) during a Ta state. External decoding logic typically uses  $\overline{\text{ADS}}$  to qualify a valid address at the rising clock edge at the end of Ta. The processor pulses ALE (address latch enable) active high for one half clock during Ta to latch the multiplexed address on AD31:2 in external address latches. An inverted signal,  $\overline{\text{ALE}}$ , is also present for compatibility with i960 Kx processor-based companion devices.

The byte enable ( $\overline{\text{BE}3:0}$ ) signals denote which bytes on the 32-bit data bus will transfer data during an access. The processor asserts byte enables during Ta and deasserts them during Tr. When the data bus is configured for 16 bits, two byte enables become byte high enable and byte low enable and an additional address bit A1 is provided. When the bus is configured for 8 bits, there are no byte enables, but additional address bits A1:0 are provided. Note that the processor always drives byte enable pins to logical 1's during the Tr state, even when they are used as addresses.

The WIDTH1:0, D/ $\overline{C}$  and W/ $\overline{R}$  signals yield useful bus access information for external memory and I/O controllers. The WIDTH1:0 signals denote programmed physical memory attributes. The data/code pin indicates whether an access is a data transaction (1) or an instruction transaction (0). The write/read pin indicates the direction of data flow relative to the i960 Jx processor. WIDTH1:0, D/ $\overline{C}$  and W/ $\overline{R}$  change state as needed during the Ta state.

DT/ $\overline{R}$  and  $\overline{\text{DEN}}$  pins are used to control data transceivers. Data transceivers may be used in a system to isolate a memory subsystem or control loading on data lines. DT/ $\overline{R}$  (data transmit/receive) is used to control transceiver direction. In the second half of the Ta state, it transitions high for write cycles or low for read cycles.  $\overline{\text{DEN}}$  (data enable) is used to enable the transceivers.  $\overline{\text{DEN}}$  is asserted during the first Tw/Td state of a bus access and deasserted during Tr. DT/ $\overline{R}$  and  $\overline{\text{DEN}}$  timings ensure that DT/ $\overline{R}$  does not change state when  $\overline{\text{DEN}}$  is asserted.

A bus access may be either non-burst or burst. A non-burst access ends after one data transfer to a single location. A burst access involves two to four data cycles to consecutive memory locations. The processor asserts  $\overline{\text{BLAST}}$  (burst last) to indicate the last data cycle of an access in both burst and non-burst situations.

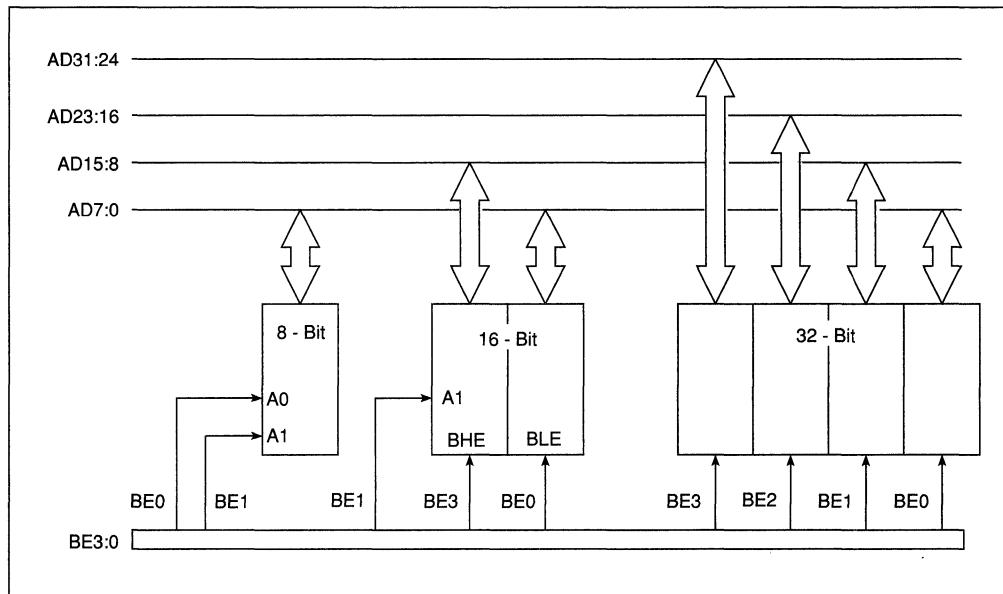
All i960 Jx processor wait states are controlled by the RDYRCV (ready/recover) input signal.

### 15.2.3 Bus Accesses

The i960 Jx microprocessor uses the bus signals to transfer data between the processor and another component. The maximum transfer rate is achieved when performing burst accesses at the rate of four 32-bit data words per six clocks.

### 15.2.3.1 Bus Width

Each region's data bus width is programmed in a Physical Memory Region Configuration (PMCON) register. The processor allows an 8-, 16- or 32-bit data bus width for each region. The processor places 8- and 16-bit data on low-order data pins, simplifying the interface to narrow bus external devices. As shown in Figure 15-2, 8-bit data is placed on lines AD7:0; 16-bit data is placed on lines AD15:0; 32-bit data is placed on lines AD31:0. The processor encodes bus width on the WIDTH1:0 pins so that external logic may enable the bus correctly.



**Figure 15-2. Data Width and Byte Encodings**

Depending on the programmed bus width, the byte enable signals provide either data enables or low-order address lines:

- 8-bit region:  $\overline{BE0:1}$  provide the byte address (A0, A1) (see Table 15-2).
- 16-bit region:  $\overline{BE1}$  provides the short-word address (A1);  $\overline{BE3}$  is the byte high enable signal (BHE);  $\overline{BE0}$  is the byte low enable signal (BLE) (see Table 15-3).
- 32-bit region: byte enables are not encoded as address pins. Byte enables  $\overline{BE3:0}$  select bytes 0 through 3 of the 32-bit words addressed by AD31:2 (see Table 15-4).

When the byte enables function as address lines, they increment with each transfer during burst accesses. Otherwise, byte enables never toggle between transfers of a burst, due to microcode breakup of unaligned requests.

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**Table 15-2. 8-Bit Bus Width Byte Enable Encodings**

| Byte | <b>BE3</b><br>(Not Used) | <b>BE2</b><br>(Not Used) | <b>BE1</b><br>(Used as A1) | <b>BE0</b><br>(Used as A0) |
|------|--------------------------|--------------------------|----------------------------|----------------------------|
| 0    | 1                        | 1                        | 0                          | 0                          |
| 1    | 1                        | 1                        | 0                          | 1                          |
| 2    | 1                        | 1                        | 1                          | 0                          |
| 3    | 1                        | 1                        | 1                          | 1                          |

**Table 15-3. 16-Bit Bus Width Byte Enable Encodings**

| Byte | <b>BE3</b><br>(Used as <b>BHE</b> ) | <b>BE2</b><br>(Not Used) | <b>BE1</b><br>(Used as A1) | <b>BE0</b><br>(Used as <b>BLE</b> ) |
|------|-------------------------------------|--------------------------|----------------------------|-------------------------------------|
| 0,1  | 0                                   | 1                        | 0                          | 0                                   |
| 2,3  | 0                                   | 1                        | 1                          | 0                                   |
| 0    | 1                                   | 1                        | 0                          | 0                                   |
| 1    | 0                                   | 1                        | 0                          | 1                                   |
| 2    | 1                                   | 1                        | 1                          | 0                                   |
| 3    | 0                                   | 1                        | 1                          | 1                                   |

**Table 15-4. 32-Bit Bus Width Byte Enable Encodings**

| Byte    | <b>BE3</b> | <b>BE2</b> | <b>BE1</b> | <b>BE0</b> |
|---------|------------|------------|------------|------------|
| 0,1,2,3 | 0          | 0          | 0          | 0          |
| 0,1     | 1          | 1          | 0          | 0          |
| 2,3     | 0          | 0          | 1          | 1          |
| 0       | 1          | 1          | 1          | 0          |
| 1       | 1          | 1          | 0          | 1          |
| 2       | 1          | 0          | 1          | 1          |
| 3       | 0          | 1          | 1          | 1          |

During initialization, the bus configuration data is read from the Initialization Boot Record (IBR) assuming an 8-bit bus width; however, the IBR can be in 8-bit, 16-bit, or 32-bit physical memory. **BE3** and **BE2** are defined as “1” so that reading the bus configuration data works for all bus widths. Since these byte enables are ignored for actual 8-bit memory, they can be permanently defined this way for ease of implementation.

Intel designed the i960 Jx processor to drive determinate values on all address/data pins during Tw/Td write operation states. For an 8-bit bus, the processor continues to drive address on unused data pins AD31:8. For a 16-bit bus, the processor continues to drive address on unused data pins AD31:16. However, when the processor does not use the entire bus width because of data width or misalignment (i.e., 8-bit write on a 16- or 32-bit bus or a 16-bit write on a 32-bit bus), data is replicated on those unused portions of the bus.

### 15.2.3.2 Basic Bus Accesses

The basic transaction is a read or write of one data word. The first half of Figure 15-3 shows a typical timing diagram for a non-burst, 32-bit read transaction. For simplicity, no wait states are shown.

During the Ta state, the i960 Jx microprocessor transmits the address on the address/data lines. In the figure, the SIZE bits (AD1:0) specify a single word transaction and WIDTH1:0 indicate a 32-bit wide access. The processor asserts  $\overline{ALE}$  to latch the address and drives  $\overline{ADS}$  low to denote the start of the cycle.  $\overline{BE3:0}$  specify which bytes the processor uses to read the data word. The processor brings  $W/R$  low to denote a read operation and drives  $D/C$  to the proper state. For data transceivers,  $DT/R$  goes low to define the input direction.

During the Tw/Td state, the i960 Jx microprocessor deasserts  $\overline{ADS}$  and asserts  $\overline{DEN}$  to enable any data transceivers. Since this is a non-burst transaction, the processor asserts  $\overline{BLAST}$  to signify the last transfer of a transaction. The figure shows  $\overline{RDYRCV}$  assertion by external logic, so this state is a data state and the processor latches data on a rising CLKIN edge.

The Tr state follows the Tw/Td state. This allows the system components adequate time to remove their outputs from the bus before the processor drives the next address on the address/data lines. During the Tr state,  $\overline{BLAST}$ ,  $\overline{BE3:0}$  and  $\overline{DEN}$  are inactive.  $W/R$  and  $DT/R$  hold their previous values. The figure indicates a logical high for the  $\overline{RDYRCV}$  pin, so there is only one recovery state.

After a read, notice that the address/data bus goes to an invalid state during Ti. The processor drives valid logic levels on the address/data bus instead of allowing it to float. See section 15.2.4, "Bus and Control Signals During Recovery and Idle States" (pg. 15-22) for the values that are driven during Ti.

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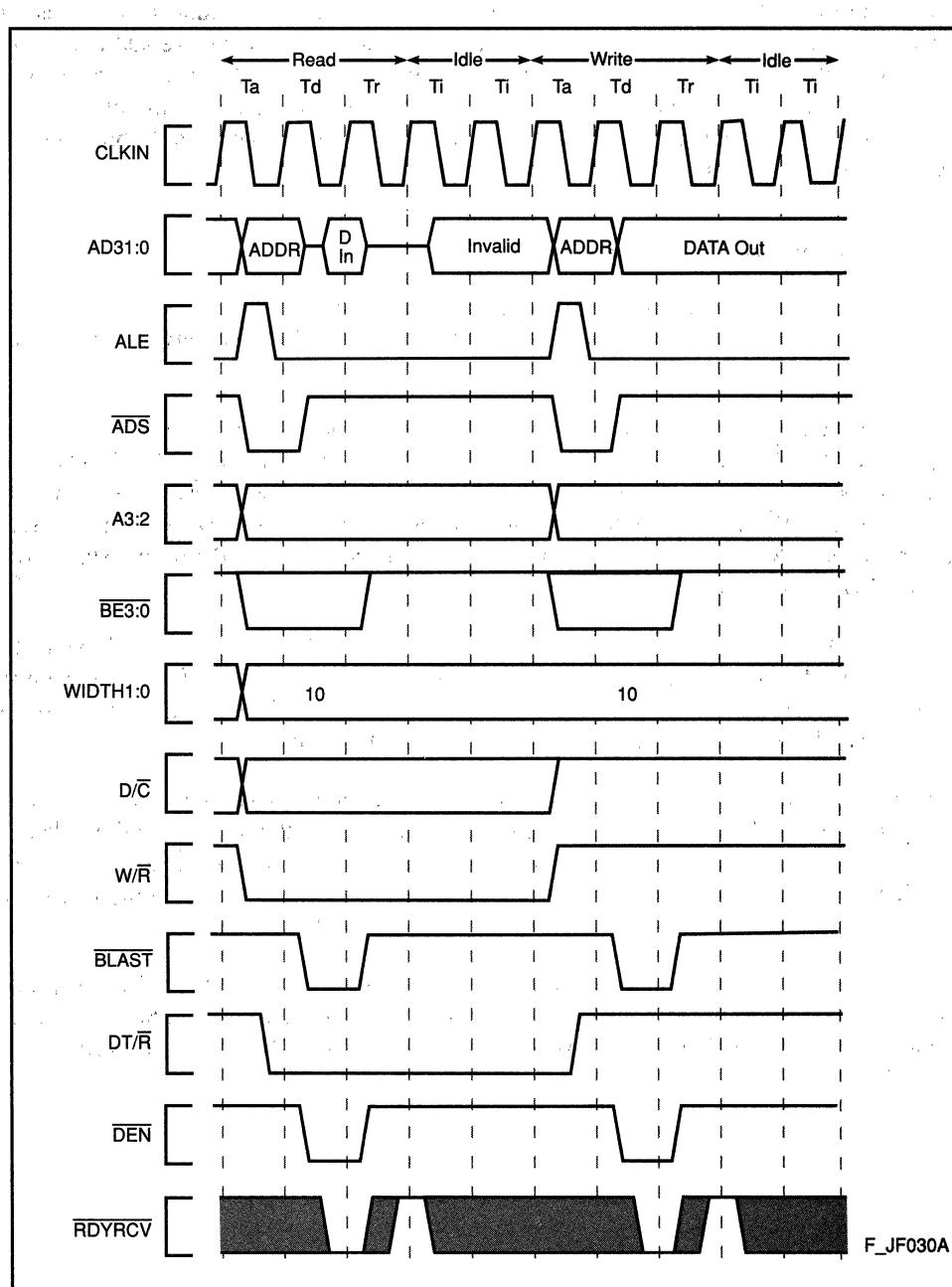


Figure 15-3. Non-Burst Read and Write Transactions Without Wait States, 32-Bit Bus

Figure 15-3 also shows a typical timing diagram for a non-burst, 32-bit write transaction. For the write operation, W/R and DT/R are high to denote the direction of the data flow. The D/C pin is high since instruction code cannot be written. During the Tw/Td state, the processor drives data on the bus, waiting to sample RDYRCV low to terminate the transfer. The figure shows RDYRCV assertion by external logic, so this state is a data state and the processor enters the recovery state.

At the end of a write, notice that the write data is driven during Tr and any subsequent Ti states. After a write, the processor will drive write data until the next Ta state. See section 15.2.4, “Bus and Control Signals During Recovery and Idle States” (pg. 15-22) for details.

### 15.2.3.3 Burst Transactions

A burst access is an address cycle followed by two to four data transfers. The i960 Jx microprocessor uses burst transactions for instruction fetching and accessing system data structures. Therefore, a system design incorporating an i960 Jx microprocessor must support burst transactions. Burst accesses can also result from instruction references to data types which exceed the width of the bus.

Maximum burst size is four data transfers, independent of bus width. A byte-wide bus has a maximum burst size of four bytes; a word-wide bus has a maximum of four words. For an 8- or 16-bit bus, this means that some bus requests may result in multiple burst accesses. For example, if a quad word load request (e.g., ldq instruction) is made to an 8-bit data region, it results in four, 4-byte, burst accesses. (See Table 15-6.)

Burst accesses on a 32-bit bus are always aligned to even-word boundaries. Quad-word and triple-word accesses always begin on quad-word boundaries (A3:2=00); double-word transfers always begin on double-word boundaries (A2=0); single-word transfers occur on single word boundaries. Figure 15-4 shows burst, stop and start addresses for a 32-bit bus.

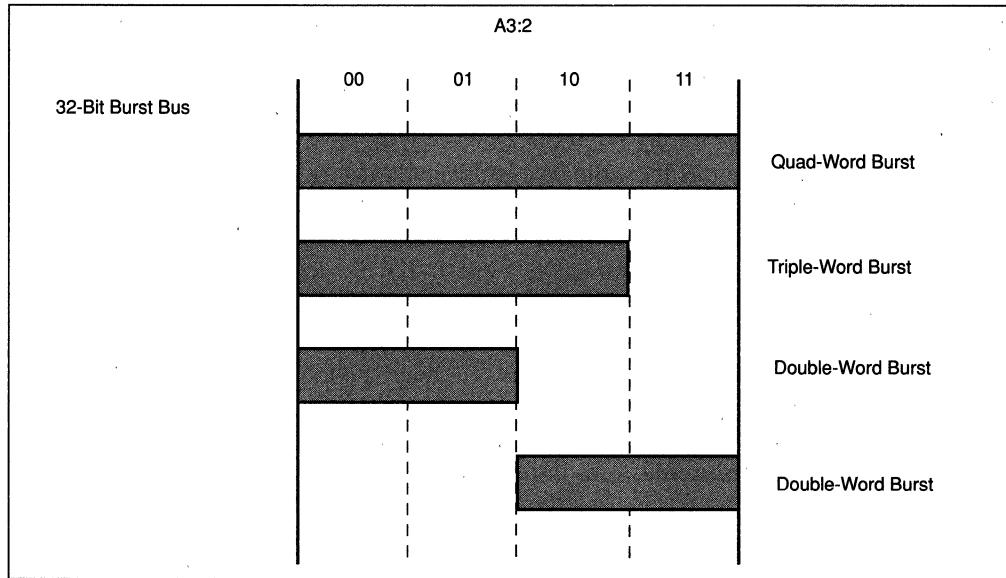


Figure 15-4. 32-Bit Wide Data Bus Bursts

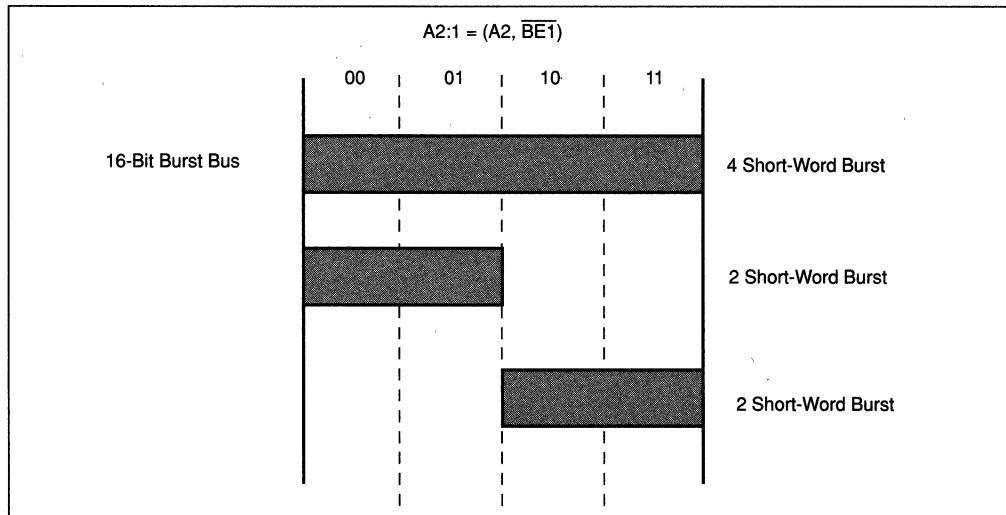
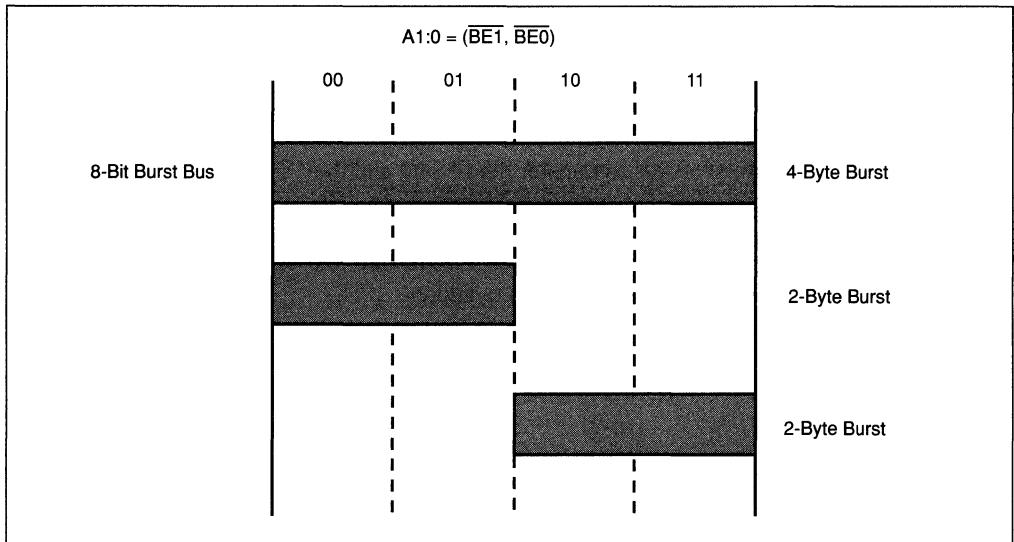


Figure 15-5. 16-Bit Wide Data Bus Bursts



**Figure 15-6. 8-Bit Wide Data Bus Bursts**

Burst accesses for a 16-bit bus are always aligned to even short-word boundaries. A four short-word burst access always begins on a four short-word boundary (A2=0, A1=0). Two short-word burst accesses always begin on an even short-word boundary (A1=0). Single short-word transfers occur on single short-word boundaries (see Figure 15-5).

Burst accesses for an 8-bit bus are always aligned to even byte boundaries. Four-byte burst accesses always begin on a 4-byte boundary (A1=0, A0=0). Two-byte burst accesses always begin on an even byte boundary (A0=0) (see Figure 15-6).

Figure 15-7 illustrates a series of bus accesses resulting from a triple-word store request to 16-bit wide memory. The top half of the figure shows the initial location of 12 data bytes contained in registers g4 through g6. The instruction's task is to move this data to memory at address 0AH. The top half of the figure also shows the final destination of the data.

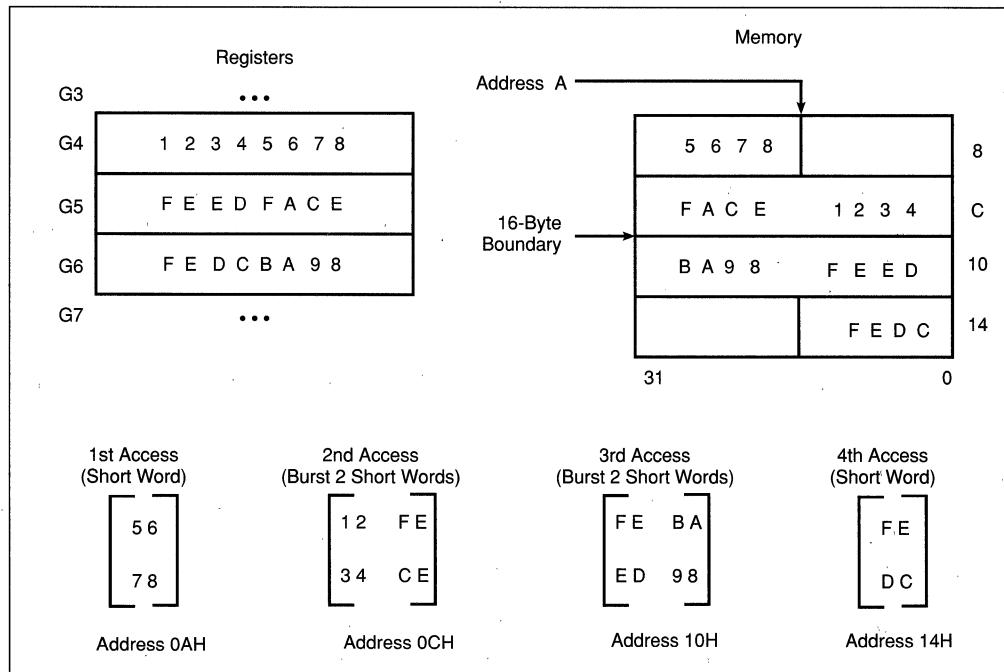
Notice that a new 16-byte boundary begins at address 10H. Since the processor stores 6 of the 12 bytes after this 16-byte boundary, the processor will split the transaction into a number of accesses. The i960 Jx processor cannot burst across 16-byte boundaries.

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The processor splits the transaction into the following accesses. It performs the following bus cycles:

1. Non-burst access to transfer the first short word (contents 5678H) to address 0AH. The short word at address 08H remains unchanged.
2. Burst access to transfer the second and third short words (contents 1234H and 0FACEH) to address 0CH.
3. Burst access to transfer the fourth and fifth short words (contents 0FEEDH and 0BA98H) to address 10H.
4. Non-burst access to transfer the last short word (contents 0FEDCH) to address 14H. The short word at address 16H remains unchanged.



**Figure 15-7. Unaligned Write Transaction**

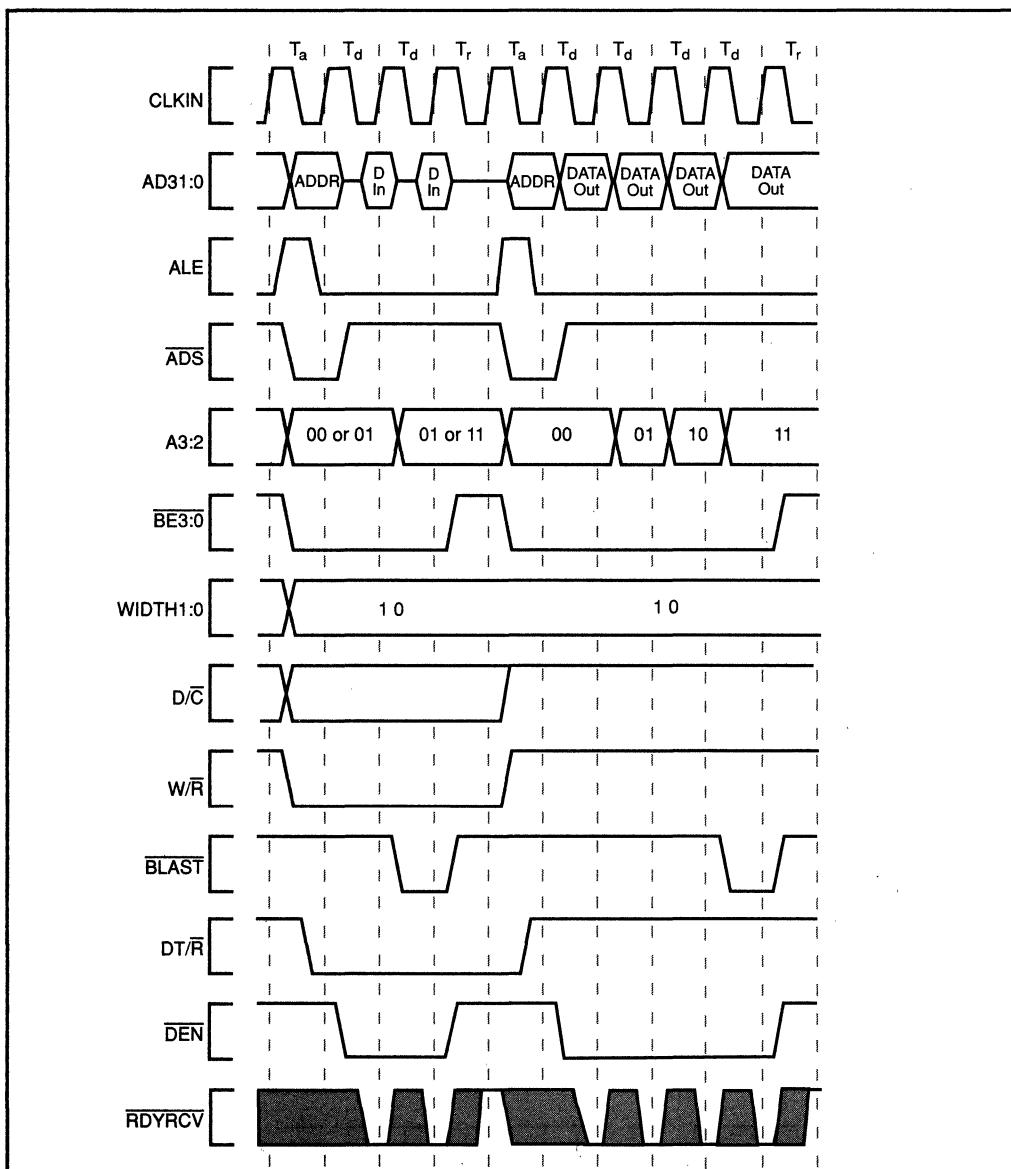


Figure 15-8. Burst Read and Write Transactions w/o Wait States, 32-bit Bus

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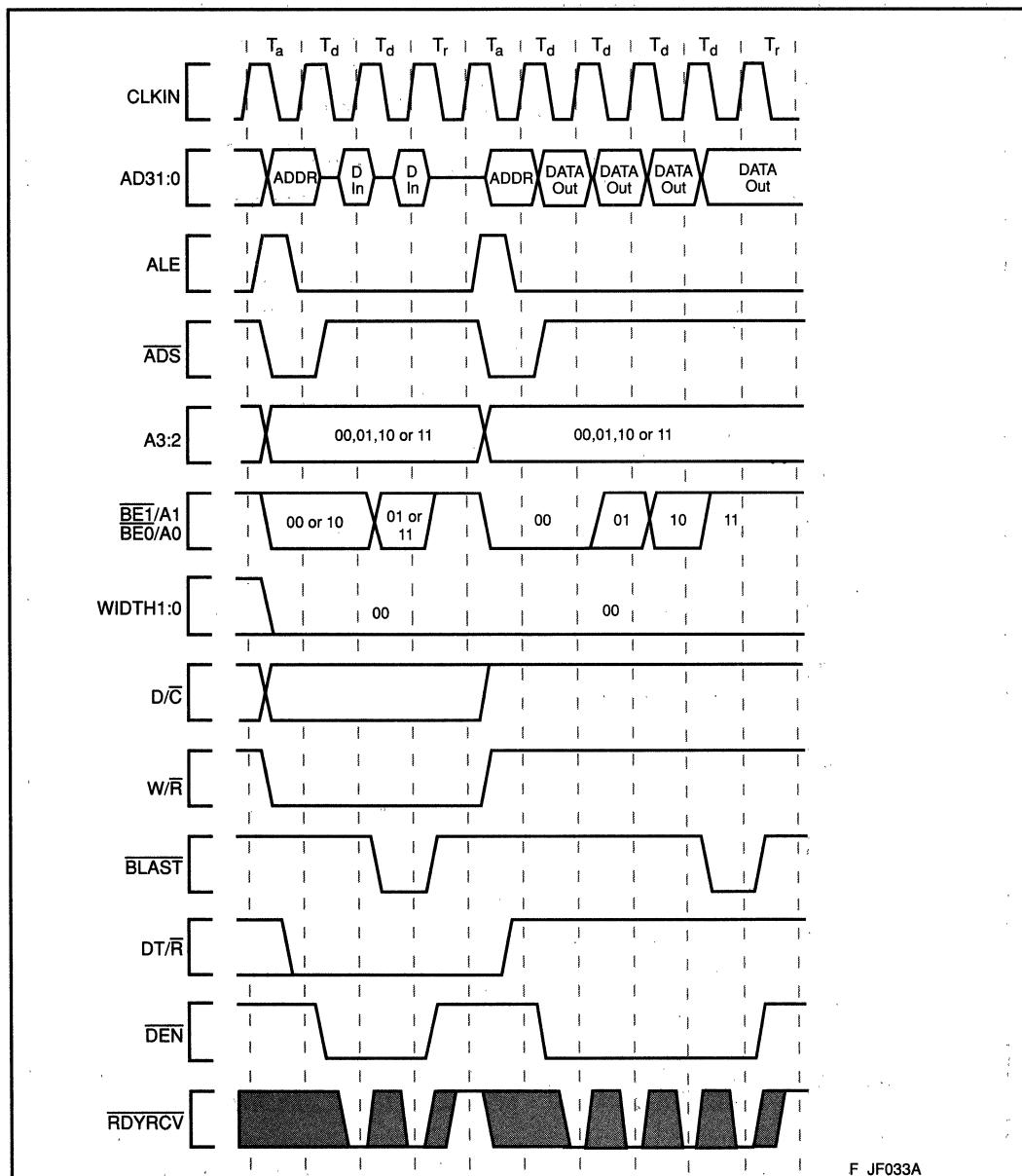


Figure 15-9. Burst Read and Write Transactions w/o Wait States, 8-bit Bus

### 15.2.3.4 Wait States

Wait states lengthen the microprocessor's bus cycles, allowing data transfers with slow memory and I/O devices. The 80960Jx supports three types of wait states: *address-to-data*, *data-to-data* and *turnaround* or *recovery*. All three types are controlled through the processor's  $\overline{\text{RDYRCV}}$  (Ready/Recover) pin, a synchronous input.

The processor's bus states follow the state diagram in Figure 15.1. After the Ta state, the processor enters the Tw/Td state to perform a data transfer. If the memory (or I/O) system is fast enough to allow the transfer to complete during this clock (i.e., "ready"), external logic asserts  $\overline{\text{RDYRCV}}$ . The processor samples  $\overline{\text{RDYRCV}}$  low on the next rising clock edge, completing the transfer; the state is a data state. If the memory system is too slow to complete the transfer during this clock, external logic drives  $\overline{\text{RDYRCV}}$  high and the state is an address-to-data wait state. Additional wait states may be inserted in similar fashion.

If the bus transaction is a burst, the processor re-enters the Tw/Td state after the first data transfer. The processor continues to sample  $\overline{\text{RDYRCV}}$  on each rising clock edge, adding a data-to-data wait state when  $\overline{\text{RDYRCV}}$  is high and completing a transfer when  $\overline{\text{RDYRCV}}$  is low. The process continues until all transfers are finished, with  $\overline{\text{RDYRCV}}$  assertion denoting every data acquisition.

Figure 15-10 illustrates a quad word burst write transaction with wait states. There are two address-to-data wait states single data-to-data wait states between transfers.

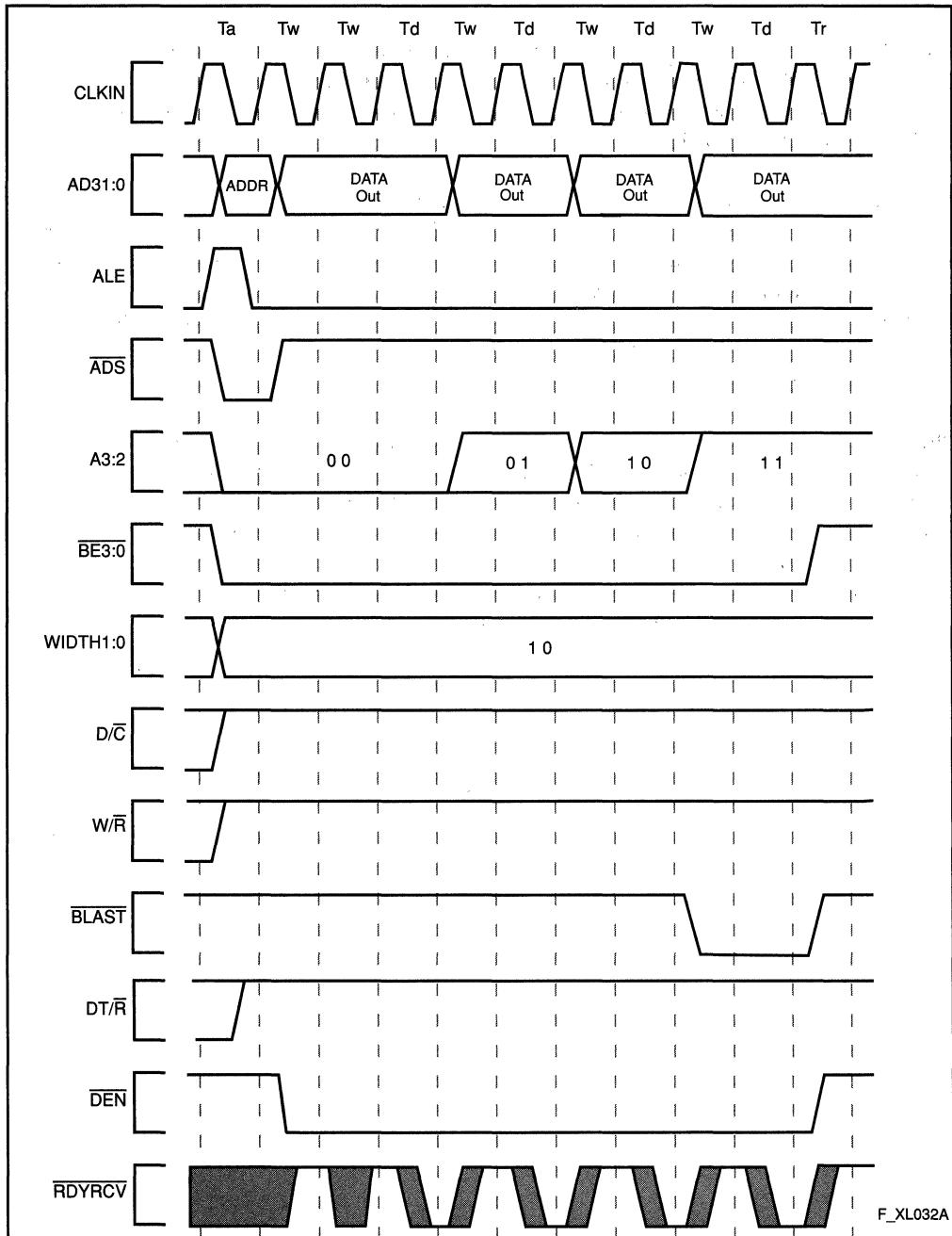


Figure 15-10. Burst Write Transactions With 2,1,1,1 Wait States, 32-bit Bus

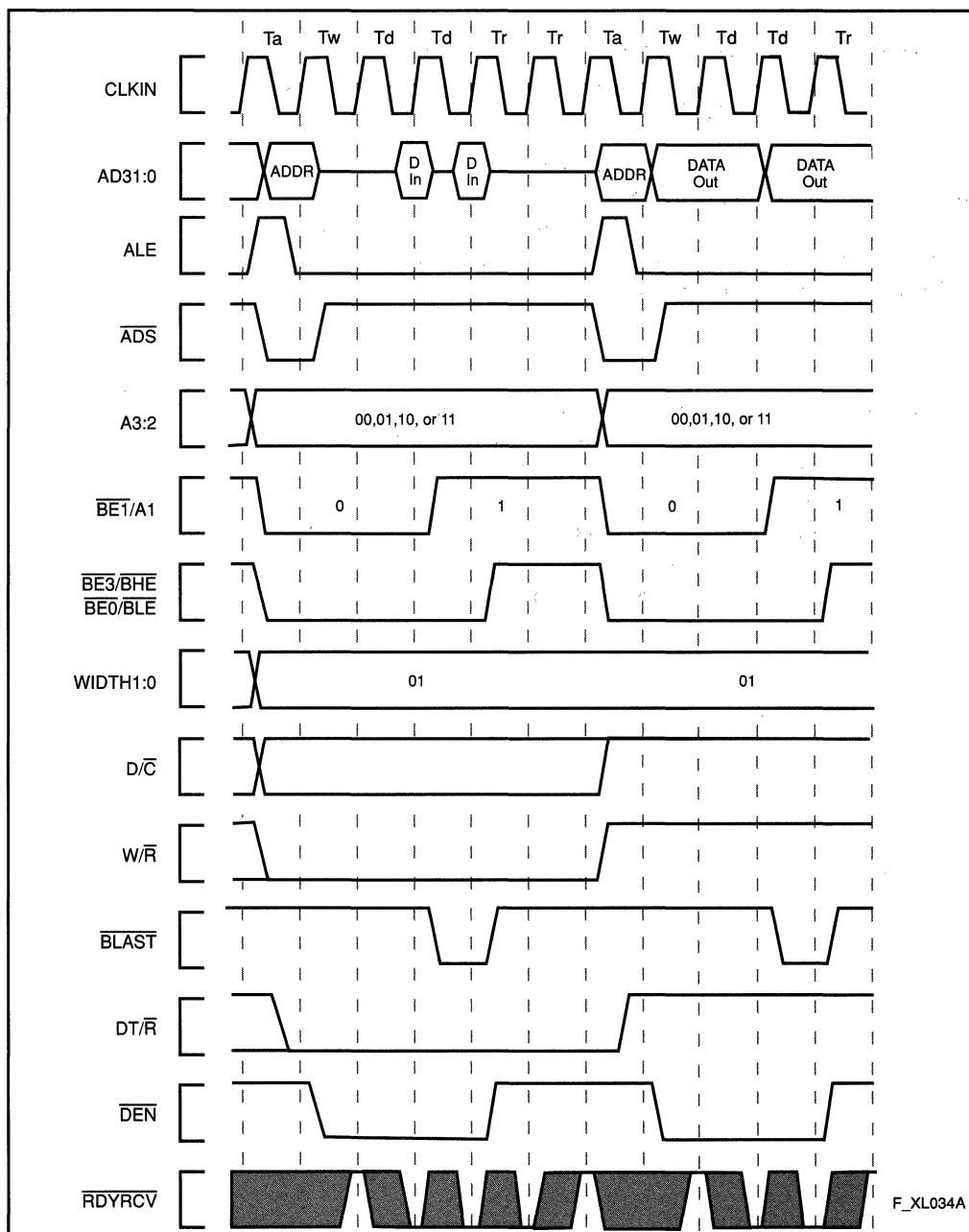
### 15.2.3.5 Recovery States

The state following the last data transfer of an access is a recovery (Tr) state. By default, i960 Jx microprocessor bus transactions have one recovery state. External logic can cause additional recovery states to be inserted by driving the RDYRCV pin low at the end of Tr.

Recovery wait states are an important feature for the Jx because it employs a multiplexed bus. Slow memory and I/O devices often need a long time to turn off their output drivers on read accesses before the microprocessor drives the address for the next bus access. Recovery wait states are also useful to force a delay between back-to-back accesses to I/O devices with their own specific access recovery requirements.

System ready logic is often described as normally-ready or normally-not-ready. Normally-ready logic asserts a microprocessor's input pin during all bus states, except when wait states are desired. Normally-not-ready logic deasserts a processor's input pin during all bus states, except when the processor is ready. The subtle nomenclature distinction is important for i960 Jx microprocessor systems because the active sense of the RDYRCV pin reverses for recovery states. During the Tr state, logic 0 means "continue to recover" or "not ready"; for Tw/Td states, logic 0 means "ready". Logic must assure "ready" and "not recover" are generated to terminate an access properly. Be certain to not hang the processor with endless recovery states. Conventional ready logic implemented as normally-not-ready will operate correctly (but without adding turnaround wait states).

Figure 15-12 is a timing waveform of a read cycle followed by a write cycle, with an extra recovery state inserted into the read cycle.



**Figure 15-11. Burst Read/Write Transactions with 1,0 Wait States - Extra Tr State on Read, 16-Bit Bus**

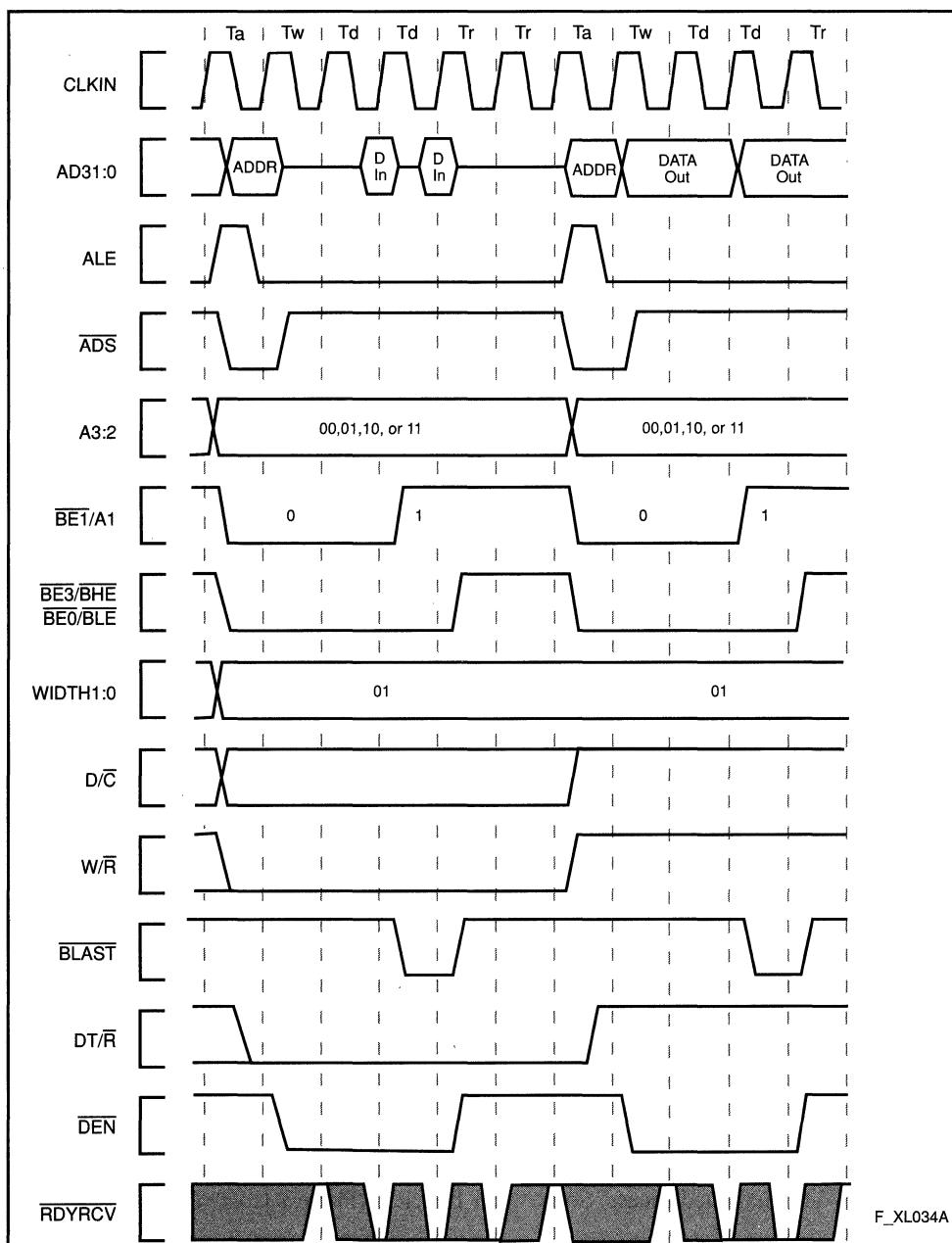


Figure 15-12. Burst Read/Write Transactions with 1.0 Wait States, Extra Tr State on Read, 16-Bit Bus

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### 15.2.4 Bus and Control Signals During Recovery and Idle States

Valid bus transactions are bounded by  $\overline{ADS}$  going active at the beginning of Ta states and  $\overline{BLAST}$  going inactive at the beginning of Tr states. During Tr and Ti states, bus and control pin logic levels are defined in such a way as to avoid unnecessary pin transitions that waste power. In all cases, the bus and control pins are completely quiet for instruction fetches and data loads that are cache hits.

If the last bus cycle is a read, the address/data bus floats during all Tr states. If the last bus cycle is a write, the address/data bus freezes during Tr states. The processor drives control pins such as ALE,  $\overline{ADS}$ ,  $\overline{BLAST}$  and  $\overline{DEN}$  to their inactive states during Tr. Byte enables  $\overline{BE3:0}$  are always driven to logic high during Tr, even when the processor uses them under alternate definitions. Outputs without clearly defined active/inactive states such as A3:2, WIDTH/HLTD1:0, D/ $\overline{C}$ , W/ $\overline{R}$  and DT/ $\overline{R}$  freeze during Tr.

When the bus enters the Ti state, the bus and control pins will likewise freeze to inactive states. The exact states of the address/data pins depend on how the processor enters the Ti state. If the processor enters Ti from a Tr ending a write cycle, the processor continues driving data on AD31:0. If the processor enters Ti from a read cycle or from a Th state, AD31:4 will be driven with the upper 28 bits of the read address. AD3:2 will be driven identically as A3:2 (the word address of the last read transfer). The processor will usually drive AD1:0 with the last SIZE information. In cases where the core cancels a previously issued bus request, AD1:0 are indeterminate.

### 15.2.5 Data Alignment

The i960 Jx microprocessor's Bus Control Unit (BCU) directly supports both big-endian and little-endian *aligned* accesses. The processor also transparently supports both big-endian and little-endian *unaligned* accesses but with reduced performance. Unaligned accesses are broken down into a series of aligned accesses with the assistance of microcode executing on the processor.

Alignment rules for loads and stores are based on address offsets from natural data boundaries. Table 15-5 lists the natural boundaries for the various data widths and Table 15-6 through 15-8 list all possible combinations of bus accesses resulting from aligned and unaligned requests. Figure 15-13 and Figure 15-14 also depict all the combinations for 32-bit buses. Figure 15-15 is a functional waveform for a series of four accesses resulting from a misaligned double word read request.

The fault configuration word in the Process Control Block (PRCB), can configure the processor to handle unaligned accesses non-transparently by generating an OPERATION.UNALIGNED fault after executing any unaligned access. See section 11.3.1.2, "Process Control Block (PRCB)" (pg. 11-14).

**Table 15-5. Natural Boundaries for Load and Store Accesses**

| Data Width  | Natural Boundary (Bytes) |
|-------------|--------------------------|
| Byte        | 1                        |
| Short Word  | 2                        |
| Word        | 4                        |
| Double Word | 8                        |
| Triple Word | 16                       |
| Quad Word   | 16                       |

**Table 15-6. Summary of Byte Load and Store Accesses**

| Address Offset from<br>Natural Boundary<br>(in Bytes) | Accesses on 8-Bit Bus<br>(WIDTH1:0=00) | Accesses on 16 Bit Bus<br>(WIDTH1:0=01) | Accesses on 32 Bit Bus<br>(WIDTH1:0=10) |
|---|--|---|---|
| +0 (aligned)  | byte access                            | byte access                             | byte access                             |

**Table 15-7. Summary of Short Word Load and Store Accesses**

| Address Offset from<br>Natural Boundary<br>(in Bytes) | Accesses on 8-Bit Bus<br>(WIDTH1:0=00) | Accesses on 16 Bit Bus<br>(WIDTH1:0=01) | Accesses on 32 Bit Bus<br>(WIDTH1:0=10) |
|---|--|---|---|
| +0 (aligned)  | burst of 2 bytes                       | short-word access                       | short-word access                       |
| +1  | 2 byte accesses                        | 2 byte accesses                         | 2 byte accesses                         |

Table 15-8. Summary of  $n$ -Word Load and Store Accesses ( $n = 1, 2, 3, 4$ )

| Address Offset from Natural Boundary in Bytes   | Accesses on 8-Bit Bus (WIDTH1:0=00)  | Accesses on 16 Bit Bus (WIDTH1:0=01)   | Accesses on 32 Bit Bus (WIDTH1:0=10)  |
|---|--|--|---|
| +0 (aligned)<br>( $n = 1, 2, 3, 4$ )  | <ul style="list-style-type: none"> <li><math>n</math> burst(s) of 4 bytes</li> </ul>   | <ul style="list-style-type: none"> <li>case <math>n=1</math>: burst of 2 short words</li> <li>case <math>n=2</math>: burst of 4 short words</li> <li>case <math>n=3</math>: burst of 4 short words<br/>burst of 2 short words</li> <li>case <math>n=4</math>: 2 bursts of 4 short words</li> </ul> | <ul style="list-style-type: none"> <li>burst of <math>n</math> word(s)</li> </ul>   |
| +1 ( $n = 1, 2, 3, 4$ )<br>+5 ( $n = 2, 3, 4$ )<br>+9 ( $n = 3, 4$ )<br>+13 ( $n = 3, 4$ )  | <ul style="list-style-type: none"> <li>byte access</li> <li>burst of 2 bytes</li> <li><math>n-1</math> burst(s) of 4 bytes</li> <li>byte access</li> </ul> | <ul style="list-style-type: none"> <li>byte access</li> <li>short-word access</li> <li><math>n-1</math> burst(s) of 2 short words</li> <li>byte access</li> </ul>  | <ul style="list-style-type: none"> <li>byte access</li> <li>short-word access</li> <li><math>n-1</math> word access(es)</li> <li>byte access</li> </ul> |
| +2 ( $n = 1, 2, 3, 4$ )<br>+6 ( $n = 2, 3, 4$ )<br>+10 ( $n = 3, 4$ )<br>+14 ( $n = 3, 4$ ) | <ul style="list-style-type: none"> <li>burst of 2 bytes</li> <li><math>n-1</math> burst(s) of 4 bytes</li> <li>burst of 2 bytes</li> </ul>                 | <ul style="list-style-type: none"> <li>short-word access</li> <li><math>n-1</math> burst(s) of 2 short words</li> <li>short-word access</li> </ul>   | <ul style="list-style-type: none"> <li>short-word access</li> <li><math>n-1</math> word access(es)</li> <li>short-word access</li> </ul>                |
| +3 ( $n = 1, 2, 3, 4$ )<br>+7 ( $n = 2, 3, 4$ )<br>+11 ( $n = 3, 4$ )<br>+15 ( $n = 3, 4$ ) | <ul style="list-style-type: none"> <li>byte access</li> <li><math>n-1</math> burst(s) of 4 bytes</li> <li>burst of 2 bytes</li> <li>byte access</li> </ul> | <ul style="list-style-type: none"> <li>byte access</li> <li><math>n-1</math> burst(s) of 2 short words</li> <li>short-word access</li> <li>byte access</li> </ul>  | <ul style="list-style-type: none"> <li>byte access</li> <li><math>n-1</math> word access(es)</li> <li>short-word access</li> <li>byte access</li> </ul> |
| +4 ( $n = 2, 3, 4$ )<br>+8 ( $n = 3, 4$ )<br>+12 ( $n = 3, 4$ )                             | <ul style="list-style-type: none"> <li><math>n</math> burst(s) of 4 bytes</li> </ul>   | <ul style="list-style-type: none"> <li><math>n</math> burst(s) of 2 short words</li> </ul>   | <ul style="list-style-type: none"> <li><math>n</math> word access(es)</li> </ul>  |

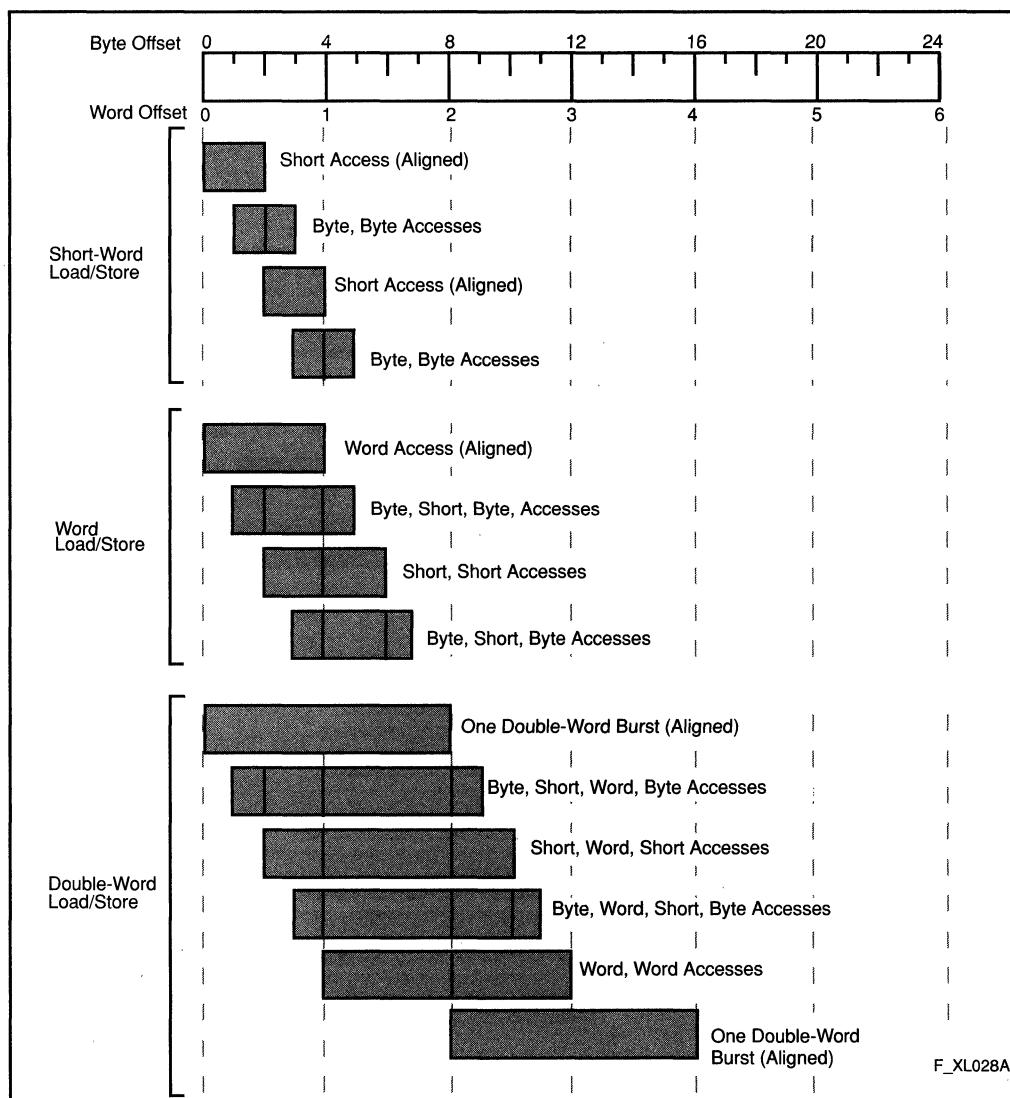
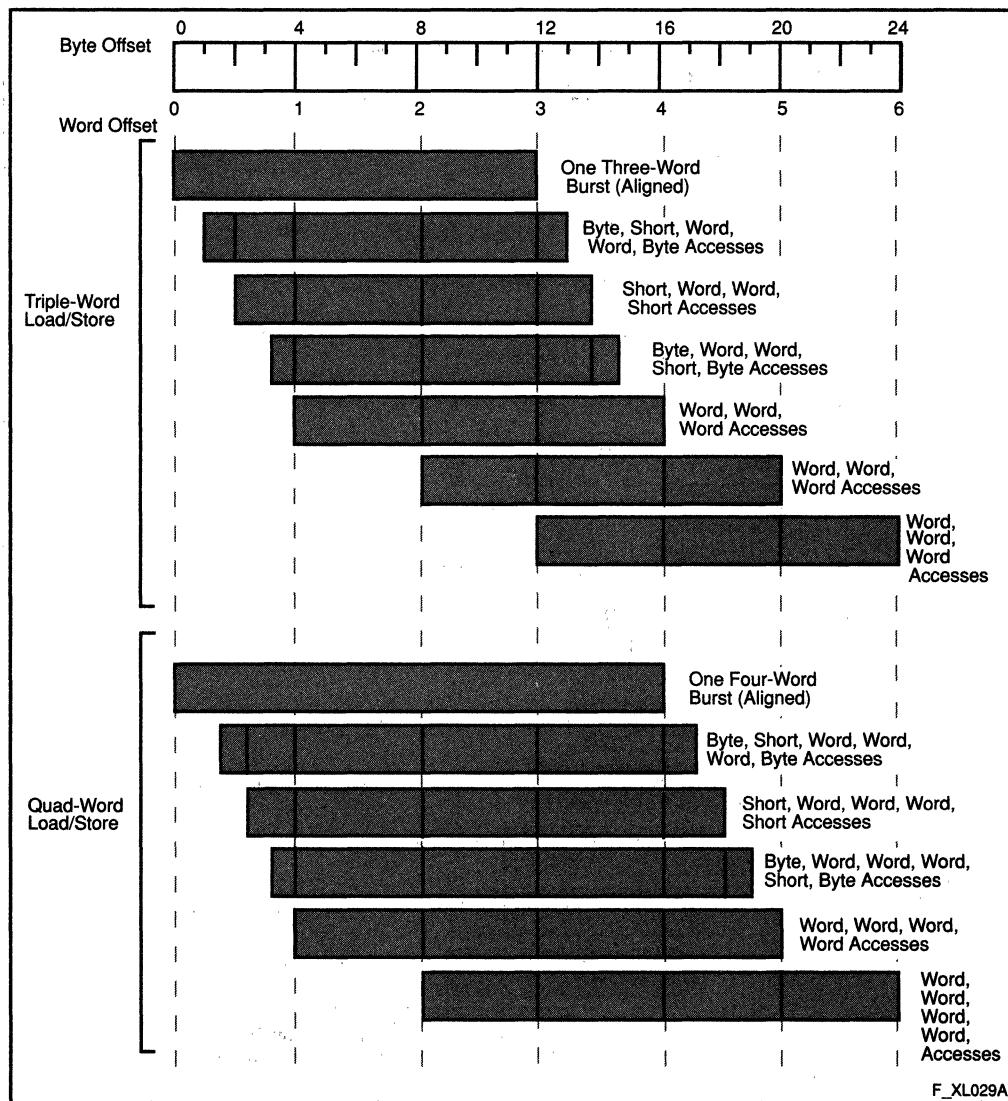


Figure 15-13. Summary of Aligned and Unaligned Accesses (32-Bit Bus)

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**Figure 15-14. Summary of Aligned and Unaligned Accesses (32-Bit Bus) (Continued)**

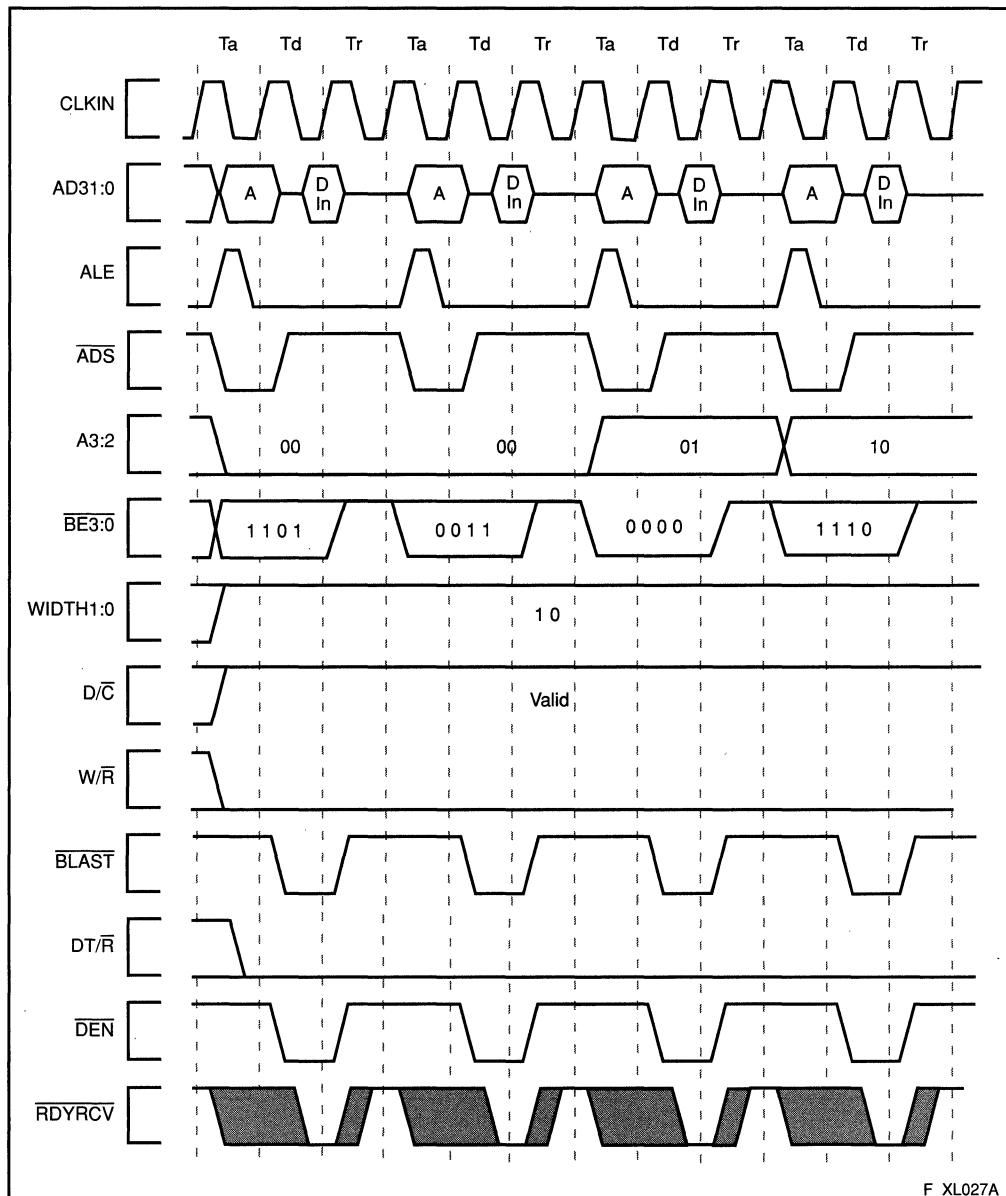


Figure 15-15. Accesses Generated by Double Word Read Bus Request, Misaligned One Byte From Quad Word Boundary, 32-Bit Bus, Little Endian

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### 15.2.6 Byte Ordering and Bus Accesses

The default byte-order for both instruction and data accesses is programmed in the DLMCON register to be either little- or big-endian. On the i960 Jx processor, DLMCON.be controls the default byte order for internal (on-chip data ram and data cache) accesses as well as external accesses. The programming of DLMCON is discussed in section 12.6.2, "Selecting the Byte Order" (pg. 12-11).

The processor handles the byte data type the same regardless of byte ordering. Table 15-9 shows byte data 0DDH being transferred on 8, 16 and 32 bit buses.

For the short word data type, assume that a hexadecimal value of 0CCDDH is stored in one of the processor's internal registers. Table 15-10 shows how this short word is transferred on the bus to either a little endian or big endian memory region. Note that the short word goes out on different data lines on a 32-bit bus depending upon whether address line A1 is odd or even. In this example, the transfer is assumed to be aligned.

For the word data type, assume that a hexadecimal value of 0AABBCDDH is stored in an internal processor register, where 0AAH is the word's most significant byte and 0DDH is the least significant byte. Table 15-11 shows how this word is transferred on the bus to an aligned address in either little endian or big endian memory.

The i960 Jx processor supports multi-word big endian data types with individual word accesses. Bytes in each word are stored in big-endian order; however, words are stored in little-endian order. Consider Figure 15-16, which illustrates a double word store to big endian memory.

**Table 15-9. Byte Ordering on Bus Transfers, Word Data Type**

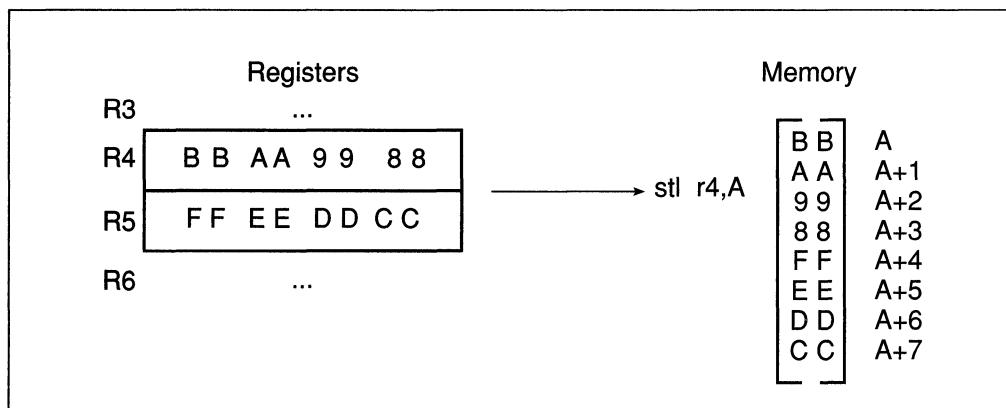
| Word Data Type |                  |      | Bus Pins (AD31:0) |       |      |     |           |       |      |     |
|----------------|------------------|------|-------------------|-------|------|-----|-----------|-------|------|-----|
| Bus Width      | Addr Bits A1, A0 | Xfer | LittleEndian      |       |      |     | BigEndian |       |      |     |
|                |                  |      | 31:24             | 23:16 | 15:8 | 7:0 | 31:24     | 23:16 | 15:8 | 7:0 |
| 32 bit         | 00               | 1st  | AA                | BB    | CC   | DD  | DD        | CC    | BB   | AA  |
| 16 bit         | 00               | 1st  | --                | --    | CC   | DD  | --        | --    | BB   | AA  |
|                | 10               | 2nd  | --                | --    | AA   | BB  | --        | --    | DD   | CC  |
| 8 bit          | 00               | 1st  | --                | --    | --   | DD  | --        | --    | --   | AA  |
|                | 01               | 2nd  | --                | --    | --   | CC  | --        | --    | --   | BB  |
|                | 10               | 3rd  | --                | --    | --   | BB  | --        | --    | --   | CC  |
|                | 11               | 4th  | --                | --    | --   | AA  | --        | --    | --   | DD  |

**Table 15-10. Byte Ordering on Bus Transfers, Short-Word Data Type**

| Short-Word Data Type |                  |      | Bus Pins (AD31:0) |       |      |     |            |       |      |     |
|----------------------|------------------|------|-------------------|-------|------|-----|------------|-------|------|-----|
| Bus Width            | Addr Bits A1, A0 | Xfer | Little Endian     |       |      |     | Big Endian |       |      |     |
|                      |                  |      | 31:24             | 23:16 | 15:8 | 7:0 | 31:24      | 23:16 | 15:8 | 7:0 |
| 32 bit               | 00               | 1st  | --                | --    | CC   | DD  | --         | --    | DD   | CC  |
|                      | 10               | 1st  | CC                | DD    | --   | --  | DD         | CC    | --   | --  |
| 16 bit               | X0               | 1st  | --                | --    | CC   | DD  | --         | --    | DD   | CC  |
| 8 bit                | X0               | 1st  | --                | --    | --   | DD  | --         | --    | --   | CC  |
|                      | X1               | 2nd  | --                |       |      | CC  | --         | --    | --   | DD  |

**Table 15-11. Byte Ordering on Bus Transfers, Byte Data Type**

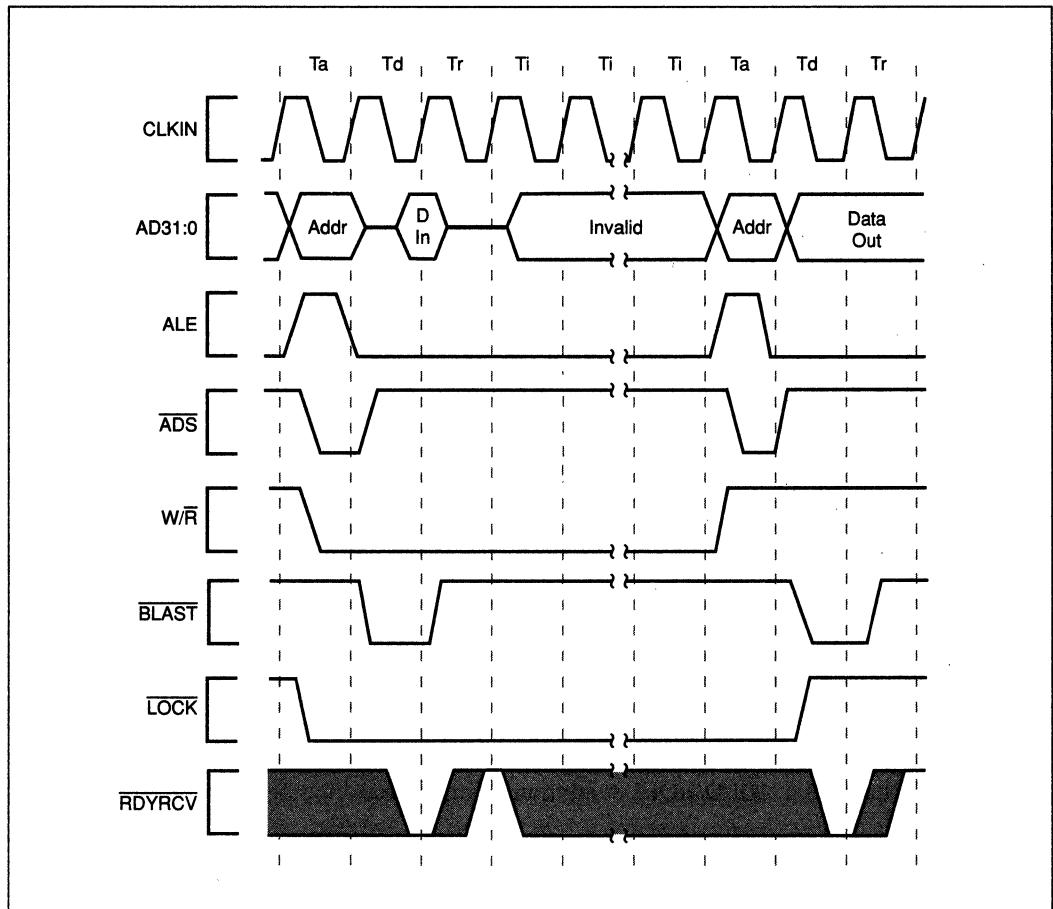
| Byte Data Type |                  |      | Bus Pins (AD31:0)     |       |      |     |
|----------------|------------------|------|-----------------------|-------|------|-----|
| Bus Width      | Addr Bits A1, A0 | Xfer | Little and Big Endian |       |      |     |
|                |                  |      | 31:24                 | 23:16 | 15:8 | 7:0 |
| 32 bit         | 00               | 1st  | --                    | --    | --   | DD  |
|                | 01               | 1st  | --                    | --    | DD   | --  |
|                | 10               | 1st  | --                    | DD    | --   | --  |
|                | 11               | 1st  | DD                    | --    | --   | --  |
| 16 bit         | X0               | 1st  | --                    | --    | --   | DD  |
|                | X1               | 1st  | --                    | --    | DD   | --  |
| 8 bit          | XX               | 1st  | --                    | --    | --   | DD  |


**Figure 15-16. Multi-Word Access to Big-Endian Memory Space**

### 15.2.7 Atomic Bus Transactions

The atomic instructions, **atadd** and **atmod**, consist of a load and store request to the same memory location. Atomic instructions require indivisible, read-modify-write access to memory. That is, another bus agent must not access the target of the atomic instruction between read and write cycles. Atomic instructions are necessary to implement software semaphores.

For atomic bus accesses, the 80960Jx processor asserts the **LOCK** pin during the first Ta of the read operation and deasserts **LOCK** in the last data transfer of the write operation. **LOCK** is deasserted at the same clock edge that **BLAST** is asserted. The i960Jx processor does not assert **LOCK** except while a read-modify-write operation is in progress. While **LOCK** is asserted, the processor can perform other, non-atomic, accesses such as fetches. However, the 80960Jx processor will not acknowledge HOLD requests. This behavior is an enhancement over earlier i960 microprocessors. Figure 15-17 illustrates locked read/write accesses associated with an atomic instruction.

Figure 15-17. The LOCK Signal

### 15.2.8 Bus Arbitration

The i960 Jx processor can share the bus with other bus masters, using its built-in arbitration protocol. The protocol assumes two bus masters: a default bus master (typically the 80960Jx) that controls the bus and another that requests bus control when it performs an operation (e.g., a DMA controller). More than two bus masters may exist on the bus, but this configuration requires external arbitration logic.

Three processor signal pins comprise the bus arbitration pin group.

### **15.2.8.1 HOLD/HOLDA Protocol**

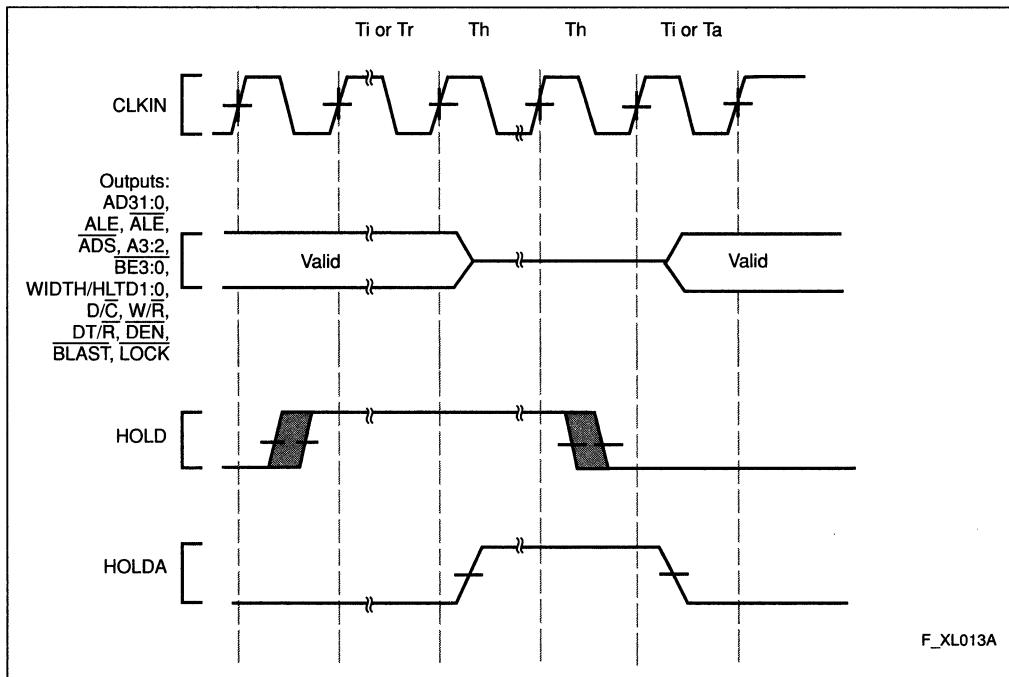
In most cases, the i960 Jx processor controls the bus; an I/O peripheral (e.g., a communications controller) requests bus control. The processor and I/O peripheral device exchange bus control with two signals, HOLD and HOLDA.

HOLD is an i960 Jx processor synchronous input signal which indicates that the alternate master needs the bus. HOLD may be asserted at any time so long as the transition meets the processor's setup and hold requirements. HOLDA (hold acknowledge) is the processor's output which indicates surrender of the bus. When the i960 Jx processor asserts HOLDA, it enters the Th (hold) state (see Figure 15.1). If the last bus state was Ti or the last Tr of a bus transaction, the processor is guaranteed to assert HOLDA and float the bus on the same clock edge in which it recognizes HOLD. Similarly, the processor deasserts HOLDA on the same edge in which it recognizes the deassertion of HOLD. Thus, bus latency is no longer than it takes the processor to finish any bus access in progress.

If the bus is in hold and the 80960Jx needs to regain the bus to perform a transaction, the processor does not deassert HOLDA. In many cases, however, it will assert the BSTAT pin (see section 15.2.8.2, BSTAT Signal).

Unaligned load and store bus requests are broken into multiple accesses and the processor can relinquish the bus between those transactions. When the alternate bus master gives control of the bus back to the 80960Jx, the processor will immediately enter a Ta state to continue those accesses and respond to any other bus requests. If no requests are pending, the processor will enter the idle state.

Figure 15-18 illustrates a HOLD/HOLDA arbitration sequence.



**Figure 15-18. Arbitration Timing Diagram for a Bus Master**

The HOLD/HOLDA arbitration functions during processor reset. The bus controller acknowledges HOLD while  $\overline{\text{RESET}}$  is asserted because the bus is idle. If  $\overline{\text{RESET}}$  is asserted while HOLDA is asserted (the processor has acknowledged the HOLD), the processor remains in the HOLDA state. The processor does not continue reset activities until HOLD is removed and the processor removes HOLDA.

### 15.2.8.2 BSTAT Signal

The i960 Jx microprocessor extends the HOLD/HOLDA protocol with a bus status (BSTAT) signal. In simplest terms, assertion of the BSTAT output pin indicates that the CPU may soon stall unless it obtains (or retains) control of the bus. This indication is a useful input to arbitration logic, whether or not the 80960 Jx is the primary bus master.

The processor asserts BSTAT when one or more of the following conditions are true:

- The bus queue in the bus control unit (BCU) becomes full for any reason.
- An instruction fetch request is pending or being serviced on the bus. This behavior promotes performance by supporting instruction cache fills.

- A load request has been issued to the BCU. This behavior promotes performance by supporting early data loading.
- A special operation is underway that requires emptying the bus queue. Examples of such operations are execution of the HALT instruction and register stores that control logical or physical memory configuration.

The processor can assert BSTAT on any rising CLKIN edge. Although BSTAT activation suggests bus starvation, it does not necessarily imply that the processor definitely stall or that it is currently stalled.

When the 80960Jx is the primary bus master and asserts BSTAT, arbitration logic can work more intelligently to anticipate and prevent processor bus stalls. Depending on the importance of the alternate bus master's task, ownership of the bus can be modulated. If the bus is in hold, control can be relinquished back to the microprocessor immediately or after an optimal delay. Of course, BSTAT can be ignored completely if the loss in processor bandwidth can be tolerated.

When the 80960Jx is not the primary bus master, the BSTAT signal becomes the means to request the bus from the primary master. As described above, BSTAT will be activated for all loads and fetches, but store requests do not activate BSTAT unless they fill the bus queue. If the processor needs priority access to the bus to perform store operations, replace store instructions with the atomic modify (**atmod**) instruction, using a mask operand of all one's. **atmod** is a read-modify-write instruction, so the processor will assert BSTAT when the load transaction is posted to the bus queue. When the load begins, LOCK# is asserted, which blocks recognition of hold requests until the store portion of **atmod** completes.

## 15.3 BUS APPLICATIONS

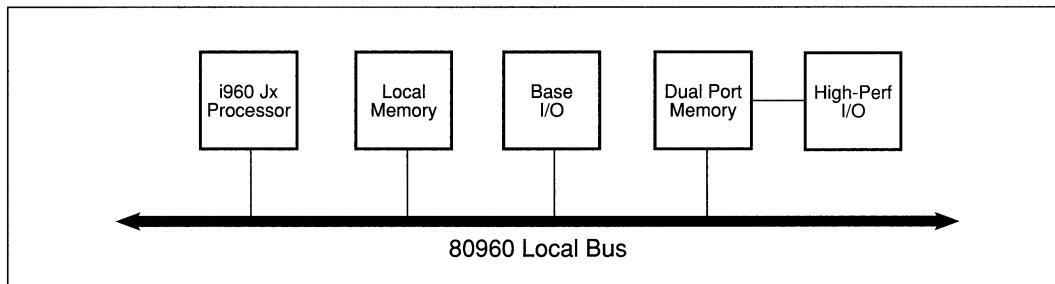
The i960Jx microprocessor is a cost-effective building block for a wide spectrum of embedded systems. This section describes common interfaces for the 80960Jx to external memory and I/O devices.

### 15.3.1 System Block Diagrams

Block diagrams in Figure 15-19 through Figure 15-21 are generalized diagrams with bus topologies representative of a number of potential 80960Jx systems. These diagrams do not represent any particular i960Jx processor-based applications.

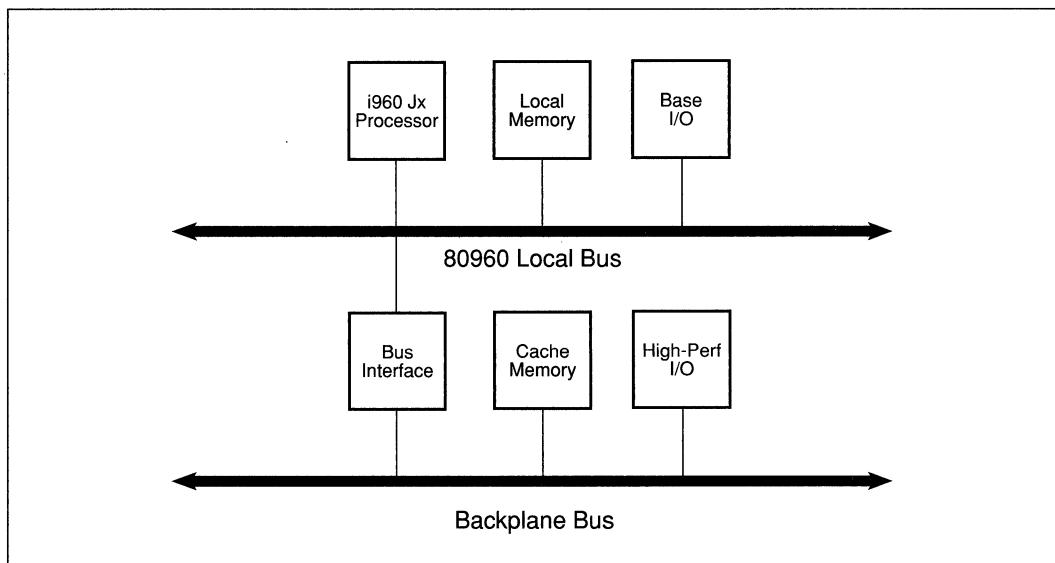
In most i960Jx processor systems, the 80960Jx is the primary master of the local bus. A number of memory and I/O devices typically interface to the processor, either directly or through buffers and transceivers. An example of such a system might be a laser beam printer.

Systems with multiple I/O channels frequently use dual-ported memory to link several identical I/O devices to the local bus, as in Figure 15-19. These systems are more complex, but performance and flexibility improve because bus traffic is partitioned away from the i960 Jx processor's local bus. An example of such a system might be a network hub.



**Figure 15-19. Generalized 80960Jx System with 80960 Local Bus**

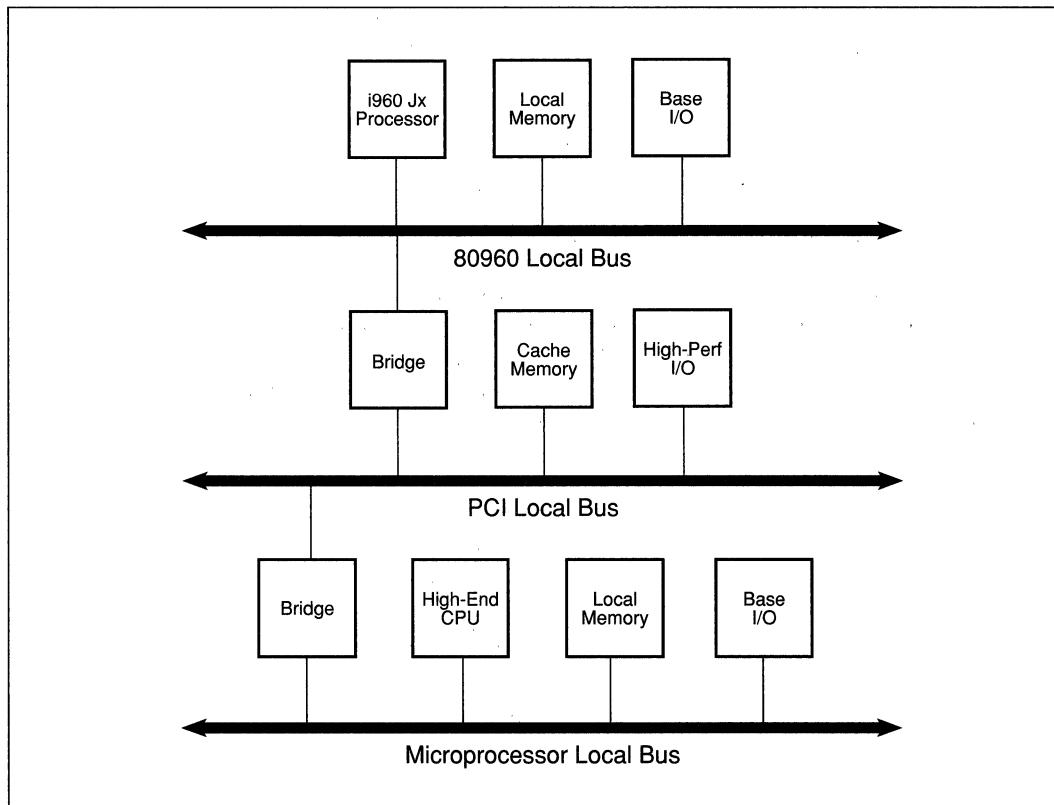
A more elaborate system would connect the 80960Jx's bus to a backplane through bus interface logic as shown in Figure 15-20. The backplane bus (or system bus) connects to multiple high performance I/O devices (often with DMA) and large buffer memory for caching packets of data from disk drives or LANs. Backplane buses can connect to other microprocessor local buses, too, creating a loosely coupled multiprocessor system for resource sharing.



**Figure 15-20. Generalized 80960Jx System with 80960 Local Bus and Backplane Bus**

## EXTERNAL BUS

Buses such as the PCI (Peripheral Component Interconnect) local bus connect to the 80960 bus through a bridge chip, which employs DMA, FIFOs and mailboxes for bus-to-bus communication. The PCI local bus can connect shared buffer memory and high performance I/O devices. The bandwidth of the PCI local bus is particularly appropriate for bridge interfacing to high-end processors such as the Pentium (R) microprocessor, as illustrated in Figure 15-21. In this way, the i960Jx can improve the performance of complex systems such as servers by sparing the main system CPU and its local memory the task of buffering low-level I/O.



**Figure 15-21. 80960Jx System with 80960 Local Bus, PCI Local Bus and Local Bus for High End Microprocessor**

### 15.3.1.1 Memory Subsystems

Memory systems for the i960 Jx processor include a mix of non-volatile and volatile devices including ROM, DRAM, SRAM or flash memory. The circuit designer may take advantage of programmable bus width to optimize the number of devices in each memory array. For example, the processor can boot from a single, slow, 8-bit ROM device, then execute from code loaded to a faster, wider and larger RAM array.

All systems must contain burstable memory, since the processor employs burst transactions for instruction fetches and stack operations. Bursting cannot be turned off on the i960Jx processor.

### 15.3.1.2 I/O Subsystems

I/O subsystems vary widely according to the needs of specific applications. Individual peripheral devices may be as generic as discrete logic I/O ports or as specialized as an ISDN controller.

Typical peripherals for desktop/server intelligent I/O applications are Small Computer System Interface controllers supporting SCSI-1 (8-bit) or SCSI-2 (8/16/32-bit) standards.

For network applications such as ATM adapters, smart hubs and routers, typical peripherals include controllers for older protocols such as Ethernet and FDDI and controllers for newer protocols such as ATM (Asynchronous Transfer Mode) and Fibre Channel.

Typical peripherals for non-impact printer controllers include printer video ports, engine command/status ports, asynchronous serial controllers, IEEE 1284 parallel ports, LocalTalk(TM) ports and PCMCIA memory card controllers.





16

HALT MODE





# CHAPTER 16

## HALT MODE

This chapter discusses HALT mode and its effect on power consumption. The i960® Jx microprocessor initially enters HALT mode when a **halt** instruction executes. The processor quickly exits the HALT mode upon receipt of **RESET** or any interrupt allowed by the current process priority. Exit through an interrupt causes execution to continue within the appropriate interrupt handler routine. HALT mode can be used as an efficient, low-power method to wait for interrupts.

### 16.1 Entering HALT Mode

Entry into HALT mode by the **halt** instruction causes the following actions to occur:

- Interrupts are enabled or disabled based on the value of the *src1* argument supplied in the **halt** instruction.
- The processor ensures that all previous load and store operations have completed before continuing. If the bus queues are not empty, the processor asserts the BSTAT pin and waits for the bus queues to empty.
- The processor attempts to reduce power consumption to more efficiently wait for exit from HALT mode.

The processor performs an implicit **SYNCF** before attempting to enter HALT mode. If a fault is detected for a previous instruction, the processor will switch control to the appropriate fault handler instead of executing the **halt**. If the fault is recoverable, the processor executes the **halt** instruction upon return from the fault handler. A trace fault on the **halt** instruction will be serviced after the processor exits HALT mode.

**halt** can only be executed while in supervisor mode; a **TYPE.MISMATCH** fault occurs when attempting to execute the instruction in user mode.

### 16.2 Processor Operation During HALT Mode

The i960 Jx processor's power needs drop by approximately an order of magnitude while in HALT mode. See the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet*. Code execution stops but the processor maintains its internal state and can still respond to certain internal and external events.

## HALT MODE



The internal timers, when enabled, continue to decrement each cycle during HALT mode and can even force the processor out of HALT mode if either timer generates an interrupt of sufficient priority.

The processor responds normally to external events such as interrupt requests, hardware RESET, and HOLD requests.

Output pins are driven to known states during HALT mode and provide a unique external indication of the mode. Most importantly, WIDTH/HLTD is set to 11<sub>2</sub>. Refer to the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* or the *80960JD Embedded 32-bit Microprocessor Data Sheet* for more information.

All other control signals are inactive. The processor attempts to drive each inactive pin to the same value the pin held before entering HALT mode; this reduces power consumption while in HALT mode.

The processor acknowledges HOLD requests on the external bus properly; however, receiving a HOLD request does not cause the processor to exit HALT mode. During the HOLD acknowledge, the processor drives all bus output pins to high impedance. When HOLD is deasserted, the processor drives the output bus pins back to the normal HALT mode state described above.

The following JTAG features are unaffected by HALT mode:

- access to Boundary-Scan through the Test-Access Port (TAP)
- access to IDCODE through TAP
- access to RUNBIST through TAP
- access to BYPASS through TAP

### 16.3 Exiting HALT Mode

A number of external events can force the processor to exit HALT mode:

- The presentation of an interrupt to the processor that should be delivered based on the processor's current process priority and the interrupt controller's normal prioritization mechanism (as described in the interrupt chapter).  
Return from an interrupt that forced the processor to exit HALT mode causes execution to resume at the instruction immediately after the halt instruction.
- The assertion of RESET. When RESET is subsequently deasserted the processor enters the normal initialization process.

Note that the WIDTH/HLTD pins stay in the "11" even after coming out of HALT mode until the next external bus access.

### 16.3.1 Exiting HALT Mode for any Interrupt

Normally, only interrupts prioritized higher than the processor's current process priority cause the processor to exit HALT mode.

In an application that requires interrupts of a lower priority to force exit from HALT mode, the process priority must be lowered. Lowering of the process priority and issuing of the **halt** instruction must be non-interruptible so that if the desired interrupt occurs too early, it does not interrupt before the **halt** instruction is issued.

The recommended way to provide a non-interruptible window is as follows. The **halt** instruction must be preceded by a sequence of an **intctl** instruction that disables interrupts, followed by a **modpc** instruction that lowers the current process priority. Subsequently issuing a **halt** instruction with a *src1* value of 1 causes interrupts to be enabled at the new process priority. Note that by lowering the process priority, interrupts that are pending at a lower priority before the **halt** instruction executes, are now free to bring the processor out of HALT mode almost immediately.





17

## TEST FEATURES

1000

100

1000  
100

1000  
100

# CHAPTER 17

## TEST FEATURES

This chapter describes the i960<sup>®</sup> Jx processor's test features, including ONCE (On-Circuit Emulation) and Boundary Scan (JTAG). Together these two features create a powerful environment for design debug and fault diagnosis.

### 17.1 ON-CIRCUIT EMULATION (ONCE)

On-circuit emulation aids board-level testing. This feature allows a mounted i960 Jx processor to electrically "remove" itself from a circuit board. This allows for system-level testing where a remote tester exercises the processor system. In ONCE mode, the processor presents a high impedance on every pin, except for the JTAG Test Data Output (TDO). All pullup transistors present on input pins are also disabled and internal clocks stop. In this state the processor's power demands on the circuit board are nearly eliminated. Once the processor is electrically removed, a functional tester such as an In-Circuit Emulator (ICE) system can emulate the mounted processor and execute a test of the i960 Jx processor system.

#### 17.1.1 Entering/Exiting ONCE Mode

The i960 Jx processor uses the dual function  $\overline{\text{LOCK/ONCE}}$  pin for ONCE. The  $\overline{\text{LOCK/ONCE}}$  pin is an input while  $\overline{\text{RESET}}$  is asserted. The i960 Jx processor uses this pin as an output when the ONCE mode conditions are not present.

ONCE mode is entered by asserting (low) the  $\overline{\text{LOCK/ONCE}}$  pin while the processor is in the reset state, or by executing the HIGHZ JTAG private instruction. The  $\overline{\text{LOCK/ONCE}}$  pin state is latched on the  $\overline{\text{RESET}}$  signal's rising edge.

- To enter ONCE mode, an external tester drives the  $\overline{\text{ONCE}}$  pin low (overcoming the internal pull-up resistor) and initiates a reset cycle.
- To exit ONCE mode, perform a hard reset with the  $\overline{\text{ONCE}}$  pin deasserted (high) prior to the rising edge of  $\overline{\text{RESET}}$ . It is not necessary to cycle power when exiting ONCE mode.

See the *80960JA/JF Embedded 32-bit Microprocessor Data Sheet* and the *80960JD Embedded 32-bit Microprocessor Data Sheet* for specific timing of the  $\overline{\text{LOCK/ONCE}}$  pin and the characteristics of the on-circuit emulation mode.

## TEST FEATURES

### 17.2 BOUNDARY SCAN (JTAG)

The i960 Jx processor provides test features compatible with IEEE Standard Test Access Port and Boundary Scan Architecture (IEEE Std. 1149.1). JTAG ensures that components function correctly, connections between components are correct, and components interact correctly on the printed circuit board.

To date, the i960 Kx, Sx and Cx processors do not implement IEEE 1491.1 Standard Test Access Port and Boundary-Scan Architecture.

#### 17.2.1 Boundary Scan Architecture

Boundary scan test logic consists of a Boundary-Scan register and support logic. These are accessed through a Test Access Port (TAP). The TAP provides a simple serial interface that allows all processor signal pins to be driven and/or sampled, thereby providing the direct control and monitoring of processor pins at the system level.

This mode of operation is valuable for design debugging and fault diagnosis since it permits examination of connections not normally accessible to the test system. The following subsections describe the boundary scan test logic elements: TAP controller, Instruction register, Test Data registers and TAP elements.

##### 17.2.1.1 TAP Controller

The TAP controller is a 16 state machine, which provides the internal control signals to the instruction register and the test data registers. The state of the TAP controller is determined by the logic present on the Test Mode Select (TMS) pin on the rising edge of TCK. See Figure 17-2 for the state diagram of the TAP controller.

##### 17.2.1.2 Instruction Register

The instruction register (IR) holds instruction codes shifted through the Test Data Input (TDI) pin. The instruction codes are used to select the specific test operation to be performed and the test data register to be accessed.

### 17.2.1.3 Test Data Registers

The four test data registers are:

- Device ID register (see section 17.3.2.1, “Device Identification Register” (pg. 17-6)).
- Bypass register (see section 17.3.2.2, “Bypass Register” (pg. 17-6)).
- RUNBIST register (see section 17.3.2.3, “RUNBIST Register” (pg. 17-7)).
- Boundary-Scan register (see section 17.3.2.4, “Boundary-Scan Register” (pg. 17-7)).

### 17.2.1.4 TAP Elements

The Test Access Port (TAP) contains a TAP controller, an instruction register, a group of test data registers, and the TAP pins as shown in the block diagram in Figure 17-1. The TAP is the general-purpose port that provides access to the test data registers and instruction registers through the TAP controller.

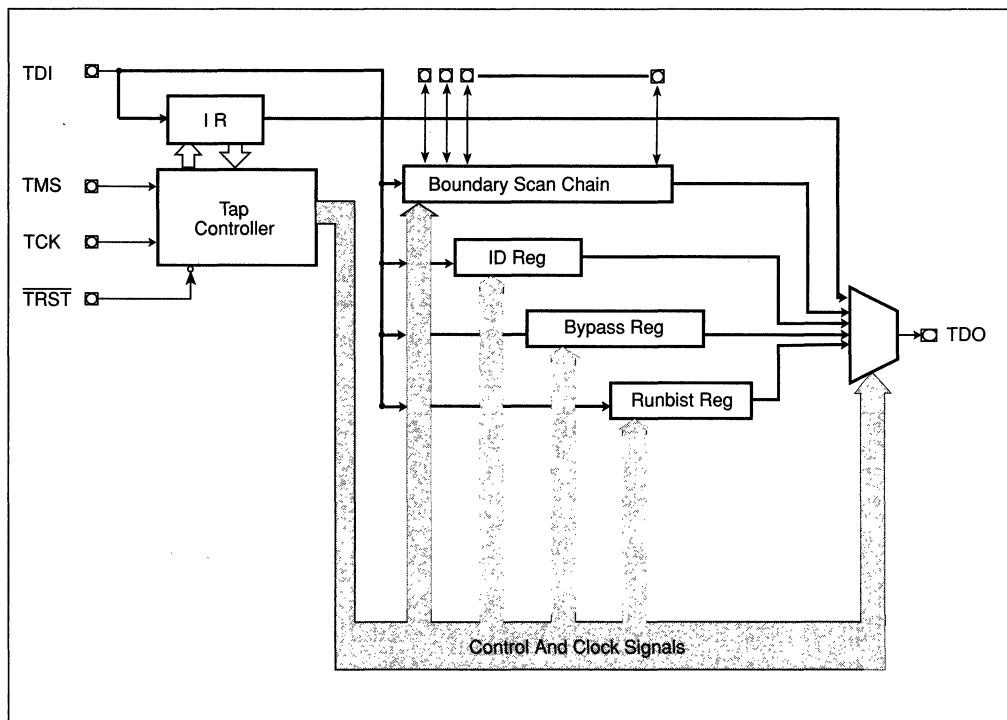


Figure 17-1. Test Access Port Block Diagram

## TEST FEATURES

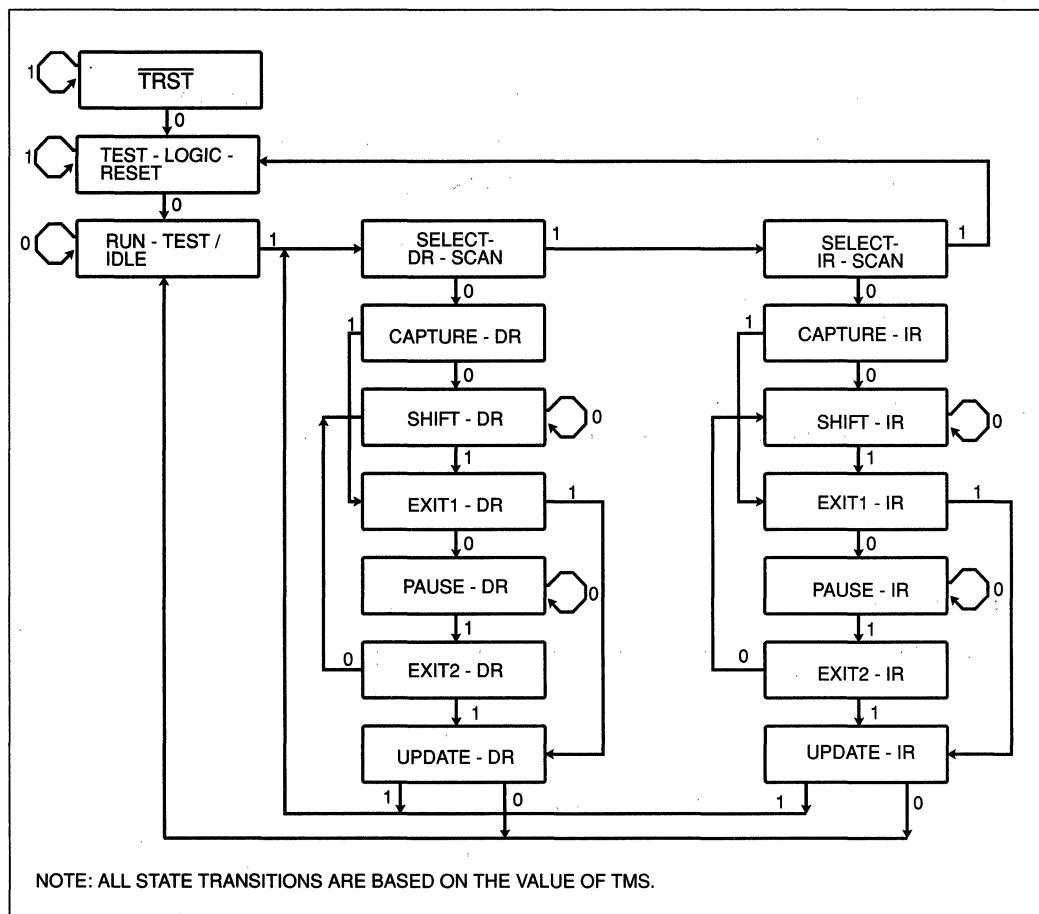


Figure 17-2. TAP Controller State Diagram

The i960 Jx processor's TAP is composed of four input connections (TMS, TCK,  $\overline{\text{TRST}}$  and TDI) and one output connection (TDO). These pins are described in Table 17-1.

**Table 17-1. TAP Controller Pin Definitions**

| Pin Name           | Mnemonic                 | Type   | Definition  |
|--------------------|--------------------------|--------|---|
| Test Clock         | TCK                      | Input  | Clock input for the TAP controller, the instruction register, and the test data registers. The JTAG unit will retain its state when TCK is stopped at "0" or "1".   |
| Test Mode Select   | TMS                      | Input  | Controls the operation of the TAP controller. The TMS input is pulled high when not being driven. TMS is sampled on the rising edge of TCK.   |
| Test Data In       | TDI                      | Input  | Serial data input to the instruction and test data registers. Data at TDI is sampled on the rising edge of TCK. Like TMS, TDI is pulled high when not being driven. Data shifted from TDI through a register to TDO appears non-inverted at TDO.  |
| Test Data Out      | TDO                      | Output | Used for serial data output. Data at TDO is driven at the falling edge of TCK and provides an inactive (high-Z) state when scanning is not in progress. The non-shift inactive state is provided to support parallel connection of TDO outputs at the board or module level.  |
| Asynchronous Reset | $\overline{\text{TRST}}$ | Input  | Provides asynchronous initialization of the test logic. $\overline{\text{TRST}}$ is pulled high when not being driven. Assertion of this pin puts the TAP controller in the Test_Logic_Reset (initial) state. For minimum pulse width specifications, see the <i>80960JA/JF Embedded 32-bit Microprocessor Data Sheet</i> or the <i>80960JD Embedded 32-bit Microprocessor Data Sheet</i> . |

## 17.3 TAP REGISTERS

The instruction and test data registers are separate shift-register paths connected in parallel. The TAP controller determines which one of these registers is connected between the TDI and TDO pins.

### 17.3.1 Instruction Register (IR)

The Instruction Register (IR) is a parallel-loadable, master/slave-configured 4-bit wide, serial-shift register with latched outputs. Data is loaded into the IR serially through the TDI pin clocked by the rising edge of TCK when the TAP controller is in the Shift\_IR state. The shifted-in instruction becomes active upon latching from the master-stage to the slave-stage in the Update\_IR state. At that time the IR outputs along with the TAP finite state machine outputs are decoded to select and control the test data register selected by that instruction. Upon latching, all actions caused by any previous instructions must terminate.

## TEST FEATURES

The instruction determines the test to be performed, the test data register to be accessed, or both (see Table 17-2). The IR is four bits wide. When the IR is selected in the Shift\_IR state, the most significant bit is connected to TDI, and the least significant bit is connected to TDO. TDI is shifted into IR on each rising edge of TCK, as long as TMS remains asserted. When the processor enters the Capture\_IR TAP controller state, fixed parallel data ( $0001_2$ ) is captured. During Shift\_IR, when a new instruction is shifted in through TDI, the value  $0001_2$  is always shifted out through TDO least significant bit first. This helps identify instructions in a long chain of serial data from several devices.

Upon activation of the  $\overline{\text{TRST}}$  reset pin, the latched instruction will asynchronously change to the **idcode** instruction. If the TAP controller moved into the Test\_Logic\_Reset state other than by reset activation, the opcode will change as TDI is shifted, and will become active on the falling edge of TCK. See Figure 17-4 for an example of loading the instruction register.

### 17.3.2 TAP Test Data Registers

The i960 Jx processor contains a device identification register and three test data registers (Bypass, Boundary-Scan and RUNBIST). Each test data register selected by the TAP controller is connected serially between TDI and TDO. TDI is connected to the test data register's most significant bit. TDO is connected to the least significant bit. Data is shifted one bit position within the register towards TDO on each rising edge of TCK. The following sections describe each of the test data registers. See Figure 17-5 for an example of loading the data register.

#### 17.3.2.1 Device Identification Register

The Device Identification register is a 32-bit register containing the manufacturer's identification code, part number code and version code in the format shown in Figure 11-8. The format of the register is discussed in Section 11.4, DEVICE IDENTIFICATION ON RESET (pg. 11-21). Table 11-7 lists the codes corresponding to the i960 Jx processor. The identification register is selected only by the **idcode** instruction. When the TAP controller's Test\_Logic\_Reset state is entered, **idcode** is automatically loaded into the instruction register. The Device Identification register has a fixed parallel input value that is loaded in the Capture\_DR state.

#### 17.3.2.2 Bypass Register

The required Bypass Register, a one-bit shift register, provides the shortest path between TDI and TDO when a **bypass** instruction is in effect. This allows rapid movement of test data to and from other components on the board. This path can be selected when no test operation is being performed. While the bypass register is selected, data is transferred from TDI to TDO without inversion.

Any instruction that does not make use of another test data register may select the Bypass register as its active TDI to TDO path.

### 17.3.2.3 RUNBIST Register

The RUNBIST register is a one-bit register that contains the result of the execution of the **runbist** instruction execution. The **runbist** instruction runs the built-in self-test (BIST) program resident inside the processor. After the built-in self-test completes, the processor must be recycled through the reset state to begin normal operation. See section 11.2.2, “Self Test Function (STEST, FAIL)” (pg. 11-6) for details of the Built-In-Self-Test algorithm.

### 17.3.2.4 Boundary-Scan Register

The Boundary-Scan register is a required set of serial-shiftable register cells, configured in master/slave stages and connected between each of the i960 Jx processor's pins and on-chip system logic. Pins NOT in the Boundary-Scan chain are power, ground and JTAG pins.

The Boundary-Scan register cells are dedicated logic and do not have any system function. Data may be loaded into the Boundary-Scan register master-cells from the device input pins and output pin-drivers in parallel by the mandatory **sample/preload** and **extest** instructions. Parallel loading takes place on the rising edge of TCK in the Capture\_DR state.

Data may be scanned into the Boundary-Scan register serially via the TDI serial-input pin, clocked by the rising edge of TCK in the Shift\_DR state. When the required data has been loaded into the master-cell stages, it is driven into the system logic at input pins or onto the output pins on the falling edge of TCK in the Update\_DR state. Data may also be shifted out of the Boundary-Scan register by means of the TDO serial-output pin at the falling edge of TCK.

## 17.3.3 Boundary Scan Instruction Set

The i960 Jx processor supports three mandatory boundary scan instructions (**bypass**, **sample/preload** and **extest**). The i960 Jx processor also contains two additional public instructions (**idcode** and **runbist**). Table 17-2 lists the i960 Jx processor's boundary scan instruction codes.

## TEST FEATURES

**Table 17-2. Boundary Scan Instruction Set**

| Instruction Code  | Instruction Name | Instruction Code  | Instruction Name |
|-------------------|------------------|-------------------|------------------|
| 0000 <sub>2</sub> | <b>extest</b>    | 1000 <sub>2</sub> | private          |
| 0001 <sub>2</sub> | <b>sampre</b>    | 1001 <sub>2</sub> | not used         |
| 0010 <sub>2</sub> | <b>idcode</b>    | 1010 <sub>2</sub> | not used         |
| 0011 <sub>2</sub> | not used         | 1011 <sub>2</sub> | private          |
| 0100 <sub>2</sub> | private          | 1100 <sub>2</sub> | private          |
| 0101 <sub>2</sub> | not used         | 1101 <sub>2</sub> | not used         |
| 0110 <sub>2</sub> | not used         | 1110 <sub>2</sub> | not used         |
| 0111 <sub>2</sub> | <b>runbist</b>   | 1111 <sub>2</sub> | <b>bypass</b>    |

### 17.3.4 IEEE Required Instructions

**Table 17-3. IEEE Instructions (Sheet 1 of 2)**

| Instruction / Requisite                  | Opcode            | Description   |
|--|-------------------|---|
| <b>extest</b><br>IEEE 1149.1<br>Required | 0000 <sub>2</sub> | <b>extest</b> initiates testing of external circuitry, typically board-level interconnects and off chip circuitry. <b>extest</b> connects the Boundary-Scan register between TDI and TDO in the Shift_IR state only. When <b>extest</b> is selected, all output signal pin values are driven by values shifted into the Boundary-Scan register and may change only on the falling-edge of TCK in the Update_DR state. Also, when <b>extest</b> is selected, all system input pin states must be loaded into the Boundary-Scan register on the rising-edge of TCK in the Capture_DR state. Values shifted into input latches in the Boundary-Scan register are never used by the processor's internal logic.   |
| <b>sampre</b><br>IEEE 1149.1<br>Required | 0001 <sub>2</sub> | <b>sample/preload</b> performs two functions: <ul style="list-style-type: none"> <li>When the TAP controller is in the Capture-DR state, the <b>sample</b> instruction occurs on the rising edge of TCK and provides a snapshot of the component's normal operation without interfering with that normal operation. The instruction causes Boundary-Scan register cells associated with outputs to sample the value being driven by or to the processor.</li> <li>When the TAP controller is in the Update-DR state, the <b>preload</b> instruction occurs on the falling edge of TCK. This instruction causes the transfer of data held in the Boundary-Scan cells to the slave register cells. Typically the slave latched data is then applied to the system outputs by means of the <b>extest</b> instruction.</li> </ul> |
| <b>idcode</b><br>IEEE 1149.1<br>Optional | 0010 <sub>2</sub> | <b>idcode</b> is used in conjunction with the device identification register. It connects the identification register between TDI and TDO in the Shift_DR state. When selected, <b>idcode</b> parallel-loads the hard-wired identification code (32 bits) on TDO into the identification register on the rising edge of TCK in the Capture_DR state.<br><b>NOTE:</b> The device identification register is not altered by data being shifted in on TDI.   |

Table 17-3. IEEE Instructions (Sheet 2 of 2)

| Instruction / Requisite                            | Opcode            | Description  |
|--|-------------------|--|
| <b>bypass</b><br>IEEE 1149.1<br>Required           | 1111 <sub>2</sub> | <b>bypass</b> instruction selects the Bypass register between TDI and TDO pins while in SHIFT_DR state, effectively bypassing the processor's test logic. O <sub>2</sub> is captured in the CAPTURE_DR state. This is the only instruction that accesses the Bypass register. While this instruction is in effect, all other test data registers have no effect on the operation of the system. Test data registers with both test and system functionality perform their system functions when this instruction is selected.  |
| <b>runbist</b><br>i960 Jx<br>Processor<br>Optional | 0111 <sub>2</sub> | <b>runbist</b> selects the one-bit RUNBIST register, loads a value of 1 into it and connects it to TDO. It also initiates the processor's built-in self test (BIST) feature which is able to detect approximately 82% of the stuck-at faults on the device. The processor AC/DC specifications for V <sub>CC</sub> and CLKIN must be met and RESET must be de-asserted prior to executing <b>runbist</b> .<br><br>After loading <b>runbist</b> instruction code into the instruction register, the TAP controller must be placed in the Run-Test/Idle state. <b>bist</b> begins on the first rising edge of TCK after the Run-Test/Idle state is entered. The TAP controller must remain in the Run-Test/Idle state until <b>bist</b> is completed. <b>runbist</b> requires approximately 414,000 core cycles to complete <b>bist</b> and report the result to the RUNBIST register's. The results are stored in bit 0 of the RUNBIST register. After the report completes, the value in the RUNBIST register is shifted out on TDO during the Shift-DR state. A value of 0 being shifted out on TDO indicates <b>bist</b> completed successfully. A value of 1 indicates a failure occurred. After <b>bist</b> completes, the processor must be recycled through the reset state to begin normal operation. |

### 17.3.5 TAP Controller

The TAP controller is a 16-state synchronous finite state machine that controls the sequence of test logic operations. The TAP can be controlled via a bus master. The bus master can be either automatic test equipment or a component (i.e. PLD) that interfaces to the Test Access Port (TAP). The TAP controller changes state only in response to a rising edge of TCK or power-up. The value of the test mode state (TMS) input signal at a rising edge of TCK controls the sequence of state changes. The TAP controller is automatically initialized on powerup. In addition, the TAP controller can be initialized by applying a high signal level on the TMS input for five TCK periods.

Behavior of the TAP controller and other test logic in each controller state is described in the following subsections. For greater detail on the state machine and the public instructions, refer to IEEE 1149.1 Standard Test Access Port and Boundary-Scan Architecture Document.

## TEST FEATURES

### 17.3.5.1 Test Logic Reset State

In this state, test logic is disabled to allow normal operation of the i960 Jx processor. Test logic is disabled by loading the IDCODE register. No matter what the state of the controller, it enters Test-Logic-Reset state when the TMS input is held high (1) for at least five rising edges of TCK. The controller remains in this state while TMS is high. The TAP controller is also forced to enter this state by enabling TRST.

If the controller exits the Test-Logic-Reset controller states as a result of an erroneous low signal on the TMS line at the time of a rising edge on TCK (for example, a glitch due to external interference), it returns to the test logic reset state following three rising edges of TCK with the TMS line at the intended high logic level. Test logic operation is such that no disturbance is caused to on-chip system logic operation as the result of such an error.

### 17.3.5.2 Run-Test/Idle State

The TAP controller enters the Run-Test/Idle state between scan operations. The controller remains in this state as long as TMS is held low. In the Run-Test/Idle state the **runbist** instruction is performed; the result is reported in the RUNBIST register. Instructions that do not call functions generate no activity in the test logic while the controller is in this state. The instruction register and all test data registers retain their current state. When TMS is high on the rising edge of TCK, the controller moves to the Select-DR-Scan state.

### 17.3.5.3 Select-DR-Scan State

The Select-DR-Scan state is a temporary controller state. The test data registers selected by the current instruction retain their previous state. If TMS is held low on the rising edge of TCK when the controller is in this state, the controller moves into the Capture-DR state and a scan sequence for the selected test data register is initiated. If TMS is held high on the rising edge of TCK, the controller moves into the Select-IR-Scan state.

The instruction does not change while the TAP controller is in this state.

### 17.3.5.4 Capture-DR State

When the controller is in this state and the current instruction is **sample/preload**, the Boundary-Scan register captures input pin data on the rising edge of TCK. Test data registers that do not have parallel input are not changed. Also if the **sample/preload** instruction is not selected while in this state, the Boundary-Scan registers retain their previous state.

The instruction does not change while the TAP controller is in this state.

If TMS is high on the rising edge of TCK, the controller enters the Exit1-DR. If TMS is low on the rising edge of TCK, the controller enters the Shift-DR state.

#### 17.3.5.5 Shift-DR State

In this controller state, the test data register, which is connected between TDI and TDO as a result of the current instruction, shifts data one bit position nearer to its serial output on each rising edge of TCK. Test data registers that the current instruction selects but does not place in the serial path, retain their previous value during this state.

The instruction does not change while the TAP controller is in this state.

If TMS is high on the rising edge of TCK, the controller enters the Exit1-DR state. If TMS is low on the rising edge of TCK, the controller remains in the Shift-DR state.

#### 17.3.5.6 Exit1-DR State

This is a temporary controller state. When the TAP controller is in the Exit1-DR state and TMS is held high on the rising edge of TCK, the controller enters the Update-DR state, which terminates the scanning process. If TMS is held low on the rising edge of TCK, the controller enters the Pause-DR state.

The instruction does not change while the TAP controller is in this state. All test data registers selected by the current instruction retain their previous value during this state.

#### 17.3.5.7 Pause-DR State

The Pause-DR state allows the test controller to temporarily halt the shifting of data through the test data register in the serial path between TDI and TDO. The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state.

The controller remains in this state as long as TMS is low. When TMS goes high on the rising edge of TCK, the controller moves to the Exit2-DR state.

#### 17.3.5.8 Exit2-DR State

This is a temporary state. If TMS is held high on the rising edge of TCK, the controller enters the Update-DR state, which terminates the scanning process. If TMS is held low on the rising edge of TCK, the controller enters the Shift-DR state.

The instruction does not change while the TAP controller is in this state. All test data registers selected by the current instruction retain their previous value during this state.

## TEST FEATURES

### 17.3.5.9 Update-DR State

The Boundary-Scan register is provided with a latched parallel output. This output prevents changes at the parallel output while data is shifted in response to the **extest**, **sample/preload** instructions. When the Boundary-Scan register is selected while the TAP controller is in the Update-DR state, data is latched onto the Boundary-Scan register's parallel output from the shift-register path on the falling edge of TCK. The data held at the latched parallel output does not change unless the controller is in this state.

While the TAP controller is in this state, all of the test data register's shift-register bit positions selected by the current instruction retain their previous values.

The instruction does not change while the TAP controller is in this state.

When the TAP controller is in this state and TMS is held high on the rising edge of TCK, the controller enters the Select-DR-Scan state. If TMS is held low on the rising edge of TCK, the controller enters the Run-Test/Idle state.

### 17.3.5.10 Select-IR Scan State

This is a temporary controller state. The test data registers selected by the current instruction retain their previous state. In this state, if TMS is held low on the rising edge of TCK, the controller moves into the Capture-IR state and a scan sequence for the instruction register is initiated. If TMS is held high on the rising edge of TCK, the controller moves to the Test-Logic-Reset state.

The instruction does not change in this state.

### 17.3.5.11 Capture-IR State

When the controller is in the Capture-IR state, the shift register contained in the instruction register loads the fixed value  $0001_2$  on the rising edge of TCK.

The test data register selected by the current instruction retains its previous value during this state. The instruction does not change in this state. While in this state, holding TMS high on the rising edge of TCK causes the controller to enter the Exit1-IR state. If TMS is held low on the rising edge of TCK, the controller enters the Shift-IR state.

### 17.3.5.12 Shift-IR State

When the controller is in this state, the shift register contained in the instruction register is connected between TDI and TDO and shifts data one bit position nearer to its serial output on each rising edge of TCK. The test data register selected by the current instruction retains its previous value during this state. The instruction does not change.

If TMS is held high on the rising edge of TCK, the controller enters the Exit1-IR state. If TMS is held low on the rising edge of TCK, the controller remains in the Shift-IR state.

#### 17.3.5.13 Exit1-IR State

This is a temporary state. If TMS is held high on the rising edge of TCK, the controller enters the Update-IR state, which terminates the scanning process. If TMS is held low on the rising edge of TCK, the controller enters the Pause-IR state.

The test data register selected by the current instruction retains its previous value during this state.

The instruction does not change and the instruction register retains its state.

#### 17.3.5.14 Pause-IR State

The Pause-IR state allows the test controller to temporarily halt the shifting of data through the instruction register. The test data registers selected by the current instruction retain their previous values during this state.

The instruction does not change and the instruction register retains its state.

The controller remains in this state as long as TMS is held low. When TMS goes high on the rising edges of TCK, the controller moves to the Exit2-IR state.

#### 17.3.5.15 Exit2-IR State

This is a temporary state. If TMS is held high on the rising edge of TCK, the controller enters the Update-IR state, which terminates the scanning process. If TMS is held low on the rising edge of TCK, the controller enters the Shift-IR state.

This test data register selected by the current instruction retains its previous value during this state. The instruction does not change and the instruction register retains its state.

#### 17.3.5.16 Update-IR State

The instruction shifted into the instruction register is latched onto the parallel output from the shift-register path on the falling edge of TCK. Once latched, the new instruction becomes the current instruction. Test data registers selected by the current instruction retain their previous values.

If TMS is held high on the rising edge of TCK, the controller enters the Select-DR-Scan state. If TMS is held low on the rising edge of TCK, the controller enters the Run-Test/Idle state.

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### 17.3.6 Boundary-Scan Register

The Boundary-Scan register contains a cell for each pin as well as cells for control of I/O and HIGHZ pins.

Table 17-4 shows the bit order of the i960 Jx processor Boundary-Scan register. All table cells that contain "CTL" select the direction of bidirectional pins or HIGHZ output pins. If a "1" is loaded into the control cell, the associated pin(s) are HIGHZ or selected as input.

Table 17-4. Boundary-Scan Register Bit Order

| Bit | Signal       | Input/<br>Output         | Bit | Signal            | Input/<br>Output         | Bit | Signal         | Input/<br>Output            |
|-----|--------------|--------------------------|-----|-------------------|--------------------------|-----|----------------|-----------------------------|
| 0   | RDYRCV (TDI) | I                        | 24  | DEN               | O                        | 48  | AD17           | I/O                         |
| 1   | HOLD         | I                        | 25  | HOLDA             | O                        | 49  | AD16           | I/O                         |
| 2   | XINT0        | I                        | 26  | ALE               | O                        | 50  | AD15           | I/O                         |
| 3   | XINT1        | I                        | 27  | LOCK/ONCE<br>cell | Enable cell <sup>1</sup> | 51  | AD14           | I/O                         |
| 4   | XINT2        | I                        | 28  | LOCK/ONCE         | I/O                      | 52  | AD13           | I/O                         |
| 5   | XINT3        | I                        | 29  | BSTAT             | O                        | 53  | AD12           | I/O                         |
| 6   | XINT4        | I                        | 30  | BE0               | O                        | 54  | AD cells       | Enable<br>cell <sup>1</sup> |
| 7   | XINT5        | I                        | 31  | BE1               | O                        | 55  | AD11           | I/O                         |
| 8   | XINT6        | I                        | 32  | BE2               | O                        | 56  | AD10           | I/O                         |
| 9   | XINT7        | I                        | 33  | BE3               | O                        | 57  | AD9            | I/O                         |
| 10  | NMI          | I                        | 34  | AD31              | I/O                      | 58  | AD8            | I/O                         |
| 11  | FAIL         | I                        | 35  | AD30              | I/O                      | 59  | AD7            | I/O                         |
| 12  | ALE          | O                        | 36  | AD29              | I/O                      | 60  | AD6            | I/O                         |
| 13  | WIDTH/HLTD1  | 1                        | 37  | AD28              | I/O                      | 61  | AD5            | I/O                         |
| 14  | WIDTH/HLTD0  | 1                        | 38  | AD27              | I/O                      | 62  | AD4            | I/O                         |
| 15  | A2           | O                        | 39  | AD26              | I/O                      | 63  | AD3            | I/O                         |
| 16  | A3           | O                        | 40  | AD25              | I/O                      | 64  | AD2            | I/O                         |
| 17  | CONTROL1     | Enable cell <sup>1</sup> | 41  | AD24              | I/O                      | 65  | AD1            | I/O                         |
| 18  | CONTROL2     | Enable cell <sup>1</sup> | 42  | AD23              | I/O                      | 66  | AD0            | I/O                         |
| 19  | BLAST        | O                        | 43  | AD22              | I/O                      | 67  | CLKIN          | I                           |
| 20  | D/C          | O                        | 44  | AD21              | I/O                      | 68  | RESET          | I                           |
| 21  | ADS          | O                        | 45  | AD20              | I/O                      | 69  | STEST<br>(TDO) | I                           |
| 22  | W/R          | O                        | 46  | AD19              | I/O                      |     |                |                             |
| 23  | DT/R         | O                        | 47  | AD18              | I/O                      |     |                |                             |

1. Enable cells are active low.

### 17.3.6.1 Example

In the example that follows, two command actions are described. The example starts in the reset state, a new instruction is loaded and executed. See Figure 17-3 for a JTAG example. The steps are:

1. Load the **sample/preload** instruction into the Instruction Register:
  - 1.1. Select the Instruction register scan.

## TEST FEATURES

- 1.2. Use the Shift-IR state four times to read the least through most significant instruction bits into the instruction register (we do not care that the old instruction is being shifted out of the TDO pin).
- 1.3. Enter the Update-IR state to make the instruction take effect.
- 1.4. Exit the Instruction register.
2. Capture and shift the data onto the TDO pin:
  - 2.1. Select the Data register scan state.
  - 2.2. Capture the pin information into the n-stage Boundary-Scan register.
  - 2.3. Enter and stay in the shift-DR state for n times while recording the TDO values as the inputs sampled. as the data sampled were shifting in the TDI was being read into the Boundary-Scan register. This could later be written the output pins.
  - 2.4. Pass through the Exit1-DR and Update-DR to continue.

This example does not make use of the pause states. Those states would be more useful where we do not control the clock directly. The pause states let the clock tick without affecting the shift registers.

The old instruction was *abcd* in the example. It is known that the original value will be the ID code since the example starts from the reset state. Other times it will represent the previous opcode. The new instruction opcode is  $0001_2$  (**sample/preload**). All pins are captured into the serial Boundary-Scan register and the values are output to the TDO pin.

The clock signal drawn at the top of the diagram is drawn as a stable symmetrical clock. This is not in practice the most common case. Instead the clocking is usually done by a program writing to a port bit. The TMS and TDI signals are written by software and then the software makes the clock go high. The software typically will often lower the clock input quickly. The program can then read the TDO pin.

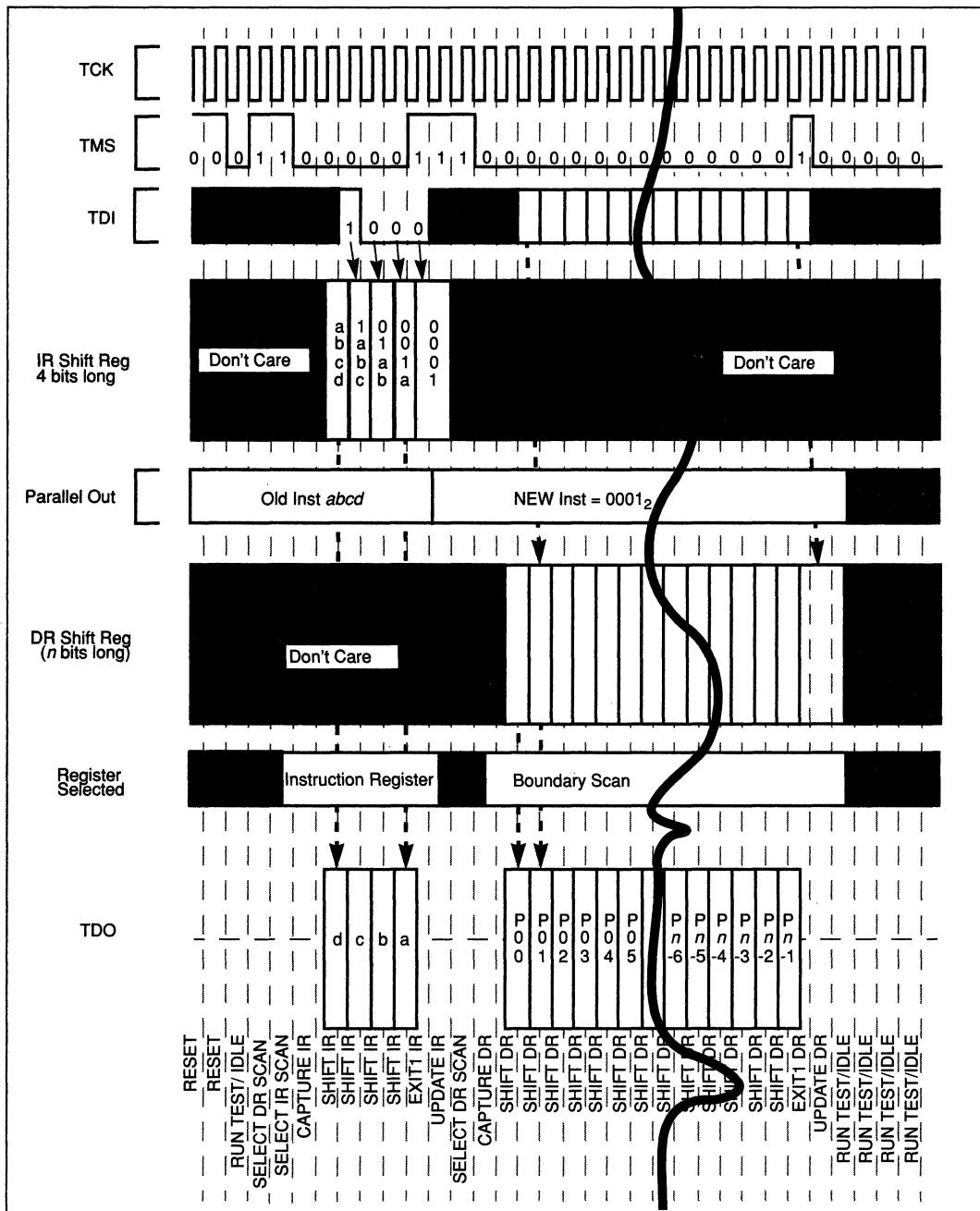


Figure 17-3. JTAG Example

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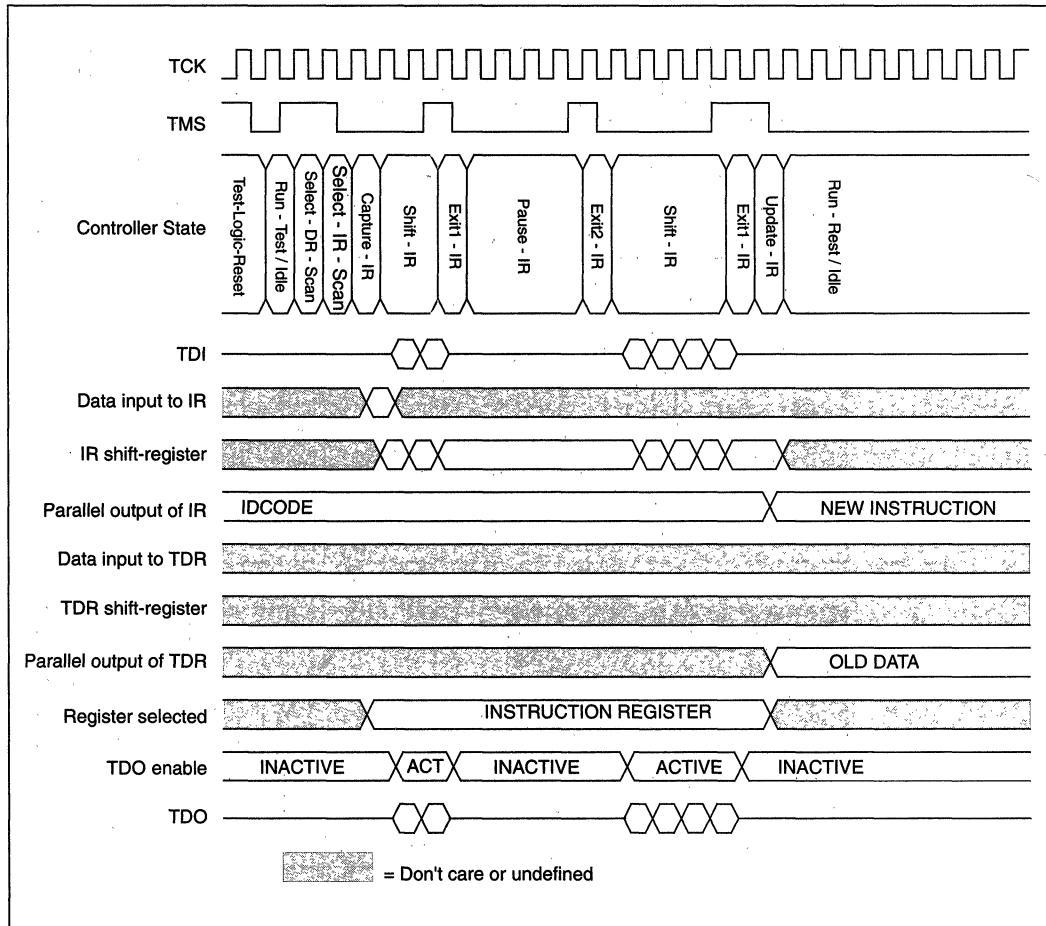
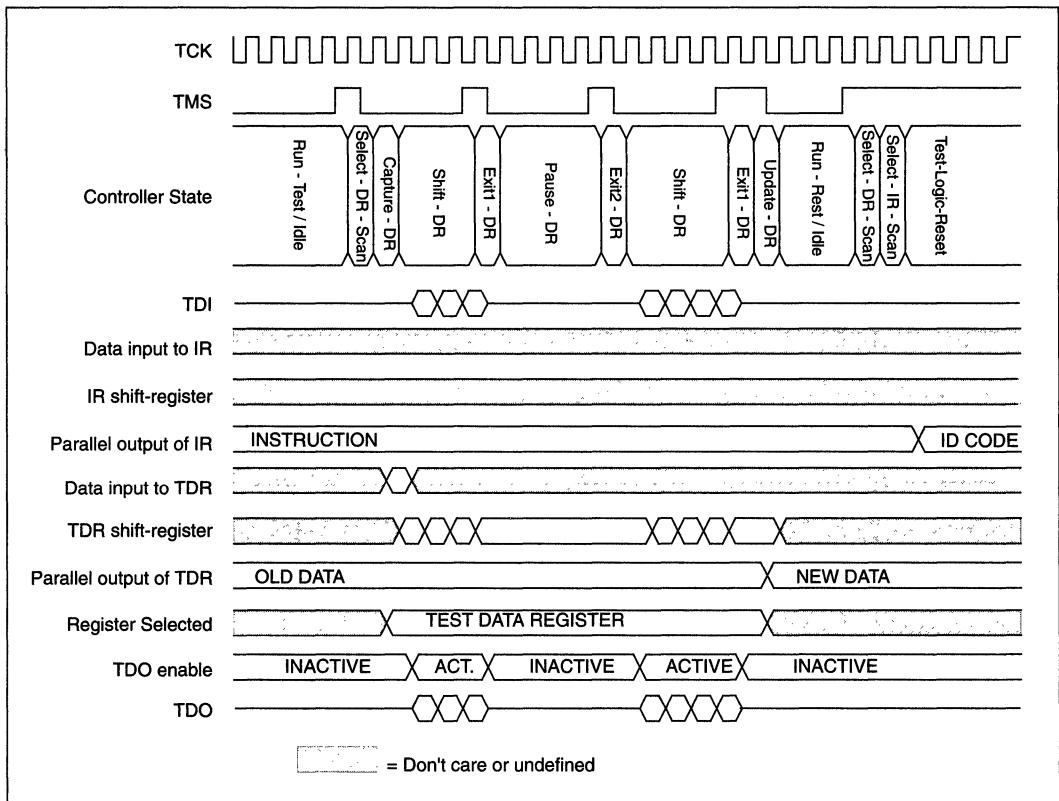


Figure 17-4. Timing diagram illustrating the loading of Instruction Register



**Figure 17-5. Timing diagram illustrating the loading of Data Register**

### 17.3.7 Boundary Scan Description Language Example

Boundary-Scan Description Language (BSDL) example 14-2 meets the de facto standard means of describing essential features of ANSI/IEEE 1149.1-1993 compliant devices.

**Example 17-1. Boundary Scan Description Language Example (Sheet 1 of 4)**

```
-- i960® Jx Processor BSDL Model

-- The following list describes all of the pins that are contained in the i960 Jx
-- microprocessor.

entity JX_Processor is
  generic(PHYSICAL_PIN_MAP : string := "PGA_14x14");
  port(TDI           : in bit;
        RDYRCVBAR    : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        TRSTBAR      : in bit;
        TCK          : in bit;
        TMS          : in bit;
        HOLD         : in bit;
        XINTBARX     : in bit_vector(0 to 7);
        NMIBAR       : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        LODRVHIDRVBAR: out bit;
        FAILBAR      : out bit;
        ALEBAR       : out bit;
        TDO          : out bit;
        WIDTH        : out bit_vector(1 downto 0);
        A32          : out bit_vector(0 to 1);
        Reserved     : out bit;
        Reserved     : out bit;
        Reserved     : out bit;
        Reserved     : out bit;
        BLASTBAR     : out bit;
        DCBAR         : out bit;
        ADSBAR        : out bit;
        WRBAR         : out bit;
        DTRBAR        : out bit;
        DENBAR        : out bit;
        HOLDA         : out bit;
        ALE           : out bit;
        LOCKONCEBAR   : inout bit;
        BSTAT         : out bit;
        BEBAR         : out bit_vector(0 to 3);
        Reserved     : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        Reserved     : inout bit_vector(7 downto 0);
        AD            : inout bit_vector(31 downto 0);
        CLKIN         : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        Reserved     : in bit;
        RESETBAR     : in bit;
        Reserved     : in bit;
        STEST         : in bit;
        VCC           : linkage bit_vector(0 to 28);
        VSS           : linkage bit_vector(0 to 28);
```

**Example 17-1. Boundary Scan Description Language Example (Sheet 2 of 4)**

```

AVCC           : linkage bit;
NC            : linkage bit_vector(1 to 3));
use STD_1149_1_1990.all;
use i960JX_a.all;
--This list describes the physical pin layout of all signals
attribute PIN_MAP of JX_Processor : entity is PHYSICAL_PIN_MAP;
constant PGA_14x14 : PIN_MAP_STRING :=          -- Define PinOut of PGA
    "TDI      : F16,"&
    "RDYRCVBAR : E15,"&
    "TRSTBAR   : C17,"&
    "TCK      : C16,"&
    "TMS      : B17,"&
    "HOLD     : C15,"&
    "XINTBARX : (B16, C14, B15, C13, B14, A15, A14, C12),"&
    "NMIBAR   : B12,"&
    "FAILBAR  : B09,"&
    "ALEBAR   : C08,"&
    "TDO      : C07,"&
    "WIDTH    : (C06, B06),"&
    "A32      : (A04, C05),"&
    "BLASTBAR : B03,"&
    "DCBAR    : C02,"&
    "ADSBAR   : C03,"&
    "WRBAR    : B01,"&
    "DTRBAR   : B02,"&
    "DENBAR   : E03,"&
    "HOLDA    : D02,"&
    "ALE      : C01,"&
    "LOCKONCEBAR : D01,"&
    "BSTAT    : F03,"&
    "BEBAR    : (E01, E02, G03, H03),"&
    "AD       : (P03, R02, Q03, R03, S03, R04, S04, Q05, Q06, Q07,"&
    "          Q08, R09, S09, Q09, Q10, Q11, Q12, S14, R14, Q13,"&
    "          S15, R15, Q14, R16, Q15, R17, Q16, P15, Q17, P16,"&
    "          M15, N15),"&
    "CLKIN   : J17,"&
    "RESETBAR : G15,"&
    "TEST     : F17,"&
    "VCC      : (S13, S12, S11, S10, S08, S07, S06, S05, N17, M17," &
    "          M01, L17, L01, K17, K01, J01, H17, H01, G17, G01," &
    "          F01, E17, A13, A11, A10, A08, A07, A06, A05), " &
    "VSS      : (R13, R12, R11, R10, R08, R07, R06, R05, N16, N02," &
    "          M02, L16, L02, K16, K02, J16, J02, H16, H02, G16," &
    "          G02, F02, E16, B13, B11, B10, B08, B07, B05)," &
    "AVCC    : L15 ";
attribute Tap_Scan_In  of TDI  : signal is true;
attribute Tap_Scan_Mode of TMS : signal is true;
attribute Tap_Scan_Out  of TDO  : signal is true;
attribute Tap_Scan_Reset of TRSTBAR : signal is true;
attribute Tap_Scan_Clock of TCK : signal is (33.0e6, BOTH);
attribute Instruction_Length of JX_Processor: entity is 4;
attribute Instruction_Opcode of JX_Processor: entity is
    "BYPASS  (1111)," &
    "EXTEST  (0000)," &
    "SAMPLE   (0001)," &
    "IDCODE   (0010)," &

```

**Example 17-1. Boundary Scan Description Language Example (Sheet 3 of 4)**

```

"RUNBIST (0111), " &
"Reserved (1100, 1011)";

attribute Instruction_Capture of JX_Processor: entity is "0001";
-- there is no Instruction_Disable attribute for JX_Processor
attribute Instruction_Private of JX_Processor: entity is "Reserved" ;
--attribute Instruction_Usage of JX_Processor: entity is
--  "RUNBIST (registers Runbist; " &
--  "result 0;" &
--  "clock CLK in Run_Test_Idle;"&
--  "length 524288)";
-- attribute Idcode_Register of JX_Processor: entity is
--  "0000" & --version, A-step
--  "0000001010100001" & --part number
--  "00000001001" & --manufacturers identity
--  "1"; --required by the standard
-- attribute Idcode_Register of JX_Processor: entity is
--  "0010" & --version, B-step
--  "0000001010110001" & --part number B0primeprime
--  "00000001001" & --manufacturers identity
--  "1"; --required by the standard
attribute Idcode_Register of JX_Processor: entity is
  "0000" & --version,
  "1000100000100000" & --part number ??
  "000000001001" & --manufacturers identity
  "1"; --required by the standard
attribute Register_Access of JX_Processor: entity is
  "Runbist[1] (RUNBIST), " &
  "Bypass";
--{*****}
--{ The first cell, cell 0, is closest to TDO }
--{ BC_4:Input BC_1: Output3, Bidirectional }
--{*****}

attribute Boundary_Cells of JX_Processor: entity is "CBSC_1, BC_1";
attribute Boundary_Length of JX_Processor: entity is 70;
attribute Boundary_Register of JX_Processor: entity is
  "0 (BC_1, STEST, input, X)," &
  "1 (BC_1, RESETBAR, input, X)," &
  "2 (BC_1, CLKIN, input, X)," &
  "3 (CBSC_1, AD(0), bidir, X, 15, 1, Z)," &
  "4 (CBSC_1, AD(1), bidir, X, 15, 1, Z)," &
  "5 (CBSC_1, AD(2), bidir, X, 15, 1, Z)," &
  "6 (CBSC_1, AD(3), bidir, X, 15, 1, Z)," &
  "7 (CBSC_1, AD(4), bidir, X, 15, 1, Z)," &
  "8 (CBSC_1, AD(5), bidir, X, 15, 1, Z)," &
  "9 (CBSC_1, AD(6), bidir, X, 15, 1, Z)," &
  "10 (CBSC_1, AD(7), bidir, X, 15, 1, Z)," &
  "11 (CBSC_1, AD(8), bidir, X, 15, 1, Z)," &
  "12 (CBSC_1, AD(9), bidir, X, 15, 1, Z)," &
  "13 (CBSC_1, AD(10), bidir, X, 15, 1, Z)," &
  "14 (CBSC_1, AD(11), bidir, X, 15, 1, Z)," &
  "15 (BC_1, *, control, 1)," &
  "16 (CBSC_1, AD(12), bidir, X, 15, 1, Z)," &
  "17 (CBSC_1, AD(13), bidir, X, 15, 1, Z)," &
  "18 (CBSC_1, AD(14), bidir, X, 15, 1, Z)," &
  "19 (CBSC_1, AD(15), bidir, X, 15, 1, Z)," &
  "20 (CBSC_1, AD(16), bidir, X, 15, 1, Z)," &

```

**Example 17-1. Boundary Scan Description Language Example (Sheet 4 of 4)**

```
"21 (CBSC_1, AD(17), bidir, X, 15, 1, Z)," &
"22 (CBSC_1, AD(18), bidir, X, 15, 1, Z)," &
"23 (CBSC_1, AD(19), bidir, X, 15, 1, Z)," &
"24 (CBSC_1, AD(20), bidir, X, 15, 1, Z)," &
"25 (CBSC_1, AD(21), bidir, X, 15, 1, Z)," &
"26 (CBSC_1, AD(22), bidir, X, 15, 1, Z)," &
"27 (CBSC_1, AD(23), bidir, X, 15, 1, Z)," &
"28 (CBSC_1, AD(24), bidir, X, 15, 1, Z)," &
"29 (CBSC_1, AD(25), bidir, X, 15, 1, Z)," &
"30 (CBSC_1, AD(26), bidir, X, 15, 1, Z)," &
"31 (CBSC_1, AD(27), bidir, X, 15, 1, Z)," &
"32 (CBSC_1, AD(28), bidir, X, 15, 1, Z)," &
"33 (CBSC_1, AD(29), bidir, X, 15, 1, Z)," &
"34 (CBSC_1, AD(30), bidir, X, 15, 1, Z)," &
"35 (CBSC_1, AD(31), bidir, X, 15, 1, Z)," &
"36 (BC_1, BEBAR(3), output3, X, 51, 1, Z)," &
"37 (BC_1, BEBAR(2), output3, X, 51, 1, Z)," &
"38 (BC_1, BEBAR(1), output3, X, 51, 1, Z)," &
"39 (BC_1, BEBAR(0), output3, X, 51, 1, Z)," &
"40 (BC_1, BSTAT, output3, X, 52, 1, Z)," &
"41 (CBSC_1, LOCKONCEBAR, bidir, X, 42, 1, Z)," &
"42 (BC_1, *, control, 1)," &
"43 (BC_1, ALE, output3, X, 51, 1, Z)," &
"44 (BC_1, HOLDAA, output3, X, 52, 1, Z)," &
"45 (BC_1, DENBAR, output3, X, 51, 1, Z)," &
"46 (BC_1, DTRBAR, output3, X, 51, 1, Z)," &
"47 (BC_1, WRBAR, output3, X, 51, 1, Z)," &
"48 (BC_1, ADSBAR, output3, X, 51, 1, Z)," &
"49 (BC_1, DCBAR, output3, X, 51, 1, Z)," &
"50 (BC_1, BLASTBAR, output3, X, 51, 1, Z)," &
"51 (BC_1, *, control, 1)," &
"52 (BC_1, *, control, 1)," &
"53 (BC_1, A32(1), output3, X, 51, 1, Z)," &
"54 (BC_1, A32(0), output3, X, 51, 1, Z)," &
"55 (BC_1, WIDTH(0), output3, X, 51, 1, Z)," &
"56 (BC_1, WIDTH(1), output3, X, 51, 1, Z)," &
"57 (BC_1, ALEBAR, output3, X, 51, 1, Z)," &
"58 (BC_1, FAILBAR, output3, X, 52, 1, Z)," &
"59 (BC_1, NMIBAR, input, X)," &
"60 (BC_1, XINTBARX(7), input, X)," &
"61 (BC_1, XINTBARX(6), input, X)," &
"62 (BC_1, XINTBARX(5), input, X)," &
"63 (BC_1, XINTBARX(4), input, X)," &
"64 (BC_1, XINTBARX(3), input, X)," &
"65 (BC_1, XINTBARX(2), input, X)," &
"66 (BC_1, XINTBARX(1), input, X)," &
"67 (BC_1, XINTBARX(0), input, X)," &
"68 (BC_1, HOLD, input, X)," &
"69 (BC_1, RDYRCVBAR, input, X)";  
end JX_Processor;
```





A

# CONSIDERATIONS FOR WRITING PORTABLE CODE







# APPENDIX A

## CONSIDERATIONS FOR WRITING PORTABLE CODE

A

This appendix describes the aspects of the microprocessor that are implementation dependent. The following information is intended as a guide for writing application code that is directly portable to other i960® architecture implementations.

### A.1 CORE ARCHITECTURE

All i960 microprocessor family products are based on the core architecture definition. An i960 processor can be thought of as consisting of two parts: the core architecture implementation and implementation-specific features. The core architecture defines the following mechanisms and structure:

- Programming environment: global and local registers, literals, processor state registers, data types, memory addressing modes, etc.
- Implementation-independent instruction set.
- Procedure call mechanism.
- Mechanism for servicing interrupts and the interrupt and process priority structure.
- Mechanism for handling faults and the implementation-independent fault types and subtypes.

Implementation-specific features are one or all of:

- Additions to the instruction set beyond the instructions defined by the core architecture.
- Extensions to the register set beyond the global, local and processor-state registers that are defined by the core architecture.
- On-chip program or data memory.
- Integrated peripherals that implement features not defined explicitly by the core architecture.

Code is directly portable (object code compatible) when it does not depend on implementation-specific instructions, mechanisms or registers. The aspects of this microprocessor that are implementation dependent are described below. Those aspects not described below are part of the core architecture.

### A.2 ADDRESS SPACE RESTRICTIONS

Address space properties that are implementation-specific to this microprocessor are described in the subsections that follow.



### A.2.1 Reserved Memory

Addresses in the range FF00 0000H to FFFF FFFFH are reserved by the i960 architecture. Any uses of reserved memory are implementation specific. The i960 Jx processor uses a section just below the reserved address space for the initialization boot record; see section 11.3.1.1, "Initialization Boot Record (IBR)" (pg. 11-12). The initialization boot record may not exist or may be structured differently for other implementations of the i960 architecture. Code that relies on structures in reserved memory is not portable to all i960 processor implementations.

### A.2.2 Internal Data RAM

Internal data RAM — an i960 Jx processor implementation-specific feature — is mapped to the first 1 Kbyte of the processors' address space (0000H – 03FFH). High performance, supervisor-protected data space and the locations assigned for interrupt functions are special features that are implemented in internal data RAM. Code that relies on these special features is not directly portable to all i960 processor implementations.

### A.2.3 Instruction Cache

The i960 architecture allows instructions to be cached on-chip in a non-transparent fashion. This means that the cache may not detect modification of the program memory by loads, stores or alteration by external agents. Each implementation of the i960 architecture that uses an integrated instruction cache provides a mechanism to purge the cache or some other method that forces consistency between external memory and internal cache.

This feature is implementation-dependent. Application code that supports modification of the code space must use this implementation-specific feature and, therefore, is not object code portable to all i960 processor implementations.

The i960 JA processor has a 2-Kbyte instruction cache; the JF and JD have a 4-Kbyte instruction cache. The instruction cache is purged using the system control (**sysctl**) or instruction cache control (**icctl**) instruction, which may not be available on other i960 processors.

The instruction cache supports locking code into none, half, or all of the cache. The unlocked portion functions as a direct-mapped cache. Refer to section 4.4, "INSTRUCTION CACHE" (pg. 4-4) for a description of cache configuration.

#### A.2.4 Data Cache

The i960 JA processor has a 1-Kbyte data cache and the i960 JF and JD processors have a 2-Kbyte data cache. With respect to data accesses on a region-by-region basis, external memory is configured as either cacheable or non-cacheable. A bit in the memory region table entry defines whether or not data accesses are cacheable. This makes it very easy to partition a system into non-cacheable regions (for I/O or shared data in a multiprocessor system) and cacheable regions (local system memory) with no external hardware logic. To maintain data cache coherency, the i960 Jx processor implements a simple single processor coherency mechanism. Also, by software control, the data cache can be globally enabled, globally disabled or globally invalidated. A data access is either:

- Explicitly defined as cacheable or non-cacheable—through the memory region table
- Implicitly defined as non-cacheable—by the nature of the access; all atomic accesses (**atmod**, **atadd**) are implicitly defined as non-cacheable data accesses

The data cache indirectly supports unaligned accesses. Microcode execution breaks unaligned accesses into aligned accesses that are cacheable or non-cacheable according to the same rules as aligned accesses. An unaligned access could be only partially in the data cache and be a combination of hits and misses. The data cache supports both big-endian and little-endian data types.

#### A.2.5 Data and Data Structure Alignment

The i960 architecture does not define how to handle loads and stores to non-aligned addresses. Therefore, code that generates non-aligned addresses may not be compatible with all i960 processor implementations. The i960 Jx processor automatically handles non-aligned load and store requests in microcode. See section 15.2.5, "Data Alignment" (pg. 15-22).

The address boundaries on which an operand begins can affect processor performance. Operands that span more word boundaries than necessary suffer a cost in speed due to extra bus cycles. In particular, an operand that spans a 16-byte (quad-word) boundary suffers a large cost in speed.

Alignment of architecturally defined data structures in memory is implementation dependent. See section 3.4, "ARCHITECTURE-DEFINED DATA STRUCTURES" (pg. 3-12). Code that relies on specific alignment of data structures in memory is not portable to every i960 processor type.

Stack frames in the i960 architecture are aligned on  $(\text{SALIGN} \times 16)$ -byte boundaries, where SALIGN is an implementation-specific parameter. For the i960 Jx processors, SALIGN = 1 so stack frames are aligned on 16-byte boundaries. The low-order N bits of the Frame Pointer are ignored and are always interpreted to be zero. The N parameter is defined by the following expression:  $\text{SALIGN} \times 16 = 2^N$ . Thus for the i960 Jx processors, N is 4.

### A.3 RESERVED LOCATIONS IN REGISTERS AND DATA STRUCTURES

Some register and data structure fields are defined as reserved locations. A reserved field may be used by future implementations of the i960 architecture. For portability and compatibility, code should initialize reserved locations to zero. When an implementation uses a reserved location, the implementation-specific feature is activated by a value of 1 in the reserved field. Setting the reserved locations to 0 guarantees that the features are disabled.

### A.4 INSTRUCTION SET

The i960 architecture defines a comprehensive instruction set. Code that uses only the architecturally-defined instruction set is object-level portable to other implementations of the i960 architecture. Some implementations may favor a particular code ordering to optimize performance. This special ordering, however, is never required by an implementation. The following subsections describe implementation-dependent instruction set properties.

#### A.4.1 Instruction Timing

An objective of the i960 architecture is to allow microarchitectural advances to translate directly into increased performance. The architecture does not restrict parallel or out-of-order instruction execution, nor does it define the time required to execute any instruction or function. Code that depends on instruction execution times, therefore, is not portable to all i960 processor architecture implementations.

#### A.4.2 Implementation-Specific Instructions

Most of the processor's instruction set is defined by the core architecture. Several instructions are specific to the i960 Jx processors. These instructions are either functional extensions to the instruction set or instructions that control implementation-specific functions. CHAPTER 6, INSTRUCTION SET REFERENCE denotes each implementation-specific instruction. These instructions are:

- **dcctl** Data cache control
- **icctl** Instruction cache control
- **intctl** Interrupt control
- **intdis** Global interrupt disable
- **inten** Global interrupt enable
- **halt** Halt CPU
- **sysctl** System control

Application code using implementation-specific instructions is not directly portable to the entire i960 processor family. Attempted execution of an unimplemented instruction results in an OPERATION.INVALID\_OPCODE fault.

The i960 Jx processor introduces several new core instructions. These instructions may or may not be supported on other i960 processors. The new core instructions include:

- **ADD<cc>** Conditional add
- **bswap** Byte swap
- **COMPARE** Byte and short compares
- **eshro** Extended shift right ordinal
- **SEL<cc>** Conditional select
- **SUB<cc>** Conditional subtract

## A.5 EXTENDED REGISTER SET

The i960 architecture defines a way to address an extended set of 32 registers in addition to the 16 global and 16 local registers. Some or all of these registers may be implemented on a specific i960 processor. There are no extended registers implemented on the i960 Jx processors.

## A.6 INITIALIZATION

The i960 architecture does not define an initialization mechanism. The way that an i960-based product is initialized is implementation dependent. Code that accesses locations in initialization data structures is not portable to other i960 processor implementations.

The i960 Jx processors use an initialization boot record (IBR).

## A.7 MEMORY CONFIGURATION

The i960 Jx processors employ Physical Memory Control (PMCON) and Logical Memory Control (LMCON) registers to control bus width, byte order and the data cache. This capability is analogous to the MCON register scheme employed by the 80960Cx. Memory configurations, like the bus control unit, are implementation-specific.

## A.8 INTERRUPTS

The i960 architecture defines the interrupt servicing mechanism. This includes priority definition, interrupt table structure and interrupt context switching that occurs when an interrupt is serviced. The core architecture does not define the means for requesting interrupts (external pins, software, etc.) or for posting interrupts (i.e., saving pending interrupts).

The method for requesting interrupts depends on the implementation. The i960 Jx processors have an interrupt controller that manages nine external interrupt pins. The organization of these pins and the registers of the interrupt controller are implementation specific. Code that configures the interrupt controller is not directly portable to other i960 implementations.

On the i960Jx processors, interrupts may also be requested in software with the **sysctl** instruction. This instruction and the software request mechanism are implementation-specific.

Posting interrupts is also implementation-specific. Different implementations may optimize interrupt posting according to interrupt type and interrupt controller configuration. A pending priorities and pending interrupts field is provided in the interrupt table for interrupt posting. However, the i960 Jx processors post hardware requested interrupts internally in the IPND register instead. Code that requests interrupts by setting bits in the pending priorities and pending interrupts field of the interrupt table is not portable. Also, application code that expects interrupts to be posted in the interrupt table is not object-code portable to all i960-based products.

The i960 Jx processors do not store a resumption record for suspended instructions in the interrupt or fault record. Portable programs must tolerate interrupt stack frames with and without these resumption records.

## **A.9 OTHER i960 Jx PROCESSOR IMPLEMENTATION-SPECIFIC FEATURES**

Subsections that follow describe additional implementation-specific features of the i960 Jx processors. These features do not relate directly to application code portability.

### **A.9.1 Data Control Peripheral Units**

The bus controller and interrupt controller are implementation-specific extensions to the core architecture. Operation, setup and control of these units is not a part of the core architecture. Other implementations of the i960 architecture are free to augment or modify such system integration features.

### **A.9.2 Timers**

The i960 Jx processor contains two 32-bit timers that are implementation-specific extensions to the i960 architecture. Code involving operation, setup and control of the timers may or may not directly portable to other i960 processors.

### **A.9.3 Fault Implementation**

The architecture defines a subset of fault types and subtypes that apply to all implementations of the architecture. Other fault types and subtypes may be defined by implementations to detect errant conditions that relate to implementation-specific features. For example, the i960 Jx microprocessors provide an OPERATION.UNALIGNED fault for detecting non-aligned memory accesses. Future i960 processor implementations that generate this fault are expected to assign the same fault type and subtype number to the fault.

## A.10 BREAKPOINTS

Breakpoint registers are not defined in the i960 architecture. The i960 Jx processor implements two instruction and two data breakpoint registers.

## A.11 LOCK PIN

The LOCK pin is not defined in the i960 architecture. Bus control logic and protocol associated with this pin may vary among i960 processor implementations. For example, the 80960Jx will not assert HOLDA in response to HOLD during LOCK'ed accesses. Earlier i960 processors will relinquish the bus.

### A.11.1 External System Requirements

External system requirements are not defined by the architecture. The external bus, RESET pin, clock input, power and ground requirements, testability features and I/O characteristics are all specific to the i960 microprocessor implementation.





B

# OPCODES AND EXECUTION TIMES





# APPENDIX B

## OPCODES AND EXECUTION TIMES

B

### B.1 INSTRUCTION REFERENCE BY OPCODE

This section lists the instruction encoding for each i960 Jx microprocessor instruction. Instructions are grouped by instruction format and listed by opcode within each format.

**Table B-1. Miscellaneous Instruction Encoding Bits**

| M3                 | M2 | M1 | S2 | S1 | T | Description  |
|--------------------|----|----|----|----|---|--|
| <b>REG Format</b>  |    |    |    |    |   |  |
| x                  | x  | 0  | x  | 0  | — | <i>src1</i> is a global or local register  |
| x                  | x  | 1  | x  | 0  | — | <i>src1</i> is a literal   |
| x                  | x  | 0  | x  | 1  | — | reserved   |
| x                  | x  | 1  | x  | 1  | — | reserved   |
| x                  | 0  | x  | 0  | x  | — | <i>src2</i> is a global or local register  |
| x                  | 1  | x  | 0  | x  | — | <i>src2</i> is a literal   |
| x                  | 0  | x  | 1  | x  | — | reserved   |
| x                  | 1  | x  | 1  | x  | — | reserved   |
| 0                  | x  | x  | x  | x  | — | <i>src/dst</i> is a global or local register   |
| 1                  | x  | x  | x  | x  | — | <i>src/dst</i> is a literal when used as a source. M3 may not be 1 when <i>src/dst</i> is used as a destination only or is used both as a source and destination in an instruction ( <b>atmod</b> , <b>modify</b> , <b>extract</b> , <b>modpc</b> ). |
| <b>COBR Format</b> |    |    |    |    |   |  |
| —                  | —  | 0  | 0  | —  | x | <i>src1 src2</i> and <i>dst</i> are global or local registers  |
| —                  | —  | 1  | 0  | —  | x | <i>src1</i> is a literal, <i>src2</i> and <i>dst</i> are global or local registers   |
| —                  | —  | 0  | 1  | —  | x | reserved   |
| —                  | —  | 1  | 1  | —  | x | reserved   |

## OPCODES AND EXECUTION TIMES



Table B-2. REG Format Instruction Encodings (Sheet 1 of 4)

| Opcode | Mnemonic        | Cycles to Execute | Opcode<br>(11 - 4) | src/dst | src2 | Mode     |    |         | Opcode<br>(3-0) | Special<br>Flags | src1 |        |          |   |   |           |
|--------|-----------------|-------------------|--------------------|---------|------|----------|----|---------|-----------------|------------------|------|--------|----------|---|---|-----------|
|        |                 |                   |                    |         |      | 31 ..... | 24 | 23...19 | 18 .. 14        | 13               | 12   | 11     | 10 ... 7 | 6 | 5 | 4 ..... 0 |
| 58:0   | <b>notbit</b>   |                   |                    |         |      |          |    |         |                 |                  |      |        |          |   |   |           |
| 58:1   | <b>and</b>      | 1                 | 0101 1000          | dst     | src  | M3       | M2 | M1      | 0000            | S2               | S1   | bitpos |          |   |   |           |
| 58:2   | <b>andnot</b>   | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 0001            | S2               | S1   | src1   |          |   |   |           |
| 58:3   | <b>setbit</b>   | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 0010            | S2               | S1   | src1   |          |   |   |           |
| 58:4   | <b>notand</b>   | 1                 | 0101 1000          | dst     | src  | M3       | M2 | M1      | 0011            | S2               | S1   | bitpos |          |   |   |           |
| 58:6   | <b>xor</b>      | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 0100            | S2               | S1   | src1   |          |   |   |           |
| 58:7   | <b>or</b>       | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 0110            | S2               | S1   | src1   |          |   |   |           |
| 58:8   | <b>nor</b>      | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 0111            | S2               | S1   | src1   |          |   |   |           |
| 58:9   | <b>xnor</b>     | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 1001            | S2               | S1   | src1   |          |   |   |           |
| 58:A   | <b>not</b>      | 1                 | 0101 1000          | dst     |      | M3       | M2 | M1      | 1010            | S2               | S1   | src    |          |   |   |           |
| 58:B   | <b>ornot</b>    | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 1011            | S2               | S1   | src1   |          |   |   |           |
| 58:C   | <b>cirbit</b>   | 1                 | 0101 1000          | dst     | src  | M3       | M2 | M1      | 1100            | S2               | S1   | bitpos |          |   |   |           |
| 58:D   | <b>notor</b>    | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 1101            | S2               | S1   | src1   |          |   |   |           |
| 58:E   | <b>nand</b>     | 1                 | 0101 1000          | dst     | src2 | M3       | M2 | M1      | 1110            | S2               | S1   | src1   |          |   |   |           |
| 58:F   | <b>alterbit</b> | 1                 | 0101 1000          | dst     | src  | M3       | M2 | M1      | 1111            | S2               | S1   | bitpos |          |   |   |           |
| 59:0   | <b>addo</b>     | 1                 | 0101 1001          | dst     | src2 | M3       | M2 | M1      | 0000            | S2               | S1   | src1   |          |   |   |           |
| 59:1   | <b>addi</b>     | 1                 | 0101 1001          | dst     | src2 | M3       | M2 | M1      | 0001            | S2               | S1   | src1   |          |   |   |           |
| 59:2   | <b>subo</b>     | 1                 | 0101 1001          | dst     | src2 | M3       | M2 | M1      | 0010            | S2               | S1   | src1   |          |   |   |           |
| 59:3   | <b>subi</b>     | 1                 | 0101 1001          | dst     | src2 | M3       | M2 | M1      | 0011            | S2               | S1   | src1   |          |   |   |           |
| 59:4   | <b>cmpob</b>    | 1                 | 0101 1001          |         | src2 | M3       | M2 | M1      | 0100            | S2               | S1   | src1   |          |   |   |           |
| 59:5   | <b>cmpib</b>    | 1                 | 0101 1001          |         | src2 | M3       | M2 | M1      | 0101            | S2               | S1   | src1   |          |   |   |           |
| 59:6   | <b>cmpos</b>    | 1                 | 0101 1001          |         | src2 | M3       | M2 | M1      | 0110            | S2               | S1   | src1   |          |   |   |           |
| 59:7   | <b>cmpis</b>    | 1                 | 0101 1001          |         | src2 | M3       | M2 | M1      | 0111            | S2               | S1   | src1   |          |   |   |           |
| 59:8   | <b>shro</b>     | 1                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1000            | S2               | S1   | len    |          |   |   |           |
| 59:A   | <b>shrdi</b>    | 6                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1010            | S2               | S1   | len    |          |   |   |           |
| 59:B   | <b>shri</b>     | 1                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1011            | S2               | S1   | len    |          |   |   |           |
| 59:C   | <b>shlo</b>     | 1                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1100            | S2               | S1   | len    |          |   |   |           |
| 59:D   | <b>rotate</b>   | 1                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1101            | S2               | S1   | len    |          |   |   |           |
| 59:E   | <b>shli</b>     | 1                 | 0101 1001          | dst     | src  | M3       | M2 | M1      | 1110            | S2               | S1   | len    |          |   |   |           |

1. Execution time based on function performed by instruction.

Table B-2. REG Format Instruction Encodings (Sheet 2 of 4)

| Opcode | Mnemonic        | Cycles to Execute   | Opcode<br>(11 - 4) | src/dst  | src2 | Mode |    |          | Opcode<br>(3-0) | Special<br>Flags |           | src1   |
|--------|-----------------|---------------------|--------------------|----------|------|------|----|----------|-----------------|------------------|-----------|--------|
| 5A:0   | <b>cmwo</b>     | 31 ..... 24         | 23 .. 19           | 18 .. 14 | 13   | 12   | 11 | 10 ... 7 | 6               | 5                | 4 ..... 0 |        |
| 5A:1   | <b>cmpi</b>     | 1                   | 0101 1010          |          | src2 | M3   | M2 | M1       | 0000            | S2               | S1        | src1   |
| 5A:2   | <b>concmwo</b>  | 1                   | 0101 1010          |          | src2 | M3   | M2 | M1       | 0010            | S2               | S1        | src1   |
| 5A:3   | <b>concmwi</b>  | 1                   | 0101 1010          |          | src2 | M3   | M2 | M1       | 0011            | S2               | S1        | src1   |
| 5A:4   | <b>cmpinco</b>  | 1                   | 0101 1010          | dst      | src2 | M3   | M2 | M1       | 0100            | S2               | S1        | src1   |
| 5A:5   | <b>cmpinci</b>  | 1                   | 0101 1010          | dst      | src2 | M3   | M2 | M1       | 0101            | S2               | S1        | src1   |
| 5A:6   | <b>cmpdeco</b>  | 1                   | 0101 1010          | dst      | src2 | M3   | M2 | M1       | 0110            | S2               | S1        | src1   |
| 5A:7   | <b>cmpdeci</b>  | 1                   | 0101 1010          | dst      | src2 | M3   | M2 | M1       | 0111            | S2               | S1        | src1   |
| 5A:C   | <b>scanbyte</b> | 1                   | 0101 1010          |          | src2 | M3   | M2 | M1       | 1100            | S2               | S1        | src1   |
| 5A:D   | <b>bswap</b>    | 10                  | 0101 1010          | dst      |      | M3   | M2 | M1       | 1101            | S2               | S1        | src1   |
| 5A:E   | <b>chkbit</b>   | 1                   | 0101 1010          |          | src  | M3   | M2 | M1       | 1110            | S2               | S1        | bitpos |
| 5B:0   | <b>addc</b>     | 1                   | 0101 1011          | dst      | src2 | M3   | M2 | M1       | 0000            | S2               | S1        | src1   |
| 5B:2   | <b>subc</b>     | 1                   | 0101 1011          | dst      | src2 | M3   | M2 | M1       | 0010            | S2               | S1        | src1   |
| 5B:4   | <b>intdis</b>   | 4                   | 0101 1011          |          |      | M3   | M2 | M1       | 0100            | S2               | S1        |        |
| 5B:5   | <b>inten</b>    | 4                   | 0101 1011          |          |      | M3   | M2 | M1       | 0101            | S2               | S1        |        |
| 5C:C   | <b>mov</b>      | 1                   | 0101 1100          | dst      |      | M3   | M2 | M1       | 1100            | S2               | S1        | src    |
| 5D:8   | <b>eshro</b>    | 11                  | 0101 1101          | dst      | src2 | M3   | M2 | M1       | 1000            | S2               | S1        | src1   |
| 5D:C   | <b>movl</b>     | 4                   | 0101 1101          | dst      |      | M3   | M2 | M1       | 1100            | S2               | S1        | src    |
| 5E:C   | <b>movt</b>     | 5                   | 0101 1110          | dst      |      | M3   | M2 | M1       | 1100            | S2               | S1        | src    |
| 5F:C   | <b>movq</b>     | 6                   | 0101 1111          | dst      |      | M3   | M2 | M1       | 1100            | S2               | S1        | src    |
| 61:0   | <b>atmod</b>    | 24                  | 0110 0010          | dst      | src2 | M3   | M2 | M1       | 0000            | S2               | S1        | src1   |
| 61:2   | <b>atadd</b>    | 24                  | 0110 0010          | dst      | src2 | M3   | M2 | M1       | 0010            | S2               | S1        | src1   |
| 64:0   | <b>spanbit</b>  | 6                   | 0110 0100          | dst      |      | M3   | M2 | M1       | 0000            | S2               | S1        | src    |
| 64:1   | <b>scanbit</b>  | 5                   | 0110 0100          | dst      |      | M3   | M2 | M1       | 0001            | S2               | S1        | src    |
| 64:5   | <b>modac</b>    | 10                  | 0110 0100          | mask     | src  | M3   | M2 | M1       | 0101            | S2               | S1        | dst    |
| 65:0   | <b>modify</b>   | 6                   | 0110 0101          | src/dst  | src  | M3   | M2 | M1       | 0000            | S2               | S1        | mask   |
| 65:1   | <b>extract</b>  | 7                   | 0110 0101          | src/dst  | len  | M3   | M2 | M1       | 0001            | S2               | S1        | bitpos |
| 65:4   | <b>modtc</b>    | 10                  | 0110 0101          | mask     | src  | M3   | M2 | M1       | 0100            | S2               | S1        | dst    |
| 65:5   | <b>modpc</b>    | 17                  | 0110 0101          | src/dst  | mask | M3   | M2 | M1       | 0101            | S2               | S1        | src    |
| 65:8   | <b>intctl</b>   | 12-16               | 0110 0101          | dst      |      | M3   | M2 | M1       | 1000            | S2               | S1        | src1   |
| 65:9   | <b>sysctl</b>   | 10-100 <sup>1</sup> | 0110 0101          | src/dst  | src2 | M3   | M2 | M1       | 1001            | S2               | S1        | src1   |

1. Execution time based on performed by instruction.

## OPCODES AND EXECUTION TIMES



Table B-2. REG Format Instruction Encodings (Sheet 3 of 4)

| Opcode | Mnemonic        | Cycles to Execute   | Opcode (11 - 4) | src/dst | src2 | Mode |    |          | Opcode (3-0) | Special Flags |         | src1 |
|--------|-----------------|---------------------|-----------------|---------|------|------|----|----------|--------------|---------------|---------|------|
| 65:B   |                 | 31 ..... 24         | 23...19         | 18..14  | 13   | 12   | 11 | 10 ... 7 | 6            | 5             | 4 ..... | 0    |
| 65:B   | <b>icctl</b>    | 10-100 <sup>1</sup> | 0110 0101       | src/dst | src2 | M3   | M2 | M1       | 1011         | S2            | S1      | src1 |
| 65:C   | <b>dcctl</b>    | 10-100 <sup>1</sup> | 0110 0101       | src/dst | src2 | M3   | M2 | M1       | 1100         | S2            | S1      | src1 |
| 65:D   | <b>halt</b>     | ∞                   | 0110 0101       |         |      | M3   | M2 | M1       | 1101         | S2            | S1      | src1 |
| 66:0   | <b>calls</b>    | 30                  | 0110 0110       |         |      | M3   | M2 | M1       | 0000         | S2            | S1      | src  |
| 66:B   | <b>mark</b>     | 8                   | 0110 0110       |         |      | M3   | M2 | M1       | 1011         | S2            | S1      |      |
| 66:C   | <b>fmark</b>    | 8                   | 0110 0110       |         |      | M3   | M2 | M1       | 1100         | S2            | S1      |      |
| 66:D   | <b>flushreg</b> | 15                  | 0110 0110       |         |      | M3   | M2 | M1       | 1101         | S2            | S1      |      |
| 66:F   | <b>syncf</b>    | 4                   | 0110 0110       |         |      | M3   | M2 | M1       | 1111         | S2            | S1      |      |
| 67:0   | <b>emul</b>     | 1                   | 0110 0111       | dst     | src2 | M3   | M2 | M1       | 0000         | S2            | S1      | src1 |
| 67:1   | <b>ediv</b>     | 6                   | 0110 0111       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 70:1   | <b>mulo</b>     | 2-4                 | 0111 0000       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 70:8   | <b>remo</b>     | 40                  | 0111 0000       | dst     | src2 | M3   | M2 | M1       | 1000         | S2            | S1      | src1 |
| 70:B   | <b>divo</b>     | 40                  | 0111 0000       | dst     | src2 | M3   | M2 | M1       | 1011         | S2            | S1      | src1 |
| 74:1   | <b>muli</b>     | 2-4                 | 0111 0100       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 74:8   | <b>remi</b>     | 40                  | 0111 0100       | dst     | src2 | M3   | M2 | M1       | 1000         | S2            | S1      | src1 |
| 74:9   | <b>modi</b>     | 40                  | 0111 0100       | dst     | src2 | M3   | M2 | M1       | 1001         | S2            | S1      | src1 |
| 74:B   | <b>divi</b>     | 8                   | 0111 0100       | dst     | src2 | M3   | M2 | M1       | 1011         | S2            | S1      | src1 |
| 78:0   | <b>addono</b>   | 1                   | 0111 1000       | dst     | src2 | M3   | M2 | M1       | 0000         | S2            | S1      | src1 |
| 78:1   | <b>addino</b>   | 1                   | 0111 1000       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 78:2   | <b>subono</b>   | 1                   | 0111 1000       | dst     | src2 | M3   | M2 | M1       | 0010         | S2            | S1      | src1 |
| 78:3   | <b>subino</b>   | 1                   | 0111 1000       | dst     | src2 | M3   | M2 | M1       | 0011         | S2            | S1      | src1 |
| 78:4   | <b>selno</b>    | 1                   | 0111 1000       | dst     | src2 | M3   | M2 | M1       | 0100         | S2            | S1      | src1 |
| 79:0   | <b>addog</b>    | 1                   | 0111 1001       | dst     | src2 | M3   | M2 | M1       | 0000         | S2            | S1      | src1 |
| 79:1   | <b>addig</b>    | 1                   | 0111 1001       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 79:2   | <b>subog</b>    | 1                   | 0111 1001       | dst     | src2 | M3   | M2 | M1       | 0010         | S2            | S1      | src1 |
| 79:3   | <b>subig</b>    | 1                   | 0111 1001       | dst     | src2 | M3   | M2 | M1       | 0011         | S2            | S1      | src1 |
| 79:4   | <b>selg</b>     | 1                   | 0111 1001       | dst     | src2 | M3   | M2 | M1       | 0100         | S2            | S1      | src1 |
| 7A:0   | <b>adde</b>     | 1                   | 0111 1010       | dst     | src2 | M3   | M2 | M1       | 0000         | S2            | S1      | src1 |
| 7A:1   | <b>addie</b>    | 1                   | 0111 1010       | dst     | src2 | M3   | M2 | M1       | 0001         | S2            | S1      | src1 |
| 7A:2   | <b>suboe</b>    | 1                   | 0111 1010       | dst     | src2 | M3   | M2 | M1       | 0010         | S2            | S1      | src1 |
| 7A:3   | <b>subie</b>    | 1                   | 0111 1010       | dst     | src2 | M3   | M2 | M1       | 0011         | S2            | S1      | src1 |

1. Execution time based on performed by instruction.

Table B-2. REG Format Instruction Encodings (Sheet 4 of 4)

| Opcode | Mnemonic      | Cycles to Execute | Opcode<br>(11 - 4) | src/dst | src2 | Mode |    |    | Opcode<br>(3-0) | Special Flags |    | src1 |
|--------|---------------|-------------------|--------------------|---------|------|------|----|----|-----------------|---------------|----|------|
|        |               | 31 ..... 24       |                    |         |      | 13   | 12 | 11 |                 | 6             | 5  |      |
| 7A:4   | <b>sele</b>   | 1                 | 0111 1010          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |
| 7B:0   | <b>addoge</b> | 1                 | 0111 1011          | dst     | src2 | M3   | M2 | M1 | 0000            | S2            | S1 | src1 |
| 7B:1   | <b>addige</b> | 1                 | 0111 1011          | dst     | src2 | M3   | M2 | M1 | 0001            | S2            | S1 | src1 |
| 7B:2   | <b>suboge</b> | 1                 | 0111 1011          | dst     | src2 | M3   | M2 | M1 | 0010            | S2            | S1 | src1 |
| 7B:3   | <b>subige</b> | 1                 | 0111 1011          | dst     | src2 | M3   | M2 | M1 | 0011            | S2            | S1 | src1 |
| 7B:4   | <b>selge</b>  | 1                 | 0111 1011          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |
| 7C:0   | <b>addol</b>  | 1                 | 0111 1100          | dst     | src2 | M3   | M2 | M1 | 0000            | S2            | S1 | src1 |
| 7C:1   | <b>addil</b>  | 1                 | 0111 1100          | dst     | src2 | M3   | M2 | M1 | 0001            | S2            | S1 | src1 |
| 7C:2   | <b>subol</b>  | 1                 | 0111 1100          | dst     | src2 | M3   | M2 | M1 | 0010            | S2            | S1 | src1 |
| 7C:3   | <b>subil</b>  | 1                 | 0111 1100          | dst     | src2 | M3   | M2 | M1 | 0011            | S2            | S1 | src1 |
| 7C:4   | <b>sell</b>   | 1                 | 0111 1100          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |
| 7D:0   | <b>addone</b> | 1                 | 0111 1101          | dst     | src2 | M3   | M2 | M1 | 0000            | S2            | S1 | src1 |
| 7D:1   | <b>addine</b> | 1                 | 0111 1101          | dst     | src2 | M3   | M2 | M1 | 0001            | S2            | S1 | src1 |
| 7D:2   | <b>subone</b> | 1                 | 0111 1101          | dst     | src2 | M3   | M2 | M1 | 0010            | S2            | S1 | src1 |
| 7D:3   | <b>subine</b> | 1                 | 0111 1101          | dst     | src2 | M3   | M2 | M1 | 0011            | S2            | S1 | src1 |
| 7D:4   | <b>selne</b>  | 1                 | 0111 1101          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |
| 7E:0   | <b>addole</b> | 1                 | 0111.1110          | dst     | src2 | M3   | M2 | M1 | 0000            | S2            | S1 | src1 |
| 7E:1   | <b>addile</b> | 1                 | 0111 1110          | dst     | src2 | M3   | M2 | M1 | 0001            | S2            | S1 | src1 |
| 7E:2   | <b>subole</b> | 1                 | 0111 1110          | dst     | src2 | M3   | M2 | M1 | 0010            | S2            | S1 | src1 |
| 7E:3   | <b>subile</b> | 1                 | 0111 1110          | dst     | src2 | M3   | M2 | M1 | 0011            | S2            | S1 | src1 |
| 7E:4   | <b>selle</b>  | 1                 | 0111 1110          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |
| 7F:0   | <b>addoo</b>  | 1                 | 0111 1111          | dst     | src2 | M3   | M2 | M1 | 0000            | S2            | S1 | src1 |
| 7F:1   | <b>adio</b>   | 1                 | 0111 1111          | dst     | src2 | M3   | M2 | M1 | 0001            | S2            | S1 | src1 |
| 7F:2   | <b>suboo</b>  | 1                 | 0111 1111          | dst     | src2 | M3   | M2 | M1 | 0010            | S2            | S1 | src1 |
| 7F:3   | <b>subio</b>  | 1                 | 0111 1111          | dst     | src2 | M3   | M2 | M1 | 0011            | S2            | S1 | src1 |
| 7F:4   | <b>sellio</b> | 1                 | 0111 1111          | dst     | src2 | M3   | M2 | M1 | 0100            | S2            | S1 | src1 |

1. Execution time based on performed by instruction.

Table B-3. COBR Format Instruction Encodings

| Opcode | Mnemonic       | Cycles to Execute  | Opcode    | src1          | src2        | M         | Displacement | T | S2 |
|--------|----------------|--------------------|-----------|---------------|-------------|-----------|--------------|---|----|
|        |                | 31 ..... 24        | 23 . 19   | 18... 14      | 13          | 12..... 2 | 1            | 0 |    |
| 20     | <b>testno</b>  | 4                  | 0010 0000 | <i>dst</i>    |             | M1        |              | T | S2 |
| 21     | <b>testg</b>   | 4                  | 0010 0001 | <i>dst</i>    |             | M1        |              | T | S2 |
| 22     | <b>teste</b>   | 4                  | 0010 0010 | <i>dst</i>    |             | M1        |              | T | S2 |
| 23     | <b>testge</b>  | 4                  | 0010 0011 | <i>dst</i>    |             | M1        |              | T | S2 |
| 24     | <b>testl</b>   | 4                  | 0010 0100 | <i>dst</i>    |             | M1        |              | T | S2 |
| 25     | <b>testne</b>  | 4                  | 0010 0101 | <i>dst</i>    |             | M1        |              | T | S2 |
| 26     | <b>testle</b>  | 4                  | 0010 0110 | <i>dst</i>    |             | M1        |              | T | S2 |
| 27     | <b>testo</b>   | 4                  | 0010 0111 | <i>dst</i>    |             | M1        |              | T | S2 |
| 30     | <b>bbc</b>     | 2 + 1 <sup>1</sup> | 0011 0000 | <i>bitpos</i> | <i>src</i>  | M1        | <i>targ</i>  | T | S2 |
| 31     | <b>cmpobg</b>  | 2 + 1              | 0011 0001 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 32     | <b>cmpobe</b>  | 2 + 1              | 0011 0010 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 33     | <b>cmpobge</b> | 2 + 1              | 0011 0011 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 34     | <b>cmpobl</b>  | 2 + 1              | 0011 0100 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 35     | <b>cmpobne</b> | 2 + 1              | 0011 0101 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 36     | <b>cmpoble</b> | 2 + 1              | 0011 0110 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 37     | <b>bbs</b>     | 2 + 1              | 0011 0111 | <i>bitpos</i> | <i>src</i>  | M1        | <i>targ</i>  | T | S2 |
| 38     | <b>cmpibno</b> | 2 + 1              | 0011 1000 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 39     | <b>cmpibg</b>  | 2 + 1              | 0011 1001 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3A     | <b>cmpibe</b>  | 2 + 1              | 0011 1010 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3B     | <b>cmpibge</b> | 2 + 1              | 0011 1011 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3C     | <b>cmpibl</b>  | 2 + 1              | 0011 1100 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3D     | <b>cmpibne</b> | 2 + 1              | 0011 1101 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3E     | <b>cmpible</b> | 2 + 1              | 0011 1110 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |
| 3F     | <b>cmpibo</b>  | 2 + 1              | 0011 1111 | <i>src1</i>   | <i>src2</i> | M1        | <i>targ</i>  | T | S2 |

1. Indicates that it takes 2 cycles to execute the instruction plus an additional cycle to fetch the target instruction if the branch is taken.

Table B-4. CTRL Format Instruction Encodings

| Opcode | Mnemonic       | Cycles to Execute  | Opcode    | Displacement | T | 0 |
|--------|----------------|--------------------|-----------|--------------|---|---|
|        |                | 31.....24          | 23.....2  |              | 1 | 0 |
| 08     | <b>b</b>       | 1 + 1 <sup>1</sup> | 0000 1000 | <i>targ</i>  | T | 0 |
| 09     | <b>call</b>    | 7                  | 0000 1001 | <i>targ</i>  | T | 0 |
| 0A     | <b>ret</b>     | 6                  | 0000 1010 |              | T | 0 |
| 0B     | <b>bal</b>     | 1 + 1              | 0000 1011 | <i>targ</i>  | T | 0 |
| 10     | <b>bno</b>     | 1 + 1              | 0001 0000 | <i>targ</i>  | T | 0 |
| 11     | <b>bg</b>      | 1 + 1              | 0001 0001 | <i>targ</i>  | T | 0 |
| 12     | <b>be</b>      | 1 + 1              | 0001 0010 | <i>targ</i>  | T | 0 |
| 13     | <b>bge</b>     | 1 + 1              | 0001 0011 | <i>targ</i>  | T | 0 |
| 14     | <b>bl</b>      | 1 + 1              | 0001 0100 | <i>targ</i>  | T | 0 |
| 15     | <b>bne</b>     | 1 + 1              | 0001 0101 | <i>targ</i>  | T | 0 |
| 16     | <b>ble</b>     | 1 + 1              | 0001 0110 | <i>targ</i>  | T | 0 |
| 17     | <b>bo</b>      | 1 + 1              | 0001 0111 | <i>targ</i>  | T | 0 |
| 18     | <b>faultno</b> | 13                 | 0001 1000 |              | T | 0 |
| 19     | <b>faultg</b>  | 13                 | 0001 1001 |              | T | 0 |
| 1A     | <b>faulte</b>  | 13                 | 0001 1010 |              | T | 0 |
| 1B     | <b>faultge</b> | 13                 | 0001 1011 |              | T | 0 |
| 1C     | <b>faultl</b>  | 13                 | 0001 1100 |              | T | 0 |
| 1D     | <b>faultne</b> | 13                 | 0001 1101 |              | T | 0 |
| 1E     | <b>faultle</b> | 13                 | 0001 1110 |              | T | 0 |
| 1F     | <b>faulto</b>  | 13                 | 0001 1111 |              | T | 0 |

1. Indicates that it takes 1 cycle to execute the instruction plus an additional cycle to fetch the target instruction if the branch is taken.

## OPCODES AND EXECUTION TIMES

**Table B-5. MEM Format Instruction Encodings**

|               |                |              |             |               |
|---------------|----------------|--------------|-------------|---------------|
| 31.....24     | 23...19        | 18.....14    | 13 .....12  | 11.....0      |
| <b>Opcode</b> | <b>src/dst</b> | <b>ABASE</b> | <b>Mode</b> | <b>Offset</b> |

|                     |                |              |                        |              |           |              |
|---------------------|----------------|--------------|------------------------|--------------|-----------|--------------|
| 31.....24           | 23...19        | 18.....14    | 13 .....12 ..11.....10 | 9.....7      | 6...5     | 4.....0      |
| <b>Opcode</b>       | <b>src/dst</b> | <b>ABASE</b> | <b>Mode</b>            | <b>Scale</b> | <b>00</b> | <b>Index</b> |
| <b>Displacement</b> |                |              |                        |              |           |              |

### Effective Address

|   |               |            |             |                     |   |   |               |                             |
|---|---------------|------------|-------------|---------------------|---|---|---------------|-----------------------------|
| <i>efa</i> = offset                                       | <b>Opcode</b> | <b>dst</b> |             | 0                   | 0 |   | <b>offset</b> |                             |
| offset( <i>reg</i> )                                      | <b>Opcode</b> | <b>dst</b> | <b>reg</b>  | 1                   | 0 |   | <b>offset</b> |                             |
| ( <i>reg</i> )  | <b>Opcode</b> | <b>dst</b> | <b>reg</b>  | 0                   | 1 | 0 | 00            |                             |
| <i>disp</i> + 8 (IP)                                      | <b>Opcode</b> | <b>dst</b> |             | 0                   | 1 | 0 | 1             | 00                          |
|   |               |            |             | <i>displacement</i> |   |   |               |                             |
| ( <i>reg1</i> )[ <i>reg2</i> * <i>scale</i> ]             | <b>Opcode</b> | <b>dst</b> | <b>reg1</b> | 0                   | 1 | 1 | 1             | <b>scale</b> 00 <b>reg2</b> |
| <i>disp</i>   | <b>Opcode</b> | <b>dst</b> |             | 1                   | 1 | 0 | 0             | 00                          |
|   |               |            |             | <i>displacement</i> |   |   |               |                             |
| <i>disp</i> ( <i>reg</i> )                                | <b>Opcode</b> | <b>dst</b> | <b>reg</b>  | 1                   | 1 | 0 | 1             | 00                          |
|   |               |            |             | <i>displacement</i> |   |   |               |                             |
| <i>disp</i> [ <i>reg</i> * <i>scale</i> ]                 | <b>Opcode</b> | <b>dst</b> |             | 1                   | 1 | 1 | 0             | <b>scale</b> 00 <b>reg</b>  |
|   |               |            |             | <i>displacement</i> |   |   |               |                             |
| <i>disp</i> ( <i>reg1</i> )[ <i>reg2</i> * <i>scale</i> ] | <b>Opcode</b> | <b>dst</b> | <b>reg1</b> | 1                   | 1 | 1 | 1             | <b>scale</b> 00 <b>reg2</b> |
|   |               |            |             | <i>displacement</i> |   |   |               |                             |

| Opcode | Mnemonic     | Cycles to Execute | Opcode | Mnemonic    | Cycles to Execute |
|--------|--------------|-------------------|--------|-------------|-------------------|
| 80     | <b>ldob</b>  | See Note 1.       | 98     | <b>ldl</b>  | See Note 1.       |
| 82     | <b>stob</b>  | See Note 1.       | 9A     | <b>stl</b>  | See Note 1.       |
| 84     | <b>bx</b>    | 4-7               | A0     | <b>ldt</b>  | See Note 1.       |
| 85     | <b>balx</b>  | 5-8               | A2     | <b>stt</b>  | See Note 1.       |
| 86     | <b>callx</b> | 9-12              | B0     | <b>ldq</b>  | See Note 1.       |
| 88     | <b>ldos</b>  | See Note 1.       | B2     | <b>stq</b>  | See Note 1.       |
| 8A     | <b>stos</b>  | See Note 1.       | C0     | <b>ldib</b> | See Note 1.       |
| 8C     | <b>lda</b>   | See Note 1.       | C2     | <b>stib</b> | See Note 1.       |
| 90     | <b>ld</b>    | See Note 1.       | C8     | <b>ldis</b> | See Note 1.       |
| 92     | <b>st</b>    | See Note 1.       | CA     | <b>stis</b> | See Note 1.       |

1. The number of cycles required to execute these instructions is based on the addressing mode used (see Table B-6).

**Table B-6. Addressing Mode Performance**

| Mode  | Assembler Syntax    | Memory Format | Number of Instruction words | Cycles to Execute |
|---|---------------------|---------------|-----------------------------|-------------------|
| Absolute Offset                             | exp                 | MEMA          | 1                           | 1                 |
| Absolute Displacement                       | exp                 | MEMB          | 2                           | 2                 |
| Register Indirect                           | (reg)               | MEMB          | 1                           | 1                 |
| Register Indirect with Offset               | exp(reg)            | MEMA          | 1                           | 1                 |
| Register Indirect with Displacement         | exp(reg)            | MEMB          | 2                           | 2                 |
| Index with Displacement                     | exp[reg*scale]      | MEMB          | 2                           | 2                 |
| Register Indirect with Index                | (reg)[reg*scale]    | MEMB          | 1                           | 6                 |
| Register Indirect with Index + Displacement | exp(reg)[reg*scale] | MEMB          | 2                           | 6                 |
| Instruction Pointer with Displacement       | exp(IP)             | MEMB          | 2                           | 6                 |





C

# REGISTER AND DATA STRUCTURES



## APPENDIX C

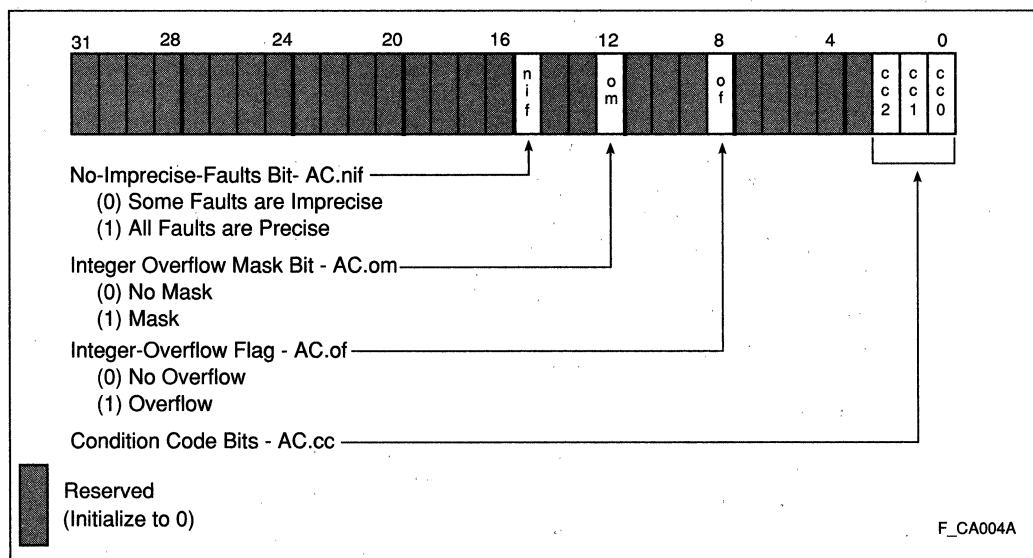
### REGISTER AND DATA STRUCTURES

This appendix is a compilation of all register and data structure figures described throughout the manual. Following each figure is a reference that indicates the section that discusses the figure.

| Fig. | Register / Data Structure                                     | Where defined in the manual  | Page |
|------|---|--|------|
| C-1  | Arithmetic Controls (AC) Register                             | Section 3.6.2, "Arithmetic Controls (AC) Register" (pg. 3-17)                                | C-2  |
| C-2  | Process Controls (PC) Register                                | Section 3.6.3, "Process Controls (PC) Register" (pg. 3-20)                                   | C-3  |
| C-3  | Trace Controls (TC) Register                                  | Section 10.1.1, "Trace Controls (TC) Register" (pg. 10-2)                                    | C-4  |
| C-4  | System Procedure Table  | Section 7.5.1, "System Procedure Table" (pg. 7-16)   | C-5  |
| C-5  | Procedure Stack Structure and Local Registers                 | Section 7.1.1, "Local Registers and the Procedure Stack" (pg. 7-2)                           | C-6  |
| C-6  | Previous Frame Pointer (PFP) Register (r0)                    | Section 7.2, "MODIFYING THE PFP REGISTER" (pg. 7-13)   | C-7  |
| C-7  | Interrupt Table   | Section 8.4, "INTERRUPT TABLE" (pg. 8-3)   | C-8  |
| C-8  | Storage of an Interrupt Record on the Interrupt Stack         | Section 8.5, "INTERRUPT STACK AND INTERRUPT RECORD" (pg. 8-5)                                | C-9  |
| C-9  | Interrupt Control (ICON) Register                             | Section 13.3.4, "Interrupt Control Register (ICON)" (pg. 13-12)                              | C-10 |
| C-10 | Interrupt Mapping (IMAP0-IMAP2) Registers                     | Section 13.3.5, "Interrupt Mapping Registers (IMAP0-IMAP2)" (pg. 13-14)                      | C-11 |
| C-11 | Interrupt Pending (IPND) Register                             | Section 13.3.5.1, "Interrupt Mask (IMSK) and Interrupt Pending (IPND) Registers" (pg. 13-16) | C-12 |
| C-12 | Interrupt Mask (IMSK) Registers                               | Section 13.3.5.1, "Interrupt Mask (IMSK) and Interrupt Pending (IPND) Registers" (pg. 13-16) | C-13 |
| C-13 | Fault Table and Fault Table Entries                           | Section 9.3, "FAULT TABLE" (pg. 9-4)   | C-14 |
| C-14 | Fault Record  | Section 9.5, "FAULT RECORD" (pg. 9-6)  | C-15 |
| C-15 | Breakpoint Control (BPCON) Register                           | Section 10.2.7.4, "Breakpoint Control Register" (pg. 10-7)                                   | C-16 |
| C-16 | Data Address Breakpoint Register Format                       | Section 10.2.7.5, "Data Address Breakpoint Registers" (pg. 10-9)                             | C-16 |
| C-17 | Instruction Breakpoint Register Format                        | Section 10.2.7.6, "Instruction Breakpoint Registers" (pg. 10-10)                             | C-17 |
| C-18 | Initial Memory Image (IMI) and Process Control Block (PRCB)   | Section 11.3.1, "Initial Memory Image (IMI)" (pg. 11-9)                                      | C-18 |
| C-19 | Control Table   | Section 11.3.3, "Control Table" (pg. 11-19)  | C-19 |
| C-20 | Process Control Block Configuration Words                     | Section 11.3.1.2, "Process Control Block (PRCB)" (pg. 11-14)                                 | C-20 |
| C-21 | IEEE 1149.1 Device Identification Register                    | Section 11.4, "DEVICE IDENTIFICATION ON RESET" (pg. 11-21)                                   | C-21 |
| C-22 | Bus Control Register (BCON)                                   | Section 12.4.1, "Bus Control (BCON) Register" (pg. 12-6)                                     | C-21 |
| C-23 | PMCON Register Bit Description                                | Section 12.3.1, "Bus Width" (pg. 12-5)   | C-22 |
| C-24 | Logical Memory Template Starting Address Registers (LMADRO-1) | Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)                         | C-22 |
| C-25 | Logical Memory Template Mask Registers (LMMR0-1)              | Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)                         | C-23 |
| C-26 | Default Logical Memory Configuration Register (DLMCON)        | Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)                         | C-23 |

| Fig. | Register / Data Structure          | Where defined in the manual                                     | Page |
|------|------------------------------------|---|------|
| C-27 | Timer Mode Register (TMR0, TMR1)   | Section 14.1.1, "Timer Mode Register (TMR0, TMR1)" (pg. 14-2)   | C-24 |
| C-28 | Timer Count Register (TCR0, TCR1)  | Section 14.1.2, "Timer Count Register (TCR0, TCR1)" (pg. 14-6)  | C-24 |
| C-29 | Timer Reload Register (TRR0, TRR1) | Section 14.1.3, "Timer Reload Register (TRR0, TRR1)" (pg. 14-7) | C-25 |

## C.1 Register and Data Structures



**Figure C-1. Arithmetic Controls (AC) Register**

Section 3.6.2, "Arithmetic Controls (AC) Register" (pg. 3-17)

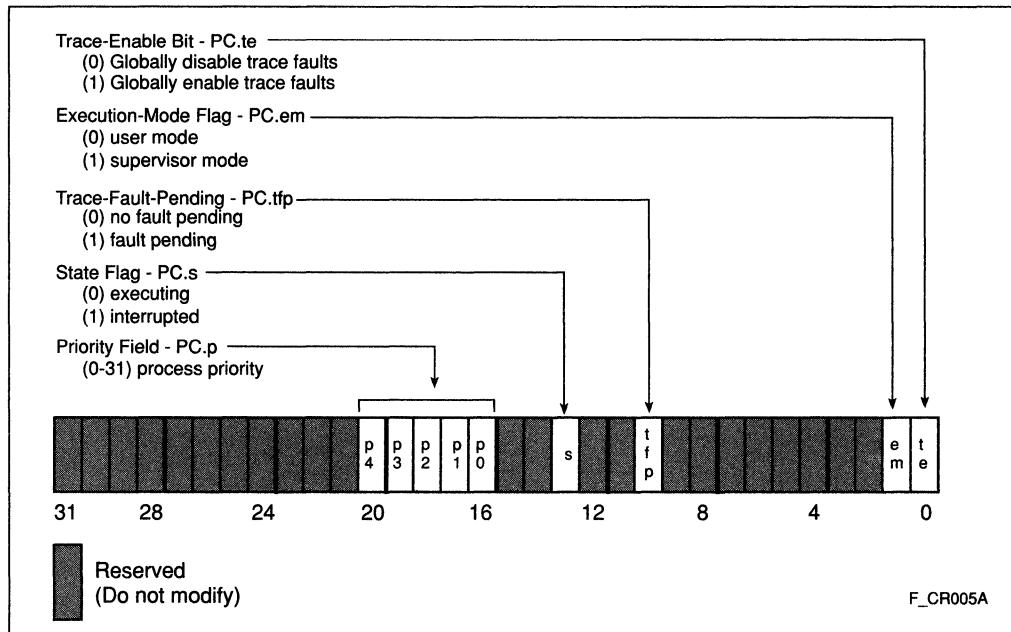
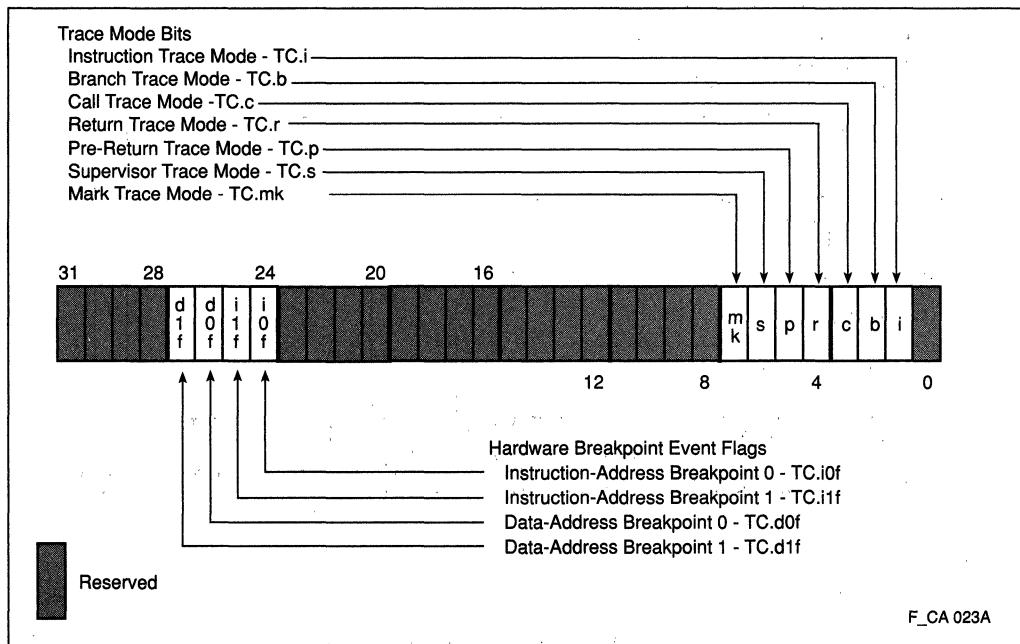


Figure C-2. Process Controls (PC) Register

Section 3.6.3, "Process Controls (PC) Register" (pg. 3-20)



**Figure C-3. Trace Controls (TC) Register**

Section 10.1.1, "Trace Controls (TC) Register" (pg. 10-2)

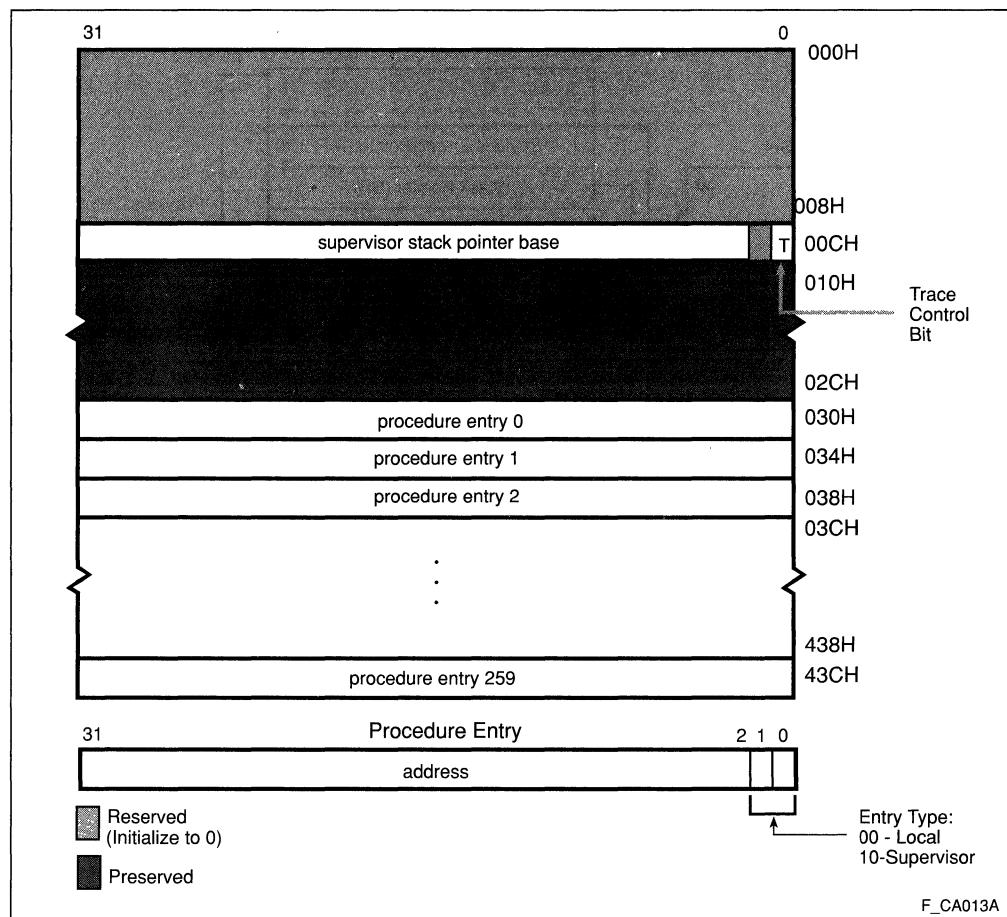
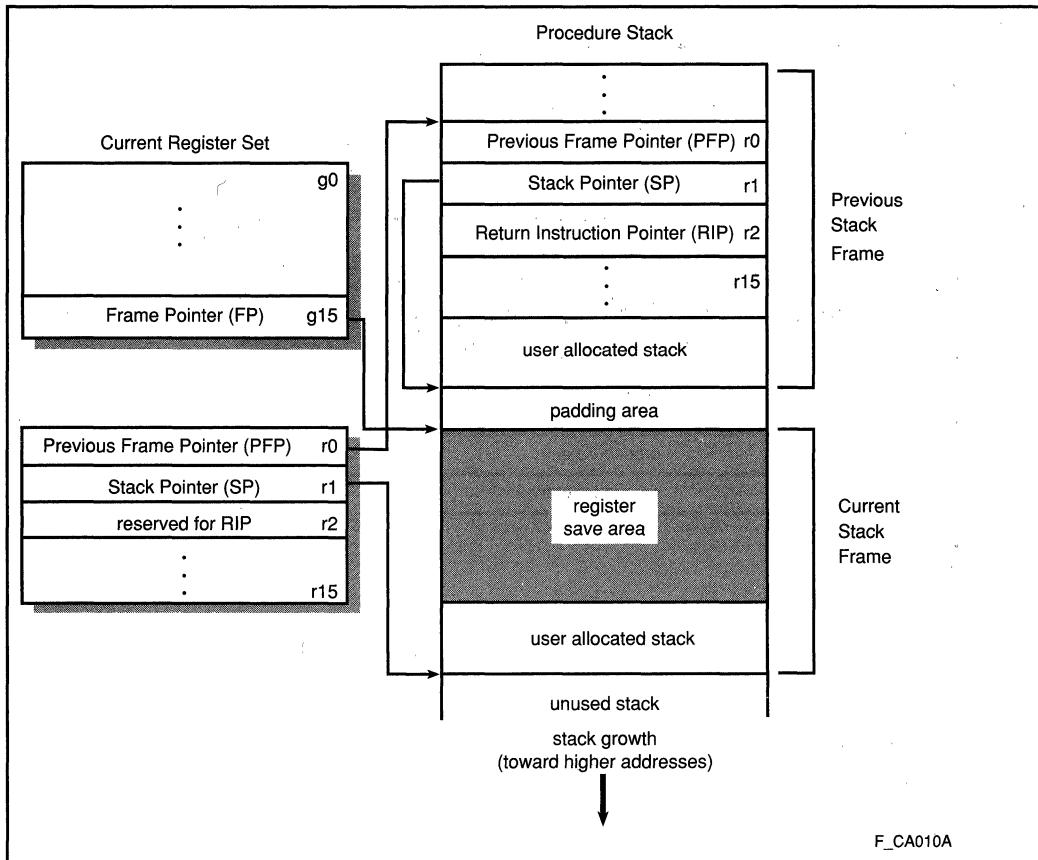


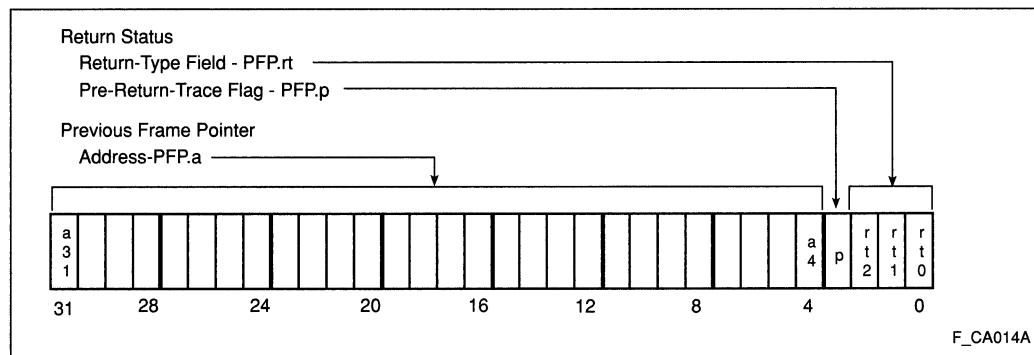
Figure C-4. System Procedure Table

Section 7.5.1, "System Procedure Table" (pg. 7-16)



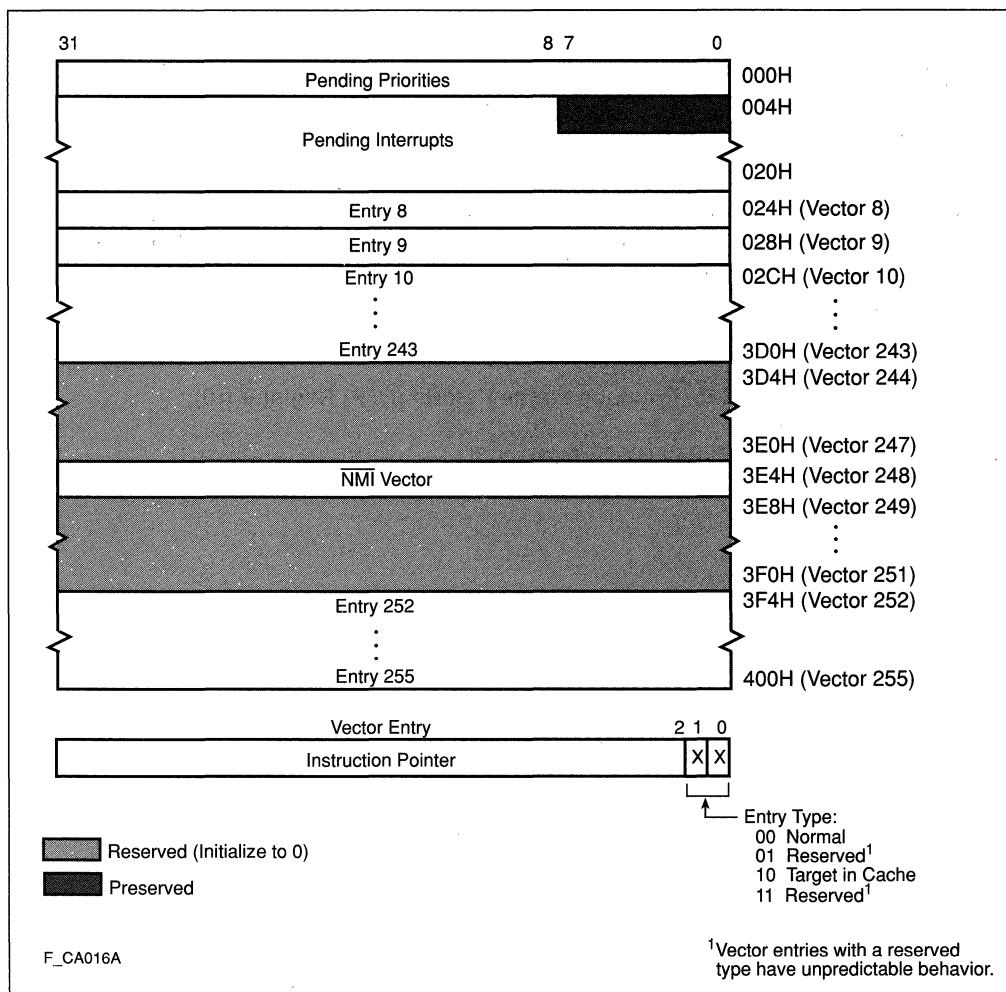
**Figure C-5. Procedure Stack Structure and Local Registers**

Section 7.1.1, "Local Registers and the Procedure Stack" (pg. 7-2)



**Figure C-6. Previous Frame Pointer (PFP) Register (r0)**

Section 7.2, “MODIFYING THE PFP REGISTER” (pg. 7-13)

**Figure C-7. Interrupt Table**

Section 8.4, "INTERRUPT TABLE" (pg. 8-3)

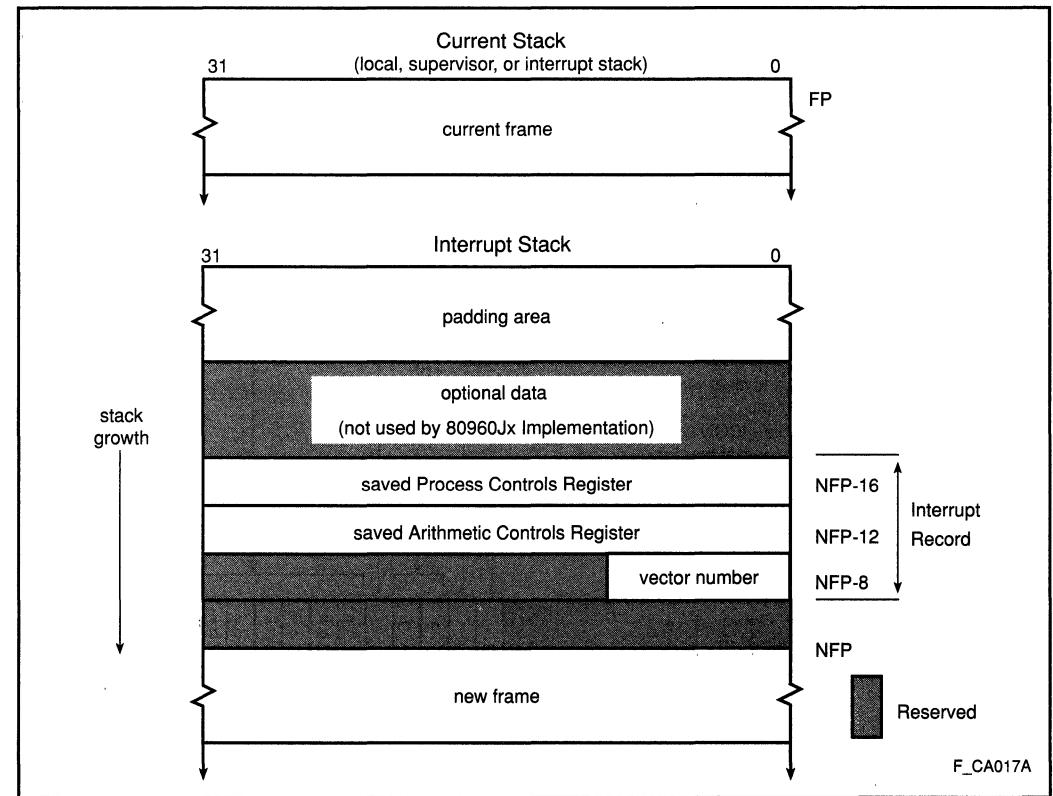
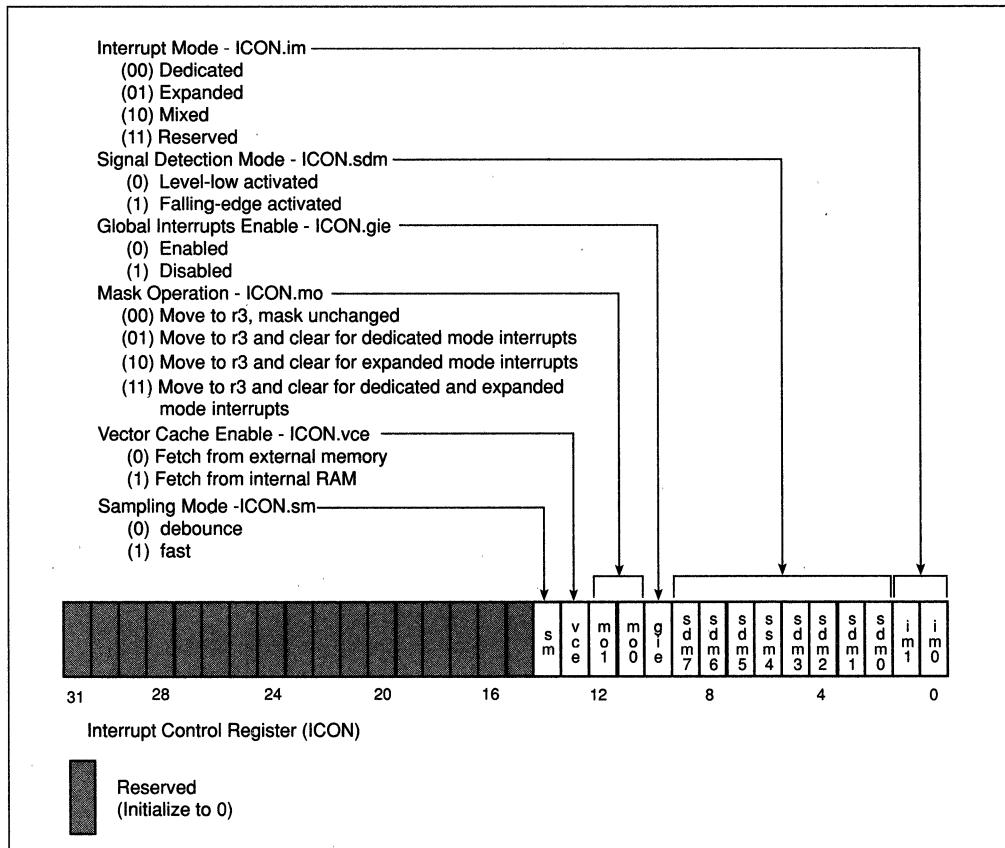


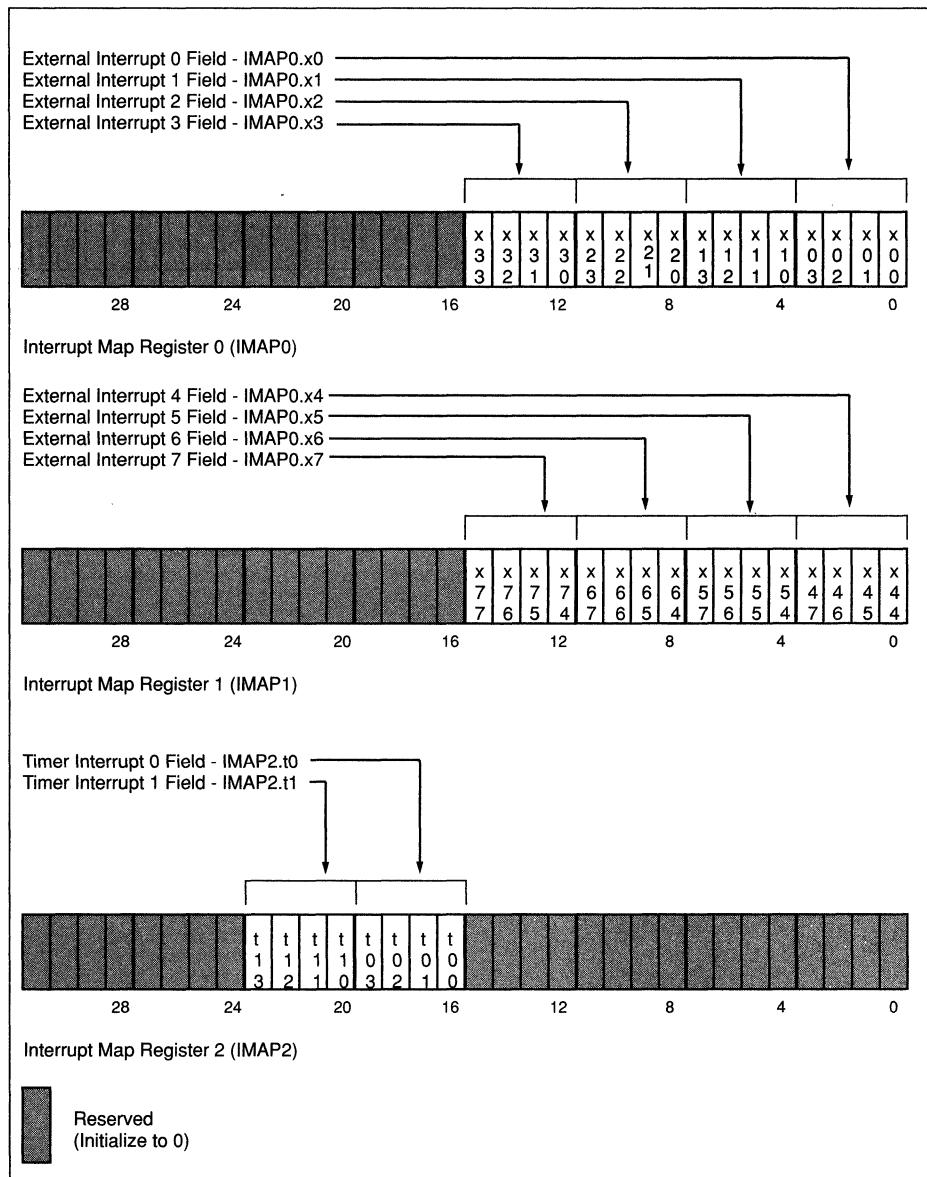
Figure C-8. Storage of an Interrupt Record on the Interrupt Stack

Section 8.5, "INTERRUPT STACK AND INTERRUPT RECORD" (pg. 8-5)



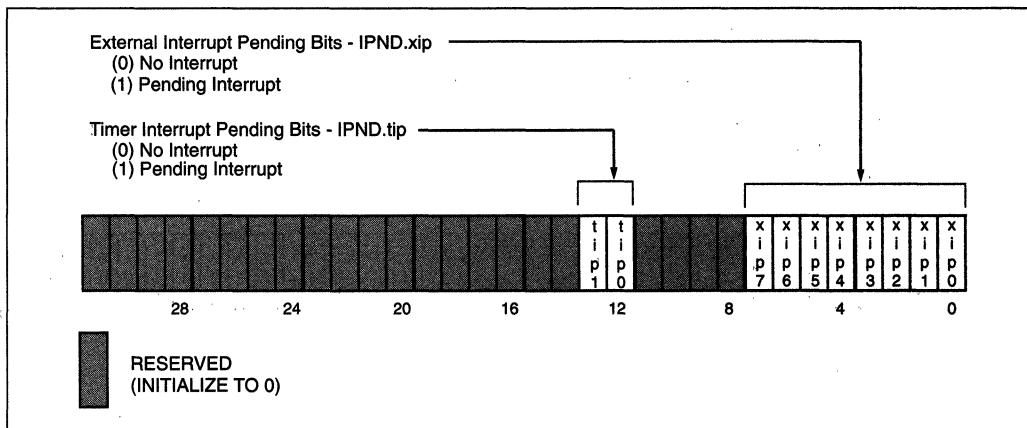
**Figure C-9. Interrupt Control (ICON) Register**

Section 13.3.4, “Interrupt Control Register (ICON)” (pg. 13-12)



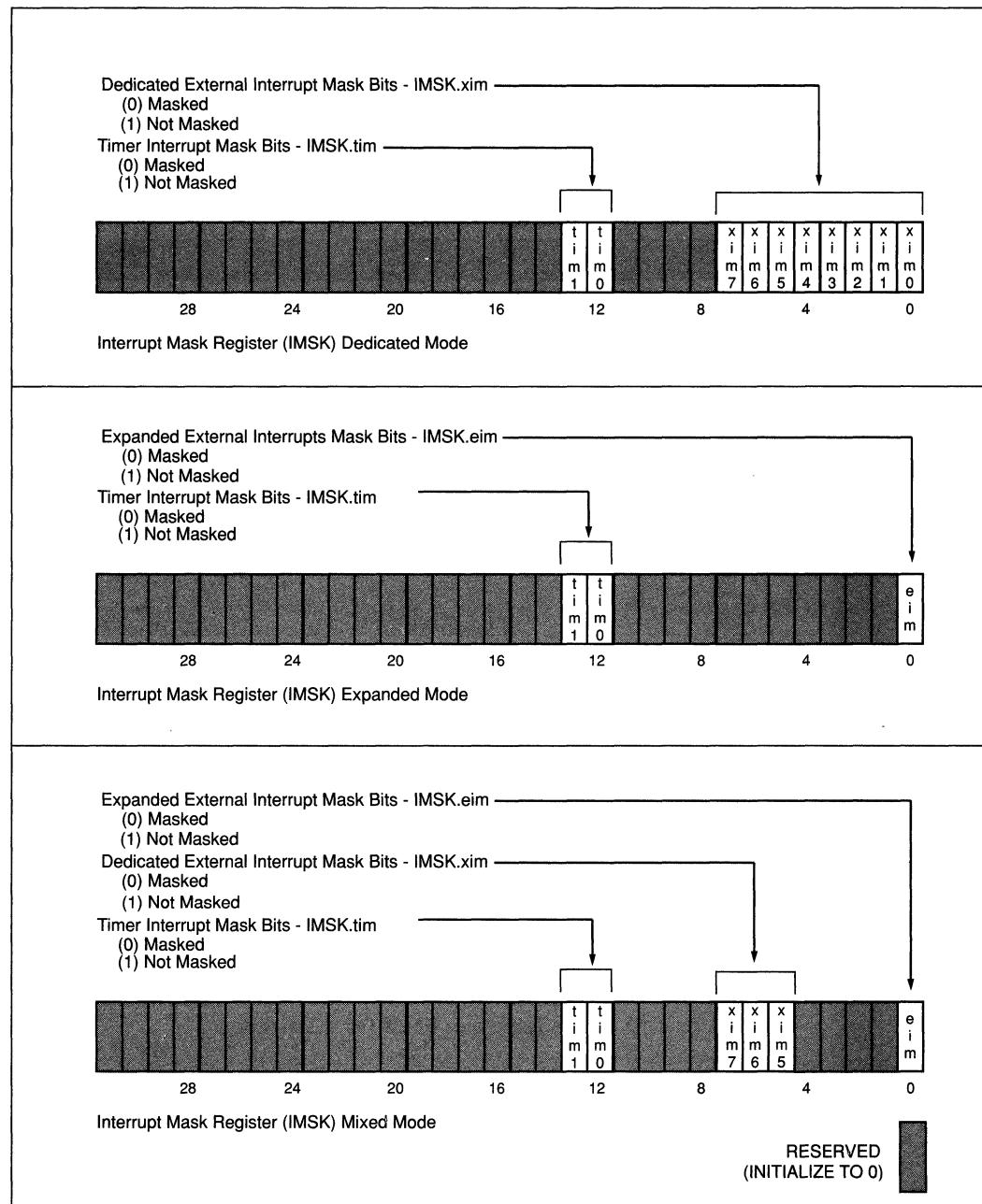
**Figure C-10. Interrupt Mapping (IMAP0-IMAP2) Registers**

Section 13.3.5, "Interrupt Mapping Registers (IMAP0-IMAP2)" (pg. 13-14)



**Figure C-11. Interrupt Pending (IPND) Register**

Section 13.3.5.1, “Interrupt Mask (IMSK) and Interrupt Pending (IPND) Registers” (pg. 13-16)

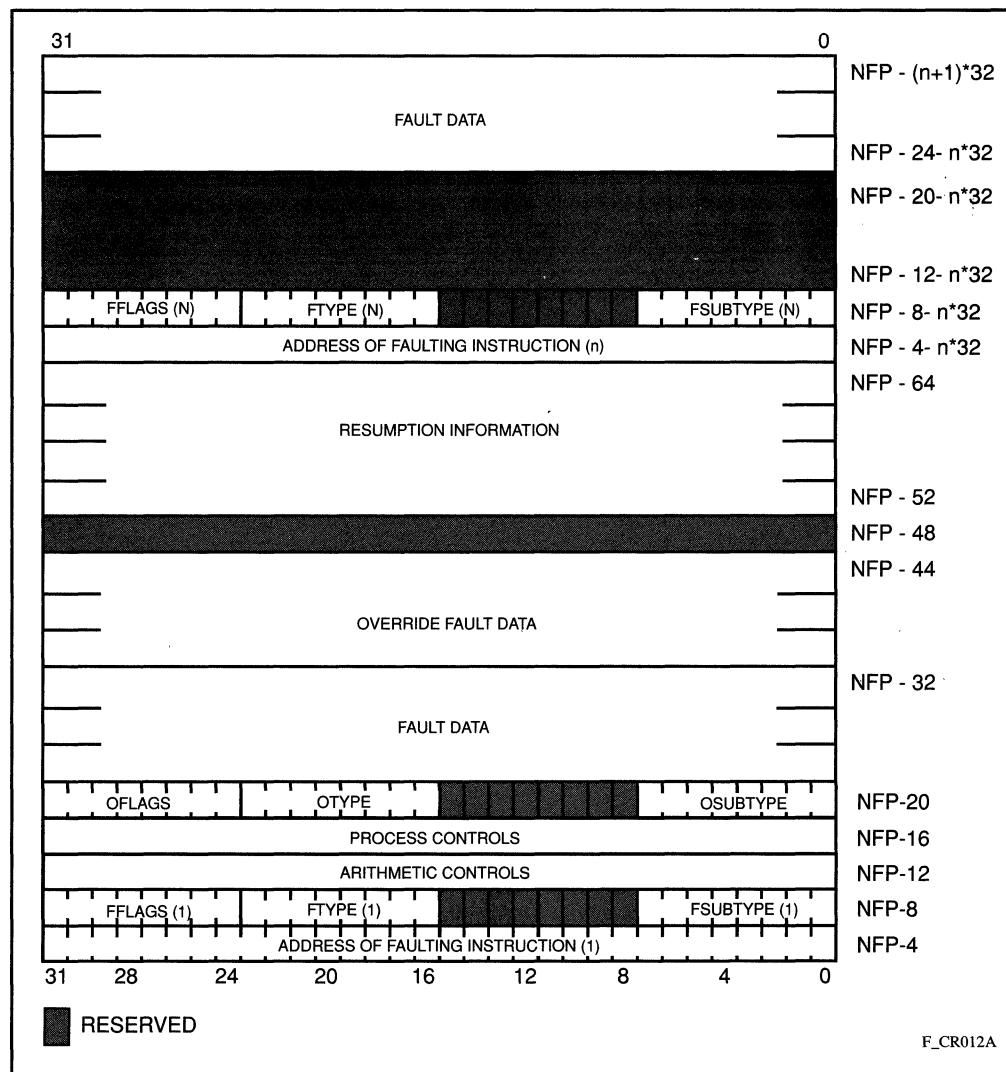
**Figure C-12. Interrupt Mask (IMSK) Registers**

Section 13.3.5.1, "Interrupt Mask (IMSK) and Interrupt Pending (IPND) Registers" (pg. 13-16)

| Fault Table       |                                 | 0        |
|-------------------|---------------------------------|----------|
|                   | Override/Parallel Fault Entry   | 00H      |
|                   | Trace Fault Entry               | 08H      |
|                   | Operation Fault Entry           | 10H      |
|                   | Arithmetic Fault Entry          | 18H      |
|                   |                                 | 20H      |
|                   | Constraint Fault Entry          | 28H      |
|                   |                                 | 30H      |
|                   | Protection Fault Entry          | 38H      |
|                   |                                 | 40H      |
|                   |                                 | 48H      |
|                   | Type Fault Entry                | 50H      |
|                   |                                 |          |
|                   |                                 | FCH      |
| Local-Call Entry  |                                 | 2 1 0    |
| 31                | Fault-Handler Procedure Address | 0 0 n    |
|                   |                                 | n+4      |
| System-Call Entry |                                 | 2 1 0    |
| 31                | Fault-Handler Procedure Number  | 1 0 n    |
|                   | 0000 027FH                      | n+4      |
|                   | Reserved (Initialize to 0)      | F_CA019A |

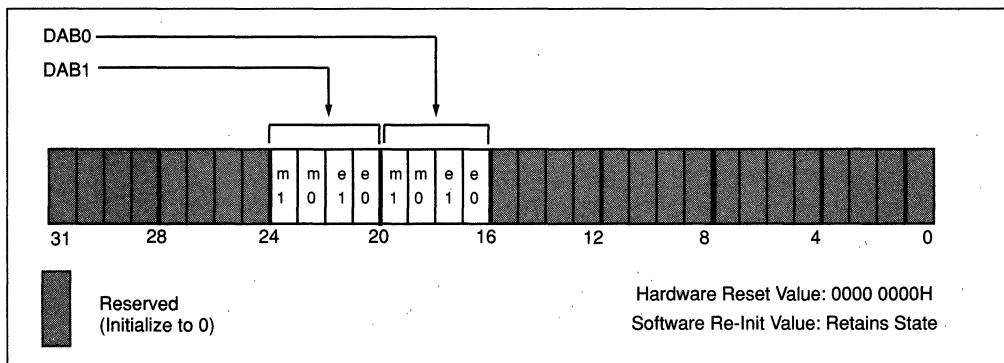
**Figure C-13. Fault Table and Fault Table Entries**

Section 9.3, "FAULT TABLE" (pg. 9-4)

**Figure C-14. Fault Record**

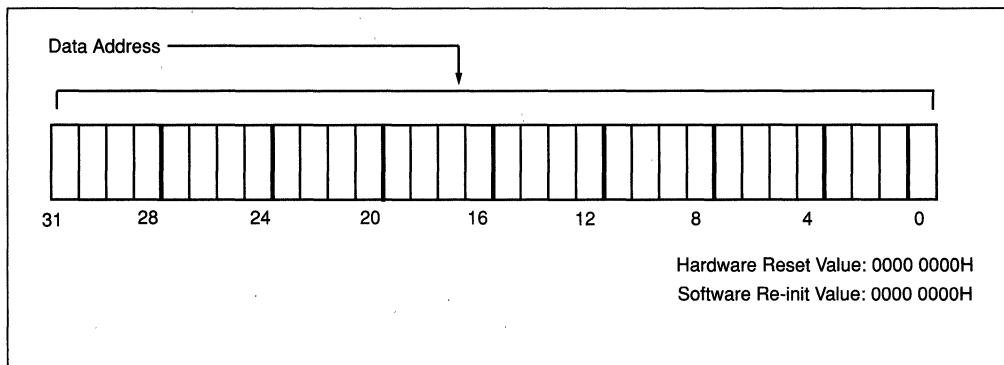
Section 9.5, "FAULT RECORD" (pg. 9-6)

## REGISTER AND DATA STRUCTURES



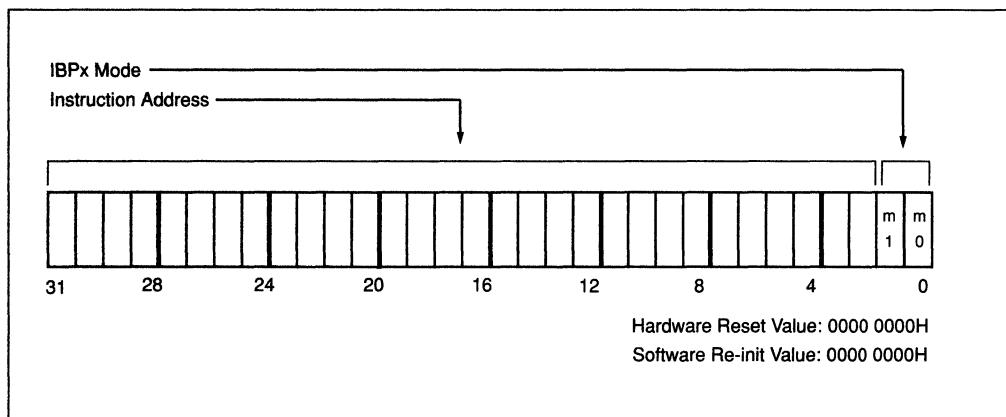
**Figure C-15. Breakpoint Control (BPCON) Register**

Section 10.2.7.4, "Breakpoint Control Register" (pg. 10-7)



**Figure C-16. Data Address Breakpoint Register Format**

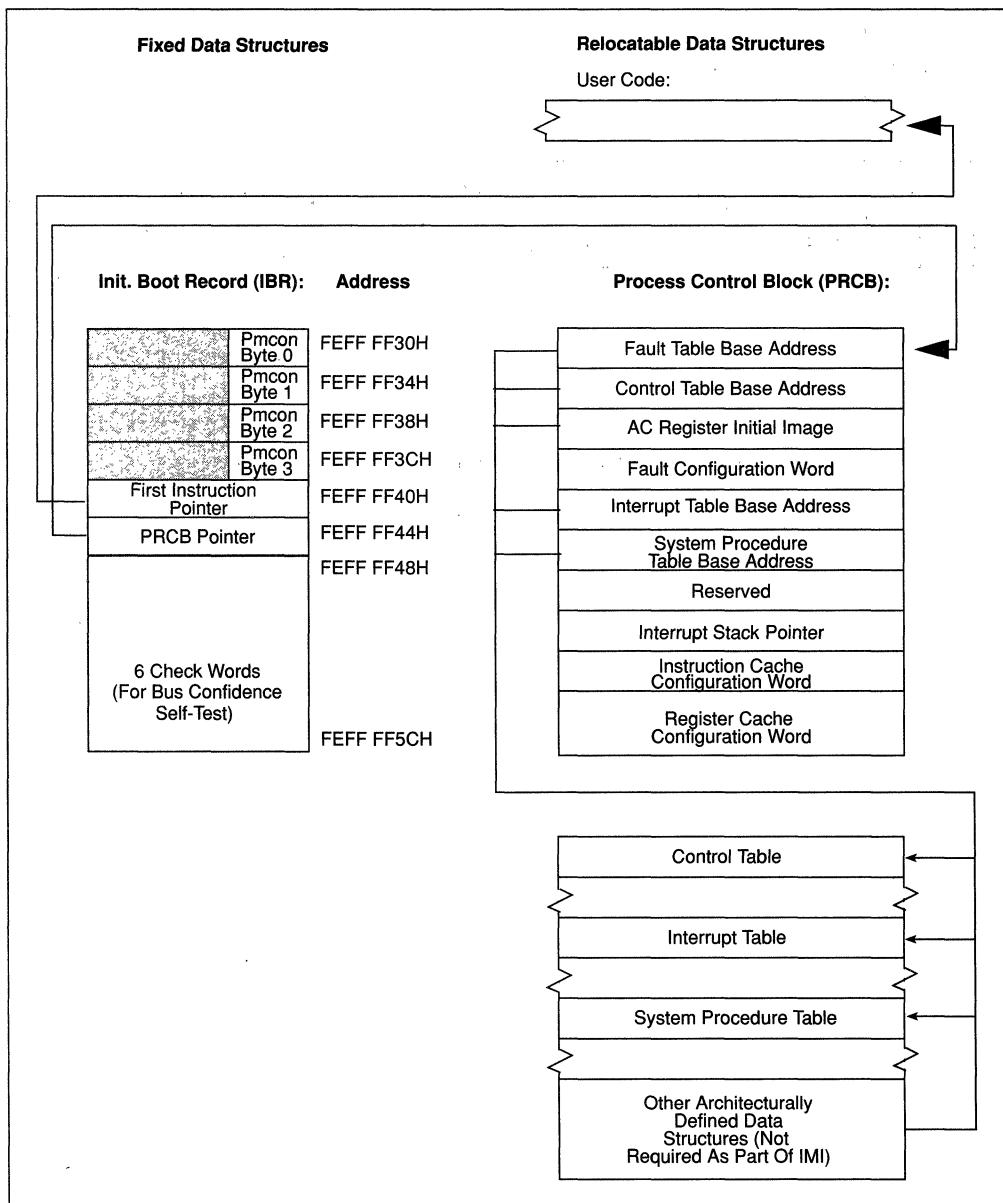
Section 10.2.7.5, "Data Address Breakpoint Registers" (pg. 10-9)



**Figure C-17. Instruction Breakpoint Register Format**

Section 10.2.7.6, “Instruction Breakpoint Registers” (pg. 10-10)

# REGISTER AND DATA STRUCTURES



**Figure C-18. Initial Memory Image (IMI) and Process Control Block (PRCB)**

### Section 11.3.1, "Initial Memory Image (IMI)" (pg. 11-9)

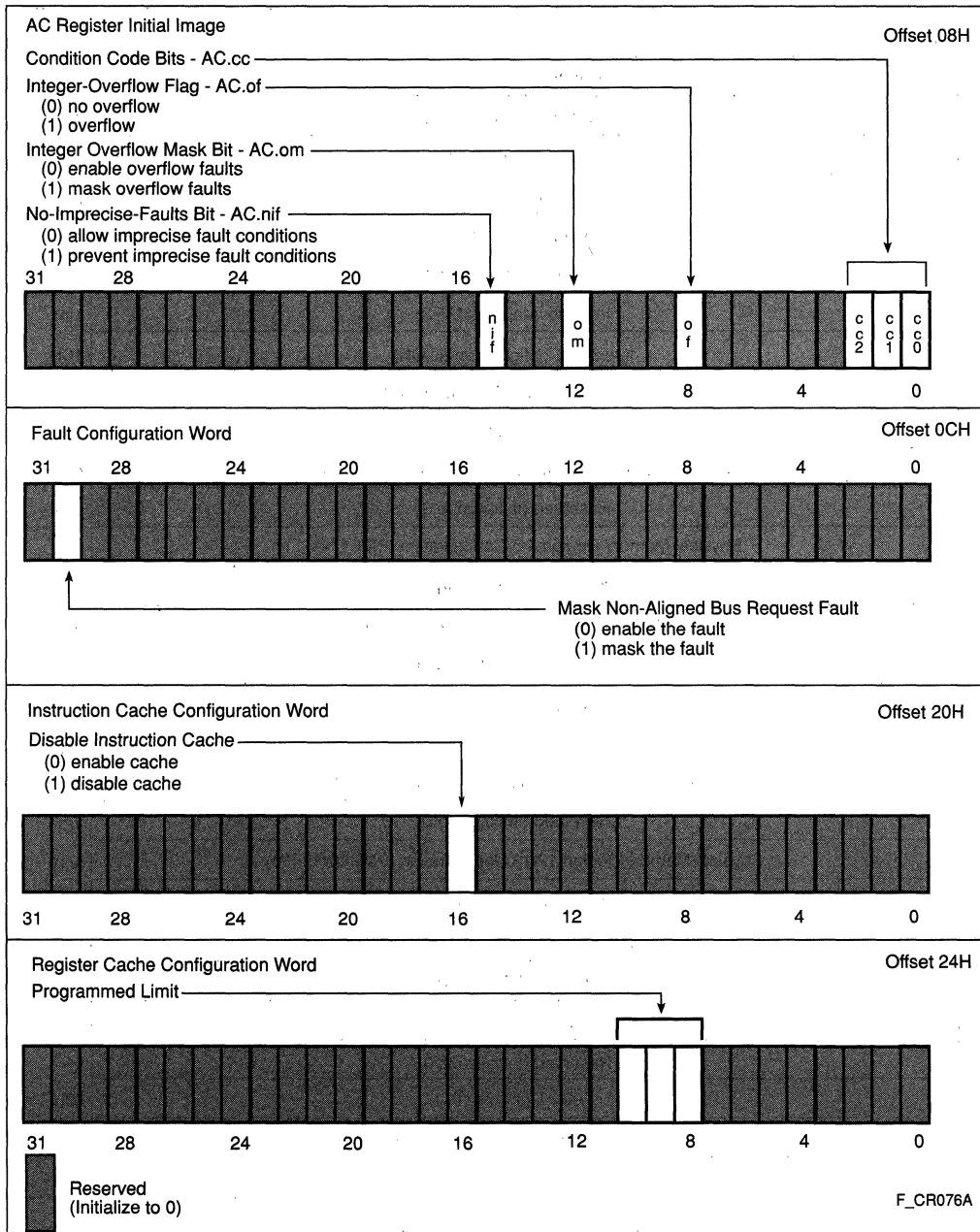
| 31  | 0   |
|---|-----|
|   | 00H |
| Reserved (Initialize to 0)                              | 04H |
| Reserved (Initialize to 0)                              | 08H |
| Reserved (Initialize to 0)                              | 0CH |
| Interrupt Map 0 (IMAP0)                                 | 10H |
| Interrupt Map 1 (IMAP1)                                 | 14H |
| Interrupt Map 2 (IMAP2)                                 | 18H |
| Interrupt Configuration (ICON)                          | 1CH |
| Physical Memory Region 0:1 Configuration (PMCON0_1)     | 20H |
| Reserved (Initialize to 0)                              | 24H |
| Physical Memory Region 2:3 Configuration (PMCON2_3)     | 28H |
| Reserved (Initialize to 0)                              | 2CH |
| Physical Memory Region 4:5 Configuration (PMCON4_5)     | 30H |
| Reserved (Initialize to 0)                              | 34H |
| Physical Memory Region 6:7 Configuration (PMCON6_7)     | 38H |
| Reserved (Initialize to 0)                              | 3CH |
| Physical Memory Region 8:9 Configuration (PMCON8_9)     | 40H |
| Reserved (Initialize to 0)                              | 44H |
| Physical Memory Region 10:11 Configuration (PMCON10_11) | 48H |
| Reserved (Initialize to 0)                              | 4CH |
| Physical Memory Region 12:13 Configuration (PMCON12_13) | 50H |
| Reserved (Initialize to 0)                              | 54H |
| Physical Memory Region 14:15 Configuration (PMCON14_15) | 58H |
| Reserved (Initialize to 0)                              | 5CH |
| Reserved (Initialize to 0)                              | 60H |
| Reserved (Initialize to 0)                              | 64H |
| Trace Controls (TC)                                     | 68H |
| Bus Configuration Control (BCON)                        | 6CH |

C

**Figure C-19. Control Table**

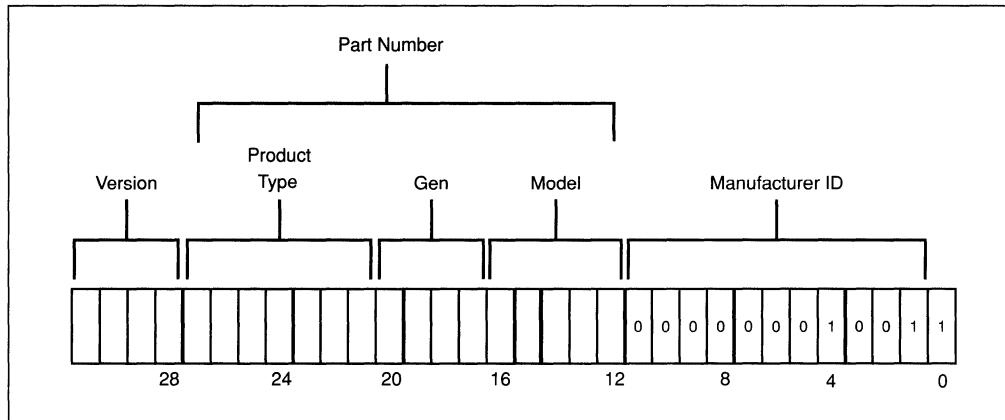
Section 11.3.3, "Control Table" (pg. 11-19)

## REGISTER AND DATA STRUCTURES



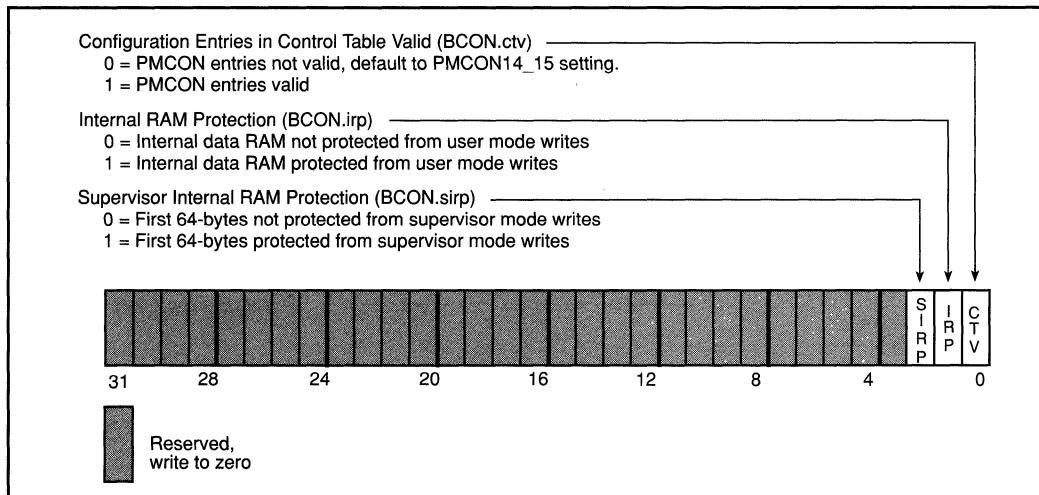
**Figure C-20. Process Control Block Configuration Words**

Section 11.3.1.2, "Process Control Block (PRCB)" (pg. 11-14)



**Figure C-21. IEEE 1149.1 Device Identification Register**

Section 11.4, "DEVICE IDENTIFICATION ON RESET" (pg. 11-21)



**Figure C-22. Bus Control Register (BCON)**

Section 12.4.1, "Bus Control (BCON) Register" (pg. 12-6)

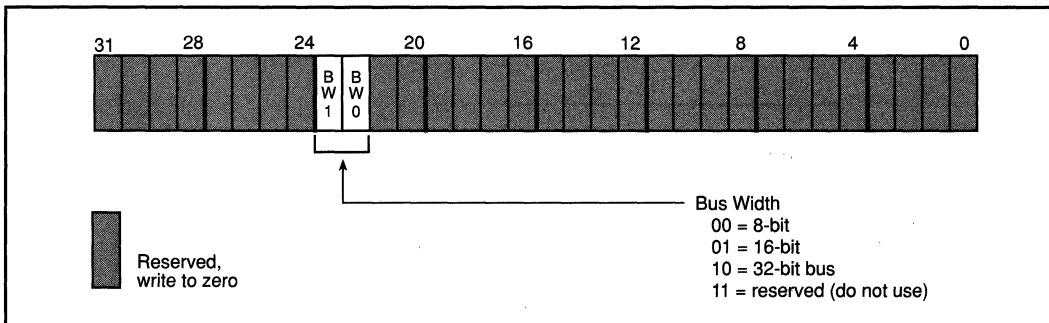


Figure C-23. PMCON Register Bit Description

Section 12.3.1, "Bus Width" (pg. 12-5)

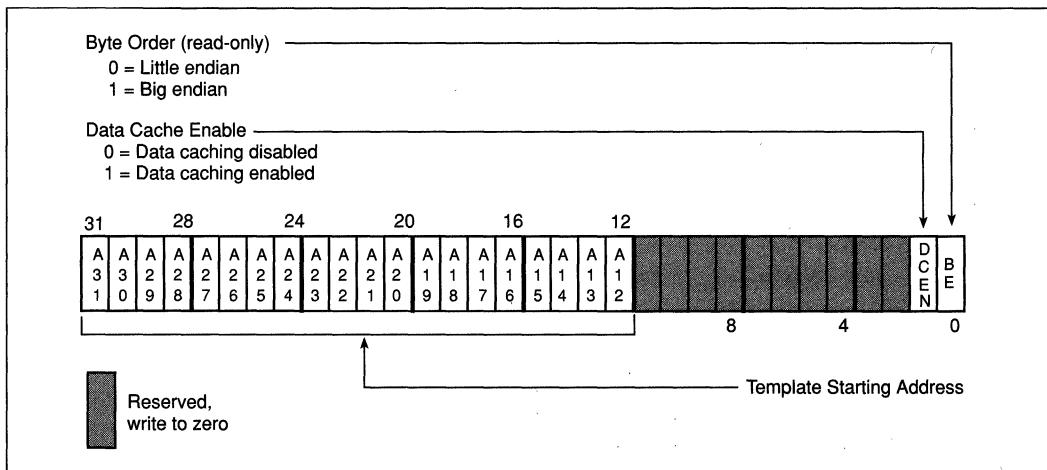
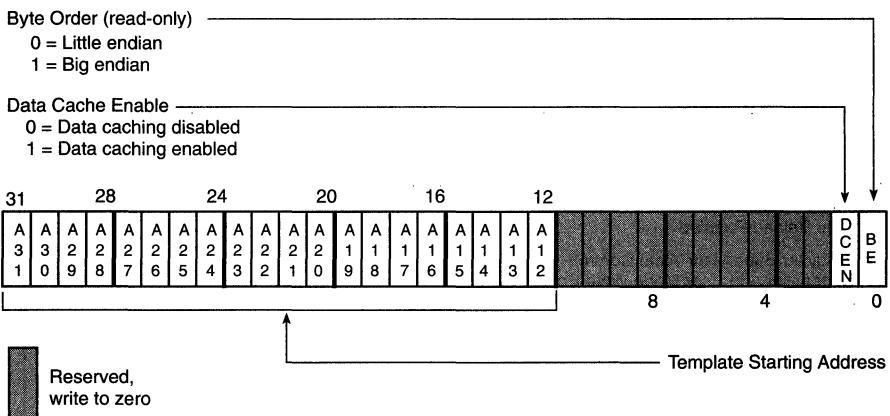


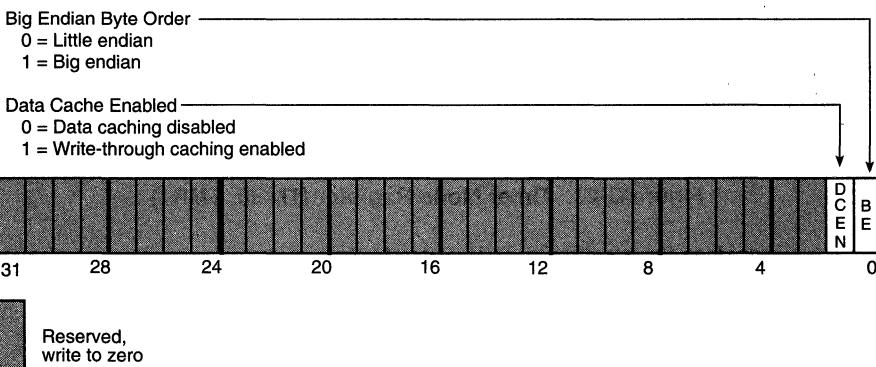
Figure C-24. Logical Memory Template Starting Address Registers (LMADRO-1)

Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)



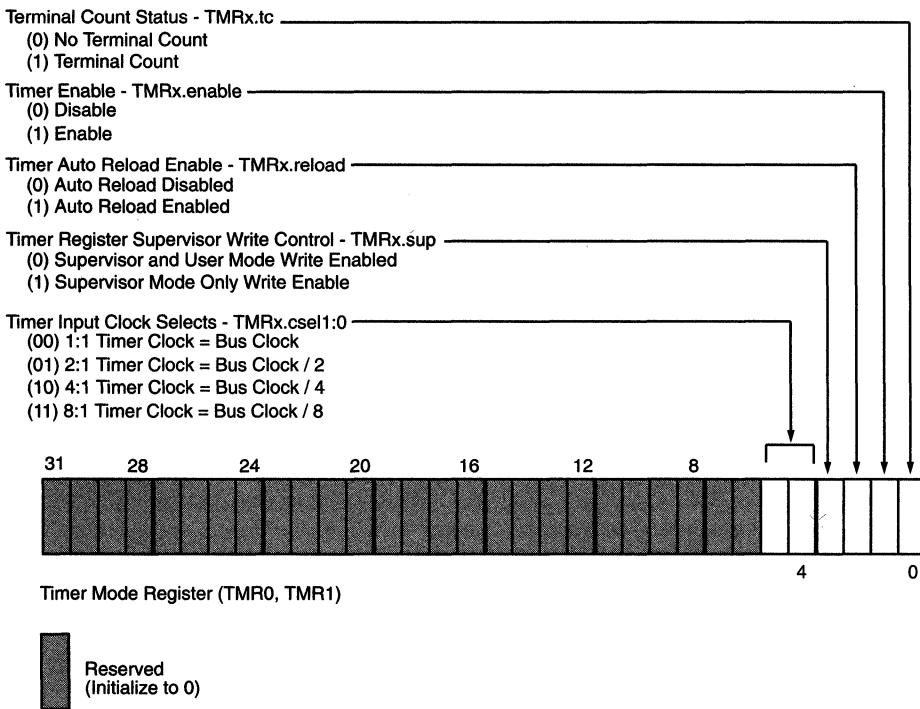
**Figure C-25. Logical Memory Template Mask Registers (LMMR0-1)**

Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)

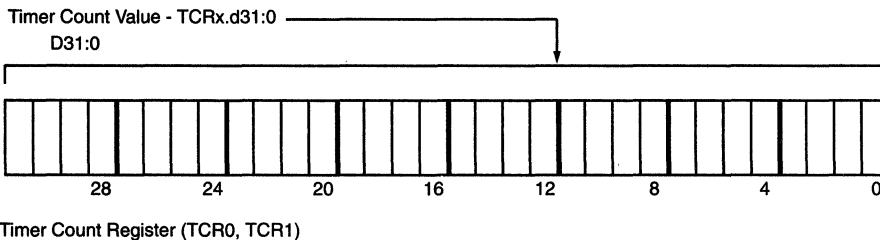


**Figure C-26. Default Logical Memory Configuration Register (DLMCON)**

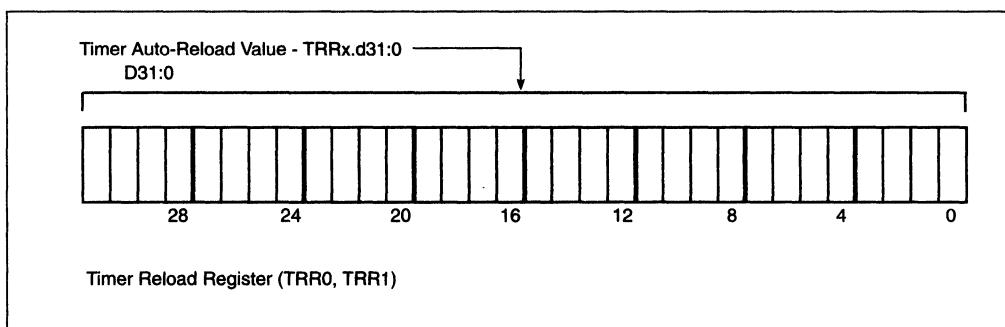
Section 12.6, "Programming the Logical Memory Attributes" (pg. 12-8)

**Figure C-27. Timer Mode Register (TMR0, TMR1)**

Section 14.1.1, "Timer Mode Register (TMR0, TMR1)" (pg. 14-2)

**Figure C-28. Timer Count Register (TCR0, TCR1)**

Section 14.1.2, "Timer Count Register (TCR0, TCR1)" (pg. 14-6)



C

**Figure C-29. Timer Reload Register (TRR0, TRR1)**

Section 14.1.3, “Timer Reload Register (TRR0, TRR1)” (pg. 14-7)

1951-1952 - 29 - 1952 - 1953 - 1953-1954 - 1954-1955



D

# MACHINE-LEVEL INSTRUCTION FORMATS



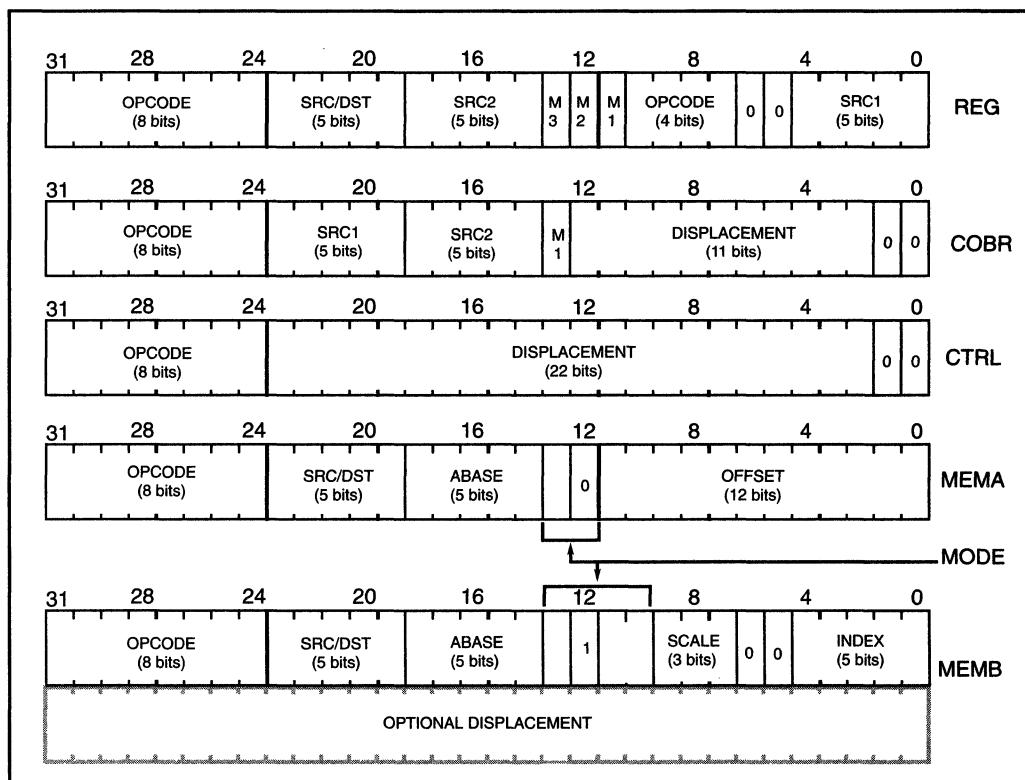
## APPENDIX D MACHINE-LEVEL INSTRUCTION FORMATS

This appendix describes the encoding format for instructions used by the i960 processors. Included is a description of the four instruction formats and how the addressing modes relate to the these formats. Refer also to APPENDIX B, OPCODES AND EXECUTION TIMES.

D

### D.1 GENERAL INSTRUCTION FORMAT

The i960 architecture defines four basic instruction encoding formats (as shown in Figure D-1 on page D-1): REG, COBR, CTRL and MEM. Most instruction uses one of these formats, which is defined by the instruction's opcode field. All instructions are one word long and all begin on word boundaries. MEM format instructions are encoded in one of two sub-formats: MEMA or MEMB. MEMB permits an optional second word to hold a displacement value. The following sections describe each format's instruction word fields.



**Figure D-1. Instruction Formats**

## MACHINE-LEVEL INSTRUCTION FORMATS

|              |   |
|--------------|---|
| OPCODE       | The opcode of the instruction. Opcode encodings are defined in section 6.1.8, "Opcode and Instruction Format" (pg. 6-6).  |
| SRC 1        | An input to the instruction. Specifies a value or address. In one case in the COBR format, this field is used to specify a register in which a result is stored.        |
| SRC 2        | An input to the instruction. Specifies a value or address.  |
| SRC/DST      | Depending on the specific instruction, this can be (1) an input value or address, (2) the register where the result is stored, or (3) both of the above.                |
| ABASE        | A register. The register's value is used in computing a memory address.   |
| INDEX        | A register. The register's value is used in computing a memory address.   |
| DISPLACEMENT | A signed two's complement number.   |
| OFFSET       | An unsigned positive number.  |
| OPTIONAL     | a signed two's complement number in case of 2-word MEMB format displacement   |
| MODE         | A specification of how a memory address for an operand is computed, and for MEMB specifies whether the instruction contains a second word to be used as a displacement. |
| SCALE        | A specification of how a register's contents are multiplied for certain addressing modes (i.e., for indexing).  |
| M1, M2, M3   | These fields further define the meaning of the SRC 1, SRC 2, and src/dest fields respectively as shown in Table D-1.  |

When a particular instruction is defined as not using a particular field, the field is ignored.

### D.2 REG FORMAT

REG format is used for operations performed on data contained in registers. Most of the i960 processor family's instructions use this format.

The opcode for the REG instructions is 12 bits long (three hexadecimal digits) and is split between bits 7 through 10 and bits 24 through 31. For example, the **addi** opcode is 591H. Here, 59H is contained in bits 24 through 31; 1H is contained in bits 7 through 10.

*src1* and *src2* fields specify the instruction's source operands. Operands can be global or local registers or literals. Mode bits (M1 for *src1* and M2 for *src2*) and the instruction type determine what an operand specifies. Table D-1 shows this relationship:

**Table D-1. Encoding of *src1* and *src2* in REG Format**

| M1 or M2 | Src1 or Src2 Operand Value | Register Number | Literal Value |
|----------|----------------------------|-----------------|---------------|
| 0        | 00000 ... 01111            | r0 ... r15      | NA            |
|          | 10000 ... 11111            | g0 ... g15      | NA            |
| 1        | 00000 ... 11111            | NA              | 0 ... 31      |

The *src/dst* field can specify a source operand, a destination operand or both, depending on the instruction. Here again, mode bit M3 determines how this field is used. If M3 is clear, the *src/dst* operand is a global or local register that is encoded as shown in Table D-2. If M3 is set, the *src/dst* operand can be used as a source-only operand that is a literal.

When a literal is specified, it is always an unsigned 5-bit value that is zero-extended to a 32-bit value and used as the operand. When the instruction defines an operand to be larger than 32 bits, values specified by literals are zero-extended to the operand size.

**Table D-2. Encoding of *src/dst* in REG Format**

| M3 | SRC/DST                  | SRC Only                 | DST Only                 |
|----|--------------------------|--------------------------|--------------------------|
| 0  | g0 ... g15<br>r0 ... r15 | g0 ... g15<br>r0 ... r15 | g0 ... g15<br>r0 ... r15 |
| 1  | Reserved                 | Literal                  | Reserved                 |

### D.3 COBR FORMAT

The COBR format is used primarily for compare-and-branch instructions. The test-if instructions also use the COBR format. The COBR opcode field is eight bits (two hexadecimal digits).

The *src1* and *src2* fields specify source operands for the instruction. The *src1* field can specify either a global or local register or a literal as determined by mode bit *m1*. The *src2* field can only specify a global or local register. Table D-3 shows the M1, *src1* relationship:

**Table D-3. Encoding of *src1* in COBR Format**

| M1 | <i>src1</i>              |
|----|--------------------------|
| 0  | g0 ... g15<br>r0 ... r15 |
| 1  | Literal                  |

## MACHINE-LEVEL INSTRUCTION FORMATS

The displacement field contains a signed two's complement number that specifies a word displacement. The processor uses this value to compute the address of a target instruction to which the processor goes as a result of a comparison. The displacement field's value can range from  $-2^{10}$  to  $2^{10}-1$ . To determine the target instruction's IP, the processor converts the displacement value to a byte displacement (i.e., multiplies the value by 4). It then adds the resulting byte displacement to the IP of the current instruction.

For the **test<cc>** instructions, only the *src1* field is used. Here, this field specifies a destination global or local register; M1 is ignored.

### D.4 CTRL FORMAT

The CTRL format is used for instructions that branch to a new IP, including the branch, **branch<cc>**, **bal** and **call** instructions; **ret** also uses this format. The CTRL opcode field is eight bits (two hexadecimal digits).

A branch target address is specified with the displacement field in the same manner as COBR format instructions. The displacement field specifies a word displacement as a signed, two's complement number in the range  $-2^{21}$  to  $2^{21}-1$ . The processor ignores the **ret** instruction's displacement field.

### D.5 MEM FORMAT

The MEM format is used for instructions that require a memory address to be computed. These instructions include the load, store and **lda** instructions. Also, the extended versions of the branch, branch-and-link and call instructions (**bx**, **balx** and **callx**) use this format.

The two MEM-format encodings are MEMA and MEMB. MEMB can optionally add a 32-bit displacement (contained in a second word) to the instruction. Bit 12 of the instruction's first word determines whether MEMA (clear) or MEMB (set) is used.

The opcode field is eight bits long for either encoding. The *src/dst* field specifies a global or local register. For load instructions, *src/dst* specifies the destination register for a word loaded into the processor from memory or, for operands larger than one word, the first of successive destination registers. For store instructions, this field specifies the register or group of registers that contain the source operand to be stored in memory.

The mode field determines the address mode used for the instruction. Table D-4 summarizes the addressing modes for the two MEM-format encodings. Fields used in these addressing modes are described in the following sections.

**Table D-4. Addressing Modes for MEM Format Instructions**

| Format | Mode | Addressing Mode                               | Address Computation                                   | # of Instr Words |
|--------|------|---|---|------------------|
| MEMA   | 00   | Absolute Offset                               | offset  | 1                |
|        | 10   | Register Indirect with Offset                 | (abase) + offset                                      | 1                |
| MEMB   | 0100 | Register Indirect                             | (abase)   | 1                |
|        | 0101 | IP with Displacement                          | (IP) + displacement + 8                               | 2                |
|        | 0110 | Reserved                                      | reserved  | NA               |
|        | 0111 | Register Indirect with Index                  | (abase) + (index) * $2^{\text{scale}}$                | 1                |
|        | 1100 | Absolute Displacement                         | displacement  | 2                |
|        | 1101 | Register Indirect w/ Displacement             | (abase) + displacement                                | 2                |
|        | 1110 | Index with Displacement                       | (index) * $2^{\text{scale}}$ + displacement           | 2                |
|        | 1111 | Register Indirect with Index and Displacement | (abase) + (index) * $2^{\text{scale}}$ + displacement | 2                |

**NOTE:**

In these address computations, a field in parentheses, e.g., (abase), indicates that the value in the specified register is used in the computation.

Usage of a reserved encoding causes generation of an OPERATION.INVALID\_OPCODE fault.

### D.5.1 MEMA Format Addressing

The MEMA format provides two addressing modes:

- absolute offset
- register indirect with offset

The *offset* field specifies an unsigned byte offset from 0 to 4096. The *abase* field specifies a global or local register that contains an address in memory.

For the absolute-offset addressing mode (*mode* = 00), the processor interprets the *offset* field as an offset from byte 0 of the current process address space; the *abase* field is ignored. Using this addressing mode along with the **Ida** instruction allows a constant in the range 0 to 4096 to be loaded into a register.

For the register-indirect-with-offset addressing mode (*mode* = 10), *offset* field value is added to the address in the *abase* register. Setting the offset value to zero creates a register indirect addressing mode; however, this operation can generally be carried out faster by using the MEMB version of this addressing mode.

### D.5.2 MEMB Format Addressing

The MEMB format provides the following seven addressing modes:

- absolute displacement
- register indirect
- register indirect with displacement
- register indirect with index and displacement
- index with displacement
- IP with displacement

The *abase* and *index* fields specify local or global registers, the contents of which are used in address computation. When the index field is used in an addressing mode, the processor automatically scales the index register value by the amount specified in the scale field. Table D-5 gives the encoding of the scale field. The optional displacement field is contained in the word following the instruction word. The displacement is a 32-bit signed two's complement value.

**Table D-5. Encoding of Scale Field**

| Scale      | Scale Factor (Multiplier) |
|------------|---------------------------|
| 000        | 1                         |
| 001        | 2                         |
| 010        | 4                         |
| 011        | 8                         |
| 100        | 16                        |
| 101 to 111 | Reserved                  |

**Note:**

Usage of a reserved encoding causes an unpredictable result.

For the IP with displacement mode, the value of the displacement field plus eight is added to the address of the current instruction.



# GLOSSARY



|  |  |
|--|--|
| <b>Address Space</b>                     | An array of bytes used to store program code, data, stacks and system data structures required to execute a program. Address space is <i>linear</i> – also called flat – and byte addressable, with addresses running contiguously from 0 to $2^{32} - 1$ . It can be mapped to read-write memory, read-only memory and memory-mapped I/O. i960 architecture does not define a dedicated, addressable I/O space.                     |
| <b>Address</b>                           | A 32-bit value in the range 0 to FFFF FFFFH used to reference in memory a single byte, half-word (2 bytes), word (4 bytes), double-word (8 bytes), triple-word (12 bytes) or quad-word (16 bytes). Choice depends on the instruction used.   |
| <b>Arithmetic Controls (AC) Register</b> | A 32-bit register that contains flags and masks used in controlling the various arithmetic and comparison operations that the processor performs. Flags and masks contained in this register include the condition code flags, integer-overflow flag and mask bit and the no-imprecise-faults (NIF) bit. All unused bits in this register are reserved and must be set to 0.   |
| <b>Asynchronous Faults</b>               | Faults that occur with no direct relationship to a particular instruction in the instruction stream. When an asynchronous fault occurs, the address of the faulting instruction in the fault record and the saved IP are undefined. i960 core architecture does not define any fault types that are asynchronous.  |
| <b>Big Endian</b>                        | The controller reads or writes a data word's least-significant byte to the bus' eight most-significant data lines (D31:24). Big endian systems store the least-significant byte at the highest byte address in memory. So, if a big endian ordered word is stored at address 600, the least-significant byte is stored at address 603 and the most-significant byte at address 600. Compare with little endian.                      |
| <b>Condition Code Flags</b>              | AC register bits 0, 1 and 2. The condition code flags indicate the results of certain instructions – usually compare instructions. Other instructions, such as conditional branch instructions, examine these flags and perform functions according to their state. Once the processor sets the condition code flags, they remain unchanged until the processor executes another instruction that uses these flags to store results. |
| <b>Execution Mode Flag</b>               | PC register bit 1. This flag determines whether the processor is operating in user mode (0) or supervisor mode (1).  |

## GLOSSARY

|   |  |
|---|--|
| <b>Fault Call</b>                       | An implicit call to a fault handling procedure. The processor performs fault calls automatically without any intervention from software. It gets pointers to fault handling procedures from the fault table.   |
| <b>Fault Table</b>                      | An architecture-defined data structure that contains pointers to fault handling procedures. Each fault table entry is associated with a particular fault type. When the processor generates a fault, it uses the fault table to select the proper fault handling procedure for the type of fault condition detected.   |
| <b>Fault</b>                            | An event that the processor generates to indicate that, while executing the program, a condition arose which could cause the processor to go down a wrong and possibly disastrous path. One example of a fault condition is a divisor operand of zero in a divide operation; another example is an instruction with an invalid opcode.   |
| <b>FP</b>                               | See Frame Pointer.   |
| <b>Frame Pointer (FP)</b>               | The address of the first byte in the current (topmost) stack frame of the procedure stack. The FP is contained in global register g15.   |
| <b>Frame</b>                            | See Stack Frame.   |
| <b>Global Registers</b>                 | A set of 16 general-purpose registers (g0 through g15) whose contents are preserved across procedure boundaries. Global registers are used for general storage of data and addresses and for passing parameters between procedures.  |
| <b>Hard Reset</b>                       | The assertion of the RESET# pin; equivalent to powerup.  |
| <b>IBR</b>                              | See Initialization Boot Record.  |
| <b>IMI</b>                              | See Initial Memory Image.  |
| <b>Inprecise Faults</b>                 | Faults that are allowed to be generated out-of-order from where they occur in the instruction stream. When an imprecise fault is generated, the processor indicates the address of the faulting instruction, but it does not guarantee that software will be able to recover from the fault and resume execution of the program with no break in the program's control flow. The NIF bit in the arithmetic controls register determines whether all faults must be precise (1) or some faults are allowed to be imprecise (0). |
| <b>Initialization Boot Record (IBR)</b> | One of three IMI components, IBR is the primary data structure required to initialize the i960 CA microprocessor. IBR is 12-word structure which must be located at address FFFF FF00H.  |

|                                   |  |
|-----------------------------------|--|
| <b>Initial Memory Image (IMI)</b> | Comprises the minimum set of data structures the processor needs to initialize its system. Performs three functions for the processor: 1) provides initial configuration information for the core and integrated peripherals; 2) provides pointers to system data structures and the first instruction to be executed after processor initialization; 3) provides checksum words that the processor uses in self-test at startup. See also IBR, PRCB and System Data Structures. |
| <b>Instruction Cache</b>          | A memory array used for temporary storage of instructions fetched from main memory. Its purpose is to streamline instruction execution by reducing the number of instruction fetches required to execute a program.  |
| <b>Instruction Pointer (IP)</b>   | A 32-bit register that contains the address (in the address space) of the instruction currently being executed. Since instructions are required to be aligned on word boundaries in memory, the IP's two least-significant bits are always zero.   |
| <b>Integer Overflow Flag</b>      | AC register bit 8. When integer overflow faults are masked, the processor sets the integer overflow flag whenever integer overflow occurs to indicate that the fault condition has occurred even though the fault has been masked. If the fault is not masked, the fault is allowed to occur and the flag is not set.  |
| <b>Integer Overflow Mask Bit</b>  | AC register bit 12. This bit masks the integer overflow fault.   |
| <b>Interrupt Call</b>             | An implicit call to an interrupt handling procedure. The processor performs interrupt calls automatically without any intervention from software. It gets vectors (pointers) to interrupt handling procedures from the interrupt table.  |
| <b>Interrupt Stack</b>            | Stack the processor uses when it executes interrupt handling procedures.   |
| <b>Interrupt Table</b>            | An architecturally-defined data structure that contains vectors to interrupt handling procedures and fields for storing pending interrupts. When the processor receives an interrupt, it uses the vector number that accompanies the interrupt to locate an interrupt vector in the interrupt table. The interrupt table's pending interrupt fields contain bits that indicate priorities and vector numbers of interrupts waiting to be serviced.                               |
| <b>Interrupt Vector</b>           | A pointer to an interrupt handling procedure. In the i960 architecture, interrupt vectors are stored in the interrupt table.   |
| <b>Interrupt</b>                  | An event that causes program execution to be suspended temporarily to allow the processor to handle a more urgent chore.   |
| <b>Leaf Procedure</b>             | Leaf procedures call no other procedures. They are called "leaf procedures" because they reside at the "leaves" of the call tree.  |

|                                      |  |
|--------------------------------------|--|
| <b>Literals</b>                      | A set of 32 ordinal values ranging from 0 to 31 (5 bits) that can be used as operands in certain instructions.   |
| <b>Little Endian</b>                 | The controller reads or writes a data word's least-significant byte to the bus' eight least-significant data lines (D7:0). Little endian systems store a word's least-significant byte at the lowest byte address in memory. For example, if a little endian ordered word is stored at address 600, the least-significant byte is stored at address 600 and the most-significant byte at address 603. Compare with big endian. |
| <b>Local Call</b>                    | A procedure call that does not require a switch in the current execution mode or a switch to another stack. Local calls can be made explicitly through the <b>call</b> , <b>callx</b> and <b>calls</b> instructions and implicitly through the fault call mechanism.   |
| <b>Local Registers</b>               | A set of 16 general-purpose data registers (r0 through r15) whose contents are associated with the procedure currently being executed. Local registers hold the local variables for a procedure. Each time a procedure is called, the processor automatically allocates a new set of local registers for that procedure and saves the local registers for the calling procedure.   |
| <b>Memory</b>                        | Array to which address space is mapped. Memory can be read-write, read-only or a combination of the two. A memory address is generally synonymous with an address in the address space.  |
| <b>“Natural” Fill Policy</b>         | The processor fetches only the amount of data that is requested by a load (i.e., a word, long word, etc.) on a data cache miss. Exceptions are byte and short word accesses, which are always promoted to words.   |
| <b>NIF</b>                           | See No Imprecise Faults Bit.   |
| <b>NMI</b>                           | See Non Maskable Interrupt.  |
| <b>No Imprecise Faults (NIF) Bit</b> | AC register bit 15. This flag determines whether or not imprecise faults are allowed to occur. If set, all faults are required to be precise; if clear, certain faults can be imprecise.   |
| <b>Non Maskable Interrupt (NMI)</b>  | Provides an interrupt that cannot be masked and has a higher priority than priority-31 interrupts and priority-31 process priority. The core services NMI requests immediately.  |
| <b>Parallel Faults</b>               | A condition which occurs when multiple execution units, executing instructions in parallel, report multiple faults simultaneously. Setting the NIF bit prohibits execution conditions which could cause parallel faults.   |

|                                       |   |
|---------------------------------------|---|
| <b>Pending Interrupt</b>              | An interrupt that the processor saves to be serviced at a later time. When the processor receives an interrupt, it compares the interrupt's priority with the priority of the current processing task. If the priority of the interrupt is equal to or less than that of the current task, the processor saves the interrupt's priority and vector number in the pending interrupt fields of the interrupt table, then continues work on the current processing task. |
| <b>PFP</b>                            | See Previous Frame Pointer.   |
| <b>Pointer</b>                        | An address in the address space (or memory). The term pointer generally refers to the first byte of a procedure or data structure or a specific byte location in a stack.   |
| <b>PRCB</b>                           | See Process Control Block.  |
| <b>Precise Faults</b>                 | Faults generated in the order in which they occur in the instruction stream and with sufficient fault information to allow software to recover from the faults without altering program's control flow. The AC register NIF bit and the <b>syncf</b> instruction allow software to force all faults to be precise.  |
| <b>Previous Frame Pointer (PFP)</b>   | The address of the previous stack frame's first byte. It is contained in bits 4 through 31 of local register r0.  |
| <b>Priority Field</b>                 | PC register bits 16 through 20. This field determines processor priority (from 0 to 31). When the processor is in the executing state, it sets its priority according to this value. It also uses this field to determine whether to service an interrupt immediately or to save the interrupt for later service.   |
| <b>Priority</b>                       | A value from 0 to 31 that indicates the priority of a program or interrupt; highest priority is 31. The processor stores the priority of the task (program or interrupt) that it is currently working on in the priority field of the PC register. See also NMI.  |
| <b>Process Control Block (PRCB)</b>   | One of three (IMI) components, PRCB contains base addresses for system data structures and initial configuration information for the core and integrated peripherals.   |
| <b>Process Controls (PC) Register</b> | A 32-bit register that contains miscellaneous pieces of information used to control processor activity and show current processor state. Flags and fields in this register include the trace enable bit, execution mode flag, trace fault pending flag, state flag, priority field and internal state field. All unused bits in this register are reserved and must be set to 0.  |

|   |  |
|---|--|
| <b>Register Scoreboarding</b>           | Internal flags that indicate a particular register or group of registers is being used in an operation. This feature enables the processor to execute some instructions in parallel and out-of-order. When the processor begins executing an instruction, it sets the scoreboard flag for the destination register in use by that instruction. If the instructions that follow do not use scoreboxed registers, the processor is able to execute one or more of those instructions concurrently with the first instruction.                              |
| <b>Return Instruction Pointer (RIP)</b> | The address of the instruction following a call or branch-and-link instruction that the processor is to execute after returning from the called procedure. The RIP is contained in local register r2. When the processor executes a procedure call, it sets the RIP to the address of the instruction immediately following the procedure call instruction.  |
| <b>Return Type Field</b>                | Bits 0, 1 and 2 of local register r0. When a procedure call is made using the integrated call and return mechanism, this field indicates the call type: local, supervisor, interrupt or fault. The processor uses this information to select the proper return mechanism when returning from the called procedure.   |
| <b>RIP</b>                              | See Return Instruction Pointer.  |
| <b>Soft Reset</b>                       | Re-running of the Reset microcode without physically asserting the RESET# pin or removing power from the CPU.  |
| <b>SP</b>                               | See Stack Pointer.   |
| <b>Stack Frame</b>                      | A block of bytes on a stack used to store local variables for a specific procedure. Another term for a stack frame is an <i>activation record</i> . Each procedure that the processor calls has its own stack frame associated with it. A stack frame is always aligned on a 64-byte boundary. The first 64 bytes in a stack frame are reserved for storage of the local registers associated with the procedure. The frame pointer (FP) and stack pointer (SP) for a particular frame indicate location and boundaries of a stack frame within a stack. |
| <b>Stack Pointer (SP)</b>               | The address of the last byte in the current (topmost) frame of the procedure stack. The SP is contained in local register r1.  |
| <b>Stack</b>                            | A contiguous array of bytes in the address space that grows from low addresses to high addresses. It consists of contiguous frames, one frame for each active procedure. i960 architecture defines three stacks: local, supervisor and interrupt.  |
| <b>State Flag</b>                       | PC register bit 10. This flag indicates to software that the processor is currently executing a program (0) or servicing an interrupt (1).   |
| <b>State</b>                            | The type of task that the processor is currently working on: a program or an interrupt handling procedure. The processor sets the PC register state flag to indicate its current state.  |

|                                     |   |
|-------------------------------------|---|
| <b>Status and Control Registers</b> | A set of four architecturally-defined registers – each 32-bits in length – that contain status and control information used in controlling program flow. These registers include the instruction pointer (IP), AC register, PC register and TC register.  |
| <b>Supervisor Call</b>              | A system call (made with the <b>calls</b> instruction) where the entry type of the called procedure is 102. If the processor is in user mode when a supervisor call is made, it switches to the supervisor stack and to supervisor mode.  |
| <b>Supervisor Mode</b>              | One of two execution modes – user and supervisor – that the processor can be in. The processor uses the supervisor stack when in supervisor mode. Also, while in supervisor mode, software is allowed to execute the <b>modpc</b> instruction and any other implementation-defined instructions that are designed to be supervisor mode instructions.   |
| <b>Supervisor Stack Pointer</b>     | The address of the first byte of the supervisor stack. The supervisor stack pointer is contained in bytes 12 through 15 of the system procedure table and the trace table.  |
| <b>Supervisor Stack</b>             | The procedure stack that the processor uses when in supervisor mode.  |
| <b>System Call</b>                  | An explicit procedure call made with the <b>calls</b> instruction. The two types of system calls are a system-local call and system-supervisor call. On a system call, the processor gets a pointer to the system procedure through the system procedure table.   |
| <b>System Data Structures</b>       | One of three IMI components. The following system data structures contain values the processor requires for initialization: PRCB, IBR, system procedure table, control table, interrupt table.  |
| <b>System Procedure Table</b>       | An architecturally-defined data structure that contains pointers to system procedures and (optionally) to fault handling procedures. It also contains the supervisor stack pointer and the trace control flag.  |
| <b>Trace Table</b>                  | An architecturally-defined data structure that contains pointers to trace-fault-handling procedures. The trace table has the same structure as the system procedure table.  |
| <b>Trace Control Bit</b>            | Bit 0 of byte 12 of the system procedure table. This bit specifies the new value of the trace enable bit when a supervisor call causes a switch from user mode to supervisor mode. Setting this bit to 1 enables tracing; setting it to 0 disables tracing.   |
| <b>Trace Controls (TC) Register</b> | A 32-bit register that controls processor tracing facilities. This register contains one event bit and one mode bit for each trace fault subtype (i.e., instruction, branch, call, return, prereturn, supervisor and breakpoint). The mode bits enable the various tracing modes; the event flags indicate that a particular type of trace event has been detected. All the unused bits in this register are reserved and must be set to 0. |

|                                 |  |
|---------------------------------|--|
| <b>Trace Enable Bit</b>         | PC register bit 0. This bit determines whether trace faults are to be generated (1) or not generated (0).  |
| <b>Trace Fault Pending Flag</b> | PC register bit 10. This flag indicates that a trace event has been detected (1) but not yet generated. Whenever the processor detects a trace fault at the same time that it detects a non-trace fault, it sets the trace fault pending flag then calls the fault handling procedure for the non-trace fault. On return from the fault procedure for the non-trace fault, the processor checks the trace fault pending flag. If set, it generates the trace fault and handles it. |
| <b>Tracing</b>                  | The ability of the processor to detect execution of certain instruction types, such as branch, call and return. When tracing is enabled, the processor generates a fault whenever it detects a trace event. A trace fault handler can then be designed to call a debug monitor to provide information on the trace event and its location in the instruction stream.   |
| <b>User Mode</b>                | One of two execution modes – user and supervisor – that the processor can be in. When the processor is in user mode, it uses the local stack and is not allowed to use the <b>modpc</b> instruction or any other implementation-defined instruction that is designed to be used only in supervisor mode.   |
| <b>Vector Number</b>            | The number of an entry in the interrupt table where an interrupt vector is stored. The vector number also indicates the priority of the interrupt.   |
| <b>Vector</b>                   | See Interrupt Vector.  |



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Almac Arrow Electronics  
8544 Baxter Place  
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Tel: (604) 420-4101  
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