## Feature Summary

- 32-bit load/store RISC architecture
- Up to 15 general-purpose 32-bit registers
- 32-bit Stack Pointer, Program Counter, and Link Register reside in register file
- Fully orthogonal instruction set
- Pipelined architecture allows one instruction per clock cycle for most instructions
- Byte, half-word, word and double word memory access
- Fast interrupts and multiple interrupt priority levels
- Optional branch prediction for minimum delay branches
- Privileged and unprivileged modes enabling efficient and secure Operating Systems
- Innovative instruction set together with variable instruction length ensuring industry leading code density
- Optional DSP extention with saturated arithmetic, and a wide variety of multiply instructions
- Optional extensions for Java, SIMD, Read-Modify-Write to memory, and Coprocessors
- Architectural support for efficient On-Chip Debug solutions
- Optional MPU or MMU allows for advanced operating systems
- FlashVault™ support through Secure State for executing trusted code alongside nontrusted code on the same CPU

# AVR32

# Architecture Document

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# 1. Introduction

AVR32 is a new high-performance 32-bit RISC microprocessor core, designed for cost-sensitive embedded applications, with particular emphasis on low power consumption and high code density. In addition, the instruction set architecture has been tuned to allow for a variety of microarchitectures, enabling the AVR32 to be implemented as low-, mid- or high-performance processors. AVR32 extends the AVR family into the world of 32- and 64-bit applications.

## 1.1 The AVR family

The AVR family was launched by Atmel in 1996 and has had remarkable success in the 8-and 16-bit flash microcontroller market. AVR32 is complements the current AVR microcontrollers. Through the AVR32 family, the AVR is extended into a new range of higher performance applications that is currently served by 32- and 64-bit processors

To truly exploit the power of a 32-bit architecture, the new AVR32 architecture is not binary compatible with earlier AVR architectures. In order to achieve high code density, the instruction format is flexible providing both compact instructions with 16 bits length and extended 32-bit instructions. While the instruction length is only 16 bits for most instructions, powerful 32-bit instructions are implemented to further increase performance. Compact and extended instructions can be freely mixed in the instruction stream.

## 1.2 The AVR32 Microprocessor Architecture

The AVR32 is a new innovative microprocessor architecture. It is a fully synchronous synthesisable RTL design with industry standard interfaces, ensuring easy integration into SoC designs with legacy intellectual property (IP). Through a quantitative approach, a large set of industry recognized benchmarks has been compiled and analyzed to achieve the best code density in its class of microprocessor architectures. In addition to lowering the memory requirements, a compact code size also contributes to the core's low power characteristics. The processor supports byte and half-word data types without penalty in code size and performance.

Memory load and store operations are provided for byte, half-word, word and double word data with automatic sign- or zero extension of half-word and byte data. The C-compiler is closely linked to the architecture and is able to exploit code optimization features, both for size and speed.

In order to reduce code size to a minimum, some instructions have multiple addressing modes. As an example, instructions with immediates often have a compact format with a smaller immediate, and an extended format with a larger immediate. In this way, the compiler is able to use the format giving the smallest code size.

Another feature of the instruction set is that frequently used instructions, like add, have a compact format with two operands as well as an extended format with three operands. The larger format increases performance, allowing an addition and a data move in the same instruction in a single cycle.

Load and store instructions have several different formats in order to reduce code size and speed up execution:

- Load/store to an address specified by a pointer register
- Load/store to an address specified by a pointer register with postincrement

- Load/store to an address specified by a pointer register with predecrement
- Load/store to an address specified by a pointer register with displacement
- Load/store to an address specified by a small immediate (direct addressing within a small page)
- Load/store to an address specified by a pointer register and an index register.

The register file is organized as 16 32-bit registers and includes the Program Counter, the Link Register, and the Stack Pointer. In addition, one register is designed to hold return values from function calls and is used implicitly by some instructions.

The AVR32 core defines several micro architectures in order to capture the entire range of applications. The microarchitectures are named AVR32A, AVR32B and so on. Different microarchitectures are suited to different end applications, allowing the designer to select a microarchitecture with the optimum set of parameters for a specific application.

### 1.2.1 Exceptions and Interrupts

The AVR32 incorporates a powerful exception handling scheme. The different exception sources, like Illegal Op-code and external interrupt requests, have different priority levels, ensuring a well-defined behavior when multiple exceptions are received simultaneously. Additionally, pending exceptions of a higher priority class may preempt handling of ongoing exceptions of a lower priority class. Each priority class has dedicated registers to keep the return address and status register thereby removing the need to perform time-consuming memory operations to save this information.

There are four levels of external interrupt requests, all executing in their own context. The contexts can provide a number of dedicated registers for the interrupts to use directly ensuring low latency. High priority interrupts may have a larger number of shadow registers available than low priority interrupts. An interrupt controller does the priority handling of the external interrupts and provides the prioritized interrupt vector to the processor core.

### 1.2.2 Java Support

Java hardware acceleration is available as an option, in the form of a Java Card or Java Virtual Machine hardware implementation.

### 1.2.3 FlashVault

Revision 3 of the AVR32 architecture introduced a new CPU state called Secure State. This state is instrumental in the new security technology named FlashVault. This innovation allows the on-chip flash and other memories to be partially programmed and locked, creating a safe on-chip storage for secret code and valuable software intellectual property. Code stored in the FlashVault will execute as normal, but reading, copying or debugging the code is not possible. This allows a device with FlashVault code protection to carry a piece of valuable software such as a math library or an encryption algorithm from a trusted location to a potentially untrustworthy partner where the rest of the source code can be developed, debugged and programmed.

## 1.3 Microarchitectures

The AVR32 architecture defines different microarchitectures. This enables implementations that are tailored to specific needs and applications. The microarchitectures provide different performance levels at the expense of area and power consumption. The following microarchitectures are defined:

### 1.3.1 AVR32A

The AVR32A microarchitecture is targeted at cost-sensitive, lower-end applications like smaller microcontrollers. This microarchitecture does not provide dedicated hardware registers for shadowing of register file registers in interrupt contexts. Additionally, it does not provide hardware registers for the return address registers and return status registers. Instead, all this information is stored on the system stack. This saves chip area at the expense of slower interrupt handling.

Upon interrupt initiation, registers R8-R12 are automatically pushed to the system stack. These registers are pushed regardless of the priority level of the pending interrupt. The return address and status register are also automatically pushed to stack. The interrupt handler can therefore use R8-R12 freely. Upon interrupt completion, the old R8-R12 registers and status register are restored, and execution continues at the return address stored popped from stack.

The stack is also used to store the status register and return address for exceptions and *scall*. Executing the *rete* or *rets* instruction at the completion of an exception or system call will pop this status register and continue execution at the popped return address.

### 1.3.2 AVR32B

The AVR32B microarchitecture is targeted at applications where interrupt latency is important. The AVR32B therefore implements dedicated registers to hold the status register and return address for interrupts, exceptions and supervisor calls. This information does not need to be written to the stack, and latency is therefore reduced. Additionally, AVR32B allows hardware shadowing of the registers in the register file. The INT0 to INT3 contexts may have dedicated versions of the registers in the register file, allowing the interrupt routine to start executing immediately.

The *scall*, *rete* and *rets* instructions use the dedicated status register and return address registers in their operation. No stack accesses are performed.

# 2. Programming Model

This chapter describes the programming model and the set of registers accessible to the user.

## 2.1 Data Formats

The AVR32 processor supports the data types shown in Table 2-1 on page 5:

**Table 2-1.** Overview of execution modes, their priorities and privilege levels.

| Type | Data Width |
|---|---|
| Byte | 8 bits |
| Halfword | 16 bits |
| Word | 32 bits |
| Double Word | 64 bits |

When any of these types are described as unsigned, the N bit data value represents a non-negative integer in the range 0 to + $2^N$-1.

When any of these types are described as signed, the N bit data value represents an integer in the range of -$2^{N-1}$ to +$2^{N-1}$-1, using two's complement format.

Some instructions operate on fractional numbers. For these numbers, the data value represents a fraction in the range of -1 to +1-$2^{-(N-1)}$, using two's complement format.

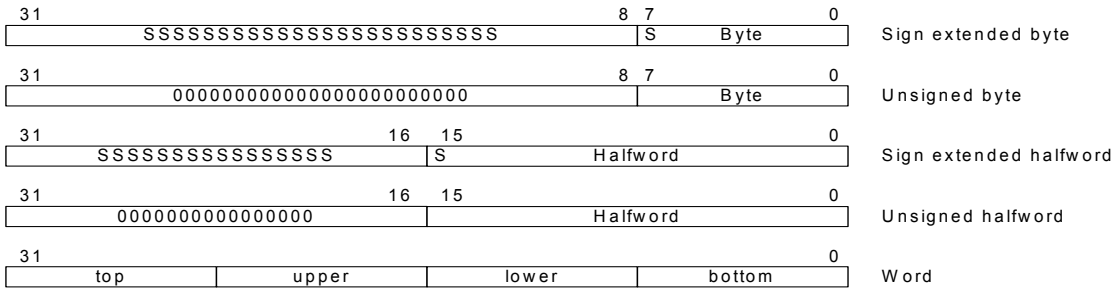
## 2.2 Data Organization

Data is usually stored in a big-endian way, see Figure 2-1 on page 5. This means that when multi-byte data is stored in memory, the most significant byte is stored at the lowest address. All instructions are interpreted as being big-endian. However, in order to support data transfers that are little-endian, special endian-translating load and store instructions are defined.

The register file can hold data of different formats. Both byte, halfword (16-bit) and word (32-bit) formats can be represented, and byte and halfword formats are supported in both unsigned and signed 2's complement formats. Some instructions also use doubleword operands. Doubleword data are placed in two consecutive registers. The most significant word is in the uppermost register. Valid register pairs are R1:R0, R3:R2, R5:R4, R7:R6, R9:R8, R11:R10 and R13:R12.

Load and store operations that transfer bytes or halfwords, automatically zero-extends or sign-extends the bytes or half-words as they are loaded.

**Figure 2-1.** Data representation in the register file



AVR32 can access data of size byte, halfword, word and doubleword using dedicated instructions. The memory system can support unaligned accesses for selected load/store instructions in some implementations. Any other unaligned access will cause an address exception.

For performance reasons, the user should make sure that the stack always is word aligned. This means that only word instructions can be used to access the stack. When manipulating the stack pointer, the user has to ensure that the result is word aligned before trying to load and store data on the stack. Failing to do so will result in performance penalties. Code will execute correctly if the stack is unaligned but with a significant performance penalty.

## 2.3 Instruction Organization

The AVR32 instruction set has both compact and extended instructions. Compact instructions denotes the instructions which have a length of 16 bits while extended instructions have a length of 32 bits.

All instructions must be placed on halfword boundaries, see Table 2-2 on page 6. Extended instructions can be both aligned and unaligned to halfword boundaries. In normal instruction flow, the instruction buffer will always contain enough entries to ensure that compact, aligned extended and unaligned extended instructions can be issued in a single cycle.

Change-of-flow operations such as branches, jumps, calls and returns may in some implementations require the instruction buffer to be flushed. The user should consult the Technical Reference Manual for the specific implementation in order to determine how alignment of the branch target address affects performance.

**Table 2-2.** Instructions are stored in memory in a big endian fashion and must be aligned on half word boundaries

| | | **Word Address** |
|---|---|---|
| I | J | N+24 |
| H1 | H2 | N+20 |
| F2 | G | N+16 |
| E2 | F1 | N+12 |
| D | E1 | N+8 |
| C1 | C2 | N+4 |
| A | B | N |

| **Byte Address** | | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |

| **Byte Address** | | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |

## 2.4 Processor States

### 2.4.1 Normal RISC State

The AVR32 processor supports several different execution contexts as shown in Table 2-3 on page 7.

**Table 2-3.** Overview of execution modes, their priorities and privilege levels.

| Priority | Mode | Security | Description |
|---|---|---|---|
| 1 | Non Maskable Interrupt | Privileged | Non Maskable high priority interrupt mode |
| 2 | Exception | Privileged | Execute exceptions |
| 3 | Interrupt 3 | Privileged | General purpose interrupt mode |
| 4 | Interrupt 2 | Privileged | General purpose interrupt mode |
| 5 | Interrupt 1 | Privileged | General purpose interrupt mode |
| 6 | Interrupt 0 | Privileged | General purpose interrupt mode |
| N/A | Supervisor | Privileged | Runs supervisor calls |
| N/A | Application | Unprivileged | Normal program execution mode |

Mode changes can be made under software control, or can be caused by external interrupts or exception processing. A mode can be interrupted by a higher priority mode, but never by one with lower priority. Nested exceptions can be supported with a minimal software overhead.

When running an operating system on the AVR32, user processes will typically execute in the application mode. The programs executed in this mode are restricted from executing certain instructions. Furthermore, most system registers together with the upper halfword of the status register cannot be accessed. Protected memory areas are also not available. All other operating modes are privileged and are collectively called System Modes. They have full access to all privileged and unprivileged resources. After a reset, the processor will be in supervisor mode.

### 2.4.2 Debug State

The AVR32 can be set in a debug state, which allows implementation of software monitor routines that can read out and alter system information for use during application development. This implies that all system and application registers, including the status registers and program counters, are accessible in debug state. The privileged instructions are also available.

All interrupt levels are by default disabled when debug state is entered, but they can individually be switched on by the monitor routine by clearing the respective mask bit in the status register.

Debug state can be entered as described in the Technical Reference Manual.

Debug state is exited by the *retd* instruction.

### 2.4.3 Java State

Some versions of the AVR32 processor core comes with a Java Extension Module (JEM). The processor can be set in a Java State where normal RISC operations are suspended. The Java state is described in chapter 3.

### 2.4.4 Secure State

The secure state added in the AVR32 Architecture revision 3 allows executing secure or trusted software in alongside nonsecure or untrusted software on the same processor. Hardware mech-

anisms are in place to make sure the nonsecure software can not read or modify instruction or data belonging to the secure software. The secure state is described in chapter 4.

## 2.5 Entry and Exit Mechanism

Table 2-4 on page 8 illustrates how the different states and modes are entered and exited.

**Table 2-4.** Entry and exit from states, modes and functions

| | Entry method | Exit method |
|---|---|---|
| Non-maskable Interrupt | Signal on NMI line | rete |
| Exception Mode | Internal error signal generated | rete |
| Interrupt3 | Signal on INT3 line | rete |
| Interrupt2 | Signal on INT2 line | rete |
| Interrupt1 | Signal on INT1 line | rete |
| Interrupt0 | Signal on INT0 line | rete |
| Supervisor Mode | *scall* instruction | rets |
| Application Mode | Returned to from any of the above modes | Can not be exited from |
| Subprogram | Function call | *ret{cond}*, *ldm*, *popm*, *mov PC, LR* |
| Secure state | *sscall* | *retss* |

## 2.6 Register File

Each of AVR32's normal operation modes described in Section 2.4.1 "Normal RISC State" on page 7 has a dedicated context. Note that the Stack Pointer (SP), Program Counter (PC) and the Link Register (LR) are mapped into the register file, making the effective register count for each context 13 general purpose registers. The mapping of SP, PC and LR allows ordinary instructions, like additions or subtractions, to use these registers. This results in efficient addressing of memory.

Register R12 is designed to hold return values from function calls, and the conditional return with move and test instruction use this register as an implicit return value operand. The load multiple and pop multiple instructions have the same functionality, which enables them to be used as return instructions.

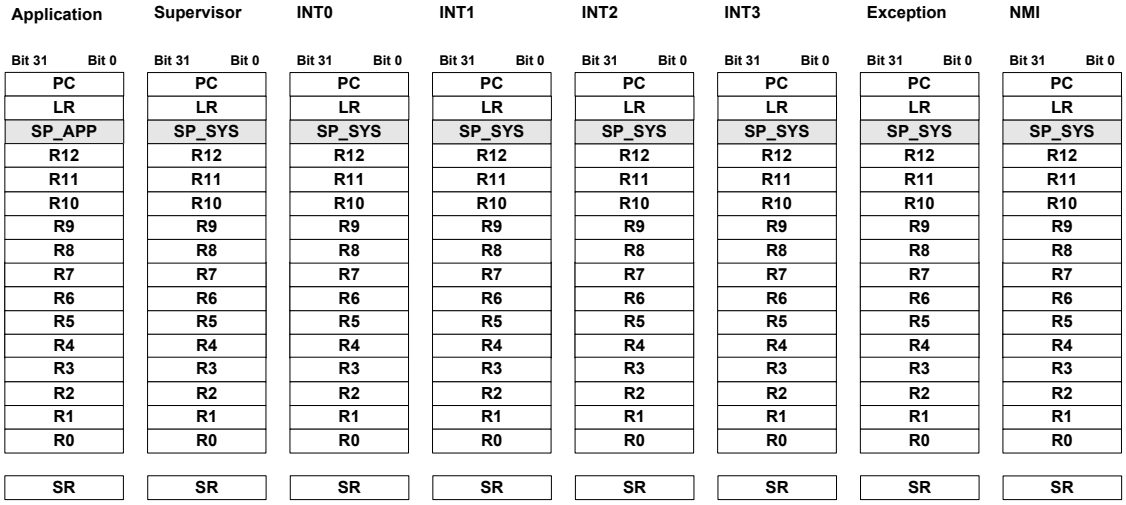
The AVR32 core's orthogonal instruction set allows all registers in the register file to be used as pointers.

### 2.6.1 Register file in AVR32A

The AVR32A is targeted for cost-sensitive applications. Therefore, no hardware-shadowing of registers is provided, see Figure 2-2 on page 9. All data that must be saved between execution states are placed on the system stack, not in dedicated registers as done in AVR32B. A shadowed stack pointer is still provided for the privileged modes, facilitating a dedicated system stack.

When an exception occurs in an AVR32A-compliant implementation, the status register and return address are pushed by hardware onto the system stack. When an INT0, INT1, INT2 or INT3 occurs, the status register, return address, R8-R12 and LR are pushed on the system stack. The corresponding registers are popped from stack by the *rete* instruction. The scall and rets instructions also use the system stack to store the return address and status register.

**Figure 2-2.** Register File in AVR32A

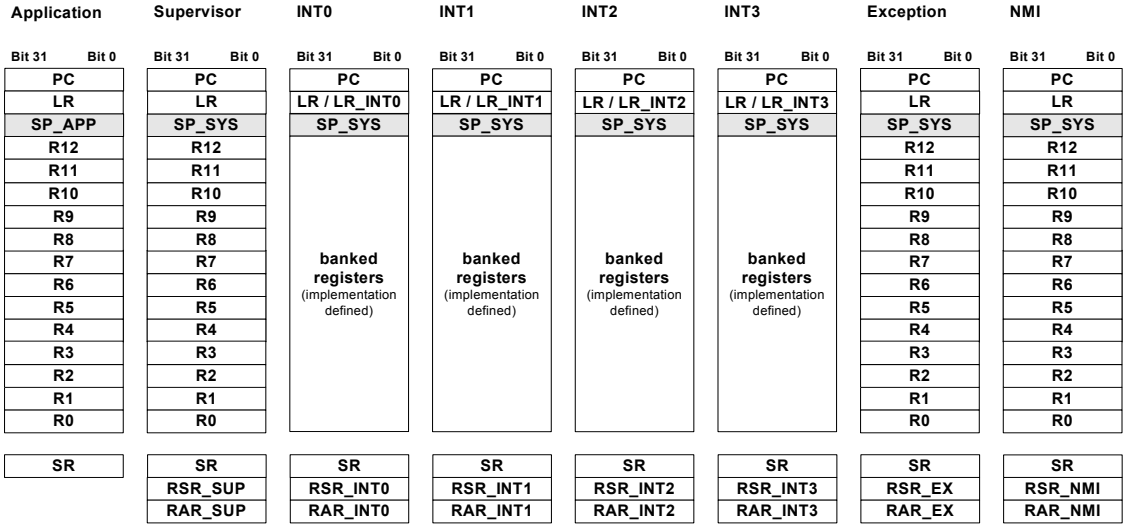



### 2.6.2 Register File in AVR32B

The AVR32B allows separate register files for the interrupt and exception modes, see Figure 2-3 on page 9. These modes have a number of implementation defined shadowed registers in order to speed up interrupt handling. The shadowed registers are automatically mapped in depending on the current execution mode.

All contexts, except Application, have a dedicated Return Status Register (RSR) and Return Address Register (RAR). The RSR registers are used for storing the Status Register value in the context to return to. The RAR registers are used for storing the address in the context to return to. The RSR and RAR registers eliminates the need to temporarily store the Status Register and return address to stack when entering a new context.

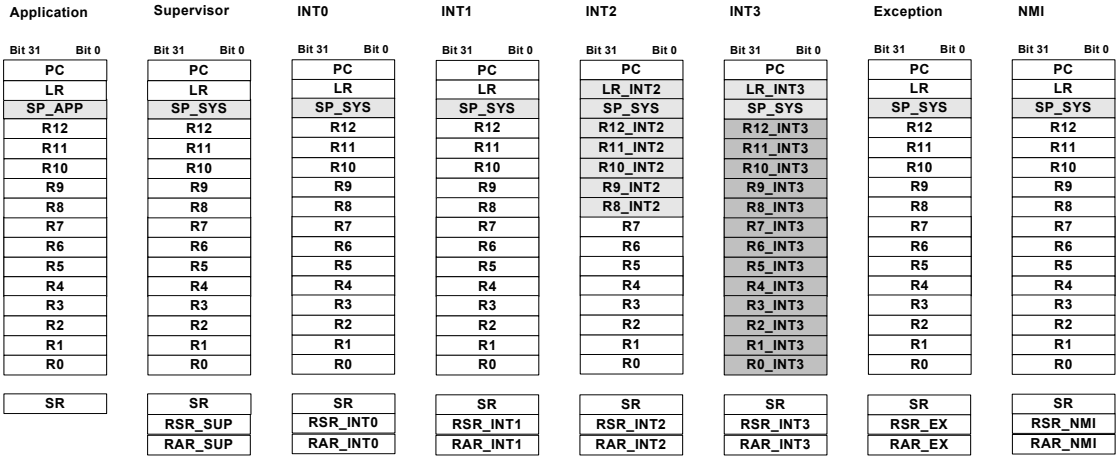
**Figure 2-3.** Register File in AVR32B




The register file is designed with an implementation specific part and an architectural defined part. Depending on the implementation, each of the interrupt modes can have different configu-

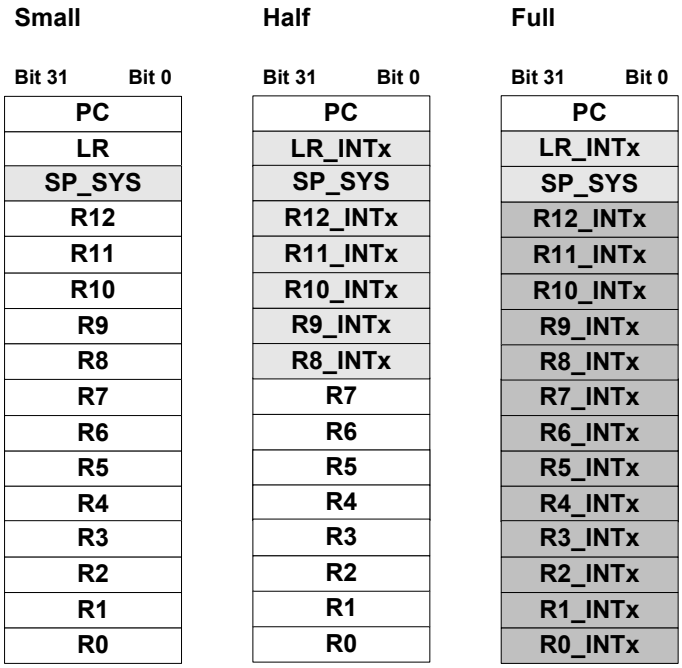
rations of shadowed registers. This allows for maximum flexibility in targeting the processor for different application, see Figure 2-4 on page 10.

**Figure 2-4.** A typical AVR32B register file implementation




Three different shadowing schemes are offered, small, half and full, ranging from no general registers shadowed to all general registers shadowed, see Figure 2-5 on page 10.

**Figure 2-5.** AVR32 offers three different models for shadowed registers.




## 2.7 The Stack Pointer

Since the Stack Pointer (SP) is located in the register file, it can be addressed as an ordinary register. This simplifies allocation and access of local variables and parameters. The Stack Pointer is also used implicitly by several instructions.

The system modes have a shadowed stack pointer different from the application mode stack pointer. This allows having a separate system stack.

## 2.8 The Program Counter

The Program Counter (PC) contains the address of the instruction being executed. The memory space is byte addressed. With the exception of Java state, the instruction size is a multiple of 2 bytes and the LSB of the Program Counter is fixed to zero. The PC is automatically incremented in normal program flow, depending on the size of the current instruction.

The PC is mapped into the register file and it can be used as a source or destination operand in all instructions using register operands. This includes arithmetical or logical instructions and load/store instructions. Instructions using PC as destination register are treated the same way as jump instructions. This implies that the pipeline is flushed, and execution resumed at the address specified by the new PC value.

## 2.9 The Link Register

The general purpose register R14 is used as a Link Register in all modes. The Link Register holds subroutine return addresses. When a subroutine call is performed by a variant of the *call* instruction, LR is set to hold the subroutine return address. The subroutine return is performed by copying LR back to the program counter, either explicitly by a *mov* instruction, by using a *ldm* or *popm* instruction or a *ret* instruction.

The Link Register R14 can be used as a general-purpose register at all other times.

## 2.10 The Status Register

The Status Register (SR) is split into two halfwords, one upper and one lower, see Figure 2-6 on page 11 and Figure 2-7 on page 12. The lower halfword contains the C, Z, N, V and Q flags, while the upper halfword contains information about the mode and state the processor executes in. The upper halfword can only be accessed from a privileged mode.

**Figure 2-6.** The Status Register high halfword

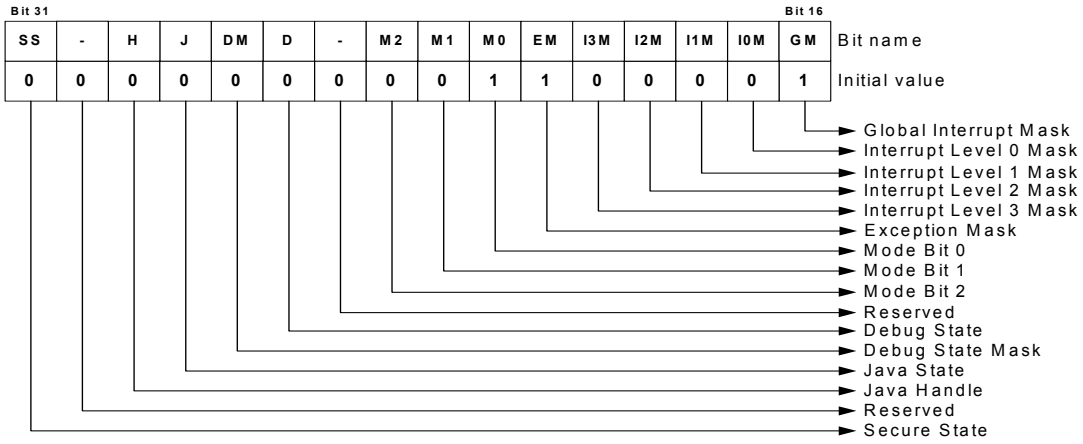
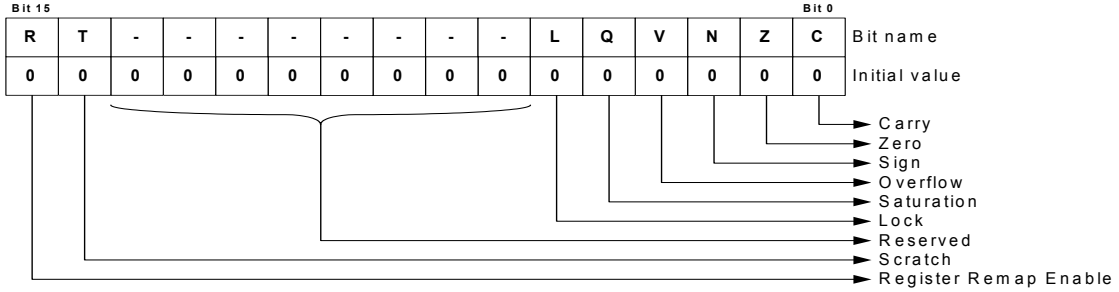


**Figure 2-7.** The Status Register low halfword




**SS - Secure State**

This bit is indicates if the processor is executing in the secure state. For more details, see chapter 4. The bit is initialized in an IMPLEMENTATION DEFINED way at reset.

**H - Java Handle**

This bit is included to support different heap types in the Java Virtual Machine. For more details, see chapter 3. The bit is cleared at reset.

**J - Java State**

The processor is in Java state when this bit is set. The incoming instruction stream will be decoded as a stream of Java bytecodes, not RISC opcodes. The bit is cleared at reset. This bit should not be modified by the user as undefined behaviour may result.

**DM - Debug State Mask**

If this bit is set, the Debug State is masked and cannot be entered. The bit is cleared at reset, and can both be read and written by software.

**D - Debug State**

The processor is in debug state when this bit is set. The bit is cleared at reset and should only be modified by debug hardware, the *breakpoint* instruction or the *retd* instruction. Undefined behaviour may result if the user tries to modify this bit manually.

**M2, M1, M0 - Execution Mode**

These bits show the active execution mode. The settings for the different modes are shown in Table 2-5 on page 13. M2 and M1 are cleared by reset while M0 is set so that the processor is in supervisor mode after reset. These bits are modified by hardware, or execution of certain instructions like *scall*, *rets* and *rete*. Undefined behaviour may result if the user tries to modify these bits manually.

**Table 2-5.** Mode bit settings

| M2 | M1 | M0 | Mode |
|---|---|---|---|
| 1 | 1 | 1 | Non Maskable Interrupt |
| 1 | 1 | 0 | Exception |
| 1 | 0 | 1 | Interrupt level 3 |
| 1 | 0 | 0 | Interrupt level 2 |
| 0 | 1 | 1 | Interrupt level 1 |
| 0 | 1 | 0 | Interrupt level 0 |
| 0 | 0 | 1 | Supervisor |
| 0 | 0 | 0 | Application |

**EM - Exception mask**

When this bit is set, exceptions are masked. Exceptions are enabled otherwise. The bit is automatically set when exception processing is initiated or Debug Mode is entered. Software may clear this bit after performing the necessary measures if nested exceptions should be supported. This bit is set at reset.

**I3M - Interrupt level 3 mask**

When this bit is set, level 3 interrupts are masked. If I3M and GM are cleared, INT3 interrupts are enabled. The bit is automatically set when INT3 processing is initiated. Software may clear this bit after performing the necessary measures if nested INT3s should be supported. This bit is cleared at reset.

**I2M - Interrupt level 2 mask**

When this bit is set, level 2 interrupts are masked. If I2M and GM are cleared, INT2 interrupts are enabled. The bit is automatically set when INT3 or INT2 processing is initiated. Software may clear this bit after performing the necessary measures if nested INT2s should be supported. This bit is cleared at reset.

**I1M - Interrupt level 1 mask**

When this bit is set, level 1 interrupts are masked. If I1M and GM are cleared, INT1 interrupts are enabled. The bit is automatically set when INT3, INT2 or INT1 processing is initiated. Software may clear this bit after performing the necessary measures if nested INT1s should be supported. This bit is cleared at reset.

**I0M - Interrupt level 0 mask**

When this bit is set, level 0 interrupts are masked. If I0M and GM are cleared, INT0 interrupts are enabled. The bit is automatically set when INT3, INT2, INT1 or INT0 processing is initiated. Software may clear this bit after performing the necessary measures if nested INT0s should be supported. This bit is cleared at reset.

**GM - Global Interrupt Mask**

When this bit is set, all interrupts are disabled. This bit overrides I0M, I1M, I2M and I3M. The bit is automatically set when exception processing is initiated, Debug Mode is entered, or a Java trap is taken. This bit is automatically cleared when returning from a Java trap. This bit is set after reset.

**R - Java register remap**

When this bit is set, the addresses of the registers in the register file is dynamically changed. This allows efficient use of the register file registers as a stack. For more details, see chapter 3.. The R bit is cleared at reset. Undefined behaviour may result if this bit is modified by the user.

**T - Scratch bit**

This bit is not set or cleared implicit by any instruction and the programmer can therefore use this bit as a custom flag to for example signal events in the program. This bit is cleared at reset.

**L - Lock flag**

Used by the conditional store instruction. Used to support atomical memory access. Automatically cleared by *rete*. This bit is cleared after reset.

**Q - Saturation flag**

The saturation flag indicates that a saturating arithmetic operation overflowed. The flag is sticky and once set it has to be manually cleared by a *csrf* instruction after the desired action has been taken. See the Instruction set description for details.

**V - Overflow flag**

The overflow flag indicates that an arithmetic operation overflowed. See the Instruction set description for details.

**N - Negative flag**

The negative flag is modified by arithmetical and logical operations. See the Instruction set description for details.

**Z - Zero flag**

The zero flag indicates a zero result after an arithmetic or logic operation. See the Instruction set description for details.

**C - Carry flag**

The carry flag indicates a carry after an arithmetic or logic operation. See the Instruction set description for details.

## 2.11 System registers

The system registers are placed outside of the virtual memory space, and are only accessible using the privileged *mfsr* and *mtsr* instructions, see Table 2-7 on page 15. The number of physical locations is IMPLEMENTATION DEFINED, but a maximum of 256 locations can be addressed with the dedicated instructions. Some of the System Registers are altered automatically by hardware.

The reset value of the System Registers are IMPLEMENTATION DEFINED.

The Compliance column describes if the register is Required, Optional or Unused in AVR32A and AVR32B, see Table 2-6 on page 15 for legend.

**Table 2-6.** Legend for the Compliance column

| Abbreviation | Meaning |
|---|---|
| RA | Required in AVR32A |
| OA | Optional in AVR32A |
| UA | Unused in AVR32A |
| RB | Required in AVR32B |
| OB | Optional in AVR32B |
| UB | Unused in AVR32B |

**Table 2-7.** System Registers

| Reg # | Address | Name | Function | Compliance | |
|---|---|---|---|---|---|
| 0 | 0 | SR | Status Register | RA | RB |
| 1 | 4 | EVBA | Exception Vector Base Address | RA | RB |
| 2 | 8 | ACBA | Application Call Base Address | RA | RB |
| 3 | 12 | CPUCR | CPU Control Register | RA | RB |
| 4 | 16 | ECR | Exception Cause Register | OA | OB |
| 5 | 20 | RSR_SUP | Return Status Register for Supervisor context | UA | RB |
| 6 | 24 | RSR_INT0 | Return Status Register for INT 0 context | UA | RB |
| 7 | 28 | RSR_INT1 | Return Status Register for INT 1 context | UA | RB |
| 8 | 32 | RSR_INT2 | Return Status Register for INT 2 context | UA | RB |
| 9 | 36 | RSR_INT3 | Return Status Register for INT 3 context | UA | RB |
| 10 | 40 | RSR_EX | Return Status Register for Exception context | UA | RB |
| 11 | 44 | RSR_NMI | Return Status Register for NMI context | UA | RB |
| 12 | 48 | RSR_DBG | Return Status Register for Debug Mode | OA | OB |
| 13 | 52 | RAR_SUP | Return Address Register for Supervisor context | UA | RB |
| 14 | 56 | RAR_INT0 | Return Address Register for INT 0 context | UA | RB |
| 15 | 60 | RAR_INT1 | Return Address Register for INT 1 context | UA | RB |
| 16 | 64 | RAR_INT2 | Return Address Register for INT 2 context | UA | RB |
| 17 | 68 | RAR_INT3 | Return Address Register for INT 3 context | UA | RB |
| 18 | 72 | RAR_EX | Return Address Register for Exception context | UA | RB |
| 19 | 76 | RAR_NMI | Return Address Register for NMI context | UA | RB |
| 20 | 80 | RAR_DBG | Return Address Register for Debug Mode | OA | OB |
| 21 | 84 | JECR | Java Exception Cause Register | OA | OB |
| 22 | 88 | JOSP | Java Operand Stack Pointer | OA | OB |
| 23 | 92 | JAVA_LV0 | Java Local Variable 0 | OA | OB |

**Table 2-7.** System Registers (Continued)

| Reg # | Address | Name | Function | Compliance | |
|---|---|---|---|---|---|
| 24 | 96 | JAVA_LV1 | Java Local Variable 1 | OA | OB |
| 25 | 100 | JAVA_LV2 | Java Local Variable 2 | OA | OB |
| 26 | 104 | JAVA_LV3 | Java Local Variable 3 | OA | OB |
| 27 | 108 | JAVA_LV4 | Java Local Variable 4 | OA | OB |
| 28 | 112 | JAVA_LV5 | Java Local Variable 5 | OA | OB |
| 29 | 116 | JAVA_LV6 | Java Local Variable 6 | OA | OB |
| 30 | 120 | JAVA_LV7 | Java Local Variable 7 | OA | OB |
| 31 | 124 | JTBA | Java Trap Base Address | OA | OB |
| 32 | 128 | JBCR | Java Write Barrier Control Register | OA | OB |
| 33-63 | 132-252 | Reserved | Reserved for future use | - | - |
| 64 | 256 | CONFIG0 | Configuration register 0 | RA | RB |
| 65 | 260 | CONFIG1 | Configuration register 1 | RA | RB |
| 66 | 264 | COUNT | Cycle Counter register | RA | RB |
| 67 | 268 | COMPARE | Compare register | RA | RB |
| 68 | 272 | TLBEHI | MMU TLB Entry High | OA | OB |
| 69 | 276 | TLBELO | MMU TLB Entry Low | OA | OB |
| 70 | 280 | PTBR | MMU Page Table Base Register | OA | OB |
| 71 | 284 | TLBEAR | MMU TLB Exception Address Register | OA | OB |
| 72 | 288 | MMUCR | MMU Control Register | OA | OB |
| 73 | 292 | TLBARLO | MMU TLB Accessed Register Low | OA | OB |
| 74 | 296 | TLBARHI | MMU TLB Accessed Register High | OA | OB |
| 75 | 300 | PCCNT | Performance Clock Counter | OA | OB |
| 76 | 304 | PCNT0 | Performance Counter 0 | OA | OB |
| 77 | 308 | PCNT1 | Performance Counter 1 | OA | OB |
| 78 | 312 | PCCR | Performance Counter Control Register | OA | OB |
| 79 | 316 | BEAR | Bus Error Address Register | OA | OB |
| 80 | 320 | MPUAR0 | MPU Address Register region 0 | OA | OB |
| 81 | 324 | MPUAR1 | MPU Address Register region 1 | OA | OB |
| 82 | 328 | MPUAR2 | MPU Address Register region 2 | OA | OB |
| 83 | 332 | MPUAR3 | MPU Address Register region 3 | OA | OB |
| 84 | 336 | MPUAR4 | MPU Address Register region 4 | OA | OB |
| 85 | 340 | MPUAR5 | MPU Address Register region 5 | OA | OB |
| 86 | 344 | MPUAR6 | MPU Address Register region 6 | OA | OB |
| 87 | 348 | MPUAR7 | MPU Address Register region 7 | OA | OB |
| 88 | 352 | MPUPSR0 | MPU Privilege Select Register region 0 | OA | OB |
| 89 | 356 | MPUPSR1 | MPU Privilege Select Register region 1 | OA | OB |

**Table 2-7.** System Registers (Continued)

| Reg # | Address | Name | Function | Compliance | |
|---|---|---|---|---|---|
| 90 | 360 | MPUPSR2 | MPU Privilege Select Register region 2 | OA | OB |
| 91 | 364 | MPUPSR3 | MPU Privilege Select Register region 3 | OA | OB |
| 92 | 368 | MPUPSR4 | MPU Privilege Select Register region 4 | OA | OB |
| 93 | 372 | MPUPSR5 | MPU Privilege Select Register region 5 | OA | OB |
| 94 | 376 | MPUPSR6 | MPU Privilege Select Register region 6 | OA | OB |
| 95 | 380 | MPUPSR7 | MPU Privilege Select Register region 7 | OA | OB |
| 96 | 384 | MPUCRA | MPU Cacheable Register A | OA | OB |
| 97 | 388 | MPUCRB | MPU Cacheable Register B | OA | OB |
| 98 | 392 | MPUBRA | MPU Bufferable Register A | OA | OB |
| 99 | 396 | MPUBRB | MPU Bufferable Register B | OA | OB |
| 100 | 400 | MPUAPRA | MPU Access Permission Register A | OA | OB |
| 101 | 404 | MPUAPRB | MPU Access Permission Register B | OA | OB |
| 102 | 408 | MPUCR | MPU Control Register | OA | OB |
| 103 | 412 | SS_STATUS | Secure State Status Register | OA | OB |
| 104 | 416 | SS_ADRF | Secure State Address Flash Register | OA | OB |
| 105 | 420 | SS_ADRR | Secure State Address RAM Register | OA | OB |
| 106 | 424 | SS_ADR0 | Secure State Address 0 Register | OA | OB |
| 107 | 428 | SS_ADR1 | Secure State Address 1 Register | OA | OB |
| 108 | 432 | SS_SP_SYS | Secure State Stack Pointer System Register | OA | OB |
| 109 | 436 | SS_SP_APP | Secure State Stack Pointer Application Register | OA | OB |
| 110 | 440 | SS_RAR | Secure State Return Address Register | OA | OB |
| 111 | 444 | SS_RSR | Secure State Return Status Register | OA | OB |
| 112-191 | 448-764 | Reserved | Reserved for future use | - | - |
| 192-255 | 768-1020 | IMPL | IMPLEMENTATION DEFINED | - | - |

**SR- Status Register**

The Status Register is mapped into the system register space. This allows it to be loaded into the register file to be modified, or to be stored to memory. The Status Register is described in detail in Section 2.10 “The Status Register” on page 11.

**EVBA - Exception Vector Base Address**

This register contains a pointer to the exception routines. All exception routines start at this address, or at a defined offset relative to the address. Special alignment requirements may apply for EVBA, depending on the implementation of the interrupt controller. Exceptions are described in detail in Section 8. “Event Processing” on page 63.

**ACBA - Application Call Base Address**

Pointer to the start of a table of function pointers. Subroutines can thereby be called by the compact *acall* instruction. This facilitates efficient reuse of code. Keeping this pointer as a register facilitates multiple function pointer tables. ACBA is a full 32 bit register, but the lowest two bits

should be written to zero, making ACBA word aligned. Failing to do so may result in erroneous behaviour.

**CPUCR - CPU Control Register**

Register controlling the configuration and behaviour of the CPU. The behaviour of this register is IMPLEMENTATION DEFINED. An example of a typical control bit in the CPUCR is an enable bit for branch prediction.

**ECR - Exception Cause Register**

This register identifies the cause of the most recently executed exception. This information may be used to handle exceptions more efficiently in certain operating systems. The register is updated with a value equal to the EVBA offset of the exception, shifted 2 bit positions to the right. Only the 9 lowest bits of the EVBA offset are considered. As an example, an ITLB miss jumps to EVBA+0x50. The ECR will then be loaded with 0x50>>2 == 0x14. The ECR register is not loaded when an *scall*, Breakpoint or OCD Stop CPU exception is taken. Note that for interrupts, the offset is given by the autovector provided by the interrupt controller. The resulting ECR value may therefore overlap with an ECR value used by a regular exception. This can be avoided by choosing the autovector offsets so that no such overlaps occur.

**RSR_SUP, RSR_INT0, RSR_INT1, RSR_INT2, RSR_INT3, RSR_EX, RSR_NMI - Return Status Registers**

If a request for a mode change, for instance an interrupt request, is accepted when executing in a context *C*, the Status Register values in context *C* are automatically stored in the Return Status Register (RSR) associated with the interrupt context *I*. When the execution in the interrupt state *I* is finished and the *rets* / *rete* instruction is encountered, the RSR associated with *I* is copied to SR, and the execution continues in the original context *C*.

**RSR_DBG - Return Status Register for Debug Mode**

When Debug mode is entered, the status register contents of the original mode is automatically saved in this register. When the debug routine is finished, the *retd* instruction copies the contents of RSR_DBG into SR.

**RAR_SUP, RAR_INT0, RAR_INT1, RAR_INT2, RAR_INT3, RAR_EX, RAR_NMI - Return Address Registers**

If a request for a mode change, for instance an interrupt request, is accepted when executing in a context *C*, the re-entry address of context *C* is automatically stored in the Return Address Register (RAR) associated with the interrupt context *I*. When the execution in the interrupt state *I* is finished and the *rets* / *rete* instruction is encountered, a change-of-flow to the address in the RAR associated with *I*, and the execution continues in the original context *C*. The calculation of the re-entry addresses is described in Section 8. “Event Processing” on page 63.

**RAR_DBG - Return Address Register for Debug Mode**

When Debug mode is entered, the Program Counter contents of the original mode is automatically saved in this register. When the debug routine is finished, the *retd* instruction copies the contents of RAR_DBG into PC.

**JECR - Java Exception Cause Register**

This register contains information needed for Java traps, see AVR32 Java Technical Reference Manual for details.

**JOSP - Java Operand Stack Pointer**

This register holds the Java Operand Stack Pointer. The register is initialized to 0 at reset.

**JAVA_LVx - Java Local Variable Registers**

The Java Extension Module uses these registers to store local variables temporary.

**JTBA - Java Trap Base Address**

This register contains the base address to the program code for the trapped Java instructions.

**JBCR - Java Write Barrier Control Register**

This register is used by the garbage collector in the Java Virtual Machine.

**CONFIG0 / 1 - Configuration Register 0 / 1**

Used to describe the processor, its configuration and capabilities. The contents and functionality of these registers is described in detail in Section 2.11.1 “Configuration Registers” on page 21.

**COUNT - Cycle Counter Register**

The COUNT register increments once every clock cycle, regardless of pipeline stalls and flushes. The COUNT register can both be read and written. The count register can be used together with the COMPARE register to create a timer with interrupt functionality. The COUNT register is written to zero upon reset and compare match. Revision 3 of the AVR32 Architecture allows some implementations to disable this automatic clearing of COUNT upon COMPARE match, usually by programming a bit in CPUCR. Refer to the Technical Reference Manual for the device for details. Incrementation of the COUNT register can not be disabled. The COUNT register will increment even though a compare interrupt is pending.

**COMPARE - Cycle Counter Compare Register**

The COMPARE register holds a value that the COUNT register is compared against. The COMPARE register can both be read and written. When the COMPARE and COUNT registers match, a compare interrupt request is generated and COUNT is reset to 0. This interrupt request is routed out to the interrupt controller, which may forward the request back to the processor as a normal interrupt request at a priority level determined by the interrupt controller. Writing a value to the COMPARE register clears any pending compare interrupt requests. The compare and exception generation feature is disabled if the COMPARE register contains the value zero. The COMPARE register is written to zero upon reset.

**TLBEHI - MMU TLB Entry Register High Part**

Used to interface the CPU to the TLB. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**TLBELO - MMU TLB Entry Register Low Part**

Used to interface the CPU to the TLB. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**PTBR - MMU Page Table Base Register**

Contains a pointer to the start of the Page Table. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**TLBEAR - MMU TLB Exception Address Register**

Contains the virtual address that caused the most recent MMU error. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**MMUCR - MMU Control Register**

Used to control the MMU and the TLB. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**TLBARLO / TLBARHI - MMU TLB Accessed Register Low / High**

Contains the Accessed bits for the TLB. The contents and functionality of the register is described in detail in Section 5. “Memory Management Unit” on page 35.

**PCCNT - Performance Clock Counter**

Clock cycle counter for performance counters. The contents and functionality of the register is described in detail in Section 7. “Performance counters” on page 57.

**PCNT0 / PCNT1 - Performance Counter 0 / 1**

Counts the events specified by the Performance Counter Control Register. The contents and functionality of the register is described in detail in Section 7. “Performance counters” on page 57.

**PCCR - Performance Counter Control Register**

Controls and configures the setup of the performance counters. The contents and functionality of the register is described in detail in Section 7. “Performance counters” on page 57.

**BEAR - Bus Error Address Register**

Physical address that caused a Data Bus Error. This register is Read Only. Writes are allowed, but are ignored.

**MPUARn - MPU Address Register n**

Registers that define the base address and size of the protection regions. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**MPUPSRn - MPU Privilege Select Register n**

Registers that define which privilege register set to use for the different subregions in each protection region. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**MPUCRA / MPUCRB - MPU Cacheable Register A / B**

Registers that define if the different protection regions are cacheable. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**MPUBRA / MPUBRB - MPU Bufferable Register A / B**

Registers that define if the different protection regions are bufferable. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**MPUAPRA / MPUAPRB - MPU Access Permission Register A / B**

Registers that define the access permissions for the different protection regions. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**MPUCR - MPU Control Register**

Register that control the operation of the MPU. Refer to Section 6. “Memory Protection Unit” on page 51 for details.

**SS_STATUS - Secure State Status Register**

Register that can be used to pass status or other information from the secure state to the nonsecure state. Refer to Section 4. “Secure state” on page 31 for details.

**SS_ADRF, SS_ADRR, SS_ADR0, SS_ADR1 - Secure State Address Registers**

Registers used to partition memories into a secure and a nonsecure section. Refer to Section 4. “Secure state” on page 31 for details.

**SS_SP_SYS, SS_SP_APP - Secure State SP_SYS and SP_APP Registers**

Read-only registers containing the SP_SYS and SP_APP values. Refer to Section 4. “Secure state” on page 31 for details.

**SS_RAR, SS_RSR - Secure State Return Address and Return Status Registers**

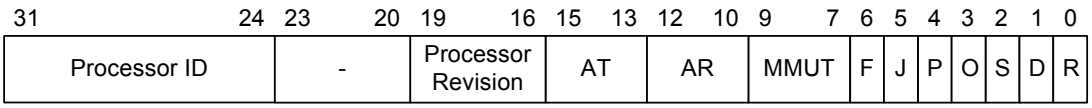
Contains the address and status register of the *sscall* instruction that called secure state. Also used when returning to nonsecure state with the *retss* instruction. Refer to Section 4. “Secure state” on page 31 for details.

### 2.11.1 Configuration Registers

Configuration registers are used to inform applications and operating systems about the setup and configuration of the processor on which it is running, see Figure 2-8 on page 21. The AVR32 implements the following read-only configuration registers.

**Figure 2-8.** Configuration Registers

CONFIG0




CONFIG1

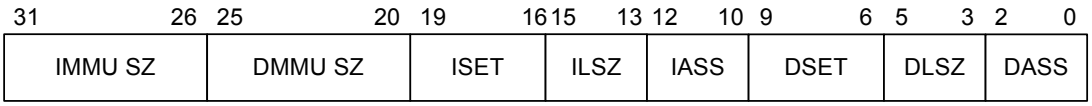



Table 2-8 on page 21 shows the CONFIG0 fields.

**Table 2-8.** CONFIG0 Fields

| Name | Bit | Description |
|---|---|---|
| Processor ID | 31:24 | Specifies the type of processor. This allows the application to distinguish between different processor implementations. |
| RESERVED | 23:20 | Reserved for future use. |
| Processor revision | 19:16 | Specifies the revision of the processor implementation. |

**Table 2-8.** CONFIG0 Fields (Continued)

| Name | Bit | Description | |
|---|---|---|---|
| AT | 15:13 | Architecture type | |
| | | Value | Semantic |
| | | 0 | AVR32A |
| | | 1 | AVR32B |
| | | Other | Reserved |
| AR | 12:10 | Architecture Revision. Specifies which revision of the AVR32 architecture the processor implements. | |
| | | Value | Semantic |
| | | 0 | Revision 0 |
| | | 1 | Revision 1 |
| | | 2 | Revision 2 |
| | | 3 | Revision 3 |
| | | Other | Reserved |
| MMUT | 9:7 | MMU type | |
| | | Value | Semantic |
| | | 0 | None, using direct mapping and no segmentation |
| | | 1 | ITLB and DTLB |
| | | 2 | Shared TLB |
| | | 3 | Memory Protection Unit |
| | | Other | Reserved |
| F | 6 | Floating-point unit implemented | |
| | | Value | Semantic |
| | | 0 | No FPU implemented |
| | | 1 | FPU implemented |
| J | 5 | Java extension implemented | |
| | | Value | Semantic |
| | | 0 | No Java extension implemented |
| | | 1 | Java extension implemented |
| P | 4 | Performance counters implemented | |
| | | Value | Semantic |
| | | 0 | No Performance Counters implemented |
| | | 1 | Performance Counters implemented |
| O | 3 | On-Chip Debug implemented | |
| | | Value | Semantic |
| | | 0 | No OCD implemented |
| | | 1 | OCD implemented |

**Table 2-8.** CONFIG0 Fields (Continued)

| Name | Bit | Description | |
|---|---|---|---|
| S | 2 | SIMD instructions implemented | |
| | | Value | Semantic |
| | | 0 | No SIMD instructions |
| | | 1 | SIMD instructions implemented |
| D | 1 | DSP instructions implemented | |
| | | Value | Semantic |
| | | 0 | No DSP instructions |
| | | 1 | DSP instructions implemented |
| R | 0 | Memory Read-Modify-Write instructions implemented | |
| | | Value | Semantic |
| | | 0 | No RMW instructions |
| | | 1 | RMW instructions implemented |

Table 2-9 on page 23 shows the CONFIG1 fields.

**Table 2-9.** CONFIG1 Fields

| Name | Bit | Description |
|---|---|---|
| IMMU SZ | 31:26 | The number of entries in the IMMU equals (IMMU SZ) + 1. Not used in single-MMU or MPU systems. |
| DMMU SZ | 25:20 | Specifies the number of entries in the DMMU or in the shared MMU in single-MMU systems. The number of entries in the DMMU or shared MMU equals (DMMU SZ + 1). In systems with MPU, DMMU SZ equals the number of MPUAR entries. |

**Table 2-9.** CONFIG1 Fields (Continued)

| Name | Bit | Description | |
|---|---|---|---|
| ISET | 19:16 | Number of sets in ICACHE | |
| | | Value | Semantic |
| | | 0 | 1 |
| | | 1 | 2 |
| | | 2 | 4 |
| | | 3 | 8 |
| | | 4 | 16 |
| | | 5 | 32 |
| | | 6 | 64 |
| | | 7 | 128 |
| | | 8 | 256 |
| | | 9 | 512 |
| | | 10 | 1024 |
| | | 11 | 2048 |
| | | 12 | 4096 |
| | | 13 | 8192 |
| | | 14 | 16384 |
| | | 15 | 32768 |
| ILSZ | 15:13 | Line size in ICACHE | |
| | | Value | Semantic |
| | | 0 | No ICACHE present |
| | | 1 | 4 bytes |
| | | 2 | 8 bytes |
| | | 3 | 16 bytes |
| | | 4 | 32 bytes |
| | | 5 | 64 bytes |
| | | 6 | 128 bytes |
| | | 7 | 256 bytes |

**Table 2-9.** CONFIG1 Fields (Continued)

| Name | Bit | Description | |
|---|---|---|---|
| IASS | 12:10 | Associativity of ICACHE | |
| | | Value | Semantic |
| | | 0 | Direct mapped |
| | | 1 | 2-way |
| | | 2 | 4-way |
| | | 3 | 8-way |
| | | 4 | 16-way |
| | | 5 | 32-way |
| | | 6 | 64-way |
| | | 7 | 128-way |
| DSET | 9:6 | Number of sets in DCACHE | |
| | | Value | Semantic |
| | | 0 | 1 |
| | | 1 | 2 |
| | | 2 | 4 |
| | | 3 | 8 |
| | | 4 | 16 |
| | | 5 | 32 |
| | | 6 | 64 |
| | | 7 | 128 |
| | | 8 | 256 |
| | | 9 | 512 |
| | | 10 | 1024 |
| | | 11 | 2048 |
| | | 12 | 4096 |
| | | 13 | 8192 |
| | | 14 | 16384 |
| | | 15 | 32768 |

**Table 2-9.** CONFIG1 Fields (Continued)

| Name | Bit | Description | |
|---|---|---|---|
| DLSZ | 5:3 | Line size in DCACHE | |
| | | Value | Semantic |
| | | 0 | No DCACHE present |
| | | 1 | 4 bytes |
| | | 2 | 8 bytes |
| | | 3 | 16 bytes |
| | | 4 | 32 bytes |
| | | 5 | 64 bytes |
| | | 6 | 128 bytes |
| | | 7 | 256 bytes |
| DASS | 2:0 | Associativity of DCACHE | |
| | | Value | Semantic |
| | | 0 | Direct mapped |
| | | 1 | 2-way |
| | | 2 | 4-way |
| | | 3 | 8-way |
| | | 4 | 16-way |
| | | 5 | 32-way |
| | | 6 | 64-way |
| | | 7 | 128-way |

## 2.12 Recommended Call Convention

The compiler vendor is free to define a call convention, but seen from a hardware point of view, there are some recommendations on how the call convention should be defined.

Register R12 is intended as return value register in connection with function calls. Some instructions will use this register implicitly. For instance, the conditional *ret* instruction will move its argument into R12.

# 3. Java Extension Module

The AVR32 architecture can optionally support execution of Java bytecodes by including a Java Extension Module (JEM). This support is included with minimal hardware overhead.

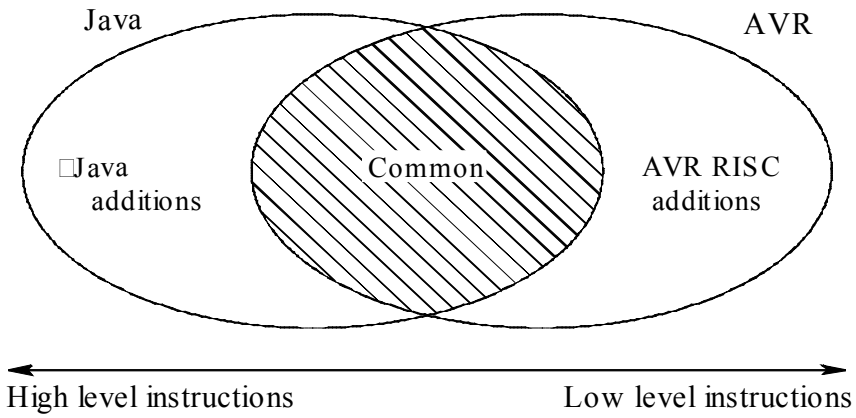
Comparing Java bytecode instructions with native AVR32 instructions, we see that a large part of the instructions overlap as illustrated in Figure 3-1 on page 27. The idea is thus to reuse the hardware resources by adding a separate Java instruction decoder and control module that executes in Java state. The processor keeps track of its execution state through the status register and changes execution mode seamlessly.

In a larger runtime system, an operating system keeps track of and dispatches different processes. A Java program will typically be one, or several, of these processes.

The Java state is not to be confused with the security modes “system” and “application”, as the JEM can execute in both modes. When the processor switches instruction decoder and enters Java state, it does not affect the security level set by the system. A Java program could also be executed from the different interrupt levels without interfering with the mode settings of the processor, although it is not recommended that interrupt routines are written in Java due to latency.

The Java binary instructions are called bytecodes. These bytecodes are one or more bytes long. A bytecode consists of an opcode and optional arguments. The bytecodes include some instructions with a high semantic content. In order to reduce the hardware overhead, these instructions are trapped and executed as small RISC programs. These programs are stored in the program memory and can be changed by the programmer (part of the Java VM implementation). This gives full flexibility with regards to future extensions of the Java instruction set. Performance is ensured through an efficient trapping mechanism and “Java tailored” RISC instructions.

**Figure 3-1.** A large part of the instruction set is shared between the AVR RISC and the Java Virtual Machine. The Java instruction set includes instructions with high semantic contents while the AVR RISC instruction set complements Java’s set with traditional hardware near RISC instructions




## 3.1 The AVR32 Java Virtual Machine

The AVR32 Java Virtual machine consists of two parts, the Java Extension Module in hardware and the AVR32 specific Java Virtual Machine software, see Figure 3-2 on page 28. Together, the two modules comply with the Java Virtual Machine specification.

The AVR32 Java Virtual Machine software loads and controls the execution of the Java classes. The bytecodes are executed in hardware, except for some instructions, for example the instructions that create or manipulate objects. These are trapped and executed in software within the Java Virtual Machine.

**Figure 3-2.** Overview of the AVR32 Java Virtual Machine and the Java Extension Module. The grey area represent the software parts of the virtual machine, while the white box to the right represents the hardware module.

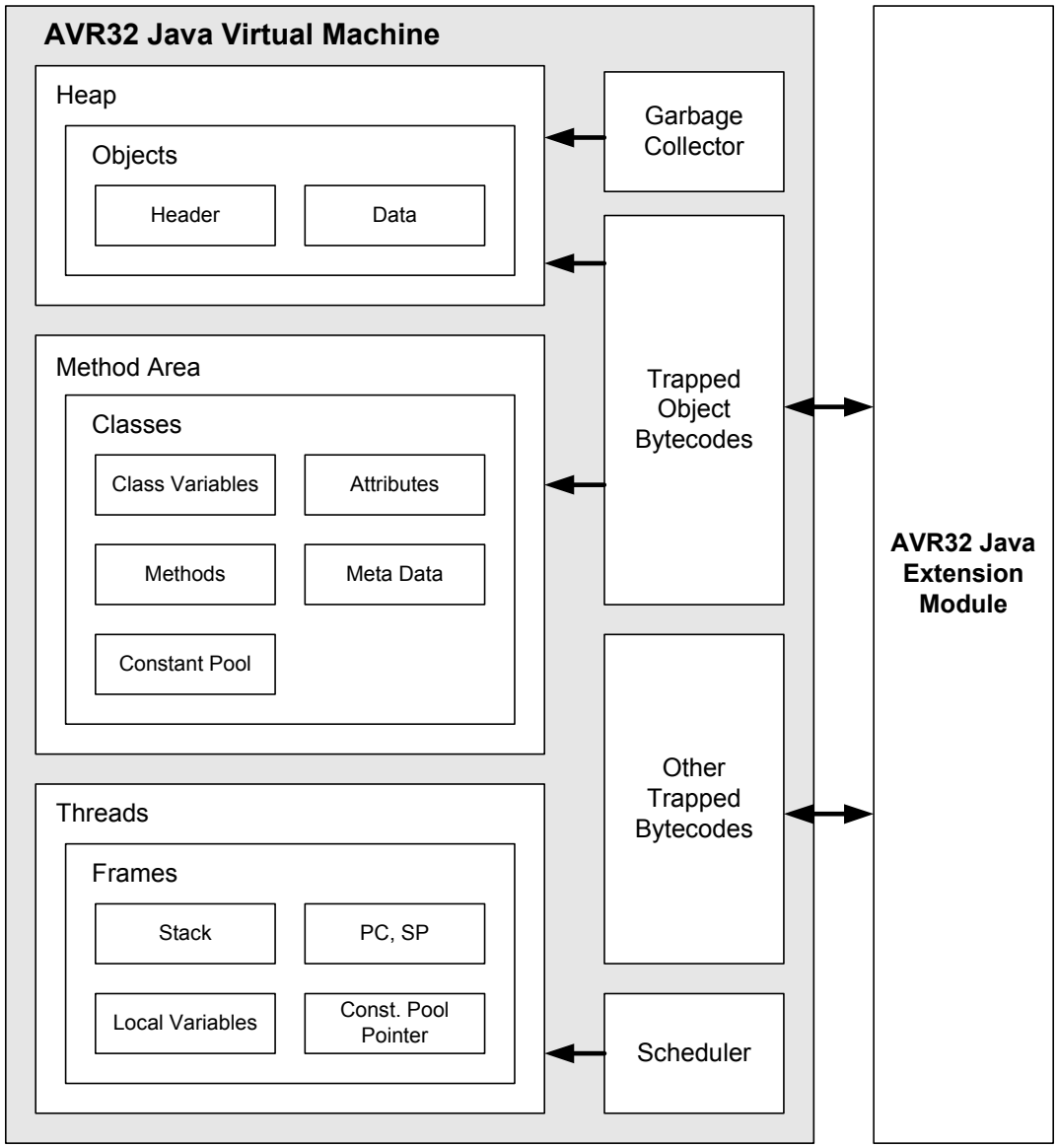
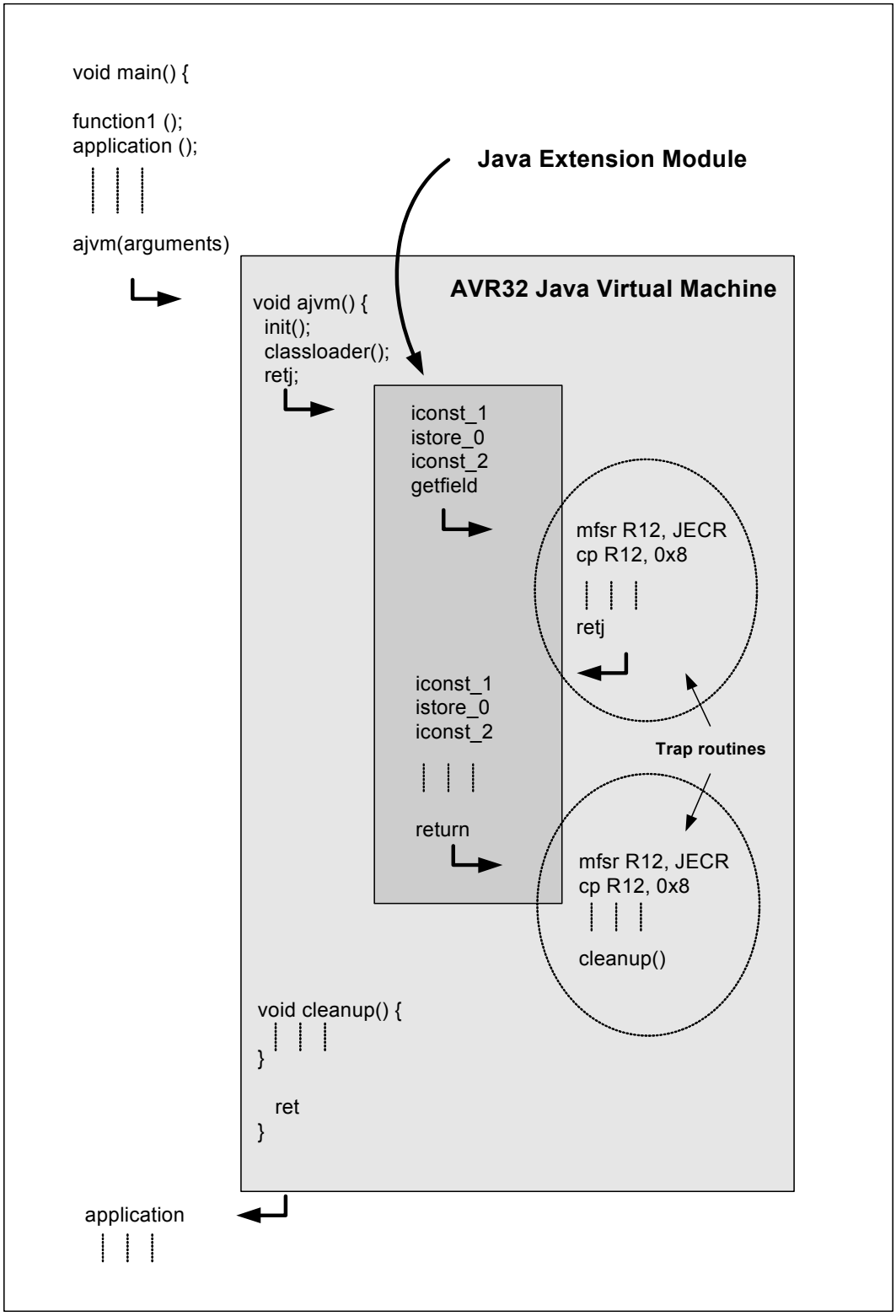



Figure 3-3 on page 29 shows one example on how a Java program is executed. The processor boots in AVR32 (RISC) state and it executes applications as a normal RISC processor. To invoke a Java program, the Java Virtual Machine is called like any other application. The Java Virtual Machine will execute an init routine followed by a class loader that parses the class and initializes all registers necessary to start executing the Java program. The last instruction in the

class loader is the “RETJ” instruction that sets the processor in the Java state. This means that the instruction decoder now decodes Java opcodes instead of the normal AVR32 opcodes.

**Figure 3-3.** Example of running a Java program



During execution of the Java program, the Java Extension Module will encounter some bytecodes that are not supported in hardware. The instruction decoder will automatically recognize these bytecodes and switch the processor back into RISC state and at the same time jump to a predefined location where it will execute a software routine that performs the semantic of the trapped bytecode. When finished, the routine ends with a “RETJ” instruction. This instruction will make the AVR32 core return to Java state and the Java program will continue at the correct location.

Detailed technical information about the Java Extension module is available in a separate Java Technical Reference document.

# 4. Secure state

Revision 3 of the AVR32 architecture introduces a secure execution state. This state is intended to allow execution of a proprietary secret code alongside code of unknown origin and intent on the same processor. For example, a company with a proprietary algorithm can program this algorithm into the secure memory sections of the device, and resell the device with the programmed algorithm to an end customer. The end customer will not be able to read or modify the preprogrammed code in any way. Examples of such preprogrammed code can be multimedia codecs, digital signal processing algorithms or telecom software stacks. Whereas previous approaches to this problem required the proprietary code and the end user application to execute on separate devices, the secure state allows integration of the two codes on the same device, saving cost and increasing performance since inter-IC communication is no longer required.

In order to keep the proprietary code secret, this code will execute in a “secure world”. The end user application will execute in a “nonsecure world”. Code in the nonsecure world can request services from the secure world by executing a special instruction, *sscall*. This instruction is executed in the context of an API specified by the provider of the proprietary code. The *sscall* instruction can be associated with arguments passed in registers or memory, and after execution of the requested algorithm, the secure world returns results to the requesting nonsecure application in registers or in memory.

Hardware is implemented to divide the memory resources into two sections, one secure and one non-secure section. The secure section of the memories can only be accessed (read, written or executed) from code running in the secure world. The nonsecure section of the memories can be read, written or executed from the nonsecure world, and read or written from the secure world.

The customer can choose if his application will enable the secure state support or not. An IMPLEMENTATION DEFINED mechanism, usually a Flash fuse, is used to enable or disable secure state support. If this mechanism is programmed so as to disable the secure state, the system will boot in nonsecure world, and its behavior will be identical to previous devices implementing older revisions of the AVR32 architecture. If the system is set up to enable secure state support, the system will boot in the secure state. This allows configuration and startup of the secure world application before execution is passed to the nonsecure world.

## 4.1 Mechanisms implementing the Secure State

The following architectural mechanisms are used to implement the secure state:

- The *sscall* and *retss* instructions are used for passing between the secure and nonsecure worlds.
- The secure world has a dedicated stack pointer, SP_SEC, which is automatically banked into the register file whenever executing in the secure world.
- The SS bit is set in the status register whenever the system is in the secure state. Only *sscall* and *retss* can alter this bit.
- Interrupts and exceptions have special handler addresses used when receiving interrupts or exceptions in the secure world. This allows executing the interrupt or exception handler in the secure world, or jumping back into the nonsecure world to execute the handler there.
- A set of secure system registers are used to configure the secure world behavior, and to aid in communication between the secure and nonsecure worlds. These registers can be written when in the secure world, but only read when in the nonsecure world.

- When trying to access secure world memories from the nonsecure world, a bus error exception will be raised, and the access will be aborted. Writes to secure system registers from within the nonsecure world will simply be disregarded without any error indication.
- The On-Chip Debug (OCD) system is modified to prevent any leak of proprietary code or data to the nonsecure world. This prevents hacking through the use of the OCD system.

## 4.2 Secure state programming model

The programming model in the secure state is similar to in normal RISC state, except that SP_SEC has been banked in, and the secure system registers are available in all privileged modes.

**Figure 4-1.** Register File in AVR32A with secure context

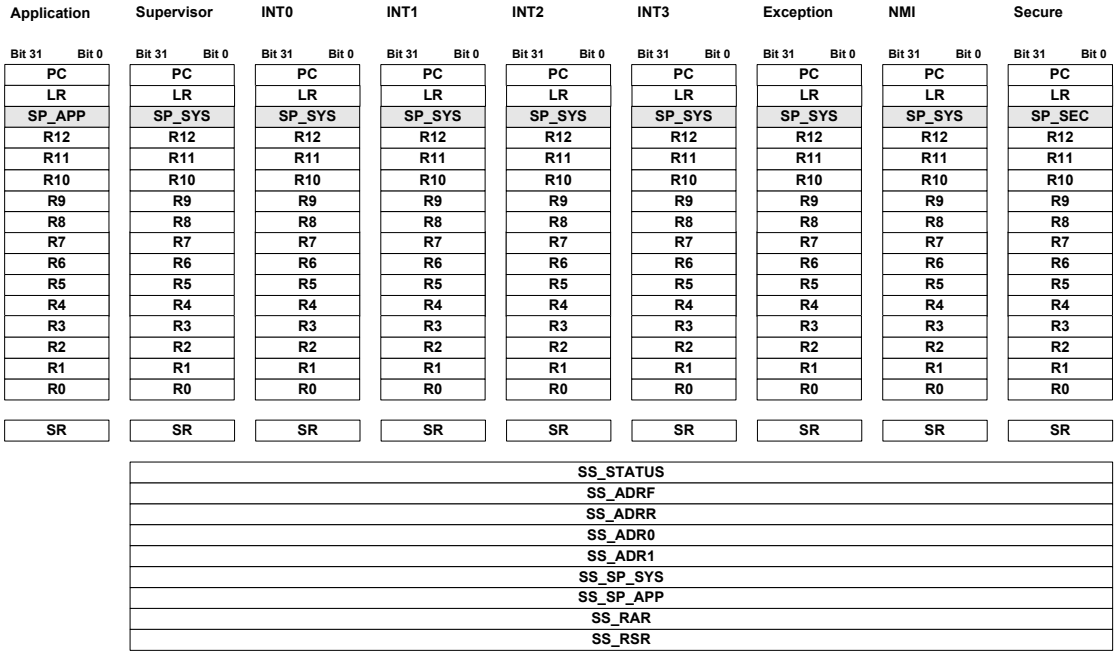
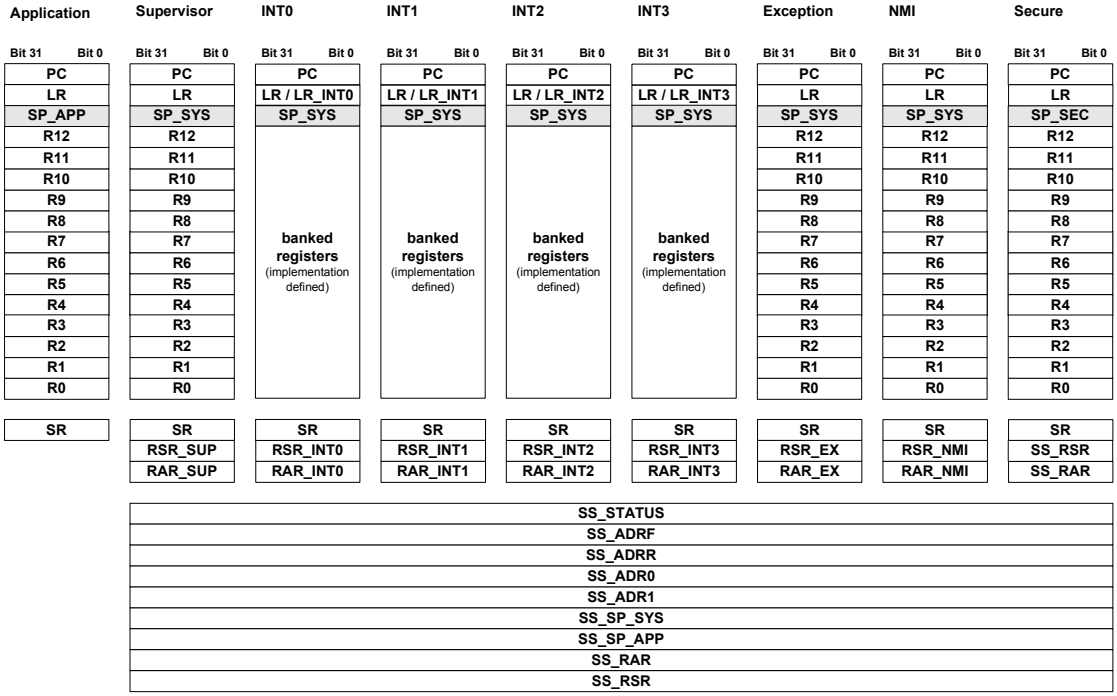


**Figure 4-2.** Register File in AVR32B with secure context




## 4.3 Details on Secure State implementation

Refer to the Technical Reference manual for the CPU core you are using for details on the Secure State implementation.

# 5. Memory Management Unit

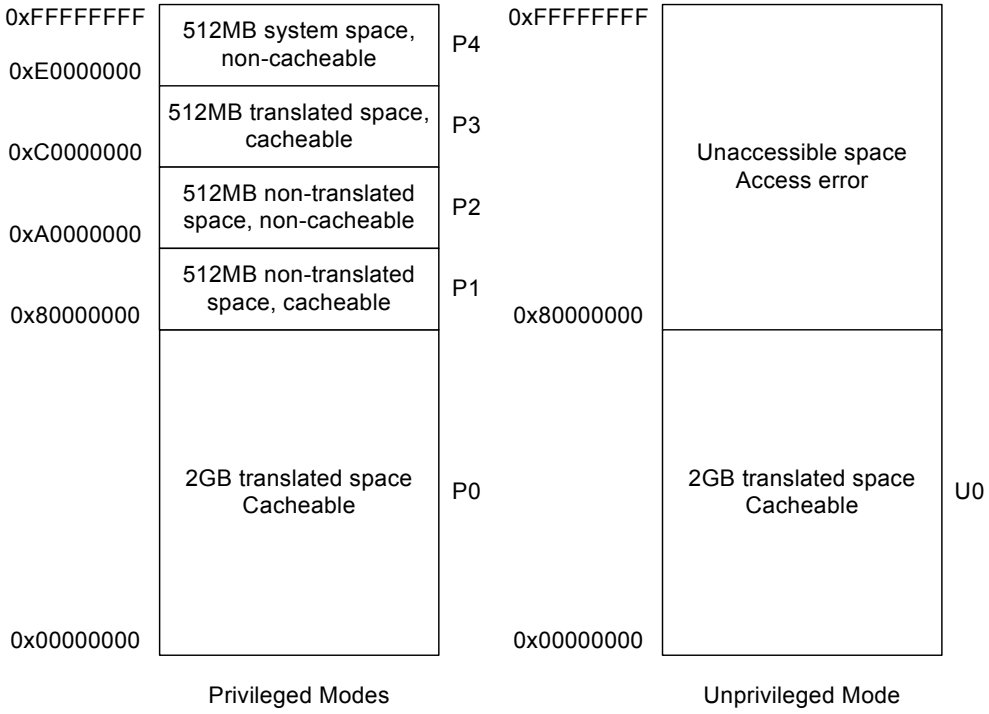
The AVR32 architecture defines an optional Memory Management Unit (MMU). This allows efficient implementation of virtual memory and large memory spaces. Virtual memory simplifies execution of multiple processes and allows allocation of privileges to different sections of the memory space.

## 5.1 Memory map in systems with MMU

The AVR32 architecture specifies a 32-bit virtual memory space. This virtual space is mapped into a 32-bit physical space by a MMU. It should also be noted that not all implementations will use caches. The cacheability information specified in the figure will therefore not apply for all implementations. Refer to the implementation-specific Hardware Manual for details.

The virtual memory map is specified in Figure 5-1.

**Figure 5-1.** The AVR32 virtual memory space




The memory map has six different segments, named P0 through P4, and U0. The P-segments are accessible in the privileged modes, while the U-segment is accessible in the unprivileged mode.

Both the P1 and P2 segments are default segment translated to the physical address range 0x00000000 to 0x1FFFFFFF. The mapping between virtual addresses and physical addresses is therefore implemented by clearing of MSBs in the virtual address. The difference between P1 and P2 is that P1 may be cached, depending on the cache configuration, while P2 is always uncached. Because P1 and P2 are segment translated and not page translated, code for initialization of MMUs and exception vectors are located in these segments. P1, being cacheable, may offer higher performance than P2.

The P3 space is also by default segment translated to the physical address range 0x00000000 to 0x1FFFFFFF. By enabling and setting up the MMU, the P3 space becomes page translated. Page translation will override segment translation.

The P4 space is intended for memory mapping special system resources like the memory arrays in caches. This segment is non-cacheable, non-translated.

The U0 segment is accessible in the unprivileged user mode. This segment is cacheable and translated, depending upon the configuration of the cache and the memory management unit. If accesses to other memory addresses than the ones within U0 is made in application mode, an access error exception is issued.

The virtual address map is summarized in Table 5-1 on page 36.

**Table 5-1.** The virtual address map

| Virtual address [31:29] | Segment name | Virtual Address Range | Segment size | Accessible from | Default segment translated | Characteristics |
|---|---|---|---|---|---|---|
| 111 | P4 | 0xFFFF_FFFF to 0xE000_0000 | 512 MB | Privileged | No | System space<br>Unmapped, Uncacheable |
| 110 | P3 | 0xDFFF_FFFF to 0xC000_0000 | 512 MB | Privileged | Yes | Mapped,<br>Cacheable |
| 101 | P2 | 0xBFFF_FFFF to 0xA000_0000 | 512 MB | Privileged | Yes | Unmapped, Uncacheable |
| 100 | P1 | 0x9FFF_FFFF to 0x8000_0000 | 512 MB | Privileged | Yes | Unmapped, Cacheable |
| 0xx | P0 / U0 | 0x7FFF_FFFF to 0x0000_0000 | 2 Gb | Unprivileged<br>Privileged | No | Mapped, Cacheable |

The segment translation can be disabled by clearing the S bit in the MMUCR. This will place all the virtual memory space into a single 4 GB mapped memory space. Doing this will give all access permission control to the AP bits in the TLB entry matching the virtual address, and allow all virtual addresses to be translated. Segment translation is enabled by default.

The AVR32 architecture has two translations of addresses.

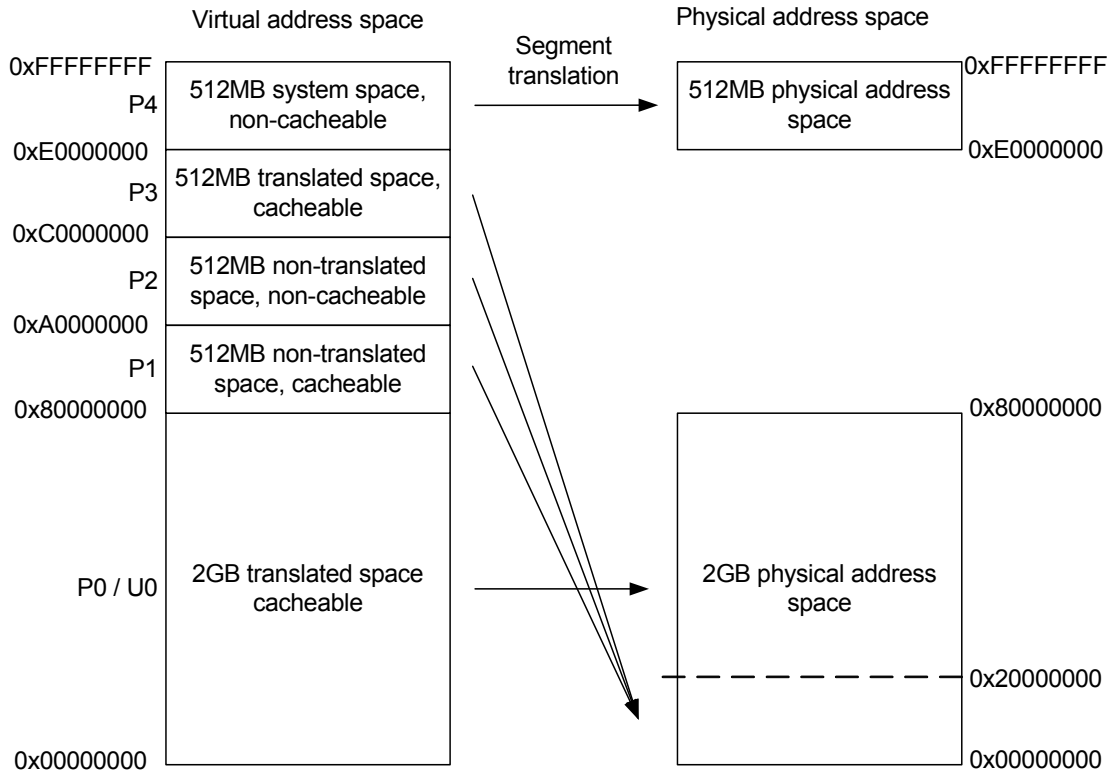
1. Segment translation (enabled by the MMUCR[S] bit)
2. Page translation (enabled by the MMUCR[E] bit)

Both these translations are performed by the MMU and they can be applied independent of each other. This means that you can enable:

1. No translation. Virtual and physical addresses are the same.
2. Segment translation only. The virtual and physical addresses are the same for addresses residing in the P0, P4 and U0 segments. P1, P2 and P3 are mapped to the physical address range 0x00000000 to 0x1FFFFFFF.
3. Page translation only. All addresses are mapped as described by the TLB entries.
4. Both segment and page translations. P1 and P2 are mapped to the physical address range 0x00000000 to 0x1FFFFFFF. U0, P0 and P3 are mapped as described by the TLB entries. The virtual and physical addresses are the same for addresses residing in the P4 segment.

The segment translation is by default turned on and the page translation is by default turned off after reset. The segment translation is summarized in Figure 5-2 on page 37.

**Figure 5-2.** The AVR32 segment translation map




## 5.2 Understanding the MMU

The AVR32 Memory Management Unit (MMU) is responsible for mapping virtual to physical addresses. When a memory access is performed, the MMU translates the virtual address specified into a physical address, while checking the access permissions. If an error occurs in the translation process, or Operating System intervention is needed for some reason, the MMU will issue an exception, allowing the problem to be resolved by software.

The MMU architecture uses paging to map memory pages from the 32-bit virtual address space to a 32-bit physical address space. Page sizes of 1, 4, 64 kilobytes and 1 megabyte are supported. Each page has individual access rights, providing fine protection granularity.

The information needed in order to perform the virtual-to-physical mapping resides in a page table. Each page has its own entry in the page table. The page table also contains protection information and other data needed in the translation process. Conceptually, the page table is accessed for every memory access, in order to read the mapping information for each page.

In order to speed up the translation process, a special page table cache is used. This cache is called a Translation Lookaside Buffer (TLB). The TLB contains the *n* most recently used page table entries. The number *n* of entries in the TLB is IMPLEMENTATION DEFINED. It is also IMPLEMENTATION DEFINED whether a single unified TLB should be used for both instruction and memory accesses, or if two separate TLBs are implemented. The architecture supports one or two TLBs with up to 64 entries in each. TLB entries can also be locked in the TLB, guaranteeing high-speed memory accesses.

### 5.2.1 Virtual Memory Models

The MMU provides two different virtual memory models, selected by the Mode (M) bit in the MMU Control Register:

- Shared virtual memory, where the same virtual address space is shared between all processes
- Private virtual memory, where each process has its own virtual address space

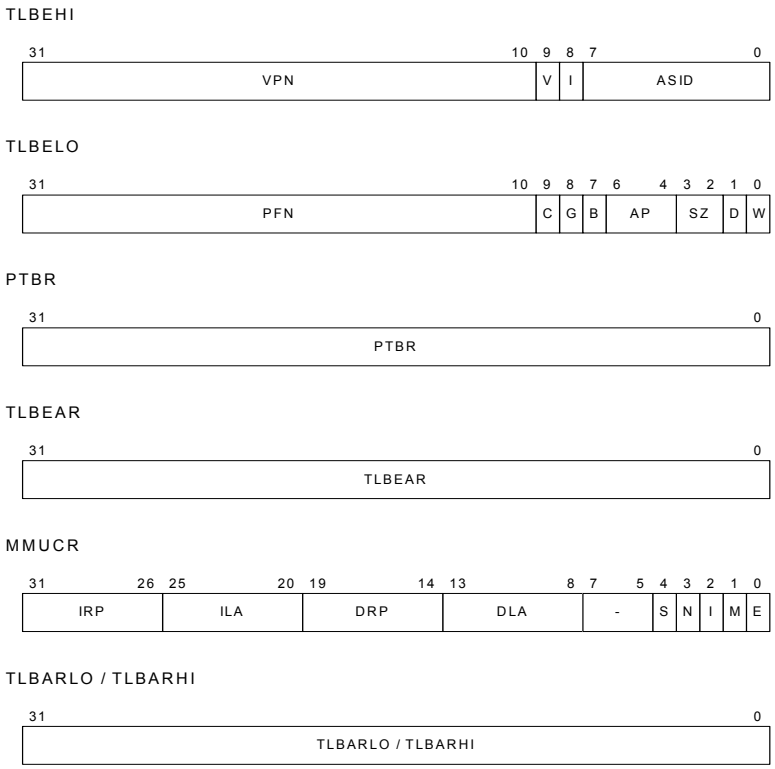
In shared virtual memory, the virtual address uniquely identifies which physical address it should be mapped to. Two different processes addressing the same virtual address will always access the same physical address. In other words, the Virtual Page Number (VPN) section of the virtual address uniquely specifies the Physical Frame Number (PFN) section in the physical address.

In private virtual memory, each process has its own virtual memory space. This is implemented by using both the VPN and the Application Space Identifier (ASID) of the current process when searching the TLB for a match. Each process has a unique ASID. Therefore, two different processes accessing the same VPN won't hit the same TLB entry, since their ASID is different. Pages can be shared between processes in private virtual mode by setting the Global (G) bit in the page table entry. This will disable the ASID check in the TLB search, causing the VPN section uniquely to identify the PFN for the particular page.

### 5.2.2 MMU interface registers

The following registers are used to control the MMU, and provide the interface between the MMU and the operating system. Most registers can be altered both by the application software (by writing to them) and by hardware when an exception occurs. All the registers are mapped into the System Register space, their addresses are presented in Section 2.11 "System registers" on page 14. The MMU interface registers are shown in Figure 5-3.

**Figure 5-3.** The MMU interface registers



#### 5.2.2.1 TLB Entry Register High Part - TLBEHI

The contents of the TLBEHI and TLBELO registers is loaded into the TLB when the *tlbw* instruction is executed. The TLBEHI register consists of the following fields:

- VPN - Virtual Page Number in the TLB entry. This field contains 22 bits, but the number of bits used depends on the page size. A page size of 1 kB requires 22 bits, while larger page sizes require fewer bits. When preparing to write an entry into the TLB, the virtual page number of the entry to write should be written into VPN. When an MMU-related exception has occurred, the virtual page number of the failing address is written to VPN by hardware.
- V - Valid. Set if the TLB entry is valid, cleared otherwise. This bit is written to 0 by a reset. If an access to a page which is marked as invalid is attempted, an TLB Miss exception is raised. Valid is set automatically by hardware whenever an MMU exception occurs.
- I - Instruction TLB. If set, the current TLBEHI and TLBELO entries should be written into the Instruction TLB. If cleared, the Data or Unified TLB should be addressed. The I bit is set by hardware when an MMU-related exception occurs, indicating whether the error occurred in the ITLB or the UTLB/DTLB.
- ASID - Application Space Identifier. The operating system allocates a unique ASID to each process. This ASID is written into TLBEHI by the OS, and used in the TLB address match if the MMU is running in Private Virtual Memory mode and the G bit of the TLB entry is cleared. ASID is never changed by hardware.

#### 5.2.2.2 TLB Entry Register Low Part - TLBELO

The contents of the TLBEHI and TLBELO registers is loaded into the TLB when the *tlbw* instruction is executed. None of the fields in TLBELO are altered by hardware. The TLBELO register consists of the following fields:

- PFN - Physical Frame Number to which the VPN is mapped. This field contains 22 bits, but the number of bits used depends on the page size. A page size of 1 kB requires 22 bits, while larger page sizes require fewer bits. When preparing to write an entry into the TLB, the physical frame number of the entry to write should be written into PFN.
- C - Cacheable. Set if the page is cacheable, cleared otherwise.
- G - Global bit used in the address comparison in the TLB lookup. If the MMU is operating in the Private Virtual Memory mode and the G bit is set, the ASID won't be used in the TLB lookup.
- B - Bufferable. Set if the page is bufferable, cleared otherwise.
- AP - Access permissions specifying the privilege requirements to access the page. The following permissions can be set, see Table 5-2 on page 40.

**Table 5-2.** Access permissions implied by the AP bits

| AP | Privileged mode | Unprivileged mode |
|---|---|---|
| 000 | Read | None |
| 001 | Read / Execute | None |
| 010 | Read / Write | None |
| 011 | Read / Write / Execute | None |
| 100 | Read | Read |
| 101 | Read / Execute | Read / Execute |
| 110 | Read / Write | Read / Write |
| 111 | Read / Write / Execute | Read / Write / Execute |

- SZ - Size of the page. The following page sizes are provided, see Table 5-3:

**Table 5-3.** Page sizes implied by the SZ bits

| SZ | Page size | Bits used in VPN | Bits used in PFN |
|---|---|---|---|
| 00 | 1 kB | TLBEHI[31:10] | TLBELO[31:10] |
| 01 | 4 kB | TLBEHI[31:12] | TLBELO[31:12] |
| 10 | 64 kB | TLBEHI[31:16] | TLBELO[31:16] |
| 11 | 1 MB | TLBEHI[31:20] | TLBELO[31:20] |

- D - Dirty bit. Set if the page has been written to, cleared otherwise. If the memory access is a store and the D bit is cleared, an Initial Page Write exception is raised.
- W - Write through. If set, a write-through cache update policy should be used. Write-back should be used otherwise. The bit is ignored if the cache only supports write-through or write-back.

#### 5.2.2.3 *Page Table Base Register - PTBR*

This register points to the start of the page table structure. The register is not used by hardware, and can only be modified by software. The register is meant to be used by the MMU-related exception routines.

#### 5.2.2.4 *TLB Exception Address Register - TLBEAR*

This register contains the virtual address that caused the most recent MMU-related exception. The register is updated by hardware when such an exception occurs.

#### 5.2.2.5 *MMU Control Register - MMUCR*

The MMUCR controls the operation of the MMU. The MMUCR has the following fields:

- IRP - Instruction TLB Replacement Pointer. Points to the ITLB entry to overwrite when a new entry is loaded by the *tlbw* instruction. The IRP field may be updated automatically in an IMPLEMENTATION DEFINED manner in order to optimize the replacement algorithm. The IRP field can also be written by software, allowing the exception routine to implement a replacement algorithm in software. The IRP field is 6 bits wide, allowing a maximum of 64

entries in the ITLB. It is IMPLEMENTATION DEFINED whether to use fewer entries. Impementations with a single unified TLB does not use the IRP field.

- ILA - Instruction TLB Lockdown Amount. Specified the number of locked down ITLB entries. All ITLB entries from entry 0 to entry (ILA-1) are locked down. If ILA equals zero, no entries are locked down. Implementations with a single unified TLB does not use the ILA field.
- DRP - Data TLB Replacement Pointer. Points to the DTLB entry to overwrite when a new entry is loaded by the *tlbw* instruction. The DRP field may be updated automatically in an IMPLEMENTATION DEFINED manner in order to optimize the replacement algorithm. The DRP field can also be written by software, allowing the exception routine to implement a replacement algorithm in software. The DRP field is 6 bits wide, allowing a maximum of 64 entries in the DTLB. It is IMPLEMENTATION DEFINED whether to use fewer entries. Implementations with a single unified TLB use the DRP field to point into the unified TLB.
- DLA - Data TLB Lockdown Amount. Specified the number of locked down DTLB or UTLB entries. All DTLB entries from entry 0 to entry (DLA-1) are locked down. If DLA equals zero, no entries are locked down.
- S - Segmentation Enable. If set, the segmented memory model is used in the translation process. If cleared, the memory is regarded as unsegmented. The S bit is set after reset.
- N - Not Found. Set if the entry searched for by the TLB Search instruction (*tlbs*) was not found in the TLB.
- I - Invalidate. Writing this bit to one invalidates all TLB entries. The bit is automatically cleared by the MMU when the invalidate operation is finished.
- M - Mode. Selects whether the shared virtual memory mode or the private virtual memory mode should be used. The M bit determines how the TLB address comparison should be performed, see Table 5-4 on page 41.

**Table 5-4.** MMU mode implied by the M bit

| M | Mode |
|---|---|
| 0 | Private Virtual Memory |
| 1 | Shared Virtual  Memory |

- E - Enable. If set, the MMU translation is enabled. If cleared, the MMU translation is disabled and the physical address is identical to the virtual address. Access permissions are not checked and no MMU-related exceptions are issued if the MMU is disabled. If the MMU is disabled, the segmented memory model is used.

#### 5.2.2.6 *TLB Accessed Register HI / LO - TLBARHI / TLBARLO*

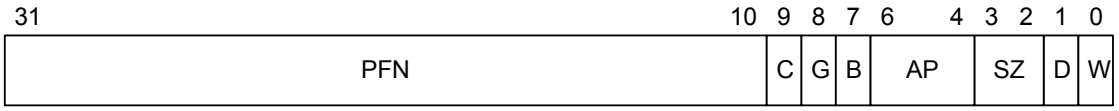
The TLBARHI and TLBARLO register form one 64-bit register with 64 1-bit fields. Each of these fields contain the Accessed bit for the corresponding TLB entry. The I bit in TLBEHI determines whether the ITLB or DTLB Accessed bits are read. The Accessed bit is 0 if the page has been accessed, and 1 if it has not been accessed. Bit 31-0 in TLBARLO correspond to TLB entry 0-31, bit 31-0 in TLBARHI correspond to TLB entry 32-63. If the TLB implementation contains less than 64 entries then nonimplemented entries are read as 0.

**Note:** The contents of TLBARHI/TLBARLO are reversed to let the Count Leading Zero (CLZ) instruction be used directly on the contents of the registers. E.g. if CLZ returns the value four on the contents of TLBARLO, then item four is the first unused item in the TLB.

### 5.2.3 Page Table Organization

The MMU leaves the page table organization up to the OS software. Since the page table handling and TLB handling is done in software, the OS is free to implement different page table organizations. It is recommended, however, that the page table entries (PTEs) are of the format shown in Figure 5-4. This allows the loaded PTE to be written directly into TLBELO, without the need for reformatting. How the PTEs are indexed and organized in memory is left to the OS.

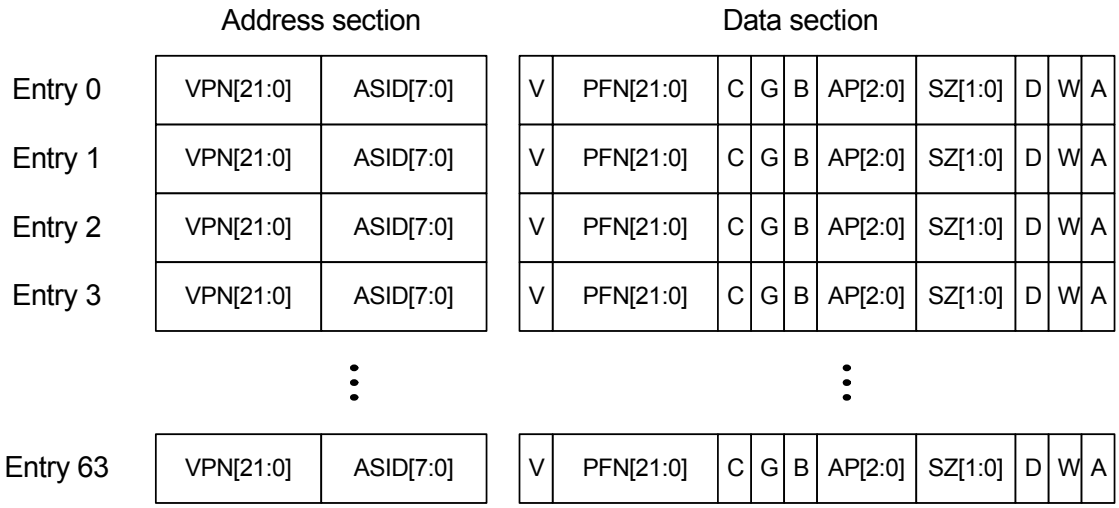
**Figure 5-4.** Recommended Page Table Entry format




### 5.2.4 TLB organization

The TLB is used as a cache for the page table, in order to speed up the virtual memory translation process. Up to two TLBs can be implemented, each with up to 64 entries. Each TLB is configured as shown in Figure 5-5 on page 42.

**Figure 5-5.** TLB organization




The D, W and AP[1] bits are not implemented in ITLBs, since they have no meaning there.

The AP[0] bits are not implemented in DTLBs, since they have no meaning there.

The A bit is the Accessed bit. This bit is set when the TLB entry is loaded with a new value using the *tlbw* instruction. It is cleared whenever the TLB matching process finds a match in the specific TLB entry. The A bit is used to implement pseudo-LRU replacement algorithms.

When an address look-up is performed by the TLB, the address section is searched for an entry matching the virtual address to be accessed. The matching process is described in chapter 5.2.5.

### 5.2.5 Translation process

The translation process maps addresses from the virtual address space to the physical address space. The addresses are generated as shown in Table 5-5, depending on the page size chosen:

**Table 5-5.** Physical address generation

| Page size | Physical address |
|---|---|
| 1 kB | PFN[31:10], VA[9:0] |
| 4 kB | PFN[31:12], VA[11:0] |
| 64 kB | PFN[31:16], VA[15:0] |
| 1 MB | PFN[31:20], VA[19:0] |

A data memory access can be described as shown in Table 5-6.

**Table 5-6.** Data memory access pseudo-code example

```
If (Segmentation disabled)
  If (! PagingEnabled)
    PerformAccess(cached, write-back);
  else
    PerformPagedAccess(VA);
else
  if (VA in Privileged space)
    if (InApplicationMode)
      SignalException(DTLB Protection, accesstype);
  endif;

  if (VA in P4 space)
    PerformAccess(non-cached);
  else if (VA in P2 space)
    PerformAccess(non-cached);
  else if (VA in P1 space)
    PerformAccess(cached, writeback);
  else
    // VA in P0, U0 or P3 space
    if ( ! PagingEnabled)
      PerformAccess(cached, writeback);
    else
      PerformPagedAccess(VA);
    endif;
  endif;
endif;
```

The translation process performed by PerformTranslatedAccess( ) can be described as shown in Table 5-7.

**Table 5-7.** PerformTranslatedAccess( ) pseudo-code example

```
match ← 0;
for (i=0; i<TLBentries; i++)
  if ( Compare(TLB[i]VPN, VA, TLB[i]SZ, TLB[i]V) )
    // VPN and VA matches for the given page size and entry valid
    if ( SharedVirtualMemoryMode or
      (PrivateVirtualMemoryMode and ( TLB[i]G or (TLB[i]ASID==TLBEHIASID) ) ) )
        if (match == 1)
          SignalException(TLBmultipleHit);
        else
          match ← 1;
          TLB[i]A  ← 1;
          ptr ← i;
          // pointer points to the matching TLB entry
        endif;
    endif;
endfor;

if (match == 0 )
  SignalException(DTLBmiss, accesstype);
endif;

if (InApplicationMode)
  if (TLB[ptr]AP[2] == 0)
    SignalException(DTLBprotection, accesstype);
  endif;
endif;

if (accesstype == write)
  if (TLB[ptr]AP[1] == 0)
    SignalException(DTLBprotection, accesstype);
  endif;
  if (TLB[ptr]D == 0)
    // Initial page write
    SignalException(DTLBmodified);
  endif;
endif;

if (TLB[ptr]C == 1)
  if (TLB[ptr]W == 1)
    PerformAccess(cached, write-through);
  else
    PerformAccess(cached, write-back);
  endif;
else
  PerformAccess(non-cached);
endif;
```

An instruction memory access can be described as shown in Table 5-8.

**Table 5-8.** Instruction memory access pseudo-code example

```
If (Segmentation disabled)
  If (! PagingEnabled)
    PerformAccess(cached, write-back);
  else
    PerformPagedAccess(VA);
else
  if (VA in Privileged space)
    if (InApplicationMode)
      SignalException(ITLB Protection, accesstype);
  endif;

  if (VA in P4 space)
    PerformAccess(non-cached);
  else if (VA in P2 space)
    PerformAccess(non-cached);
  else if (VA in P1 space)
    PerformAccess(cached, writeback);
  else
    // VA in P0, U0 or P3 space
    if ( ! PagingEnabled)
      PerformAccess(cached, writeback);
    else
      PerformPagedAccess(VA);
    endif;
  endif;
endif;
```

The translation process performed by PerformTranslatedAccess( ) can be described as as shown in Table 5-9.

**Table 5-9.** PerformTranslatedAccess( ) pseudo-code example

```
match ← 0;
for (i=0; i<TLBentries; i++)
  if ( Compare(TLB[i]VPN, VA, TLB[i]SZ, TLB[i]V) )
    // VPN and VA matches for the given page size and entry valid
    if ( SharedVirtualMemoryMode or
      (PrivateVirtualMemoryMode and ( TLB[i]G or (TLB[i]ASID==TLBEHIASID) ) ) )
        if (match == 1)
          SignalException(TLBmultipleHit);
        else
          match ← 1;
          TLB[i]A  ← 1;
          ptr ← i;
          // pointer points to the matching TLB entry
        endif;
    endif;
endfor;

if (match == 0 )
  SignalException(ITLBmiss);
endif;

if (InApplicationMode)
  if (TLB[ptr]AP[2] == 0)
    SignalException(ITLBprotection);
  endif;
endif;

if (TLB[ptr]AP[0] == 0)
  SignalException(ITLBprotection);
endif;

if (TLB[ptr]C == 1)
  PerformAccess(cached);
else
  PerformAccess(non-cached);
endif;
```

## 5.3 Operation of the MMU and MMU exceptions

The MMU uses both hardware and software mechanisms in order to perform its memory remapping operations. The following tasks are performed by hardware:

1. The MMU decodes the virtual address and tries to find a matching entry in the TLB. This entry is used to generate a physical address. If no matching entry is found, a TLB miss exception is issued.
2. The matching entry is used to determine whether the access has the appropriate access rights, cacheability, bufferability and so on. If the access is not permitted, a TLB Protection Violation exception is issued.
3. If any other event arises that requires software intervention, an appropriate exception is issued.
4. If the correct entry was found in the TLB, and the access permissions were not violated, the memory access is performed without any further software intervention.

The following tasks must be performed by software:

1. Setup of the MMU hardware by initializing the MMU-related registers and data structures if needed.
2. Maintenance of the TLB structure. TLB entries are written, invalidated and replaced by means of software. A *tlbw* instruction is included in the instruction set to support this.
3. The MMU may generate several exceptions. Software exception handlers must be written in order to service these exceptions.

### 5.3.1 The tlbw instruction

The *tlbw* instruction is implemented in order to aid in performing TLB maintenance. The instruction copies the contents of TLBEHI and TLBELO into the TLB entry pointed to by the ITLB or DTLB Replacement Pointers (IRP/DRP) in the MMU Control Register. The TLBEHI[I] bit decides if the ITLB or the DTLB should be addressed. IRP and DRP may in some implementations be automatically updated by hardware in order to implement a TLB replacement algorithm in hardware. Software may update them before executing *tlbw* in order to implement a software replacement algorithm.

In some implementations, the TLB data structures may be mapped into the P4 space. In such implementations, the TLB data structures may be updated with regular memory access instructions.

### 5.3.2 TLB synonyms

Implementations using virtually indexed caches may be subject to cache inconsistencies, depending on the page size used and number of lines in the cache. These inconsistencies may occur when multiple virtual addresses are mapped to the same physical address, since a translated part of VPN may be used to index the cache. This implies that the same physical address may be mapped to different cache lines, causing cache inconsistency.

Synonym problems can only appear when addressing data residing in a virtually indexed cache. Addressing uncached memory or accessing untranslated memory will never cause synonym problems.

It is the responsability of the OS to define a policy ensuring that no synonym problems may arise. No hardware support is provided to avoid TLB synonyms.

### 5.3.3 MMU exception handling

This chapter describes the software actions that must be performed for MMU-related exceptions. The hardware actions performed by the exceptions are described in detail in Section 8.3.1 “Description of events in AVR32A” on page 68.

#### *5.3.3.1 ITLB / DTLB Multiple Hit*

If multiple matching entries are found when searching the ITLB or DTLB, this exception is issued. This situation is a critical error, since memory consistency can no longer be guaranteed. The exception hardware therefore jumps to the reset vector, where software should execute the required reset code. This exception is a sign of erroneous code and is not normally generated.

The software handler should perform a normal system restart. However, debugging code may be inserted in the handler.

#### *5.3.3.2 ITLB / DTLB Miss*

This exception is issued if no matching entries are found in the TLBs, or when a matching entry is found with the Valid bit cleared. The same actions must be performed for both exceptions, but DTLB entries contains more control bits than the ITLB entries.

1. Examine the TLBEAR and TLBEHI registers in order to identify the page that caused the fault. Use this to index the page table pointed to by PTBR and fetch the desired page table entry.
2. Use the fetched page table entry to update the necessary bits in PTEHI and PTELO. The following bits must be updated, not all bits apply to ITLB entries: V, PFN, C, G, B, AP[2:0], SZ[1:0], W, D.
3. The TLBEHI[I] register is updated by hardware to indicate if it was a ITLB or a DTLB miss. The MMUCR[IRP] and MMUCR[DRP] pointers may be updated in an IMPLEMENTATION DEFINED way in order to select which TLB entry to replace. The software may override this value by writing a value directly to MMUCR[IRP] or MMUCR[DRP], depending on which TLB to update.
4. Execute the *tlbw* instruction in order to update the TLB entry.
5. Finish the exception handling and return to the application by executing the *rete* instruction.

#### *5.3.3.3 ITLB / DTLB Protection Violation*

This exception is issued if the access permision bits in the matching TLB entry does not match the privilege level the CPU is currently executing in. The exception is also issued if the MMU is disabled or absent and non-translated areas are accessed with illegal access rights. The same actions must be performed for both exceptions, but DTLB entries contains more control bits than the ITLB entries.

Software must examine the TLBEAR and TLBEHI registers in order to identify the instruction and process that caused the error. Corrective measures like terminating the process must then be performed before returning to normal execution with *rete*.

#### 5.3.3.4 DTLB Modified

This exception is issued if a valid memory write operation is performed to a page that has never been written before. This is detected by the Dirty-bit in the matching TLB entry reading zero.

1. Examine the TLBEAR and TLBEHI registers in order to identify the page that caused the fault. Use this to index the page table pointed to by PTBR and fetch the desired page table entry.
2. Set the Dirty bit in the read page table entry and write this entry back to the page table
3. Use the fetched page table entry to update the necessary bits in PTEHI and PTELO. The following bits must be updated: V, PFN, C, G, B, AP[2:0], SZ[1:0], W, D.
4. The TLBEHI[I] register is updated by hardware to indicate that it was a DTLB miss. Ensure that MMUCR[DRP] points to the TLB entry to replace. An entry for the faulting page must already exist in the DTLB, and MMUCR[DRP] must point to this entry, otherwise multiple DTLB hits may occur.
5. Execute the *tlbw* instruction in order to update the TLB entry.
6. Finish the exception handling and return to the application by executing the *rete* instruction.

# 6. Memory Protection Unit

The AVR32 architecture defines an optional Memory Protection Unit (MPU). This is a simpler alternative to a full MMU, while at the same time allowing memory protection. The MPU allows the user to divide the memory space into different protection regions. These protection regions have a user-defined size, and starts at a user-defined address. The different regions can have different cacheability attributes and bufferability attributes. Each region is divided into 16 subregions, each of these subregions can have one of two possible sets of access permissions.

The MPU does not perform any address translation.

## 6.1 Memory map in systems with MPU

An AVR32 implemetation with a MPU has a flat, unsegmented memory space. Access permissions are given only by the different protection regions.

## 6.2 Understanding the MPU

The AVR32 Memory Protection Unit (MPU) is responsible for checking that memory transfers have the correct permissions to complete. If a memory access with unsatisfactory privileges is attempted, an exception is generated and the access is aborted. If an access to a memory address that does not reside in any protection region is attempted, an exception is generated and the access is aborted.

The user is able to allow different privilege levels to different blocks of memory by configuring a set of registers. Each such block is called a protection region. Each region has a user-programmable start address and size. The MPU allows the user to program 8 different protection regions. Each of these regions have 16 sub-regions, which can have different access permissions, cacheability and bufferability.

The “DMMU SZ” fields in the CONFIG1 system register identifies the number of implemented protection regions, and therefore also the number of MPU registers. A system with caches also have MPU cacheability and bufferability registers.

A protection region can be from 4 KB to 4 GB in size, and the size must be a power of two. All regions must have a start address that is aligned to an address corresponding to the size of the region. If the region has a size of 8 KB, the 13 lowest bits in the start address must be 0. Failing to do so will result in UNDEFINED behaviour. Since each region is divided into 16 sub-regions, each sub-region is 256 B to 256 MB in size.

When an access hits into a memory region set up by the MPU, hardware proceeds to determine which subregion the access hits into. This information is used to determine whether the access permissions for the subregion are given in MPUAPRA/MPUBRA/MPUCRA or in MPUAPRB/MPUBRB/MPUCRB.

If an access does not hit in any region, the transfer is aborted and an exception is generated.

The MPU is enabled by writing setting the E bit in the MPUCR register. The E bit is cleared after reset. If the MPU is disabled, all accesses are treated as uncacheable, unbufferable and will not generate any access violations. Before setting the E bit, at least one valid protection region must be defined.

### 6.2.1 MPU interface registers

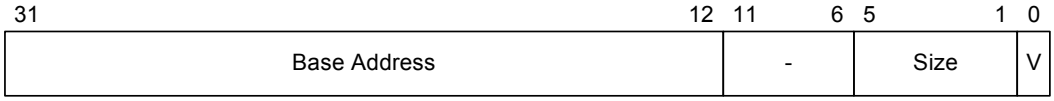
The following registers are used to control the MPU, and provide the interface between the MPU and the operating system, see Figure 6-1 on page 52. All the registers are mapped into the Sys-

tem Register space, their addresses are presented in “System registers” on page 14. They are accessed with the *mtsr* and *mfsr* instructions.

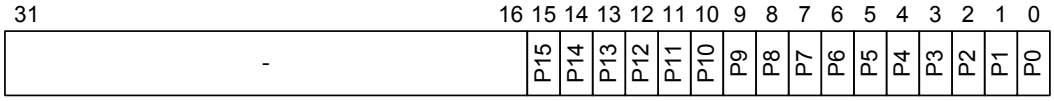
The MPU interface registers are shown below. The suffix n can have the range 0-7, indicating which region the register is associated with.

**Figure 6-1.** The MPU interface registers

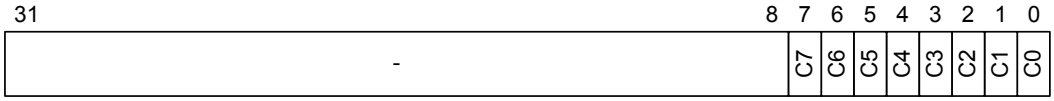
MPUARn



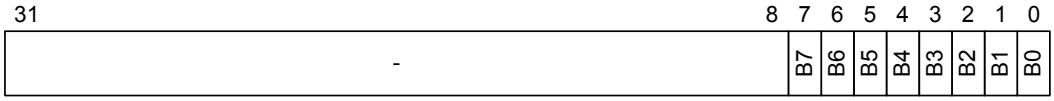

MPUPSRn



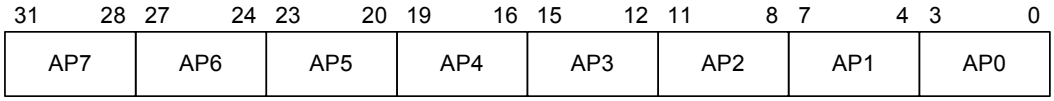

MPUCRA / MPUCRB



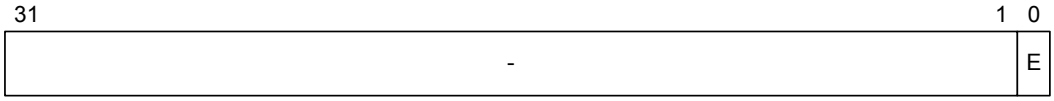

MPUBRA / MPUBRB




MPUAPRA / MPUAPRB




MPUCR




### 6.2.1.1 *MPU Address Register - MPUARn*

A MPU Address register is implemented for each of the 8 protection regions. The MPUAR registers specify the start address and size of the regions. The start address must be aligned so that its alignment corresponds to the size of the region. The minimum allowable size of a region is 4 KB, so only bits 31:12 in the base address needs to be specified. The other bits are always 0. Each MPUAR also has a valid bit that specifies if the protection region is valid. Only valid regions are considered in the protection testing.

The MPUAR register consists of the following fields:

- Base address - The start address of the region. The minimum size of a region is 4KB, so only the 20 most significant bits in the base address needs to be specified. The 12 lowermost base address bits are implicitly set to 0. If protection regions larger than 4 KB is used, the user must write the appropriate bits in Base address to 0, so that the base address is aligned to the size of the region. Otherwise, the result is UNDEFINED.

- Size - Size of the protection region. The possible sizes are shown in Table 6-1 on page 53.

**Table 6-1.** Protection region sizes implied by the Size field

| Size | Region size | Constraints on Base address |
|---|---|---|
| B'00000 to B'01010 | UNDEFINED | - |
| B'01011 | 4 KB | None |
| B'01100 | 8 KB | Bit [12] in Size must be 0 |
| B'01101 | 16 KB | Bit [13:12] in Size must be 0 |
| B'01110 | 32 KB | Bit [14:12] in Size must be 0 |
| B'01111 | 64 KB | Bit [15:12] in Size must be 0 |
| B'10000 | 128 KB | Bit [16:12] in Size must be 0 |
| B'10001 | 256 KB | Bit [17:12] in Size must be 0 |
| B'10010 | 512 KB | Bit [18:12] in Size must be 0 |
| B'10011 | 1 Mb | Bit [19:12] in Size must be 0 |
| B'10100 | 2 MB | Bit [20:12] in Size must be 0 |
| B'10101 | 4 MB | Bit [21:12] in Size must be 0 |
| B'10110 | 8 MB | Bit [22:12] in Size must be 0 |
| B'10111 | 16 MB | Bit [23:12] in Size must be 0 |
| B'11000 | 32 MB | Bit [24:12] in Size must be 0 |
| B'11001 | 64 MB | Bit [25:12] in Size must be 0 |
| B'11010 | 128 MB | Bit [26:12] in Size must be 0 |
| B'11011 | 256 MB | Bit [27:12] in Size must be 0 |
| B'11100 | 512 MB | Bit [28:12] in Size must be 0 |
| B'11101 | 1 GB | Bit [29:12] in Size must be 0 |
| B'11110 | 2 GB | Bit [30:12] in Size must be 0 |
| B'11111 | 4 GB | Bit [31:12] in Size must be 0 |

- V - Valid. Set if the protection region is valid, cleared otherwise. This bit is written to 0 by a reset. The region is not considered in the protection testing if the V bit is cleared.

#### 6.2.1.2 *MPU Permission Select Register - MPUPSRn*

A MPU Permission Select register is implemented for each of the 8 protection regions. Each MPUPSR register divides the protection region into 16 subregions. The bitfields in MPUPSR specifies whether each subregion has access permissions as specified by the region entry in either MPUAPRA or MPUAPRB.

**Table 6-2.** Subregion access permission implied by MPUPSR bitfields

| MPUPSRn[P] | Access permission |
|---|---|
| 0 | MPUAPRA[APn] |
| 1 | MPUAPRB[APn] |

#### 6.2.1.3 *MPU Cacheable Register A / B- MPUCRA / MPUCRB*

The MPUCR registers have one bit per region, indicating if the region is cacheable. If the corresponding bit is set, the region is cacheable. The register is written to 0 upon reset.

AVR32UC implementations may optionally choose not to implement the MPUCR registers.

#### 6.2.1.4 *MPU Bufferable Register A / B- MPUBRA / MPUBRB*

The MPUBR registers have one bit per region, indicating if the region is bufferable. If the corresponding bit is set, the region is bufferable. The register is written to 0 upon reset.

AVR32UC implementations may optionally choose not to implement the MPUBR registers.

#### 6.2.1.5 *MPU Access Permission Register A / B - MPUAPRA / MPUAPRB*

The MPUAPR registers indicate the access permissions for each region. The MPUAPR is written to 0 upon reset. The possible access permissions are shown in Table 6-3 on page 54.

**Table 6-3.** Access permissions implied by the APn bits

| AP | Privileged mode | Unprivileged mode |
|---|---|---|
| B'0000 | Read | None |
| B'0001 | Read / Execute | None |
| B'0010 | Read / Write | None |
| B'0011 | Read / Write / Execute | None |
| B'0100 | Read | Read |
| B'0101 | Read / Execute | Read / Execute |
| B'0110 | Read / Write | Read / Write |
| B'0111 | Read / Write / Execute | Read / Write / Execute |
| B'1000 | Read / Write | Read |
| B'1001 | Read / Write | Read / Execute |
| B'1010 | None | None |
| Other | UNDEFINED | UNDEFINED |

#### 6.2.1.6 *MPU Control Register - MPUCR*

The MPUCR controls the operation of the MPU. The MPUCR has only one field:

- E - Enable. If set, the MPU address checking is enabled. If cleared, the MPU address checking is disabled and no exceptions will be generated by the MPU.

### 6.2.2 MPU exception handling

This chapter describes the exceptions that can be signalled by the MPU.

#### 6.2.2.1 *ITLB Protection Violation*

An ITLB protection violation is issued if an instruction fetch violates access permissions. The violating instruction is not executed. The address of the failing instruction is placed on the system stack.

#### 6.2.2.2 DTLB Protection Violation

An DTLB protection violation is issued if a data access violates access permissions. The violating access is not executed. The address of the failing instruction is placed on the system stack.

#### 6.2.2.3 ITLB Miss Violation

An ITLB miss violation is issued if an instruction fetch does not hit in any region. The violating instruction is not executed. The address of the failing instruction is placed on the system stack.

#### 6.2.2.4 DTLB Miss Violation

An DTLB miss violation is issued if a data access does not hit in any region. The violating access is not executed. The address of the failing instruction is placed on the system stack.

#### 6.2.2.5 TLB Multiple Hit Violation

An access hit in multiple protection regions. The address of the failing instruction is placed on the system stack. This is a critical system error that should not occur.

## 6.3 Example of MPU functionality

As an example, consider region 0. Let region 0 be of size 16 KB, thus each subregion is 1KB. Subregion 0 has offset 0-1KB from the base address, subregion 1 has offset 1KB-2KB and so on.

MPUAPRA and MPUAPRB each has one field per region. Each subregion in region 0 can get its access permissions from either MPUAPRA[AP0] or MPUAPRB[AP0], this is selected by the subregion's bitfield in MPUPSR0.

Let:

MPUPSR0 = {0b0000_0000_0000_0000, 0b1010_0000_1111_0101}

MPUAPRA = {A, B, C, D, E, F, G, H}

MPUAPRB = {a, b, c, d, e, f, g, h}

where {A-H, a-h} have legal values as defined in Table 6-3.

Thus for region 0:

**Table 6-4.** Example of access rights for subregions

| Subregion | Access permission | Subregion | Access permission |
|---|---|---|---|
| 0 | h | 8 | H |
| 1 | H | 9 | H |
| 2 | h | 10 | H |
| 3 | H | 11 | H |
| 4 | h | 12 | H |
| 5 | h | 13 | h |
| 6 | h | 14 | H |
| 7 | h | 15 | h |

# 7. Performance counters

## 7.1 Overview

A set of performance counters let users evaluate the performance of the system. This is useful when scheduling code and performing optimizations. Two configurable event counters are provided in addition to a clock cycle counter. These three counters can be used to collect information about for example cache miss rates, branch prediction hit rate and data hazard stall cycles.

The three counters are implemented as 32-bit registers accessible through the system register interface. They can be configured to issue an interrupt request in case of overflow, allowing a software overflow counter to be implemented.

A performance counter control register is implemented in addition to the three counter registers. This register controls which events to record in the counter, counter overflow interrupt enable and other configuration data.

## 7.2 Registers

### 7.2.1 Performance clock counter - PCCNT

This register counts CPU clock cycles. When it reaches 0xFFFF_FFFF, it rolls over. The overflow flag is set and an exception is generated if configured by PCCR. The register can be reset by writing to the C bit in PCCR. PCCNT can be preset to a value by writing directly to it. PCCNT is written to zero upon reset.

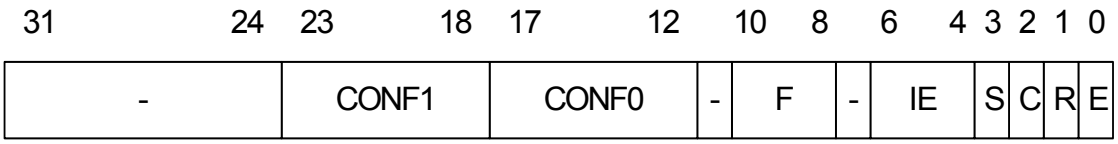
### 7.2.2 Performance counter 0,1 - PCNT0, PCNT1

These counters monitor events as configured by PCCR. When they reach 0xFFFF_FFFF, they roll over. The overflow flag is set and an exception is generated if configured by PCCR. The registers can be reset by writing the R bit in PCCR. The registers can be preset to a value by writing directly to them. PCNT0 and PCNT1 are written to zero upon reset.

### 7.2.3 Performance counter control register - PCCR

This register controls the behaviour of the entire performance counter system, see Figure 7-1 on page 57. This register is read and written by the *mtsr* and *mfsr* instructions. PCCR is written to zero upon reset.

**Figure 7-1.** Performance counter control register



The following fields exist in PCCR, see Table 7-1 on page 58.

**Table 7-1.** Performance counter control register

| Bit | Access | Name | Description |
|---|---|---|---|
| 23:18 | Read/write | CONF1 | Configures which events to count with PCNT1. See Table 7-2 for a legend. |
| 17:12 | Read/write | CONF0 | Configures which events to count with PCNT0. See Table 7-2 for a legend. |
| 10:8 | Read/write | F | Interrupt flag. If read as 1, the corresponding overflow has occurred. Bit 8 corresponds to PCCNT.<br>Bit 9 corresponds to PCNT0.<br>Bit 10 corresponds to PCNT1.<br>Flags are cleared by writing a 1 to the flag. |
| 6:4 | Read/write | IE | Interrupt enable. If set, an overflow of the corresponding counter will cause an interrupt request.<br>Bit 4 corresponds to PCCNT.<br>Bit 5 corresponds to PCNT0.<br>Bit 6 corresponds to PCNT1. |
| 3 | Read/write | S | Clock counter scaler. If set, the clock counter increments once every 64'th clock cycle. This expands the period-to-overflow to $2^{38}$ cycles. |
| 2 | Read-0/write | C | Clock counter reset. If written to 1, the clock counter will be reset. |
| 1 | Read-0/write | R | Performance counter reset. If written to 1, all three counters will be reset. |
| 0 | Read/write | E | Clock counter enable. If set, all three counters will count their configured events. If cleared, the counters are disabled and will not count. |
| Other | Read-0/write-0 | - | Unused. Read as 0. Should be written as 0. |

## 7.3 Monitorable events

The following events can be monitored by the performance counters, depending on the setting of CONF0 and CONF1, see Table 7-2 on page 59.

**Table 7-2.** Monitorable events

| Configure field setting | Event monitored and counted |
|---|---|
| 0x0 | Instruction cache miss. Incremented once for each instruction fetch from a cacheable memory area that did not hit in the cache. |
| 0x1 | Instruction fetch stage stall. Incremented every cycle the memory system is unable to deliver an instruction to the CPU. |
| 0x2 | Data hazard stall. Incremented every cycle the condition is true. |
| 0x3 | ITLB miss. |
| 0x4 | DTLB miss. |
| 0x5 | Branch instruction executed. May or may not be taken. |
| 0x6 | Branch mispredicted. |
| 0x7 | Instruction executed. Incremented once each time an instruction is completed. |
| 0x8 | Stall due to data cache write buffers full. Incremented once for each occurrence. |
| 0x9 | Stall due to data cache write buffers full. Incremented every cycle the condition is true. |
| 0xA | Stall due to data cache read miss. Incremented once for each data access to a cacheable memory area that did not hit in the cache. |
| 0xB | Stall due to data cache read miss. Incremented every cycle the pipeline is stalled due to a data access to a cacheable memory area that did not hit in the cache. |
| 0xC | Write access counter. Incremented once for each write access. |
| 0xD | Write access counter. Incremented every cycle a write access is ongoing. |
| 0xE | Read access counter. Incremented once for each read access. |
| 0xF | Read access counter. Incremented every cycle a read access is ongoing. |
| 0x10 | Cache stall counter. Incremented once for each read or write access that stalls. |
| 0x11 | Cache stall counter. Incremented every cycle a read or write access stalls. Write accesses are counted only until the write is put in the write buffer. |
| 0x12 | Cache access counter. Incremented once for each read or write access. |
| 0x13 | Cache access counter. Incremented every cycle a read or write access is ongoing. Write accesses are counted only until the write is put in the write buffer. |
| 0x14 | Data cache line writeback. Incremented once when a line containing dirty data is replaced in the cache. |
| 0x15 | Accumulator cache hit |
| 0x16 | Accumulator cache miss |
| 0x17 | BTB hit. Incremented once per hit occurrence. |
| 0x18 | Micro-ITLB miss. Incremented once per miss occurrence. |
| 0x19 | Micro-DTLB miss. Incremented once per miss occurrence. |
| Other | Reserved. |

## 7.4 Usage

The performance counters can be used to monitor several different events and perform different measurements. Some of the most useful are explained below.

### 7.4.1 Cycles per instruction

CONF0: 0x7 (Instruction executed)

CPI = CCNT / PCNT0

Cycles-per-instruction (CPI) measures the average time it took to execute an instruction.

### 7.4.2 Icache miss rate

CONF0: 0x7 (Instruction executed)

CONF1: 0x0 (Icache miss)

ICMR = PCNT1 / PCNT0

The instruction cache miss rate (ICMR) mesures the fraction of instruction cache misses per executed instruction.

### 7.4.3 Dcache read miss rate

CONF0: 0xE (Dcache read access)

CONF1: 0xA (Dcache read miss)

DCMR = PCNT1 / PCNT0

The data cache read miss rate (DCRMR) mesures the fraction of data cache read misses per data cache read access.

### 7.4.4 Average instruction fetch miss latency

CONF0: 0x1 (Instruction fetch stall)

CONF1: 0x0 (Icache miss)

AIFML = PCNT0 / PCNT1

The average instruction fetch miss latency (AIFML) mesures the average number of clock cycles spent per instruction cache miss. This measure does not consider cycles spent due to ITLB misses.

### 7.4.5 Fraction of execution time spent stalling due to instruction fetch misses

CONF0: 0x1 (Instruction fetch stall)

AIFML = PCNT0 / PCCNT

The fraction of execution time spent stalling due to instruction fetch misses mesures the ratio of clock cycles spent waiting for an instruction to be fetched to the total number of execution cycles.

### 7.4.6 Average writeback stall duration

CONF0: 0x8 (Write buffer full occurrences)

CONF1: 0x9 (Write buffer full cycles)

AWSD = PCNT0 / PCNT1

The average writeback stall duration (AWSD) mesures the average number of clock cycles spent stalling due to a full writebuffer.

### 7.4.7 Fraction of execution time spent stalling due to writeback

CONF0: 0x9 (Write buffer full cycles)

FETW=CONF0/PCCNT

The fraction of execution time spent stalling due to writeback (FETW) is the ratio of writebuffer full stall cycles to the total number of cycles.

### 7.4.8 ITLB miss rate

CONF0: 0x3 (ITLB miss)

CONF1: 0x7 (Instruction count)

IMR = PCNT0 / PCNT1

The ITLB miss rate (IMR) is the ratio of ITLB misses to the number of instructions executed.

### 7.4.9 DTLB miss rate

CONF0: 0x4 (DTLB miss)

CONF1: 0x7 (Instruction count)

IMR = PCNT0 / PCNT1

The DTLB miss rate (DMR) is the ratio of DTLB misses to the number of instructions executed.

### 7.4.10 Branch prediction hit rate

CONF0: 0x17 (BTB hit)

CONF1: 0x5 (Branch executed)

BPHR = PCNT0 / PCNT1

The branch prediction hit rate (BPHR) is the ratio of BTB hits to the number of branches executed.

### 7.4.11 Branch prediction correct rate

CONF0: 0x5 (Branch executed)

CONF1: 0x6 (Branch mispredicted)

BPCR = PCNT1 / PCNT0

The branch prediction correct rate (BPCR) is the ratio of branch mispredictions to the total number of executed branches.

# 8. Event Processing

Due to various reasons, the CPU may be required to abort normal program execution in order to handle special, high-priority events. When handling of these events is complete, normal program execution can be resumed. Traditionally, events that are generated internally in the CPU are called exceptions, while events generated by sources external to the CPU are called interrupts. The possible sources of events are listed in Table 8-1 on page 67.

The AVR32 has a powerful event handling scheme. The different event sources, like Illegal Opcode and external interrupt requests, have different priority levels, ensuring a well-defined behaviour when multiple events are received simultaneously. Additionally, pending events of a higher priority class may preempt handling of ongoing events of a lower priority class.

When an event occurs, the execution of the instruction stream is halted, and execution control is passed to an event handler at an address specified in Table 8-1 on page 67. Most of the handlers are placed sequentially in the code space starting at the address specified by EVBA, with four bytes between each handler. This gives ample space for a jump instruction to be placed there, jumping to the event routine itself. A few critical handlers have larger spacing between them, allowing the entire event routine to be placed directly at the address specified by the EVBA-relative offset generated by hardware. All external interrupt sources have autovectored interrupt service routine (ISR) addresses. This allows the interrupt controller to directly specify the ISR address as an address relative to EVBA. The address range reachable by this autovector offset is IMPLEMENTATION DEFINED. Implementations may require EVBA to be aligned in an IMPLEMENTATION DEFINED way in order to support autovectoring.

The same mechanisms are used to service all different types of events, including external interrupt requests, yielding a uniform event handling scheme.

If the application is executing in the secure state, the event handling is modified as explained in "Event handling in secure state" on page 92. This is to protect from hacking secure code using the event system.

## 8.1 Event handling in AVR32A

### 8.1.1 Exceptions and interrupt requests

When an event other than *scall* or debug request is received by the core, the following actions are performed atomically:

1. The pending event will not be accepted if it is masked. The I3M, I2M, I1M, I0M, EM and GM bits in the Status Register are used to mask different events. Not all events can be masked. A few critical events (NMI, Unrecoverable Exception, TLB Multiple Hit and Bus Error) can not be masked. When an event is accepted, hardware automatically sets the mask bits corresponding to all sources with equal or lower priority. This inhibits acceptance of other events of the same or lower priority, except for the critical events listed above. Software may choose to clear some or all of these bits after saving the necessary state if other priority schemes are desired. It is the event source's responsability to ensure that their events are left pending until accepted by the CPU.
2. When a request is accepted, the Status Register and Program Counter of the current context is stored to the system stack. If the event is an INT0, INT1, INT2 or INT3, registers R8 to R12 and LR are also automatically stored to stack. Storing the Status Register ensures that the core is returned to the previous execution mode when the current event handling is completed. When exceptions occur, both the EM and GM bits are set, and the application may manually enable nested exceptions if desired by clear-

ing the appropriate bit. Each exception handler has a dedicated handler address, and this address uniquely identifies the exception source.

3. The Mode bits are set to reflect the priority of the accepted event, and the correct register file bank is selected. The address of the event handler, as shown in Table 8-1, is loaded into the Program Counter.

The execution of the event handler routine then continues from the effective address calculated.

The *rete* instruction signals the end of the event. When encountered, the Return Status Register and Return Address Register are popped from the system stack and restored to the Status Register and Program Counter. If the *rete* instruction returns from INT0, INT1, INT2 or INT3, registers R8 to R12 and LR are also popped from the system stack. The restored Status Register contains information allowing the core to resume operation in the previous execution mode. This concludes the event handling.

### 8.1.2 Supervisor calls

The AVR32 instruction set provides a supervisor mode call instruction. The *scall* instruction is designed so that privileged routines can be called from any context. This facilitates sharing of code between different execution modes. The *scall* mechanism is designed so that a minimal execution cycle overhead is experienced when performing supervisor routine calls from time-critical event handlers.

The *scall* instruction behaves differently depending on which mode it is called from. The behaviour is detailed in the instruction set reference. In order to allow the *scall* routine to return to the correct context, a return from supervisor call instruction, *rets*, is implemented. In the AVR32A microarchitecture, *scall* and *rets* uses the system stack to store the return address and the status register.

### 8.1.3 Debug requests

The AVR32 architecture defines a dedicated debug mode. When a debug request is received by the core, Debug mode is entered. Entry into Debug mode can be masked by the DM bit in the status register. Upon entry into Debug mode, hardware sets the SR[D] bit and jumps to the Debug Exception handler. By default, debug mode executes in the exception context, but with dedicated Return Address Register and Return Status Register. These dedicated registers remove the need for storing this data to the system stack, thereby improving debuggability. The mode bits in the status register can freely be manipulated in Debug mode, to observe registers in all contexts, while retaining full privileges.

Debug mode is exited by executing the *retd* instruction. This returns to the previous context.

## 8.2 Event handling in AVR32B

### 8.2.1 Exceptions and interrupt requests

When an event other than *scall* or debug request is received by the core, the following actions are performed atomically:

1. The pending event will not be accepted if it is masked. The I3M, I2M, I1M, I0M, EM and GM bits in the Status Register are used to mask different events. Not all events can be masked. A few critical events (NMI, Unrecoverable Exception, TLB Multiple Hit and Bus Error) can not be masked. When an event is accepted, hardware automatically sets the mask bits corresponding to all sources with equal or lower priority. This inhibits acceptance of other events of the same or lower priority, except for the critical events listed above. Software may choose to clear some or all of these bits after saving the neces-

sary state if other priority schemes are desired. It is the event source's responsability to ensure that their events are left pending until accepted by the CPU.

2. When a request is accepted, the Status Register and Program Counter of the current context is stored in the Return Status Register and Return Address Register corresponding to the new context. Saving the Status Register ensures that the core is returned to the previous execution mode when the current event handling is completed. When exceptions occur, both the EM and GM bits are set, and the application may manually enable nested exceptions if desired by clearing the appropriate bit. Each exception handler has a dedicated handler address, and this address uniquely identifies the exception source.
3. The Mode bits are set correctly to reflect the priority of the accepted event, and the correct register file banks are selected. The address of the event handler, as shown in Table 8-1, is loaded into the Program Counter.

The execution of the event routine then continues from the effective address calculated.

The *rete* instruction signals the end of the event. When encountered, the values in the Return Status Register and Return Address Register corresponding to the event context are restored to the Status Register and Program Counter. The restored Status Register contains information allowing the core to resume operation in the previous execution mode. This concludes the event handling.

### 8.2.2 Supervisor calls

The AVR32 instruction set provides a supervisor mode call instruction. The *scall* instruction is designed so that privileged routines can be called from any context. This facilitates sharing of code between different execution modes. The *scall* mechanism is designed so that a minimal execution cycle overhead is experienced when performing supervisor routine calls from time-critical event handlers.

The *scall* instruction behaves differently depending on which mode it is called from. The behaviour is detailed in the instruction set reference. In order to allow the *scall* routine to return to the correct context, a return from supervisor call instruction, *rets*, is implemented.

### 8.2.3 Debug requests

The AVR32 architecture defines a dedicated debug mode. When a debug request is received by the core, Debug mode is entered. Entry into Debug mode can be masked by the DM bit in the status register. Upon entry into Debug mode, hardware sets the SR[D] bit and jumps to the Debug Exception handler. By default, debug mode executes in the exception context, but with dedicated Return Address Register and Return Status Register. These dedicated registers remove the need for storing this data to the system stack, thereby improving debuggability. The mode bits in the status register can freely be manipulated in Debug mode, to observe registers in all contexts, while retaining full privileges.

Debug mode is exited by executing the *retd* instruction. This returns to the previous context.

## 8.3 Entry points for events

Several different event handler entry points exists. For AVR32A, the reset routine is placed at address 0x8000_0000. This places the reset address in the flash memory area. For AVR32B, the reset routine entry address is always fixed to 0xA000_0000. This address resides in unmapped, uncached space in order to ensure well-defined resets.

TLB miss exceptions and *scall* have a dedicated space relative to EVBA where their event handler can be placed. This speeds up execution by removing the need for a jump instruction placed at the program address jumped to by the event hardware. All other exceptions have a dedicated event routine entry point located relative to EVBA. The handler routine address identifies the exception source directly.

All external interrupt requests have entry points located at an offset relative to EVBA. This autovector offset is specified by an external Interrupt Controller. The programmer must make sure that none of the autovector offsets interfere with the placement of other code. The reach of the autovector offset is IMPLEMENTATION DEFINED.

Special considerations should be made when loading EVBA with a pointer. Due to security considerations, the event handlers should be located in the privileged address space, or in a privileged memory protection region. In a system with MPU, the event routines could be placed in a cacheable protection region. In a segmented AVR32B system, some segments of the virtual memory space may be better suited than others for holding event handlers. This is due to differences in translateability and cacheability between segments. A cacheable, non-translated segment may offer the best performance for event handlers, as this will eliminate any TLB misses and speed up instruction fetch. The user may also consider to lock the event handlers in the instruction cache.

If several events occur on the same instruction, they are handled in a prioritized way. The priority ordering is presented in Table 8-1. If events occur on several instructions at different locations in the pipeline, the events on the oldest instruction are always handled before any events on any younger instruction, even if the younger instruction has events of higher priority than the oldest instruction. An instruction B is younger than an instruction A if it was sent down the pipeline later than A.

The addresses and priority of simultaneous events are shown in Table 8-1 on page 67

**Table 8-1.** Priority and handler addresses for events

| Priority | Handler Address | Name | Event source | Stored Return Address |
|---|---|---|---|---|
| 1 | 0x8000_0000 for AVR32A. 0xA000_0000 for AVR32B. | Reset | External input | Undefined |
| 2 | Provided by OCD system | OCD Stop CPU | OCD system | First non-completed instruction |
| 3 | EVBA+0x00 | Unrecoverable exception | Internal | PC of offending instruction |
| 4 | EVBA+0x04 | TLB multiple hit | Internal signal | PC of offending instruction |
| 5 | EVBA+0x08 | Bus error data fetch | Data bus | First non-completed instruction |
| 6 | EVBA+0x0C | Bus error instruction fetch | Data bus | First non-completed instruction |
| 7 | EVBA+0x10 | NMI | External input | First non-completed instruction |
| 8 | Autovectored | Interrupt 3 request | External input | First non-completed instruction |
| 9 | Autovectored | Interrupt 2 request | External input | First non-completed instruction |
| 10 | Autovectored | Interrupt 1 request | External input | First non-completed instruction |
| 11 | Autovectored | Interrupt 0 request | External input | First non-completed instruction |
| 12 | EVBA+0x14 | Instruction Address | ITLB | PC of offending instruction |
| 13 | EVBA+0x50 | ITLB Miss | ITLB | PC of offending instruction |
| 14 | EVBA+0x18 | ITLB Protection | ITLB | PC of offending instruction |
| 15 | EVBA+0x1C | Breakpoint | OCD system | First non-completed instruction |
| 16 | EVBA+0x20 | Illegal Opcode | Instruction | PC of offending instruction |
| 17 | EVBA+0x24 | Unimplemented instruction | Instruction | PC of offending instruction |
| 18 | EVBA+0x28 | Privilege violation | Instruction | PC of offending instruction |
| 19 | EVBA+0x2C | Floating-point | FP Hardware | PC of offending instruction |
| 20 | EVBA+0x30 | Coprocessor absent | Instruction | PC of offending instruction |
| 21 | EVBA+0x100 | Supervisor call | Instruction | PC(Supervisor Call) +2 |
| 22 | EVBA+0x34 | Data Address (Read) | DTLB | PC of offending instruction |
| 23 | EVBA+0x38 | Data Address (Write) | DTLB | PC of offending instruction |
| 24 | EVBA+0x60 | DTLB Miss (Read) | DTLB | PC of offending instruction |
| 25 | EVBA+0x70 | DTLB Miss (Write) | DTLB | PC of offending instruction |
| 26 | EVBA+0x3C | DTLB Protection (Read) | DTLB | PC of offending instruction |
| 27 | EVBA+0x40 | DTLB Protection (Write) | DTLB | PC of offending instruction |
| 28 | EVBA+0x44 | DTLB Modified | DTLB | PC of offending instruction |

The interrupt system requires that an interrupt controller is present outside the core in order to prioritize requests and generate a correct offset if more than one interrupt source exists for each priority level. An interrupt controller generating different offsets depending on interrupt request source is referred to as autovectoring. Note that the interrupt controller should generate autovector addresses that do not conflict with addresses in use by other events or regular program code.

The addresses of the interrupt routines are calculated by adding the address on the autovector offset bus to the value of the Exception Vector Base Address (EVBA). The INT0, INT1, INT2, INT3, and NMI signals indicate the priority of the pending interrupt. INT0 has the lowest priority, and NMI the highest priority of the interrupts. Implementations may require that EVBA is aligned in an IMPLEMENTATION DEFINED way in order to support autovectoring.

### 8.3.1 Description of events in AVR32A

#### *8.3.1.1 Reset Exception*

The Reset exception is generated when the reset input line to the CPU is asserted. The Reset exception can not be masked by any bit. The Reset exception resets all synchronous elements and registers in the CPU pipeline to their default value, and starts execution of instructions at address 0x8000_0000.

```
SR = reset_value_of_SREG;
PC = 0x8000_0000;
```

All other system registers are reset to their reset value, which may or may not be defined. Refer to the Programming Model chapter for details.

#### *8.3.1.2 OCD Stop CPU Exception*

The OCD Stop CPU exception is generated when the OCD Stop CPU input line to the CPU is asserted. The OCD Stop CPU exception can not be masked by any bit. This exception is identical to a non-maskable, high priority breakpoint. Any subsequent operation is controlled by the OCD hardware. The OCD hardware will take control over the CPU and start to feed instructions directly into the pipeline.

```
RSR_DBG = SR;
RAR_DBG = PC;
SR[M2:M0] = B’110;
SR[R] = 0;
SR[J] = 0;
SR[D] = 1;
SR[DM] = 1;
SR[EM] = 1;
SR[GM] = 1;
```

#### 8.3.1.3 *Unrecoverable Exception*

The Unrecoverable Exception is generated when an exception request is issued when the Exception Mask (EM) bit in the status register is asserted. The Unrecoverable Exception can not be masked by any bit. The Unrecoverable Exception is generated when a condition has occurred that the hardware cannot handle. The system will in most cases have to be restarted if this condition occurs.

```
*(--SP_SYS) = PC of offending instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x00;
```

#### 8.3.1.4 *TLB Multiple Hit Exception*

TLB Multiple Hit exception is issued when multiple address matches occurs in the TLB, causing an internal inconsistency.

This exception signals a critical error where the hardware is in an undefined state. All interrupts are masked, and PC is loaded with EVBA + 0x04. MMU-related registers are updated with information in order to identify the failing address and the failing TLB if multiple TLBs are present. TLBEHI[ASID] is unchanged after the exception, and therefore identifies the ASID that caused the exception.

```
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0/1, depending on which TLB caused the error;
*(--SP_SYS) = PC of offending instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x04;
```

#### 8.3.1.5 Bus Error Exception on Data Access

The Bus Error on Data Access exception is generated when the data bus detects an error condition. This exception is caused by events unrelated to the instruction stream, or by data written to the cache write-buffers many cycles ago. Therefore, execution can not be resumed in a safe way after this exception. The value placed in RAR_EX is unrelated to the operation that caused the exception. The exception handler is responsible for performing the appropriate action.

```
*(--SP_SYS) = PC of first non-issued instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x08;
```

#### 8.3.1.6 Bus Error Exception on Instruction Fetch

The Bus Error on Instruction Fetch exception is generated when the data bus detects an error condition. This exception is caused by events related to the instruction stream. Therefore, execution can be restarted in a safe way after this exception, assuming that the condition that caused the bus error is dealt with.

```
*(--SP_SYS) = PC of first non-issued instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x0C;
```

#### 8.3.1.7 NMI Exception

The NMI exception is generated when the NMI input line to the core is asserted. The NMI exception can not be masked by the SR[GM] bit. However, the core ignores the NMI input line when processing an NMI Exception (the SR[M2:M0] bits are B'111). This guarantees serial execution of NMI Exceptions, and simplifies the NMI hardware and software mechanisms.

Since the NMI exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the NMI exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
*(--SP_SYS) = PC of first noncompleted instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'111;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x10;
```

#### 8.3.1.8 INT3 Exception

The INT3 exception is generated when the INT3 input line to the core is asserted. The INT3 exception can be masked by the SR[GM] bit, and the SR[I3M] bit. Hardware automatically sets the SR[I3M] bit when accepting an INT3 exception, inhibiting new INT3 requests when processing an INT3 request.

The INT3 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT3 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT3 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
*(--SP_SYS) = R8;
*(--SP_SYS) = R9;
*(--SP_SYS) = R10;
*(--SP_SYS) = R11;
*(--SP_SYS) = R12;
*(--SP_SYS) = LR;
*(--SP_SYS) = PC of first noncompleted instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'101;
SR[I3M] = 1;
SR[I2M] = 1;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.1.9 INT2 Exception

The INT2 exception is generated when the INT2 input line to the core is asserted. The INT2 exception can be masked by the SR[GM] bit, and the SR[I2M] bit. Hardware automatically sets the SR[I2M] bit when accepting an INT2 exception, inhibiting new INT2 requests when processing an INT2 request.

The INT2 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT2 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT2 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
*(--SP_SYS) = R8;
*(--SP_SYS) = R9;
*(--SP_SYS) = R10;
*(--SP_SYS) = R11;
*(--SP_SYS) = R12;
*(--SP_SYS) = LR;
```

```
*(--SP_SYS) = PC of first noncompleted instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'100;
SR[I2M] = 1;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.1.10 *INT1 Exception*

The INT1 exception is generated when the INT1 input line to the core is asserted. The INT1 exception can be masked by the SR[GM] bit, and the SR[I1M] bit. Hardware automatically sets the SR[I1M] bit when accepting an INT1 exception, inhibiting new INT1 requests when processing an INT1 request.

The INT1 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT1 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT1 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
*(--SP_SYS) = R8;
*(--SP_SYS) = R9;
*(--SP_SYS) = R10;
*(--SP_SYS) = R11;
*(--SP_SYS) = R12;
*(--SP_SYS) = LR;
*(--SP_SYS) = PC of first noncompleted instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'011;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.1.11 INT0 Exception

The INT0 exception is generated when the INT0 input line to the core is asserted. The INT0 exception can be masked by the SR[GM] bit, and the SR[I0M] bit. Hardware automatically sets the SR[I0M] bit when accepting an INT0 exception, inhibiting new INT0 requests when processing an INT0 request.

The INT0 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT0 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT0 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
*(--SP_SYS) = R8;
*(--SP_SYS) = R9;
*(--SP_SYS) = R10;
*(--SP_SYS) = R11;
*(--SP_SYS) = R12;
*(--SP_SYS) = LR;
*(--SP_SYS) = PC of first noncompleted instruction;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’010;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.1.12 Instruction Address Exception

The Instruction Address Error exception is generated if the generated instruction memory address has an illegal alignment.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x14;
```

#### 8.3.1.13 ITLB Miss Exception

The ITLB Miss exception is generated when no TLB entry matches the instruction memory address, or if the Valid bit in a matching entry is 0.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 1;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x50;
```

#### 8.3.1.14 ITLB Protection Exception

The ITLB Protection exception is generated when the instruction memory access violates the access rights specified by the protection bits of the addressed virtual page.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 1;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x18;
```

#### 8.3.1.15 Breakpoint Exception

The Breakpoint exception is issued when a *breakpoint* instruction is executed, or the OCD breakpoint input line to the CPU is asserted, and SREG[DM] is cleared.

An external debugger can optionally assume control of the CPU when the Breakpoint Exception is executed. The debugger can then issue individual instructions to be executed in Debug mode. Debug mode is exited with the *retd* instruction. This passes control from the debugger back to the CPU, resuming normal execution.

```
RSR_DBG = SR;
RAR_DBG = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[D] = 1;
SR[DM] = 1;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x1C;
```

#### 8.3.1.16 Illegal Opcode

This exception is issued when the core fetches an unknown instruction, or when a coprocessor instruction is not acknowledged. When entering the exception routine, the return address on stack points to the instruction that caused the exception.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x20;
```

#### 8.3.1.17 Unimplemented Instruction

This exception is issued when the core fetches an instruction supported by the instruction set but not by the current implementation. This allows software implementations of unimplemented instructions. When entering the exception routine, the return address on stack points to the instruction that caused the exception.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x24;
```

#### 8.3.1.18 Data Read Address Exception

The Data Read Address Error exception is generated if the address of a data memory read has an illegal alignment.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x34;
```

#### 8.3.1.19 Data Write Address Exception

The Data Write Address Error exception is generated if the address of a data memory write has an illegal alignment.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x38;
```

#### 8.3.1.20 DTLB Read Miss Exception

The DTLB Read Miss exception is generated when no TLB entry matches the data memory address of the current read operation, or if the Valid bit in a matching entry is 0.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x60;
```

#### 8.3.1.21 DTLB Write Miss Exception

The DTLB Write Miss exception is generated when no TLB entry matches the data memory address of the current write operation, or if the Valid bit in a matching entry is 0.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x70;
```

#### 8.3.1.22 DTLB Read Protection Exception

The DTLB Protection exception is generated when the data memory read violates the access rights specified by the protection bits of the addressed virtual page.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x3C;
```

#### 8.3.1.23 DTLB Write Protection Exception

The DTLB Protection exception is generated when the data memory write violates the access rights specified by the protection bits of the addressed virtual page.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x40;
```

#### 8.3.1.24 *Privilege Violation Exception*

If the application tries to execute privileged instructions, this exception is issued. The complete list of priveleged instructions is shown in Table 8-2 on page 78. When entering the exception routine, the address of the instruction that caused the exception is stored as the stacked return address.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x28;
```

**Table 8-2.** List of instructions which can only execute in privileged modes.

| Privileged Instructions | Comment |
|---|---|
| csrf - clear status register flag | Privileged only when accessing upper half of status register |
| cache - perform cache operation | |
| tlbr - read addressed TLB entry into TLBEHI and TLBELO | |
| tlbw - write TLB entry registers into TLB | |
| tlbs - search TLB for entry matching TLBEHI[VPN] | |
| mtsr - move to system register | Unpriviledged when accessing JOSP and JECR |
| mfsr - move from system register | Unpriviledged when accessing JOSP and JECR |
| mtdr - move to debug register | |
| mfdr - move from debug register | |
| rete- return from exception | |
| rets - return from supervisor call | |
| retd - return from debug mode | |
| sleep - sleep | |
| ssrf - set status register flag | Privileged only when accessing upper half of status register |

#### 8.3.1.25 *DTLB Modified Exception*

The DTLB Modified exception is generated when a data memory write hits a valid TLB entry, but the Dirty bit of the entry is 0. This indicates that the page is not writable.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x44;
```

#### 8.3.1.26 *Floating-point Exception*

The Floating-point exception is generated when the optional Floating-Point Hardware signals that an IEEE exception occurred, or when another type of error from the floating-point hardware occurred..

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x2C;
```

#### 8.3.1.27 *Coprocessor Exception*

The Coprocessor exception occurs when the addressed coprocessor does not acknowledge an instruction. This permits software implementation of coprocessors.

```
*(--SP_SYS) = PC;
*(--SP_SYS) = SR;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x30;
```

#### 8.3.1.28 Supervisor call

Supervisor calls are signalled by the application code executing a supervisor call (*scall*) instruction. The *scall* instruction behaves differently depending on which context it is called from. This allows *scall* to be called from other contexts than Application.

When the exception routine is finished, execution continues at the instruction following *scall*. The *rets* instruction is used to return from supervisor calls.

```
If ( SR[M2:M0] == {B'000 or B'001} )
  *(--SP_SYS) = PC;
  *(--SP_SYS) = SR;
  PC ← EVBA + 0x100;
  SR[M2:M0] ← B'001;
else
  LR_Current Context ← PC + 2;
  PC ← EVBA + 0x100;
```

### 8.3.2 Description of events in AVR32B

#### *8.3.2.1 Reset Exception*

The Reset exception is generated when the reset input line to the CPU is asserted. The Reset exception can not be masked by any bit. The Reset exception resets all synchronous elements and registers in the CPU pipeline to their default value, and starts execution of instructions at address 0xA000_0000.

```
SR = reset_value_of_SREG;
PC = 0xA000_0000;
```

All other system registers are reset to their reset value, which may or may not be defined. Refer to the Programming Model chapter for details.

#### *8.3.2.2 OCD Stop CPU Exception*

The OCD Stop CPU exception is generated when the OCD Stop CPU input line to the CPU is asserted. The OCD Stop CPU exception can not be masked by any bit. This exception is identical to a non-maskable, high priority breakpoint. Any subsequent operation is controlled by the OCD hardware. The OCD hardware will take control over the CPU and start to feed instructions directly into the pipeline.

```
RSR_DBG = SR;
RAR_DBG = PC;
SR[M2:M0] = B’110;
SR[R] = 0;
SR[J] = 0;
SR[D] = 1;
SR[DM] = 1;
SR[EM] = 1;
SR[GM] = 1;
```

#### *8.3.2.3 Unrecoverable Exception*

The Unrecoverable Exception is generated when an exception request is issued when the Exception Mask (EM) bit in the status register is asserted. The Unrecoverable Exception can not be masked by any bit. The Unrecoverable Exception is generated when a condition has occurred that the hardware cannot handle. The system will in most cases have to be restarted if this condition occurs.

```
RSR_EX = SR;
RAR_EX = PC of offending instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x00;
```

#### 8.3.2.4 TLB Multiple Hit Exception

TLB Multiple Hit exception is issued when multiple address matches occurs in the TLB, causing an internal inconsistency.

This exception signals a critical error where the hardware is in an undefined state. All interrupts are masked, and PC is loaded with EVBA + 0x04. MMU-related registers are updated with information in order to identify the failing address and the failing TLB if multiple TLBs are present. TLBEHI[ASID] is unchanged after the exception, and therefore identifies the ASID that caused the exception.

```
RSR_EX = SR;
RAR_EX = PC of offending instruction;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0/1, depending on which TLB caused the error;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x04;
```

#### 8.3.2.5 Bus Error Exception on Data Access

The Bus Error on Data Access exception is generated when the data bus detects an error condition. This exception is caused by events unrelated to the instruction stream, or by data written to the cache write-buffers many cycles ago. Therefore, execution can not be resumed in a safe way after this exception. The value placed in RAR_EX is unrelated to the operation that caused the exception. The exception handler is responsible for performing the appropriate action.

```
RSR_EX = SR;
RAR_EX = PC of first non-issued instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x08;
```

#### 8.3.2.6 Bus Error Exception on Instruction Fetch

The Bus Error on Instruction Fetch exception is generated when the data bus detects an error condition. This exception is caused by events related to the instruction stream. Therefore, execution can be restarted in a safe way after this exception, assuming that the condition that caused the bus error is dealt with.

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
```

```
SR[GM] = 1;
PC = EVBA + 0x0C;
```

#### 8.3.2.7 NMI Exception

The NMI exception is generated when the NMI input line to the core is asserted. The NMI exception can not be masked by the SR[GM] bit. However, the core ignores the NMI input line when processing an NMI Exception (the SR[M2:M0] bits are B'111). This guarantees serial execution of NMI Exceptions, and simplifies the NMI hardware and software mechanisms.

Since the NMI exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the NMI exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
RSR_NMI = SR;
RAR_NMI = Address of first noncompleted instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'111;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x10;
```

#### 8.3.2.8 INT3 Exception

The INT3 exception is generated when the INT3 input line to the core is asserted. The INT3 exception can be masked by the SR[GM] bit, and the SR[I3M] bit. Hardware automatically sets the SR[I3M] bit when accepting an INT3 exception, inhibiting new INT3 requests when processing an INT3 request.

The INT3 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT3 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT3 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
RSR_INT3 = SR;
RAR_INT3 = Address of first noncompleted instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B'101;
SR[I3M] = 1;
SR[I2M] = 1;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.2.9 INT2 Exception

The INT2 exception is generated when the INT2 input line to the core is asserted. The INT2 exception can be masked by the SR[GM] bit, and the SR[I2M] bit. Hardware automatically sets the SR[I2M] bit when accepting an INT2 exception, inhibiting new INT2 requests when processing an INT2 request.

The INT2 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT2 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT2 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
RSR_INT2 = SR;
RAR_INT2 = Address of first noncompleted instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’100;
SR[I2M] = 1;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.2.10 INT1 Exception

The INT1 exception is generated when the INT1 input line to the core is asserted. The INT1 exception can be masked by the SR[GM] bit, and the SR[I1M] bit. Hardware automatically sets the SR[I1M] bit when accepting an INT1 exception, inhibiting new INT1 requests when processing an INT1 request.

The INT1 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT1 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT1 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
RSR_INT1 = SR;
RAR_INT1 = Address of first noncompleted instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’011;
SR[I1M] = 1;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.2.11 INT0 Exception

The INT0 exception is generated when the INT0 input line to the core is asserted. The INT0 exception can be masked by the SR[GM] bit, and the SR[I0M] bit. Hardware automatically sets the SR[I0M] bit when accepting an INT0 exception, inhibiting new INT0 requests when processing an INT0 request.

The INT0 Exception handler address is calculated by adding EVBA to an interrupt vector offset specified by an interrupt controller outside the core. The interrupt controller is responsible for providing the correct offset.

Since the INT0 exception is unrelated to the instruction stream, the instructions in the pipeline are allowed to complete. After finishing the INT0 exception routine, execution should continue at the instruction following the last completed instruction in the instruction stream.

```
RSR_INT0 = SR;
RAR_INT0 = Address of first noncompleted instruction;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’010;
SR[I0M] = 1;
PC = EVBA + INTERRUPT_VECTOR_OFFSET;
```

#### 8.3.2.12 Instruction Address Exception

The Instruction Address Error exception is generated if the generated instruction memory address has an illegal alignment.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x14;
```

#### 8.3.2.13 ITLB Miss Exception

The ITLB Miss exception is generated when no TLB entry matches the instruction memory address, or if the Valid bit in a matching entry is 0.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 1;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x50;
```

#### 8.3.2.14 ITLB Protection Exception

The ITLB Protection exception is generated when the instruction memory access violates the access rights specified by the protection bits of the addressed virtual page.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 1;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x18;
```

#### 8.3.2.15 Breakpoint Exception

The Breakpoint exception is issued when a *breakpoint* instruction is executed, or the OCD breakpoint input line to the CPU is asserted, and SREG[DM] is cleared.

An external debugger can optionally assume control of the CPU when the Breakpoint Exception is executed. The debugger can then issue individual instructions to be executed in Debug mode. Debug mode is exited with the *retd* instruction. This passes control from the debugger back to the CPU, resuming normal execution.

```
RSR_DBG = SR;
RAR_DBG = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[D] = 1;
SR[DM] = 1;
```

```
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x1C;
```

#### 8.3.2.16 *Illegal Opcode*

This exception is issued when the core fetches an unknown instruction, or when a coprocessor instruction is not acknowledged. When entering the exception routine, the return address on stack points to the instruction that caused the exception.

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x20;
```

#### 8.3.2.17 *Unimplemented Instruction*

This exception is issued when the core fetches an instruction supported by the instruction set but not by the current implementation. This allows software implementations of unimplemented instructions. When entering the exception routine, the return address on stack points to the instruction that caused the exception.

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x24;
```

#### 8.3.2.18 *Data Read Address Exception*

The Data Read Address Error exception is generated if the address of a data memory read has an illegal alignment.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x34;
```

#### 8.3.2.19 Data Write Address Exception

The Data Write Address Error exception is generated if the address of a data memory write has an illegal alignment.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x38;
```

#### 8.3.2.20 DTLB Read Miss Exception

The DTLB Read Miss exception is generated when no TLB entry matches the data memory address of the current read operation, or if the Valid bit in a matching entry is 0.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x60;
```

#### 8.3.2.21 DTLB Write Miss Exception

The DTLB Write Miss exception is generated when no TLB entry matches the data memory address of the current write operation, or if the Valid bit in a matching entry is 0.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x70;
```

#### 8.3.2.22 DTLB Read Protection Exception

The DTLB Protection exception is generated when the data memory read violates the access rights specified by the protection bits of the addressed virtual page.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x3C;
```

#### 8.3.2.23 DTLB Write Protection Exception

The DTLB Protection exception is generated when the data memory write violates the access rights specified by the protection bits of the addressed virtual page.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x40;
```

#### 8.3.2.24 Privilege Violation Exception

If the application tries to execute privileged instructions, this exception is issued. The complete list of priveleged instructions is shown in Table 8-2. When entering the exception routine, the address of the instruction that caused the exception is stored as yhe stacked return address.

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x28;
```

**Table 8-3.** List of instructions which can only execute in privileged modes.

| Privileged Instructions | Comment |
|---|---|
| csrf - clear status register flag | Privileged only when accessing upper half of status register |
| cache - perform cache operation | |
| tlbr - read addressed TLB entry into TLBEHI and TLBELO | |
| tlbw - write TLB entry registers into TLB | |
| tlbs - search TLB for entry matching TLBEHI[VPN] | |
| mtsr - move to system register | Unpriviledged when accessing JOSP and JECR |
| mfsr - move from system register | Unpriviledged when accessing JOSP and JECR |
| - move to debug register | |
| mfdr - move from debug register | |
| rete- return from exception | |
| rets - return from supervisor call | |
| retd - return from debug mode | |
| sleep - sleep | |
| ssrf - set status register flag | Privileged only when accessing upper half of status register |

#### 8.3.2.25 *DTLB Modified Exception*

The DTLB Modified exception is generated when a data memory write hits a valid TLB entry, but the Dirty bit of the entry is 0. This indicates that the page is not writable.

```
RSR_EX = SR;
RAR_EX = PC;
TLBEAR = FAILING_VIRTUAL_ADDRESS;
TLBEHI[VPN] = FAILING_PAGE_NUMBER;
TLBEHI[I] = 0;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x44;
```

#### 8.3.2.26 *Floating-point Exception*

The Floating-point exception is generated when the optional Floating-Point Hardware signals that an IEEE exception occurred, or when another type of error from the floating-point hardware occurred..

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x2C;
```

#### 8.3.2.27 *Coprocessor Exception*

The Coprocessor exception occurs when the addressed coprocessor does not acknowledge an instruction. This permits software implementation of coprocessors.

```
RSR_EX = SR;
RAR_EX = PC;
SR[R] = 0;
SR[J] = 0;
SR[M2:M0] = B’110;
SR[EM] = 1;
SR[GM] = 1;
PC = EVBA + 0x30;
```

#### 8.3.2.28 *Supervisor call*

Supervisor calls are signalled by the application code executing a supervisor call (*scall*) instruction. The *scall* instruction behaves differently depending on which context it is called from. This allows *scall* to be called from other contexts than Application.

When the exception routine is finished, execution continues at the instruction following *scall*. The *rets* instruction is used to return from supervisor calls.

```
If ( SR[M2:M0] == {B’000 or B’001} )
  RAR_SUP ← PC + 2;
  RSR_SUP ←  SR;
  PC ← EVBA + 0x100;
  SR[M2:M0] ← B’001;
else
  LR_Current Context ← PC + 2;
  PC ← EVBA + 0x100;
```

## 8.4 Event priority

Several instructions may be in the pipeline at the same time, and several events may be issued in each pipeline stage. This implies that several pending exceptions may be in the pipeline simultaneously. Priorities must therefore be imposed, ensuring that the correct event is serviced first. The priority scheme obeys the following rules:

1. If several instructions trigger events, the instruction furthest down the pipeline is serviced first, even if upstream instructions have pending events of higher priority.
2. If this instruction has several pending events, the event with the highest priority is serviced first. After this event has been serviced, all pending events are cleared and the instruction is restarted.

Details about the timing of events is IMPLEMENTATION DEFINED, and given in the hardware manual for the specific implementation.

## 8.5 Event handling in secure state

Interrupt and exception handling in AVR32A and AVR32B has been described in the previous chapters. This behavior is modified in the following way when interrupts and exceptions are received in secure state:

- A *sscall* instruction will set SR[GM]. In secure state, SR[GM] masks both INT0-INT3, and NMI. Clearing SR[GM], INT0-INT3 and NMI will remove the mask of these event sources. INT0-INT3 are still additionally masked by the I0M-I3M bits in the status register.
- *sscall* has handler address at offset 0x4 relative to the reset handler address.
- Exceptions have a handler address at offset 0x8 relative to the reset handler address.
- NMI has a handler address at offset 0xC relative to the reset handler address.
- BREAKPOINT has a handler address at offset 0x10 relative to the reset handler address.
- INT0-INT3 are not autovectored, but have a common handler address at offset 0x14 relative to the reset handler address.

Note that in the secure state, all exception sources share the same handler address. It is therefore not possible to separate different exception causes when in the secure world. The secure world system must be designed to support this, the most obvious solution is to design the secure software so that exceptions will not arise.

# 9. AVR32 RISC Instruction Set

## 9.1 Instruction Set Nomenclature

### 9.1.1 Registers and Operands

| | |
|---|---|
| **R**{d, s, …} | The uppercase '**R**' denotes a 32-bit (word) register. |
| R**d** | The lowercase '**d**' denotes the *destination* register number. |
| R**s** | The lowercase '**s**' denotes the *source* register number. |
| R**x** | The lowercase '**x**' denotes the *first source* register number for three register operations. |
| R**y** | The lowercase '**y**' denotes the *second source* register number for three register operations. |
| R**b** | The lowercase '**b**' denotes the *base* register number for indexed addressing modes. |
| R**i** | The lowercase '**i**' denotes the *index* register number for indexed addressing modes. |
| R**p** | The lowercase '**p**' denotes the *pointer* register number. |
| PC | Program Counter, equal to R15 |
| LR | Link Register, equal to R14 |
| SP | Stack Pointer, equal to R13 |
| Reglist8 | Reglist8 ∈ {R0-R3, R4-R7, R8-R9, R10, R11, R12, LR, PC} |
| Reglist16 | Reglist16 ∈ {R0, R1, R2, ..., R12, LR, SP, PC} |
| ReglistCPH8 | ReglistCPH8 ∈ {CR8, CR9, CR10, ..., CR15} |
| ReglistCPL8 | ReglistCPL8 ∈ {CR0, CR1, CR2, ..., CR7} |
| ReglistCP8 | ReglistCPD8 ∈ {CR0-CR1,CR2-CR3,CR4-CR5,CR6-CR7,CR8-CR9, CR10-CR11,CR12-CR13,CR14-CR15} |
| SysRegName | Name of source or destination system register. |
| cond3 | cond3 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl} |
| cond4 | cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al} |
| disp | Displacement |
| disp**:E** | Displacement of n bits. If the both compact and extended versions of the instruction exists, then use the extended version. The compact version is used by default. |
| imm | Immediate value |
| imm**:E** | Immediate of n bits. If the both compact and extended versions of the instruction exists, then use the extended version. The compact version is used by default. |
| sa | Shift amount |
| bp | Bit postion |
| w | Width of a bit field |
| [i] | Denotes bit **i** in a immediate value. Example: imm6[4] denotes bit 4 in an 6-bit immediate value. |

| | |
|---|---|
| [i:j] | Denotes bit **i** to **j** in an immediate value. |

Some instructions access or use doubleword operands. These operands must be placed in two consecutive register addresses where the first register must be an even register. The even register contains the least significant part and the odd register contains the most significant part. This ordering is reversed in comparison with how data is organized in memory (where the most significant part would receive the lowest address) and is intentional.

The programmer is responsible for placing these operands in properly aligned register pairs. This is also
specified in the "Operands" section in the detailed description of each instruction. Failure to do so will
result in an undefined behaviour.

### 9.1.2 Operator Symbols

| | |
|---|---|
| $\wedge$ | Bitwise logical AND operation. |
| $\vee$ | Bitwise logical OR operation. |
| $\otimes$ | Bitwise logical EOR operation. |
| $\neg$ | Bitwise logical NOT operation. |
| Sat | Saturate operand |

### 9.1.3 Operations

| | |
|---|---|
| ASR(x, n) | SE(x, Bits(x) + n) >> n |
| Bits(x) | Number of bits in operand x |
| LSR(x, n) | x >> n |
| LSL(x, n) | x << n |
| SATS(x, n) | Signed Saturation ( x is treated as a signed value ):<br>If (x > ($2^{n-1}$-1)) then ($2^{n-1}$-1); elseif (x < $-2^{n-1}$) then $-2^{n-1}$; else x; |
| SATSU(x, n) | Signed to Unsigned Saturation ( x is treated as a signed value ):<br>If (x > ($2^{n}$-1)) then ($2^{n-1}$-1); elseif ( x < 0 ) then 0; else x; |
| SATU(x, n) | Unsigned Saturation ( x is treated as an unsigned value ):<br>If (x > ($2^{n}$-1)) then ($2^{n-1}$-1); else x; |
| SE(x, n) | Sign Extend x to an n-bit value |
| SE(x) | Identical to SE(x, 32) |
| ZE(x, n) | Zero Extend x to an n-bit value |
| ZE(x) | Identical to ZE(x, 32) |

### 9.1.4 Status Register Flags

| | |
|---|---|
| **C**: | Carry / Borrow flag. |
| **Z:** | Zero flag, set if the result of the operation is zero. |
| **N**: | Bit 31 of the result. |
| **V:** | Set if 2's complement overflow occurred. |
| **Q:** | Saturated flag, set if saturation and/or overflow has occurred after some instructions. |
| **M0**: | Mode bit 0 |

**M1**: Mode bit 1
**M2**: Mode bit 2

### 9.1.5 Data Type Extensions

**.d** Double (64-bit) operation.
**.w** Word (32-bit) operation.
**.h** Halfword (16-bit) operation.
**.b** Byte operation (8-bit) operation.

### 9.1.6 Halfword selectors

**t** Top halfword, bits 31-16.
**b** Bottom halfword, bits 15-0.

### 9.1.7 Byte selectors

**t** Top byte, bits 31-24.
**u** Upper byte, bits 23-16.
**l** Lower byte, bits 15-8.
**b** Bottom byte, bits 7-0.

### 9.1.8 CPU System Registers

**RSR_INT0**: Interrupt level 0 **R**eturn **S**tatus **R**egister.
**RSR_INT1**: Interrupt level 1 **R**eturn **S**tatus **R**egister.
**RSR_INT2**: Interrupt level 2 **R**eturn **S**tatus **R**egister.
**RSR_INT3**: Interrupt level 3 **R**eturn **S**tatus **R**egister.
**RSR_EX**: Exception **R**eturn **S**tatus **R**egister.
**RSR_NMI**: Non maskable interrupt **R**eturn **S**tatus **R**egister.
**RSR_SUP**: Supervisor **R**eturn **S**tatus **R**egister.

**RAR_INT0**: Interrupt level 0 **R**eturn **A**ddress **R**egister.
**RAR_INT1**: Interrupt level 1 **R**eturn **A**ddress **R**egister.
**RAR_INT2**: Interrupt level 2 **R**eturn **A**ddress **R**egister.
**RAR_INT3**: Interrupt level 3 **R**eturn **A**ddress **R**egister.
**RAR_EX**: Exception **R**eturn **A**ddress **R**egister.
**RAR_NMI**: Non maskable interrupt **R**eturn **A**ddress **R**egister.
**RAR_SUP**: Supervisor **R**eturn **A**ddress **R**egister.

**ACBA**: **A**pplication **C**all **B**ase **A**ddress register.
**EVBA**: **E**xception **V**ector **B**ase **A**ddress register.

### 9.1.9 Branch conditions

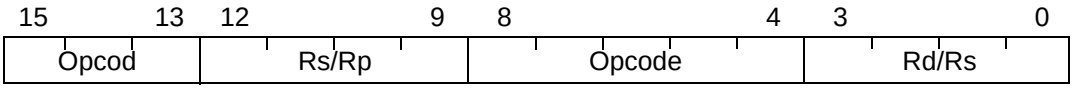
**Table 9-1.** Branch conditions

| Coding in cond3 | Coding in cond4 | Condition mnemonic | Evaluated expression | Numerical format | Meaning |
|---|---|---|---|---|---|
| B’000 | B’0000 | eq | Z | | Equal |
| B’001 | B’0001 | ne | $\neg$Z | | Not equal |
| B’010 | B’0010 | cc / hs | $\neg$C | Unsigned | Higher or same |
| B’011 | B’0011 | cs / lo | C | Unsigned | Lower |
| B’100 | B’0100 | ge | N == V | Signed | Greater than or equal |
| B’101 | B’0101 | lt | N $\oplus$ V | Signed | Less than |
| B’110 | B’0110 | mi | N | Signed | Minus / negative |
| B’111 | B’0111 | pl | $\neg$N | Signed | Plus / positive |
| N/A | B’1000 | ls | C $\vee$ Z | Unsigned | Lower or same |
| N/A | B’1001 | gt | $\neg$Z $\wedge$ (N==V) | Signed | Greater than |
| N/A | B’1010 | le | Z $\vee$ (N $\oplus$ V) | Signed | Less than or equal |
| N/A | B’1011 | hi | $\neg$C $\wedge$ $\neg$Z | Unsigned | Higher |
| N/A | B’1100 | vs | V | | Overflow |
| N/A | B’1101 | vc | $\neg$V | | No overflow |
| N/A | B’1110 | qs | Q | Fractional | Saturation |
| N/A | B’1111 | al | True | | Always |

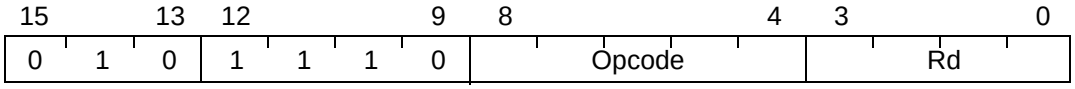
## 9.2 Instruction Formats

This is an overview of the different instruction formats.

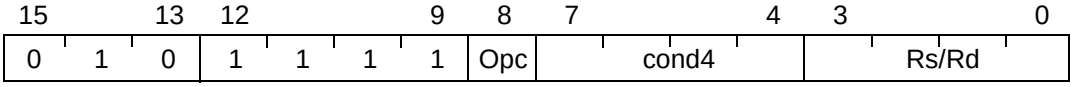
### 9.2.1 Two Register Instructions



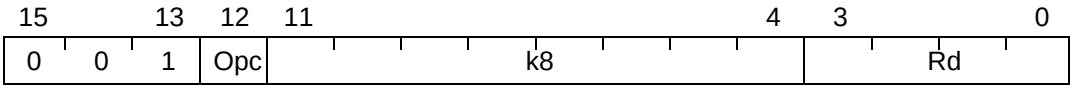

### 9.2.2 Single Register Instructions



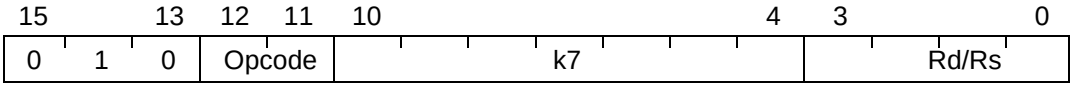

### 9.2.3 Return and test



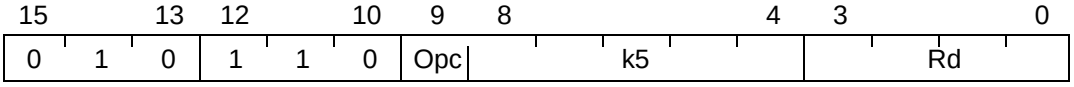

### 9.2.4 K8 immediate and single register



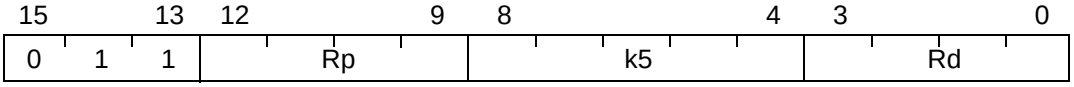

### 9.2.5 SP / PC relative load / store



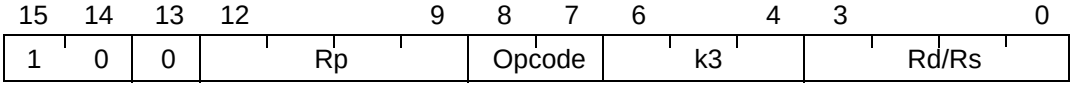

### 9.2.6 K5 immediate and single register



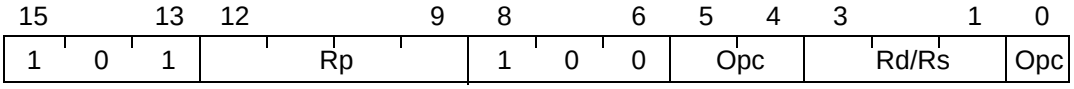

### 9.2.7 Displacement load with k5 immediate



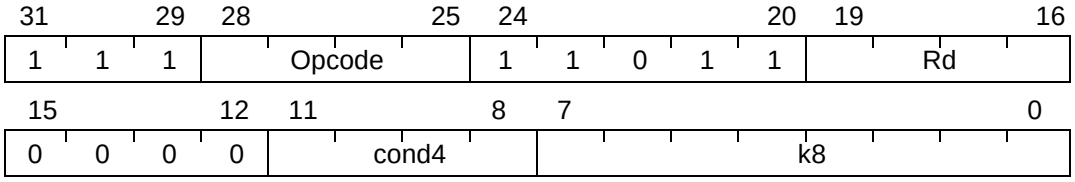

### 9.2.8 Displacement load / store with k3 immediate



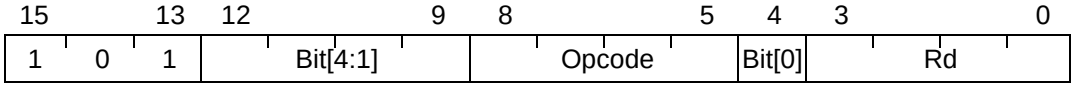
### 9.2.9 One register and a register pair



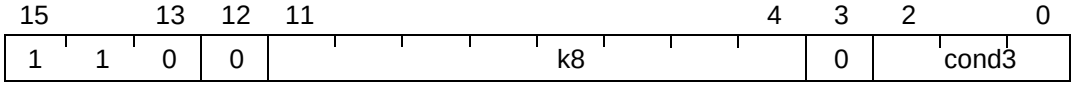

### 9.2.10 One register with k8 immediate and cond4



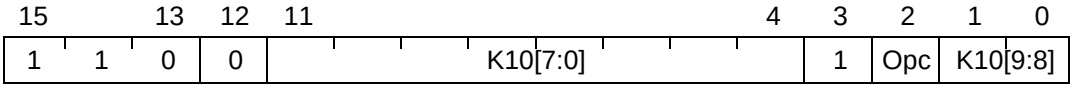

### 9.2.11 One register with bit addressing



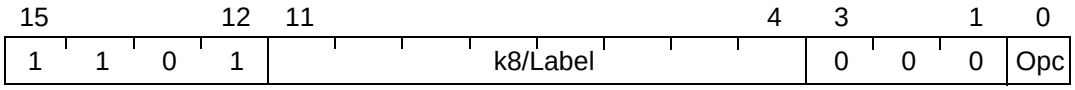

### 9.2.12 Short branch



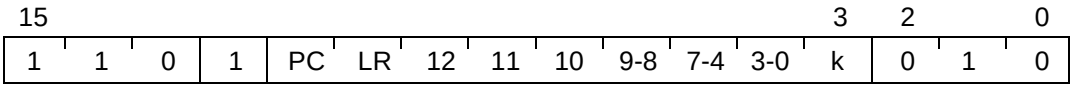

### 9.2.13 Relative jump and call



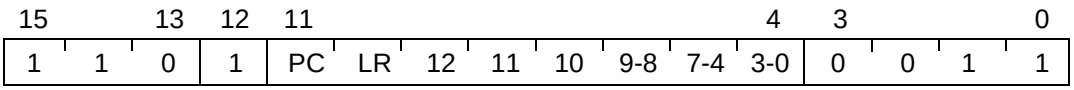

### 9.2.14 K8 and no register



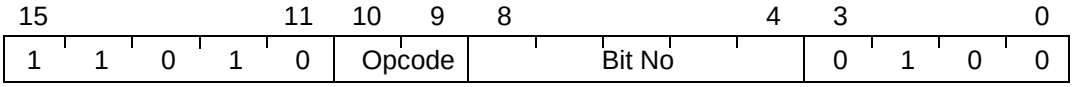

### 9.2.15 Multiple registers (POPM)



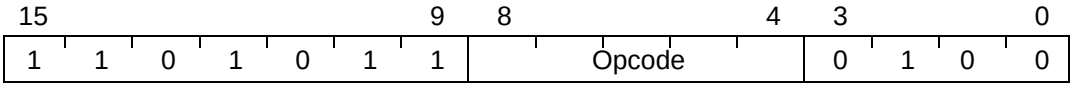

### 9.2.16 Multiple registers (PUSHM)



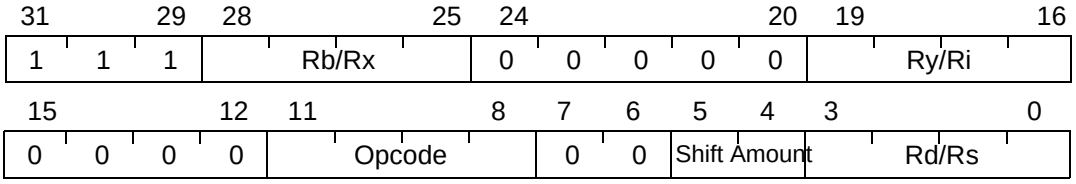

### 9.2.17 Status register bit specification



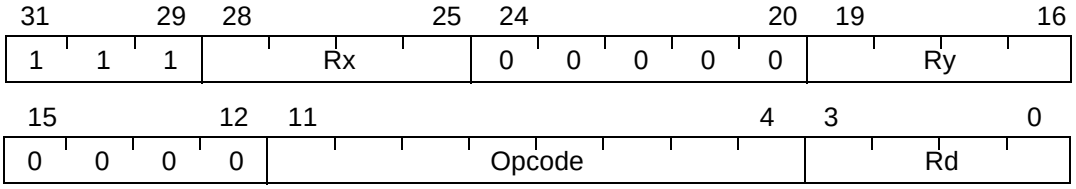
### 9.2.18 Only Opcode



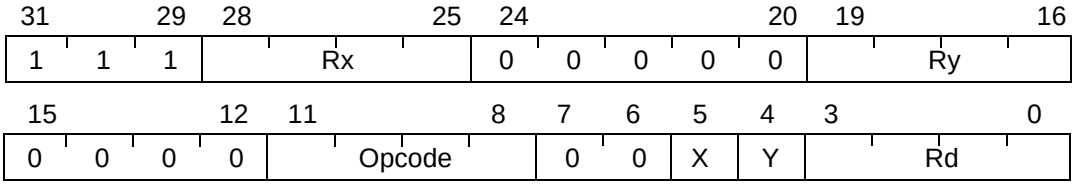

### 9.2.19 3 registers shifted



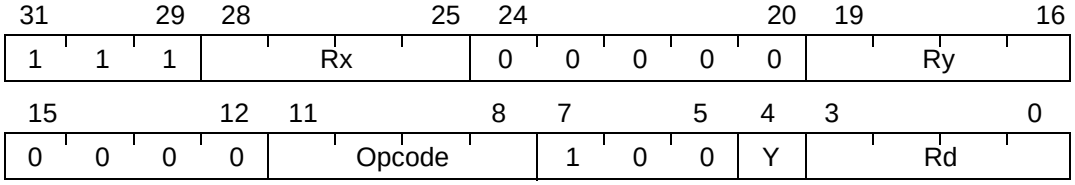

### 9.2.20 3 registers unshifted



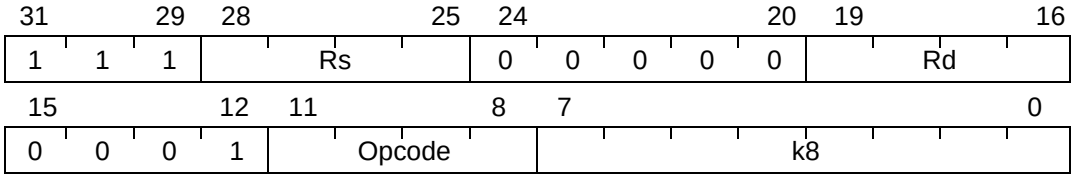

### 9.2.21 DSP Halfword Multiply



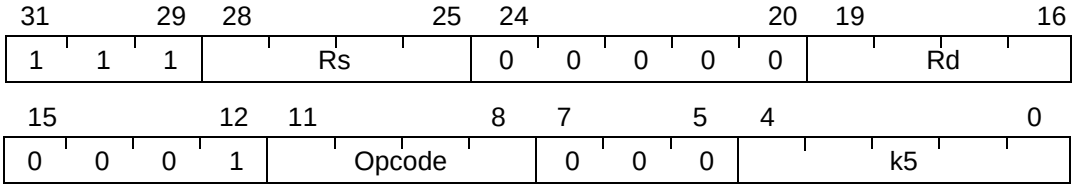

### 9.2.22 DSP Word and Halfword Multiply



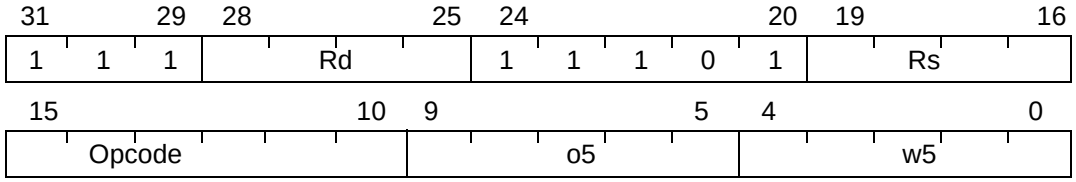

### 9.2.23 2 register operands with k8 immediate



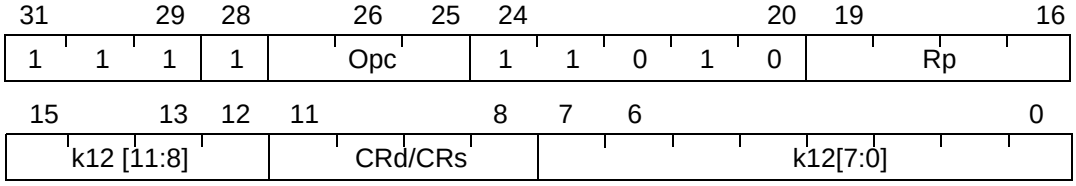
### 9.2.24 2 register operands with k5 immediate



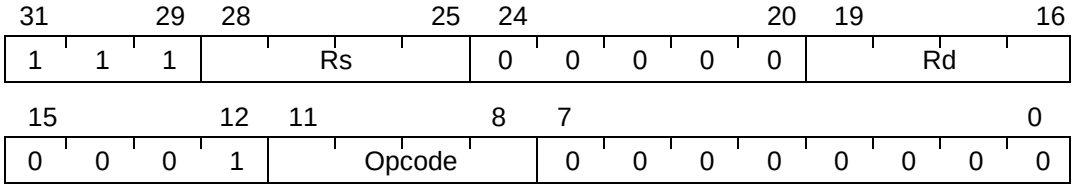

### 9.2.25 2 Registers with w5 and o5



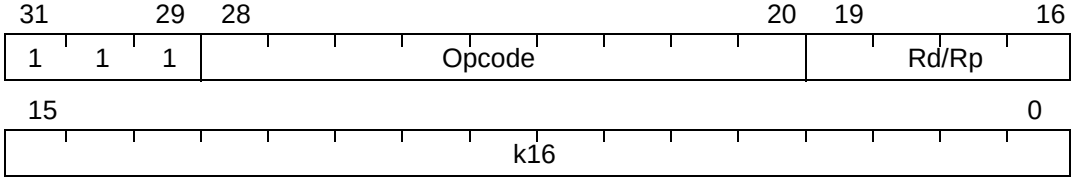

### 9.2.26 Coprocessor 0 load and store



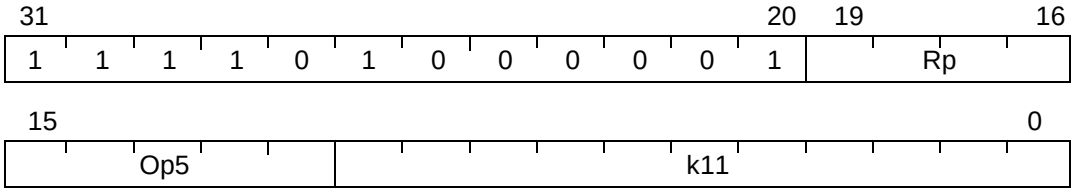

### 9.2.27 2 register operands



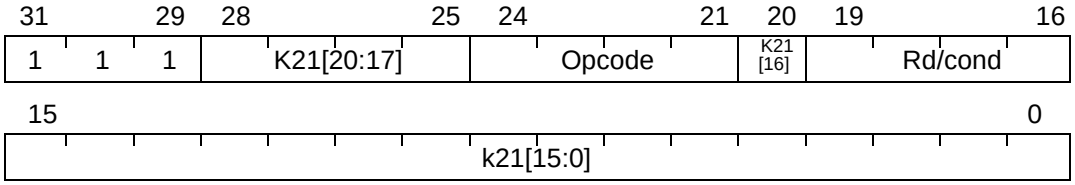

### 9.2.28 Register operand with K16



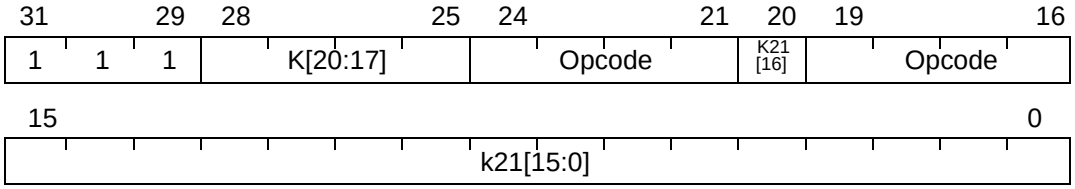

### 9.2.29 Cache operation



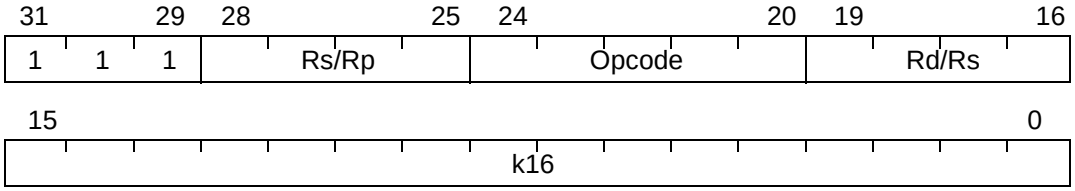
### 9.2.30 Register or condition code and K21



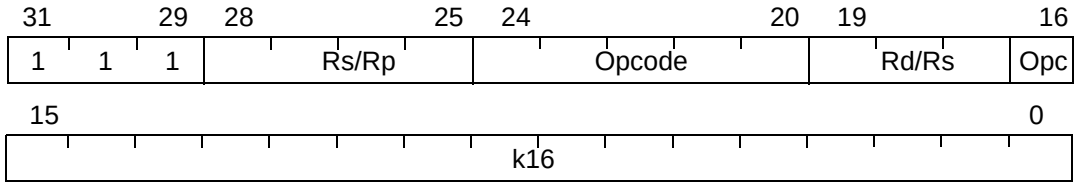

### 9.2.31 No register and k21



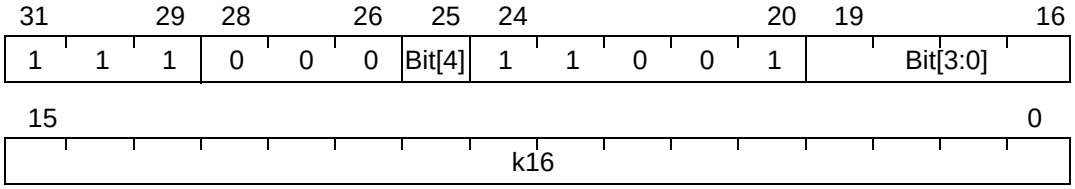

### 9.2.32 Two registers and K16



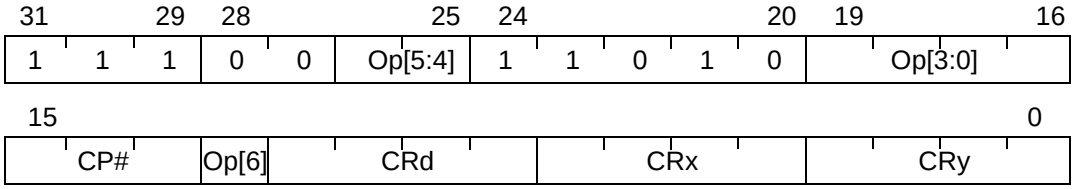

### 9.2.33 Register, doubleword register and K16



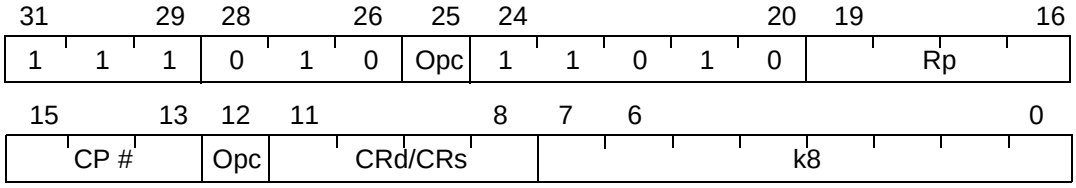

### 9.2.34 K16 and bit address



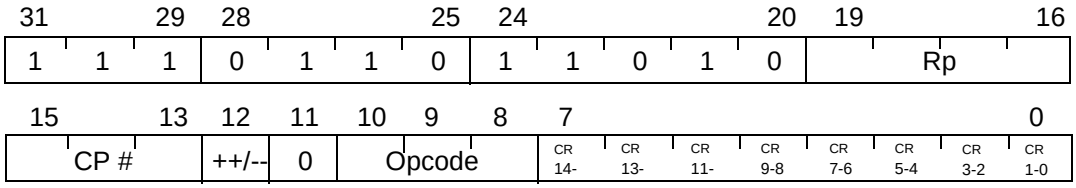

### 9.2.35 Coprocessor Operation



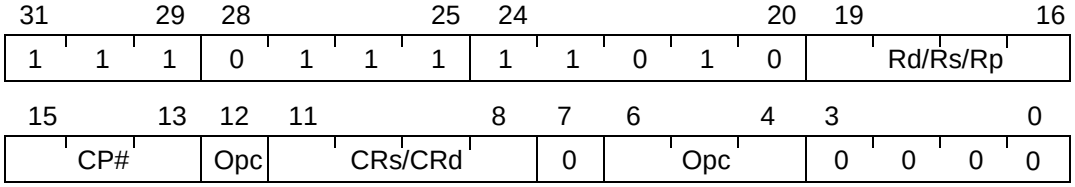
### 9.2.36 Coprocessor load and store



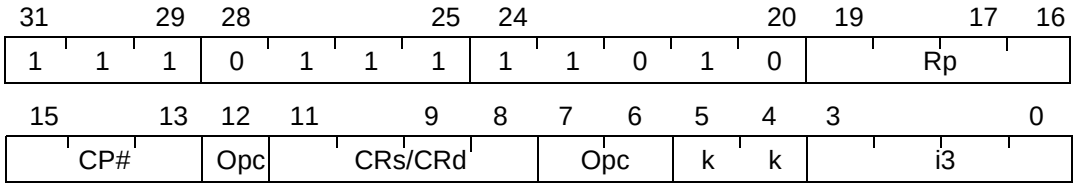

### 9.2.37 Coprocessor load and store multiple registers



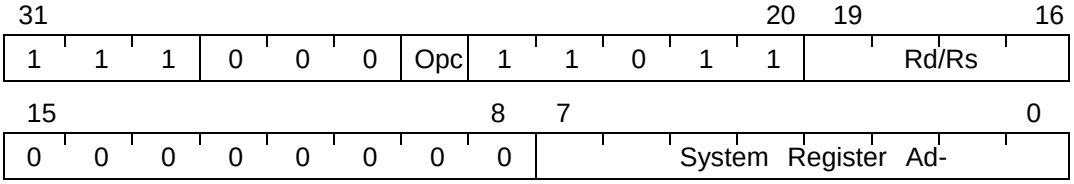

### 9.2.38 Coprocessor load, store and move



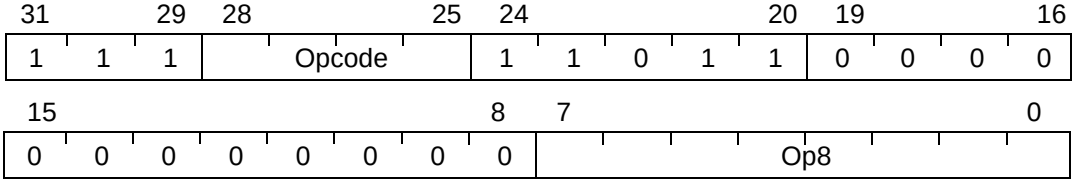

### 9.2.39 Coprocessor load and store with indexed addressing



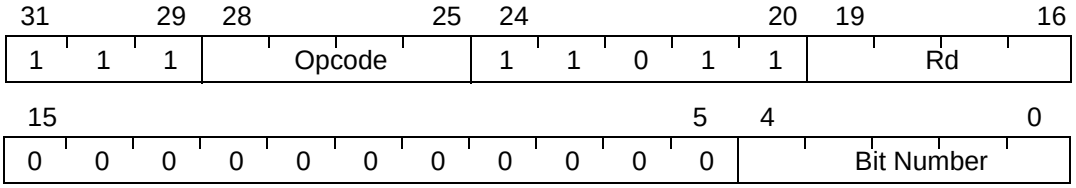

### 9.2.40 Register and system register



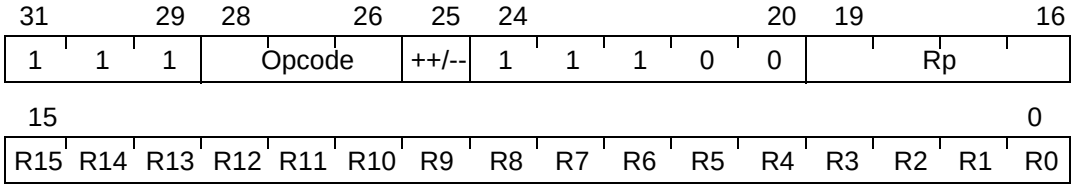

### 9.2.41 Sleep and sync



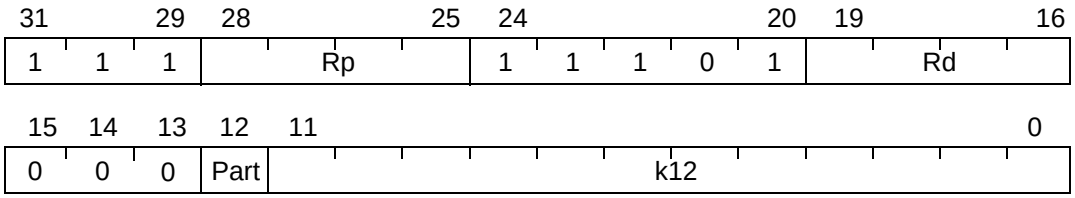
### 9.2.42 Register and bit address



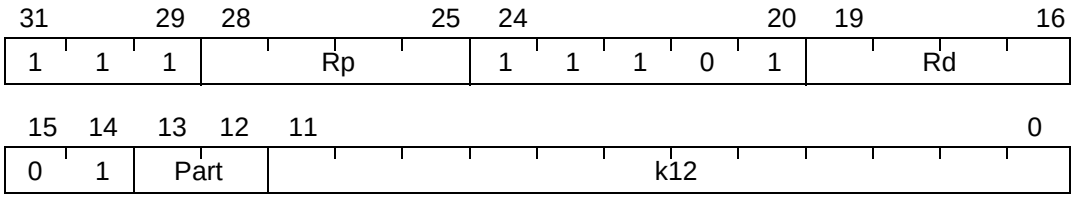

### 9.2.43 Load and store multiple registers



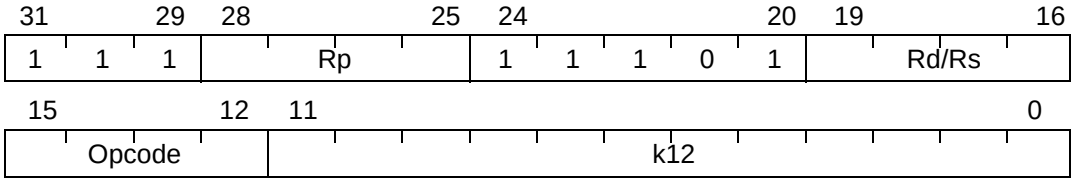

### 9.2.44 Register, k12 and halfword select



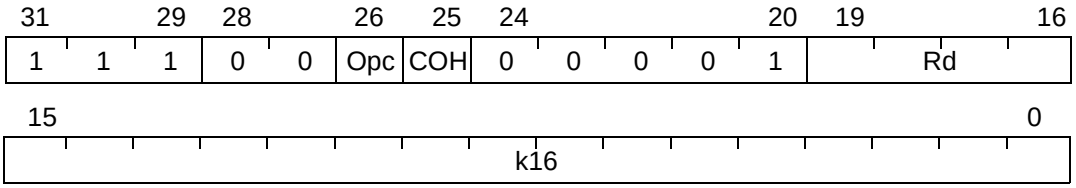

### 9.2.45 Register, k12 and byte select



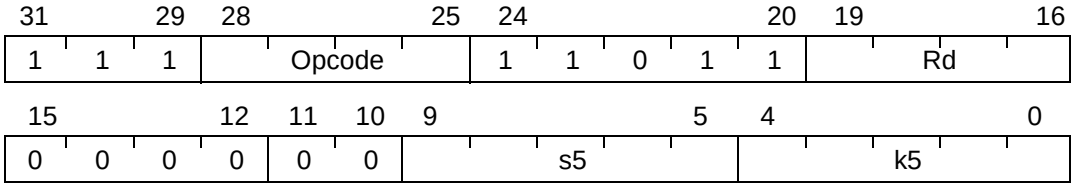

### 9.2.46 2 Register and k12



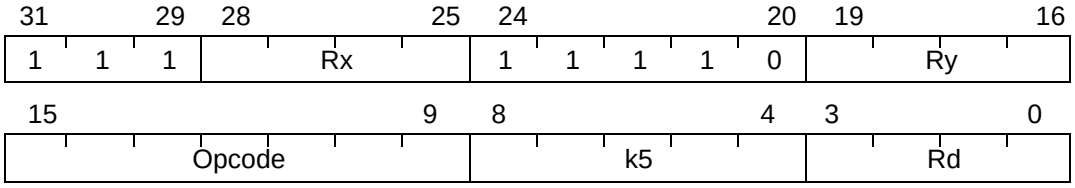

### 9.2.47 ANDL / ANDH



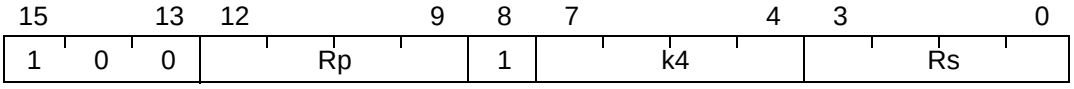
### 9.2.48 Saturate



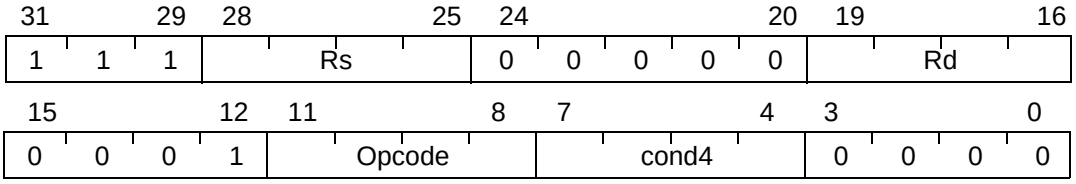

### 9.2.49 3 Registers with k5



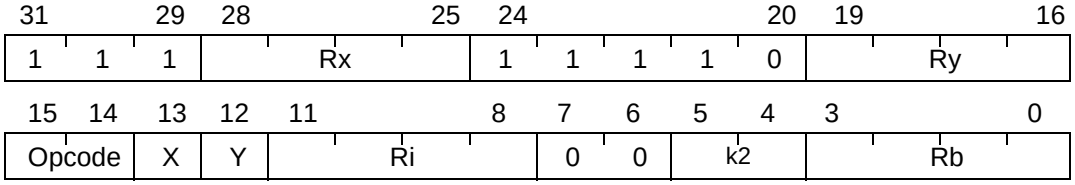

### 9.2.50 2 Registers with k4



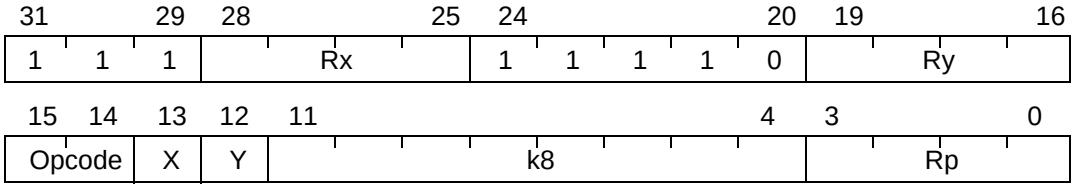

### 9.2.51 2 Registers with cond4



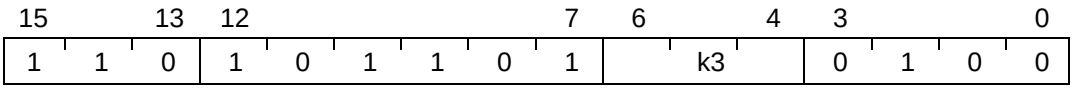

### 9.2.52 4 Registers with k2



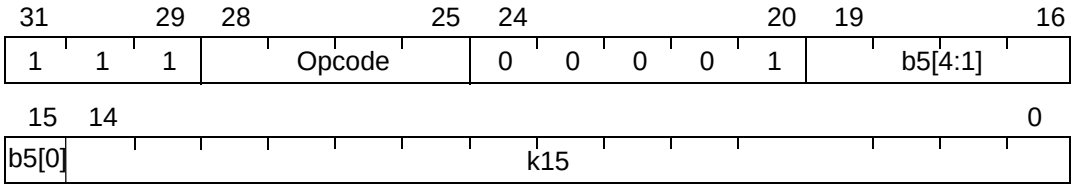

### 9.2.53 3 Registers with k8 and sa



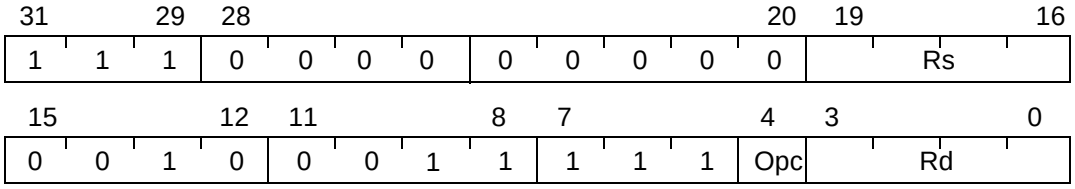

### 9.2.54 k3 immediate



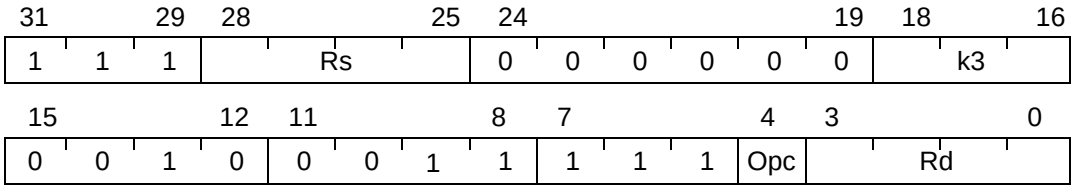
### 9.2.55 Address and b5



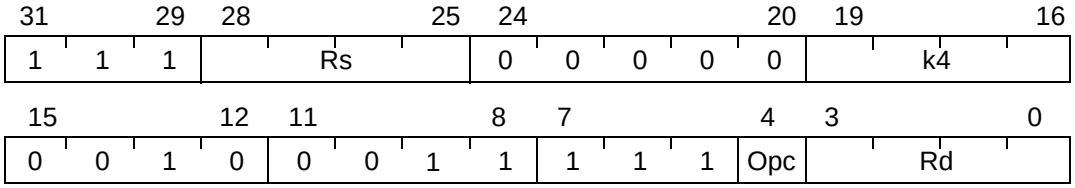

### 9.2.56 2 register operands




### 9.2.57 2 register operands and k3




### 9.2.58 2 register operands and k4



## 9.3 Instruction Set Summary

### 9.3.1 Architecture revision

Unless otherwise noted, all instructions are part of revision 1 of the AVR32 architecture. The following instructions were added in revision 2, none were removed:

- movh Rd, imm
- {add, sub, and, or, eor}{cond4}, Rd, Rx, Ry
- ld.{sb, ub, sh, uh, w}{cond4} Rd, Rp[disp]
- st.{b, h, w}{cond4} Rp[disp], Rs
- rsub{cond4} Rd, imm

### 9.3.2 Arithmetic Operations

**Table 9-2.** Arithmetic Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| abs | C | Rd | Absolute value. | Rd ← \|Rd\| | 1 |
| acr | C | Rd | Add carry to register. | Rd ← Rd + C | 1 |
| adc | E | Rd, Rx, Ry | Add with carry. | Rd ← Rx + Ry + C | 1 |
| add | C | Rd, Rs | Add. | Rd ← Rd + Rs | 1 |
| | E | Rd, Rx, Ry << sa | Add shifted. | Rd ← Rx + (Ry<<sa2) | 1 |
| add{cond4} | E | Rd, Rx, Ry | Add if condition satisfied. | if (cond4) Rd ← Rx + Ry | 2 |
| addabs | E | Rd, Rx, Ry | Add with absolute value. | Rd ← Rx + \|Ry\| | 1 |
| cp.b | E | Rd, Rs | Compare Byte | Rd - Rs | 1 |
| cp.h | E | Rd, Rs | Compare Halfword | Rd - Rs | 1 |
| cp.w | C | Rd, Rs | Compare. | Rd - Rs | 1 |
| | C | Rd, imm | | Rd - SE(imm6) | 1 |
| | E | Rd, imm | | Rd - SE(imm21) | 1 |
| cpc | C | Rd | Compare with carry. | Rd - C | 1 |
| | E | Rd, Rs | | Rd - Rs - C | 1 |
| max | E | Rd, Rx, Ry | Return signed maximum | Rd ← max(Rx, Ry) | 1 |
| min | E | Rd, Rx, Ry | Return signed minimum | Rd ← min(Rx, Ry) | 1 |
| neg | C | Rd | Two's Complement. | Rd ← 0 - Rd | 1 |
| rsub | C | Rd, Rs | Reverse subtract. | Rd ← Rs - Rd | 1 |
| | E | Rd, Rs, imm | | Rd ← SE(imm8) - Rs | 1 |
| rsub{cond4} | E | Rd, imm | Reverse subtract immediate if condition satisfied. | if (cond4) Rd ← SE(imm8) - Rd | 2 |
| sbc | E | Rd, Rx, Ry | Subtract with carry. | Rd ← Rx - Ry - C | 1 |
| scr | C | Rd | Subtract carry from register. | Rd ← Rd - C | 1 |

**Table 9-2.** Arithmetic Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| sub | C | Rd, Rs | Subtract. | Rd ← Rd - Rs | 1 |
| | E | Rd, Rx, Ry << sa | | Rd ← Rx - (Ry<<sa2) | 1 |
| | C | Rd, imm | | if (Rd==SP)<br>  Rd ← Rd - SE(imm8<<2)<br>else<br>  Rd ← Rd - SE(imm8) | 1 |
| | E | Rd, imm | | Rd ← Rd - SE(imm21) | 1 |
| | E | Rd, Rs, imm | | Rd ← Rs - SE(imm16) | 1 |
| sub{cond4} | E | Rd, imm | Subtract immediate if condition satisfied. | if (cond4) Rd ← Rd - SE(imm8) | 1 |
| | E | Rd, Rx, Ry | Subtract if condition satisfied. | if (cond4) Rd ← Rx - Ry | 2 |
| tnbz | C | Rd | Test no byte equal to zero. | if (Rd[31:24] == 0 ∨<br>  Rd[23:16] == 0 ∨<br>  Rd[15:8] == 0 ∨ Rd[7:0] == 0 )<br>  Z ← 1<br>else<br>  Z ← 0 | 1 |

### 9.3.3 Multiplication Operations

**Table 9-3.** Multiplication Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| divs | E | Rd, Rx, Ry | Signed divide.<br>(32 ← 32/32) | Rd ← Rx / Ry<br>Rd+1 ← Rx % Ry | 1 |
| divu | E | Rd, Rx, Ry | Unsigned divide.<br>(32 ← 32/32) | Rd ← Rx / Ry<br>Rd+1 ← Rx % Ry | 1 |
| mac | E | Rd, Rx, Ry | Multiply accumulate.<br>(32 ← 32x32 + 32) | Rd ← Rx * Ry + Rd | 1 |
| macs.d | E | Rd, Rx, Ry | Multiply signed accumulate.<br>(64 ← 32x32 + 64) | Rd+1:Rd ← Rx * Ry + Rd+1:Rd | 1 |
| macu.d | E | Rd, Rx, Ry | Multiply unsigned accumulate.<br>(64 ← 32x32 + 64) | Rd+1:Rd ← Rx * Ry + Rd+1:Rd | 1 |
| mul | C | Rd, Rs | Multiply.<br>(32 ← 32 x 32) | Rd ← Rx * Rs | 1 |
| | E | Rd, Rx, Ry | Multiply.<br>(32 ← 32 x 32) | Rd ← Rx * Ry | 1 |
| | E | Rd, Rs, imm | Multiply immediate. | Rd ← Rs * SE(imm8) | 1 |
| muls.d | E | Rd, Rx, Ry | Signed Multiply.<br>(64 ← 32 x 32) | Rd+1:Rd ← Rx * Ry | 1 |
| mulu.d | E | Rd, Rx, Ry | Unsigned Multiply.<br>(64 ← 32 x 32) | Rd+1:Rd ← Rx * Ry | 1 |

### 9.3.4 DSP Operations

**Table 9-4.** DSP Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| addhh.w | E | Rd, Rx:<part>, Ry:<part> | Add signed halfwords.<br>(32 ← 16 +16) | Rd ← SE(Rx:<part>) + SE(Ry:<part>) | 1 |
| machh.d | E | Rd, Rx:<part>, Ry:<part> | Multiply signed halfwords and accumulate.<br>(48 ← 16x16 + 48) | Rd+1:Rd ← Rx:<part> * Ry:<part> + Rd+1:Rd | 1 |
| machh.w | E | Rd, Rx:<part>, Ry:<part> | Multiply signed halfwords and accumulate.<br>(32 ← 16x16 + 32) | Rd ← Rx:<part> * Ry:<part> + Rd | 1 |
| macwh.d | E | Rd, Rx, Ry:<part> | Multiply signed word and halfword and accumulate.<br>(48 ← 32x16 + 48) | Rd+1:Rd ← ((Rx * Ry:<part>) <<16) + Rd+1:Rd | 1 |
| mulhh.w | E | Rd, Rx:<part>, Ry:<part> | Signed Multiply of halfwords.<br>(32 ← 16 x 16) | Rd ← Rx:<part> * Ry:<part> | 1 |
| mulwh.d | E | Rd, Rx, Ry:<part> | Unsigned Multiply, word and halfword.<br>48 ← (32 x 16) | Rd+1:Rd ← ((Rx * Ry:<part>) <<16) | 1 |
| mulnhh.w | E | Rd, Rx:<part>, Ry:<part> | Signed Multiply of halfwords.<br>(32 ← 16 x 16) | Rd ← Rx:<part> * (- Ry:<part>) | 1 |
| mulnwh.d | E | Rd, Rx, Ry:<part> | Signed Multiply, word and negated halfword.<br>48 ← (32 x 16) | Rd+1:Rd ← ((Rx * (- Ry:<part>)) << 16) | 1 |
| satadd.h | E | Rd, Rx, Ry | Saturated add halfwords. | Rd ← SE(Sat(Rx[15:0] + Ry[15:0])) | 1 |
| satadd.w | E | Rd, Rx, Ry | Saturated add. | Rd ← Sat(Rx + Ry) | 1 |
| satsub.h | E | Rd, Rx, Ry | Saturated subtract halfwords. | Rd ← SE(Sat(Rx[15:0] - Ry[15:0])) | 1 |
| satsub.w | E | Rd, Rx, Ry | Saturated subtract. | Rd ← Sat(Rx - Ry) | 1 |
| | E | Rd, Rs, imm | | Rd ← Sat(Rs - SE(imm16) ) | 1 |
| satrnds | E | Rd >> sa, bp | Signed saturate from bit given by sa5 after a right shift with rounding of bp5 bit positions. | Rd ← Sat(Round((Rd >> sa5)), bp5) | 1 |
| satrndu | E | Rd >> sa, bp | Unsigned saturate from bit given by sa5 after a right shift with rounding of bp5 bit positions. | Rd ← Sat(Round((Rd >> sa5)), bp5) | 1 |
| sats | E | Rd >> sa, bp | Signed saturate from bit given by sa5 after a right shift of bp5 bit positions. | Rd ← Sat((Rd >> sa5), bp5) | 1 |
| satu | E | Rd >> sa, bp | Unsigned saturate from bit given by sa5 after a right shift of bp5 bit positions. | Rd ← Sat((Rd >> sa5),bp5) | 1 |
| subhh.w | E | Rd, Rx:<part>, Ry:<part> | Subtract signed halfwords.<br>(32 ← 16 -16) | Rd ← SE(Rx:<part>) - SE(Ry:<part>) | 1 |

**Table 9-4.** DSP Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| mulsathh.h | E | Rd, Rx:<part>, Ry:<part> | Fractional signed multiply with saturation. Return halfword. (16 ← 16 x 16) | Rd ← SE(Sat(Rx:<part> *Ry:<part> << 1) >> 16) | 1 |
| mulsathh.w | E | Rd, Rx:<part>, Ry:<part> | Fractional signed multiply with saturation. Return word. (32 ← 16 x 16) | Rd ← Sat( Rx:<part>*Ry:<part> << 1 ) | 1 |
| mulsatrndhh.h | E | Rd, Rx:<part>, Ry:<part> | Fractional signed multiply with rounding. Return halfword. (16 ← 16 x 16) | Rd ← SE(( Sat(Rx:<part> *Ry:<part> << 1) +0x8000 ) >> 16) | 1 |
| mulsatrndwh.w | E | Rd, Rx, Ry:<part> | Fractional signed multiply with rounding. Return word. (32 ← 32 x 16) | Rd ← SE(( Sat(Rx*Ry:<part> << 1) +0x8000 ) >> 16) | 1 |
| mulsatwh.w | E | Rd, Rx, Ry:<part> | Fractional signed multiply with saturation. Return word. (32 ← 32 x 16) | Rd ← Sat(Rx*Ry:<part> << 1) >>16 | 1 |
| macsathh.w | E | Rd, Rx:<part>, Ry:<part> | Fractional signed multiply accumulate with saturation. Return word. (32 ← 16 x 16 + 32) | Rd ← Sat (Sat(Rx:<part> *Ry:<part> << 1) +Rd) | 1 |

### 9.3.5 Logic Operations

**Table 9-5.** Logic Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| and | C | Rd, Rs | Logical AND. | Rd ← Rd ∧ Rs | 1 |
| | E | Rd, Rx, Ry << sa | | Rd ← Rx ∧ (Ry << sa5) | 1 |
| | E | Rd, Rx, Ry >> sa | | Rd ← Rx ∧ (Ry >> sa5) | 1 |
| and{cond4} | E | Rd, Rx, Ry | Logical AND if condition satisfied. | if (cond4) Rd ← Rx ∧ Ry | 2 |
| andn | C | Rd, Rs | Logical AND NOT. | Rd ← Rd ∧ ¬Rs | 1 |
| andh | E | Rd, imm | Logical AND High Halfword, low halfword is unchanged. | Rd[31:16] ← Rd[31:16] ∧ imm16 | 1 |
| | E | Rd, imm, COH | Logical AND High Halfword, clear other halfword. | Rd[31:16] ← Rd[31:16] ∧ imm16<br>Rd[15:0] ← 0 | 1 |
| andl | E | Rd, imm | Logical AND Low Halfword, high halfword is unchanged. | Rd[15:0] ← Rd[15:0] ∧ imm16 | 1 |
| | E | Rd, imm, COH | Logical AND Low Halfword, clear other halfword. | Rd[15:0] ← Rd[15:0] ∧ imm16<br>Rd[31:16] ← 0 | 1 |
| com | C | Rd | One's Complement (NOT). | Rd ← ¬Rd | 1 |
| eor | C | Rd, Rs | Logical Exclusive OR. | Rd ← Rd ⊕ Rs | 1 |
| | E | Rd, Rx, Ry << sa | | Rd ← Rd ⊕ (Rs << sa5) | 1 |
| | E | Rd, Rx, Ry >> sa | | Rd ← Rd ⊕ (Rs >> sa5) | 1 |
| eor{cond4} | E | Rd, Rx, Ry | Logical EOR if condition satisfied. | if (cond4) Rd ← Rx ⊕ Ry | 2 |
| eorh | E | Rd, imm | Logical Exclusive OR (High Halfword). | Rd[31:16] ← Rd[31:16] ⊕ imm16 | 1 |
| eorl | E | Rd, imm | Logical Exclusive OR (Low Halfword). | Rd[15:0] ← Rd[15:0] ⊕ imm16 | 1 |
| or | C | Rd, Rs | Logical (Inclusive) OR. | Rd ← Rd ∨ Rs | 1 |
| | E | Rd, Rx, Ry << sa | | Rd ← Rd ∨ (Rs << sa5) | 1 |
| | E | Rd, Rx, Ry >> sa | | Rd ← Rd ∨ (Rs >> sa5) | 1 |
| or{cond4} | E | Rd, Rx, Ry | Logical OR if condition satisfied. | if (cond4) Rd ← Rx ∨ Ry | 2 |
| orh | E | Rd, imm | Logical OR (High Halfword). | Rd[31:16] ← Rd[31:16] ∨ imm16 | 1 |
| orl | E | Rd, imm | Logical OR (Low Halfword). | Rd[15:0] ← Rd[15:0] ∨ imm16 | 1 |
| tst | C | Rd, Rs | Test register for zero. | Rd ∧ Rs | 1 |

### 9.3.6 Bit Operations

**Table 9-6.** Bit Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| bfexts | E | Rd, Rs, o5, w5 | Extract and sign-extend the w5 bits in Rs starting at bit-offset o5 to Rd. | See Instruction Set Reference | 1 |
| bfextu | E | Rd, Rs, o5, w5 | Extract and zero-extend the w5 bits in Rs starting at bit-offset o5 to Rd. | See Instruction Set Reference | 1 |
| bfins | E | Rd, Rs, o5, w5 | Insert the lower w5 bits of Rs in Rd at bit-offset o5. | See Instruction Set Reference | 1 |
| bld | E | Rd, bp | Bit load. | C ← Rd[bp5]<br>Z ← Rd[bp5] | 1 |
| brev | C | Rd | Bit reverse. | Rd[0:31] ← Rd[31:0] | 1 |
| bst | E | Rd, bp | Bit store. | Rd[bp5] ← C | 1 |
| casts.b | C | Rd | Typecast byte to signed word. | Rd ← SE(Rd[7:0]) | 1 |
| casts.h | C | Rd | Typecast halfword to signed word. | Rd ← SE(Rd[15:0]) | 1 |
| castu.b | C | Rd | Typecast byte to unsigned word. | Rd ← ZE(Rd[7:0]) | 1 |
| castu.h | C | Rd | Typecast halfword to unsigned word. | Rd ← ZE(Rd[15:0]) | 1 |
| cbr | C | Rd, bp | Clear bit in register. | Rd[bp5] ← 0 | 1 |
| clz | E | Rd, Rs | Count leading zeros. | See Instruction Set Reference | 1 |
| sbr | C | Rd, bp | Set bit in register. | Rd[bp5] ← 1 | 1 |
| swap.b | C | Rd | Swap bytes in register. | Rd[31:24] ← Rd[7:0],<br>Rd[23:16] ← Rd[15:8],<br>Rd[15:8] ← Rd[23:16],<br>Rd[7:0] ← Rd[31:24] | 1 |
| swap.bh | C | Rd | Swap bytes in each halfword. | Rd[31:24] ← Rd[23:16],<br>Rd[23:16] ← Rd[31:24],<br>Rd[15:8] ← Rd[7:0],<br>Rd[7:0] ← Rd[15:8] | 1 |
| swap.h | C | Rd | Swap halfwords in register. | Rd[31:16] ← Rd[15:0],<br>Rd[15:0] ← Rd[31:16] | 1 |

### 9.3.7 Shift Operations

**Table 9-7.** Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| asr | E | Rd, Rx, Ry | Arithmetic shift right (signed) . | See Instruction Set Reference | 1 |
| | E | Rd, Rs, sa | | | 1 |
| | C | Rd, sa | | | 1 |
| lsl | E | Rd, Rx, Ry | Logical shift left. | See Instruction Set Reference | 1 |
| | E | Rd, Rs, sa | | | 1 |
| | C | Rd, sa | | | 1 |
| lsr | E | Rd, Rx, Ry | Logical shift right. | See Instruction Set Reference | 1 |
| | E | Rd, Rs, sa | | | 1 |
| | C | Rd, sa | | | 1 |
| rol | C | Rd | Rotate left through carry. | See Instruction Set Reference | 1 |
| ror | C | Rd | Rotate right through carry. | See Instruction Set Reference | 1 |

### 9.3.8 Instruction Flow

**Table 9-8.** Instruction Flow

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| br{cond3} | C | disp | Branch if condition satisfied. | if (cond3)<br>PC ← PC + (SE(disp8)<<1) | 1 |
| br{cond4} | E | disp | | if (cond4)<br>PC ← PC + (SE(disp21)<<1) | 1 |
| rjmp | C | disp | Relative jump. | PC ← PC + (SE(disp10)<<1) | 1 |
| acall | C | disp | Application call | LR ← PC + 2<br>PC ← *(ACBA + (ZE(disp8)<<2)) | 1 |
| icall | C | Rd | Register inderect call. | LR ← PC + 2<br>PC ← Rd | 1 |
| mcall | E | Rp[disp] | Memory call. | LR ← PC + 4<br>PC ← *((Rp && 0xFFFF_FFFC) + (SE(disp16)<<2)) | 1 |
| rcall | C | disp | Relative call. | LR ← PC + 2<br>PC ← PC + (SE(disp10)<<1) | 1 |
| | E | disp | | LR ← PC + 4<br>PC ← PC + (SE(disp21)<<1) | 1 |
| scall | C | | Supervisor call | See Instruction Set Reference. | 1 |
| sscall | C | | Secure State call | See Instruction Set Reference. | 1 |
| ret{cond4} | C | Rs | Conditional return from subroutine with move and test of return value. | if (Rs != {SP, PC})<br>R12 ← Rs<br>PC ←LR | 1 |
| | | | Conditional return from subroutine with return of false value. | if (Rs = LR)<br>R12 ← -1<br>PC ←LR | 1 |
| | | | Conditional return from subroutine with return of false value. | if (Rs = SP)<br>R12 ← 0<br>PC ←LR | 1 |
| | | | Conditional return from subroutine with return of true value. | if (Rs = PC)<br>R12 ← 1<br>PC ←LR | 1 |
| retd | C | | Return from debug mode | SR ←RSR_DBG<br>PC ←LR_DBG | 1 |
| rete | C | | Return from event handler | See Instruction Set Reference. | 1 |
| rets | C | | Return from supervisor call | See Instruction Set Reference. | 1 |
| retss | C | | Return from secure state | See Instruction Set Reference. | 1 |

### 9.3.9 Data Transfer

#### *9.3.9.1 Move/Load Immediate operations*

**Table 9-9.** Move/Load Immediate Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| mov | C | Rd, imm | Load immediate into register. | Rd ← SE(imm8) | 1 |
| | E | Rd, imm | | Rd ← SE(imm21) | 1 |
| | C | Rd, Rs | Copy register. | Rd ← Rs | 1 |
| mov{cond4} | E | Rd, Rs | Copy register if condition is true | if (cond4) Rd ← Rs | 1 |
| | E | Rd, imm | Load immediate into register if condition is true | if (cond4) Rd ← SE(imm8) | 1 |
| movh | E | Rd, imm | Load immediate into high halfword of register. | Rd ← imm16<<16 | 2 |

#### *9.3.9.2 Load/Store operations*

**Table 9-10.** Load/Store Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| ld.ub | C | Rd, Rp++ | Load unsigned byte with post-increment. | Rd ← ZE(*(Rp++)) | 1 |
| | C | Rd, --Rp | Load unsigned byte with pre-decrement. | Rd ← ZE(*(--Rp)) | 1 |
| | C | Rd, Rp[disp] | Load unsigned byte with displacement. | Rd ← ZE(*(Rp+ZE(disp3))) | 1 |
| | E | Rd, Rp[disp] | | Rd ← ZE(*(Rp+SE(disp16))) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load unsigned byte. | Rd ← ZE(*(Rb+(Ri << sa2))) | 1 |
| ld.ub{cond4} | E | Rd, Rp[disp] | Load unsigned byte with displacement if condition satisfied. | if {cond4}<br>Rd ← ZE(*(Rp+ZE(disp9))) | 2 |
| ld.sb | E | Rd, Rp[disp] | Load signed byte with displacement. | Rd ← SE(*(Rp+SE(disp16))) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load signed byte. | Rd ← SE(*(Rb+(Ri << sa2))) | 1 |
| ld.sb{cond4} | E | Rd, Rp[disp] | Load signed byte with displacement if condition satisfied. | if {cond4}<br>Rd ← SE(*(Rp+ZE(disp9))) | 2 |
| ld.uh | C | Rd, Rp++ | Load unsigned halfword with post-increment. | Rd ← ZE(*(Rp++)) | 1 |
| | C | Rd, --Rp | Load unsigned halfword with pre-decrement. | Rd ← ZE(*(--Rp)) | 1 |
| | C | Rd, Rp[disp] | Load unsigned halfword with displacement. | Rd ← ZE(*(Rp+(ZE(disp3)<<1))) | 1 |
| | E | Rd, Rp[disp] | | Rd ← ZE(*(Rp+(SE(disp16)))) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load unsigned halfword. | Rd ← ZE(*(Rb+(Ri << sa2))) | 1 |
| ld.uh{cond4} | E | Rd, Rp[disp] | Load unsigned halfword with displacement if condition satisfied. | if {cond4}<br>Rd ← ZE(*(Rp+ZE(disp9<<1))) | 2 |

**Table 9-10.** Load/Store Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| ld.sh | C | Rd, Rp++ | Load signed halfword with post-increment. | Rd ← SE(*(Rp++)) | 1 |
| | C | Rd, --Rp | Load signed halfword with pre-decrement. | Rd ← SE(*(--Rp)) | 1 |
| | C | Rd, Rp[disp] | Load signed halfword with displacement. | Rd ← SE(*(Rp+(ZE(disp3)<<1))) | 1 |
| | E | Rd, Rp[disp] | | Rd ← SE(*(Rp+(SE(disp16)))) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load signed halfword. | Rd ← SE(*(Rb+(Ri << sa2))) | 1 |
| ld.sh{cond4} | E | Rd, Rp[disp] | Load signed halfword with displacement if condition satisfied. | if {cond4}<br>Rd ← SE(*(Rp+ZE(disp9<<1))) | 2 |
| ld.w | C | Rd, Rp++ | Load word with post-increment. | Rd ← *(Rp++) | 1 |
| | C | Rd, --Rp | Load word with pre-decrement. | Rd ← *(--Rp) | 1 |
| | C | Rd, Rp[disp] | Load word with displacement. | Rd ← *(Rp+(ZE(disp5)<<2)) | 1 |
| | E | Rd, Rp[disp] | | Rd ← *(Rp+(SE(disp16))) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load word. | Rd ← *(Rb+(Ri << sa2)) | 1 |
| | E | Rd, Rb[Ri:<part> << 2] | Load word with extracted index into Rd. | Rd ← *(Rb+(Ri:<part> << 2)) | 1 |
| ld.w{cond4} | E | Rd, Rp[disp] | Load word with displacement if condition satisfied. | if {cond4}<br>Rd ← *(Rp+ZE(disp9<<2)) | 2 |
| ld.d | C | Rd, Rp++ | Load doubleword with post-increment. | Rd+1:Rd ← (*(Rp++)) | 1 |
| | C | Rd, --Rp | Load doubleword with pre-decrement. | Rd+1:Rd ← (*(--Rp)) | 1 |
| | C | Rd, Rp | Load doubleword. | Rd+1:Rd ← *(Rp) | 1 |
| | E | Rd, Rp[disp] | Load double with displacement. | Rd+1:Rd ← *(Rp+SE(disp16)) | 1 |
| | E | Rd, Rb[Ri<<sa] | Indexed Load double. | Rd+1:Rd ← *(Rb+(Ri << sa2)) | 1 |
| ldins.b | E | Rd:<part>, Rp[disp] | Load byte with displacement and insert at specified byte location in Rd. | Rd:<part>← *(Rp+(SE(disp12))) | 1 |
| ldins.h | E | Rd:<part>, Rp[disp] | Load halfword with displacement and insert at specified halfword location in Rd. | Rd:<part> ← *(Rp+(SE(disp12)<<1)) | 1 |
| ldswp.sh | E | Rd, Rp[disp] | Load halfword with displacement, swap bytes and sign-extend | Temp ← *(Rp+(SE(disp12) << 1)<br>Rd ← SE(Temp[7:0], Temp[15:8]) | 1 |
| ldswp.uh | E | | Load halfword with displacement, swap bytes and zero-extend | Temp ← *(Rp+(SE(disp12) << 1)<br>Rd ← ZE(Temp[7:0], Temp[15:8]) | 1 |
| ldswp.w | E | | Load word with displacement and swap bytes. | Temp ← *(Rp+(SE(disp12) << 2)<br>Rd[31:24] ← Temp[7:0],<br>Rd[23:16] ← Temp[15:8],<br>Rd[15:8] ← Temp[23:16],<br>Rd[7:0] ← Temp[31:24] | 1 |
| lddpc | C | Rd, PC[disp] | Load with displacement from PC. | Rd ← *((PC && 0xFFFF_FFFC) +(ZE(disp7)<<2)) | 1 |
| lddsp | C | Rd, SP[disp] | Load with displacement from SP. | Rd ← *((SP && 0xFFFF_FFFC) +(ZE(disp7)<<2)) | 1 |

**Table 9-10.** Load/Store Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| st.b | C | Rp++, Rs | Store with post-increment. | *(Rp++) ← Rs[7:0] | 1 |
| | C | --Rp, Rs | Store with pre-decrement. | *(--Rp) ← Rs[7:0] | 1 |
| | C | Rp[disp], Rs | Store byte with displacement. | *(Rp+ZE(disp3)) ← Rs[7:0] | 1 |
| | E | Rp[disp], Rs | | *(Rp+SE(disp16)) ← Rs[7:0] | 1 |
| | E | Rb[Ri<<sa], Rs | Indexed Store byte. | *(Rb+(Ri << sa2)) ← Rs[7:0] | 1 |
| st.b{cond4} | E | Rp[disp], Rs | Store byte with displacement if condition satisfied. | if {cond4}<br>*(Rp+SE(disp9)) ← Rs[7:0] | 2 |
| st.d | C | Rp++, Rs | Store with post-increment. | *(Rp++) ← (Rs+1:Rs) | 1 |
| | C | --Rp, Rs | Store with pre-decrement. | *(--Rp) ← (Rs+1:Rs) | 1 |
| | C | Rp, Rs | Store doubleword | *(Rp) ← (Rs+1:Rs) | 1 |
| | E | Rp[disp], Rs | Store double with displacement | *(Rp+SE(disp16)) ← (Rs+1:Rs) | 1 |
| | E | Rb[Ri<<sa], Rs | Indexed Store double. | *(Rb+(Ri << sa2)) ← (Rs+1:Rs) | 1 |
| st.h | C | Rp++, Rs | Store with post-increment. | *(Rp++) ← Rs[15:0] | 1 |
| | C | --Rp, Rs | Store with pre-decrement. | *(--Rp) ← Rs[15:0] | 1 |
| | C | Rp[disp], Rs | Store halfword with displacement. | *(Rp+(ZE(disp3)<<1)) ← Rs[15:0] | 1 |
| | E | Rp[disp], Rs | | *(Rp+(SE(disp16))) ← Rs[15:0] | 1 |
| | E | Rb[Ri<<sa], Rs | Indexed Store halfword. | *(Rb+(Ri << sa2)) ← Rs[15:0] | 1 |
| st.h{cond4} | E | Rp[disp], Rs | Store halfword with displacement if condition satisfied. | if {cond4}<br>*(Rp+SE(disp9<<1)) ← Rs[15:0] | 2 |
| st.w | C | Rp++, Rs | Store with post-increment. | *(Rp++) ← Rs | 1 |
| | C | --Rp, Rs | Store with pre-decrement. | *(--Rp) ← Rs | 1 |
| | C | Rp[disp], Rs | Store word with displacement. | *(Rp+(ZE(disp4)<<2)) ← Rs | 1 |
| | E | Rp[disp], Rs | | *(Rp+(SE(disp16))) ← Rs | 1 |
| | E | Rb[Ri<<sa], Rs | Indexed Store word. | *(Rb+(Ri << sa2)) ← Rs | 1 |
| st.w{cond4} | E | Rp[disp], Rs | Store word with displacement if condition satisfied. | if {cond4}<br>*(Rp+ZE(disp9<<2)) ← Rs | 2 |
| stcond | C | Rp[disp], Rs | Conditional store with displacement. | SREG[Z] ← SREG[L]<br>if (SREG[L])<br>*(Rp+(SE(disp16))) ← Rs | 1 |
| stdsp | C | SP[disp], Rs | Store with displacement from SP. | *( (SP && 0xFFFF_FFFC)<br>+(ZE(disp7)<<2)) ← Rs | 1 |
| sthh.w | E | Rp[disp], Rx:<part>, Ry:<part> | Combine halfwords to word and store with displacement. | *(Rp+(ZE(disp8)<<2)) ←<br>{Rx:<part>, Ry:<part>} | 1 |
| | E | Rb[Ri<<sa], Rx:<part>, Ry:<part> | Combine halfwords to word and store indexed. | *(Rb+(Ri << sa2)) ← {Rx:<part>, Ry:<part>} | 1 |

**Table 9-10.** Load/Store Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| stswp.h | E | Rp[disp], Rs | Swap bytes and store halfword with displacement. | Temp ← Rs[7:0], Rs[15:8]<br>*(Rp+(SE(disp12) << 1) ← Temp | 1 |
| stswp.w | E | | Swap bytes and store word with displacement. | Temp[31:24] ← Rs[7:0],<br>Temp[23:16] ← Rs[15:8],<br>Temp[15:8] ← Rs[23:16],<br>Temp[7:0] ← Rs[31:24]<br>*(Rp+(SE(disp12) << 2) ← Temp | 1 |
| xchg | E | Rd, Rx, Ry | Exchange register and memory | See Instruction Set Reference | 1 |

*9.3.9.3 Multiple data*

**Table 9-11.** Mutiple data

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| ldm | E | Rp{++}, Reglist16 {, R12={-1,0,1}} | Load multiple registers. R12 is tested if PC is loaded. | See Instruction Set Reference | 1 |
| ldmts | E | Rp{++}, Reglist16 | Load multiple registers in application context for task switch. | See Instruction Set Reference | 1 |
| popm | C | Reglist8 {, R12={-1,0,1}} | Pop multiple registers from stack. R12 is tested if PC is popped. | See Instruction Set Reference | 1 |
| pushm | C | Reglist8 | Push multiple registers to stack. | See Instruction Set Reference | 1 |
| stm | E | {--}Rp, Reglist16 | Store multiple registers. | See Instruction Set Reference | 1 |
| stmts | E | {--}Rp, Reglist16 | Store multiple registers in application context for task switch. | See Instruction Set Reference | 1 |

### 9.3.10 System/Control

**Table 9-12.** System/Control

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| breakpoint | C | | Breakpoint. | See Instruction Set Reference | 1 |
| cache | E | Rp[disp], Op | Perform cache operation | See Instruction Set Reference | 1 |
| csrf | C | bp | Clear status register flag. | SR[bp5] ← 0 | 1 |
| csrfcz | C | bp | Copy status register flag to C and Z. | C ← SR[bp5]<br>Z ← SR[bp5] | 1 |
| frs | C | frs | Invalidates the return address stack | See Instruction Set Reference | 1 |
| mfdr | E | Rd, DebugRegAddress | Move debug register to Rd. | Rd ←DebugRegister[DebugRegAddr] | 1 |
| mfsr | E | Rd, SysRegNo | Move system register to Rd. | Rd ← SystemRegister[SysRegNo] | 1 |
| mtdr | E | DebugRegAddress, Rs | Move Rs to debug register. | DebugRegister[DebugRegAddr] ← Rs | 1 |
| mtsr | E | SysRegNo, Rs | Move Rs to system register. | SystemRegister[SysRegNo] ← Rs | 1 |
| musfr | C | Rs | Move Rs to status register | SR[3:0] ← Rs[3:0] | 1 |
| mustr | C | Rd | Move status register to Rd | Rd ← ZE(SR[3:0]) | 1 |

**Table 9-12.** System/Control (Continued)

| | | | | | |
|---|---|---|---|---|---|
| nop | C | | No operation | See Instruction Set Reference | 1 |
| pref | E | Rp[disp] | Prefetch cache line | See Instruction Set Reference | 1 |
| sleep | E | Op8 | Enter SLEEP mode. | See Instruction Set Reference | 1 |
| sr{cond4} | C | Rd | Conditionally set register to true or false. | if (cond4)<br>Rd ← 1;<br>else<br>Rd ← 0; | 1 |
| ssrf | C | bp | Set status register flag. | SR[bp5] ← 1 | 1 |
| sync | E | Op8 | Flush write buffer | See Instruction Set Reference | 1 |
| tlbr | C | | Read TLB entry | See Instruction Set Reference | 1 |
| tlbs | C | | Search TLB for entry | See Instruction Set Reference | 1 |
| tlbw | C | | Write TLB entry | See Instruction Set Reference | 1 |

### 9.3.11 Coprocessor interface

**Table 9-13.** Coprocessor Interface

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| cop | E | CP#, CRd, CRx, CRy, Op | Coprocessor operation. | CRd ← CRx Op CRy | 1 |
| ldc.d | E | CP#, CRd, Rp[disp] | Load coprocessor register | CRd+1:CRd ← *(Rp+ZE(disp8<<2)) | 1 |
| | E | CP#, CRd, --Rp | Load coprocessor register with pre-decrement | CRd+1:CRd ← *(--Rp) | 1 |
| | E | CP#, CRd, Rb[Ri<<sa] | Load coprocessor register with indexed addressing | CRd+1:CRd ← *(Rb+(Ri << sa2)) | 1 |
| ldc0.d | E | CRd, Rp[disp] | Load coprocessor 0 register | CRd+1:CRd ← *(Rp+ZE(disp12<<2)) | 1 |
| ldc.w | E | CP#, CRd, Rp[disp] | Load coprocessor register | CRd ← *(Rp+ZE(disp8<<2)) | 1 |
| | E | CP#, CRd, --Rp | Load coprocessor register with pre-decrement | CRd ← *(--Rp) | 1 |
| | E | CP#, CRd, Rb[Ri<<sa] | Load coprocessor register with indexed addressing | CRd ← *(Rb+(Ri << sa2)) | 1 |
| ldc0.w | E | CRd, Rp[disp] | Load coprocessor 0 register | CRd ← *(Rp+ZE(disp12<<2)) | 1 |
| ldcm.d | E | CP#, Rp{++}, ReglistCPD8 | Load multiple coprocessor double registers | See instruction set reference | 1 |
| ldcm.w | E | CP#, Rp{++}, ReglistCPH8 | Load multiple coprocessor high registers | See instruction set reference | 1 |
| ldcm.w | E | CP#, Rp{++}, ReglistCPL8 | Load multiple coprocessor low registers | See instruction set reference | 1 |
| mvcr.d | E | CP#, Rd, CRs | Move from coprocessor to register | Rd+1:Rd ← CRs+1:CRs | 1 |
| mvcr.w | E | CP#, Rd, CRs | Move from coprocessor to register | Rd ← CRs | 1 |
| mvrc.d | E | CP#, CRd, Rs | Move from register to coprocessor | CRd+1:CRd ← Rs+1:Rs | 1 |
| mvrc.w | E | CP#, CRd, Rs | Move from register to coprocessor | CRd ← Rs | 1 |
| stc.d | E | CP#, Rp[disp], CRs | Store coprocessor register | *(Rp+ZE(disp8<<2)) ← CRs+1:CRs | 1 |
| | E | CP#, Rp++, CRs | Store coprocessor register with post-increment | *(Rp--) ← CRs+1:CRs | 1 |
| | E | CP#, Rb[Ri<<sa], CRs | Store coprocessor register with indexed addressing | *(Rb+(Ri << sa2)) ← CRs+1:CRs | 1 |
| stc0.d | E | Rp[disp], CRs | Store coprocessor 0 register | *(Rp+ZE(disp12<<2)) ← CRs+1:CRs | 1 |
| stc.w | E | CP#, Rp[disp], CRs | Store coprocessor register | *(Rp+ZE(disp8<<2)) ← CRs | 1 |
| | E | CP#, Rp++, CRs | Store coprocessor register with post-increment | *(Rp++) ← CRs | 1 |
| | E | CP#, Rb[Ri<<sa], CRs | Store coprocessor register with indexed addressing | *(Rb+(Ri << sa2)) ← CRs | 1 |
| stc0.d | E | Rp[disp], CRs | Store coprocessor 0 register | *(Rp+ZE(disp12<<2)) ← CRs | 1 |

**Table 9-13.** Coprocessor Interface (Continued)

| | | | | | |
|---|---|---|---|---|---|
| stcm.d | E | CP#, {--}Rp, ReglistCPD8 | Store multiple coprocessor double registers | See instruction set reference | 1 |
| stcm.w | E | CP#, {--}Rp, ReglistCPH8 | Store multiple coprocessor high registers | See instruction set reference | 1 |
| stcm.w | E | CP#, {--}Rp, ReglistCPL8 | Store multiple coprocessor low registers | See instruction set reference | 1 |

### 9.3.12 Instructions to aid Java execution

**Table 9-14.** Instructions to aid Java (Card) execution

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| incjosp | C | imm | Increment Java stack pointer | JOSP + {-4, -3, -2, -1, 1, 2, 3, 4} | 1 |
| popjc | C | | Pop Java context from Frame | See instruction set reference | 1 |
| pushjc | C | | Push Java context to Frame | See instruction set reference | 1 |
| retj | C | | Return from Java Trap | See instruction set reference | 1 |

### 9.3.13 SIMD Operations

**Table 9-15.** SIMD Operations

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| pabs.{sb/sh} | E | Rd, Rs | Packed Absolute Value | See instruction set reference | 1 |
| packsh.{ub/sb} | E | Rd, Rx, Ry | Pack Halfwords to Bytes | See instruction set reference | 1 |
| packw.sh | E | Rd, Rx, Ry | Pack Words to Halfwords | See instruction set reference | 1 |
| padd.{b/h} | E | Rd, Rx, Ry | Packed Addition | See instruction set reference | 1 |
| paddh.{ub/sh} | E | Rd, Rx, Ry | Packed Addition with halving | See instruction set reference | 1 |
| padds.{ub/sb/uh/sh} | E | Rd, Rx, Ry | Packed Addition with Saturation | See instruction set reference | 1 |
| paddsub.h | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Addition and Subtraction | See instruction set reference | 1 |
| paddsubh.sh | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Addition and Subtraction with halving | See instruction set reference | 1 |
| paddsubs.{uh/sh} | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Addition and Subtraction with Saturation | See instruction set reference | 1 |
| paddx.h | E | Rd, Rx, Ry | Packed Halfword Addition with Crossed Operand | See instruction set reference | 1 |
| paddxh.sh | E | Rd, Rx, Ry | Packed Halfword Addition with Crossed Operand and Halving | See instruction set reference | 1 |
| paddxs.{uh/sh} | E | Rd, Rx, Ry | Packed Halfword Addition with Crossed Operand and Saturation | See instruction set reference | 1 |
| pasr.{b/h} | E | Rd, Rs, {sa} | Packed Arithmetic Shift Left | See instruction set reference | 1 |
| pavg.{ub/sh} | E | Rd, Rx, Ry | Packed Average | See instruction set reference | 1 |
| plsl.{b/h} | E | Rd, Rs, {sa} | Packed Logic Shift Left | See instruction set reference | 1 |

**Table 9-15.** SIMD Operations (Continued)

| | | | | | |
|---|---|---|---|---|---|
| plsr.{b/h} | E | Rd, Rs, {sa} | Packed Logic Shift Right | See instruction set reference | 1 |
| pmax.{ub/sh} | E | Rd, Rx, Ry | Packed Maximum Value | See instruction set reference | 1 |
| pmin.{ub/sh} | E | Rd, Rx, Ry | Packed Minimum Value | See instruction set reference | 1 |
| psad | E | Rd, Rx, Ry | Sum of Absolute Differences | See instruction set reference | 1 |
| psub.{b/h} | E | Rd, Rx, Ry | Packed Subtraction | See instruction set reference | 1 |
| psubadd.h | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Subtraction and Addition | See instruction set reference | 1 |
| psubaddh.sh | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Subtraction and Addition with halving | See instruction set reference | 1 |
| psubadds.{uh/sh} | E | Rd, Rx:<part>, Ry:<part> | Packed Halfword Subtraction and Addition with Saturation | See instruction set reference | 1 |
| psubh.{ub/sh} | E | Rd, Rx, Ry | Packed Subtraction with halving | See instruction set reference | 1 |
| psubs.{ub/sb/uh/sh} | E | Rd, Rx, Ry | Packed Subtraction with Saturation | See instruction set reference | 1 |
| psubx.h | E | Rd, Rx, Ry | Packed Halfword Subtraction with Crossed Operand | See instruction set reference | 1 |
| psubxh.sh | E | Rd, Rx, Ry | Packed Halfword Subtraction with Crossed Operand and Halving | See instruction set reference | 1 |
| psubxs.{uh/sh} | E | Rd, Rx, Ry | Packed Halfword Subtraction with Crossed Operand and Saturation | See instruction set reference | 1 |
| punpck{ub/sb}.h | E | Rd, Rs:<part> | Unpack Bytes to Halfwords | See instruction set reference | 1 |

### 9.3.14 Memory read-modify-write instructions

**Table 9-16.** Memory read-modify-write Instructions

| Mnemonics | | Operands / Syntax | Description | Operation | Rev |
|---|---|---|---|---|---|
| memc | E | imm, bp | Clear bit in memory | Memory[(imm15<<2)[bp5]] = 0 | 1 |
| mems | E | imm, bp | Set bit in memory | Memory[(imm15<<2)[bp5]] = 1 | 1 |
| memt | E | imm, bp | Toggle bit in memory | Memory[(imm15<<2)[bp5]] = ¬Memory[(imm15<<2)[bp5]] | 1 |

## 9.4 Base Instruction Set Description

The following chapter describes the instructions in the base instruction set.

## ABS – Absolute Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The absolute value of the contents to the register specified is written back to the register. If the initial value equals the maximum negative value (0x80000000), the result will equal the initial value.

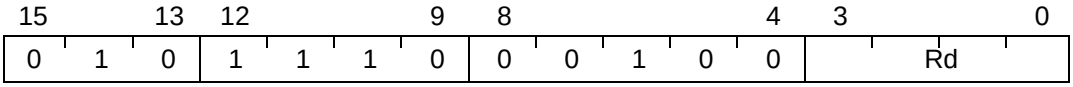
**Operation:**
I. Rd ← |Rd|;

**Syntax:**
I. abs Rd

**Operands:**
I. d ∈ {0, 1, …, 15}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** (RES[31:0] == 0)
**C:** Not affected

**Opcode:**



## ACALL – Application Call

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The ACALL instruction performs an application function call.

**Operation:**
I. LR ← PC + 2;
PC ← *(ACBA + (ZE(disp8)<<2));

**Syntax:**
I. acall disp

**Operands:**
I. disp ∈ {0, 4, ..., 1020}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

| 15 | | | 12 | 11 … 4 | 3 | | | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | disp8/Label | 0 | 0 | 0 | | 0 |

**Note:**
ACBA must be word aligned. Failing to align ACBA correctly may lead to erronous behavior.

## ACR – Add Carry to Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds carry to the specified destination register.

**Operation:**

I. Rd ← Rd + C;

**Syntax:**

I. acr Rd

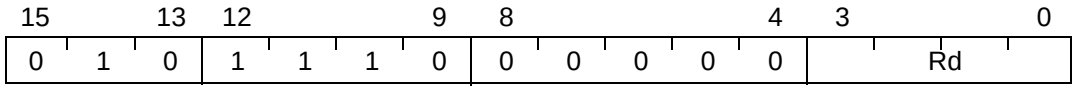
**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags**

**Q:** Not affected
**V:** V ← RES[31] ∧ ¬Rd[31]
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0) ∧ Z
**C:** C ← ¬RES[31] ∧ Rd[31]

**Opcode:**




**Example:**

```
; Add a 32-bit variable (R0) to a 64-bit variable (R2:R1)
add     R1, R0
acr     R2
```

## ADC – Add with Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds carry and the two registers specified and stores the result in destination register.

**Operation:**
I. Rd ← Rx + Ry + C;

**Syntax:**
I. adc Rd, Rx, Ry

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected

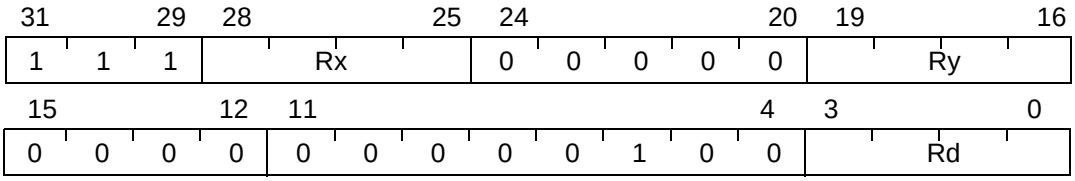
**V:** V ← (Rx[31] ∧ Ry[31] ∧ ¬RES[31]) ∨ (¬Rx[31] ∧ ¬Ry[31] ∧ RES[31])

**N:** N ← RES[31]

**Z:** Z ← (RES[31:0] == 0) ∧ Z

**C:** C ← Rx[31] ∧ Ry[31] ∨ Rx[31] ∧ ¬RES[31] ∨ Ry[31] ∧ ¬RES[31]

**Opcode:**




**Example**

```
; Add two 64-bit variables R1:R0 and R3:R2 and store the result in R1:R0
add     R0, R2
adc     R1, R1, R3
```

## ADD– Add without Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds the two registers specified and stores the result in destination register. Format II allows shifting of the second operand.

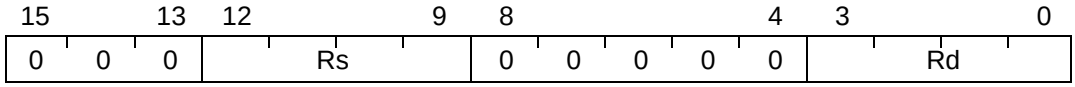
**Operation:**
I. Rd ← Rd + Rs;
II. Rd ← Rx + (Ry<< sa2);

**Syntax:**
I. add Rd, Rs
II. add Rd, Rx, Ry << sa

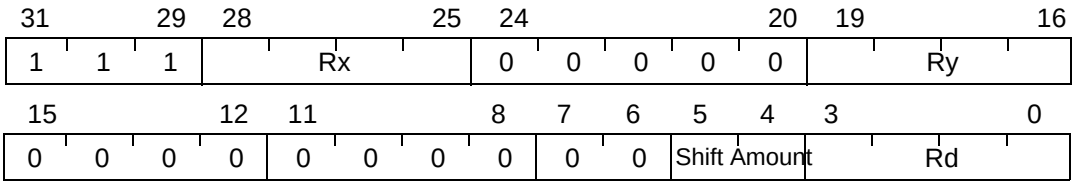
**Operands:**
I. {d, s} ∈ {0, 1, …, 15}
II. {d, x, y}∈ {0, 1, …, 15}
sa ∈ {0, 1, 2, 3}

**Status Flags**
**Format I: OP1 = Rd, OP2 = Rs**
**Format II:OP1 = Rx, OP2 = Ry << sa2**
**Q:** Not affected
**V:** V ← (OP1[31] ∧ OP2[31] ∧ ¬RES[31]) ∨ (¬OP1[31] ∧ ¬OP2[31] ∧ RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← OP1[31] ∧ OP2[31] ∨ OP1[31] ∧ ¬RES[31] ∨ OP2[31] ∧ ¬RES[31]

**Opcode:**
**Format I:**




**Format II:**



## ADD{cond4} – Conditional Add

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Performs an addition and stores the result in destination register.

**Operation:**
I. if ( cond4)
Rd ← Rx + Ry;

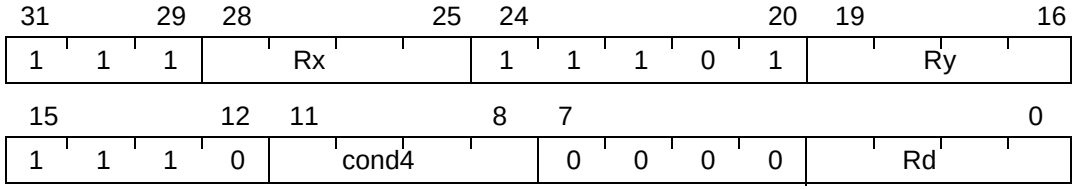
**Syntax:**
I. add{cond4}Rd, Rx, Ry

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## ADDABS– Add Absolute Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds Rx and the absolute value of Ry and stores the result in destination register. Useful for calculating the sum of absolute differences.

**Operation:**
I. Rd ← Rx + |Ry|;

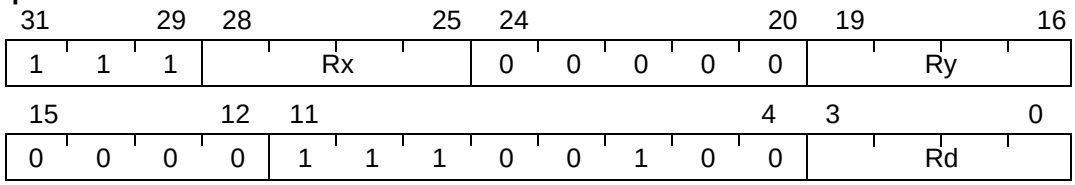
**Syntax:**
I. addabs Rd, Rx, Ry

**Operands:**
I. {d, x, y}∈ {0, 1, …, 15}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Z ← (RES[31:0] == 0) |
| **C:** | Not affected |

**Opcode:**



## ADDHH.W– Add Halfwords into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds the two halfword registers specified and stores the result in the destination word-register. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
Rd ← operand1 + operand2;

**Syntax:**

I. addhh.wRd, Rx:<part>, Ry:<part>

**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**OP1 = operand1, OP2 = operand2**

**Q:** Not affected

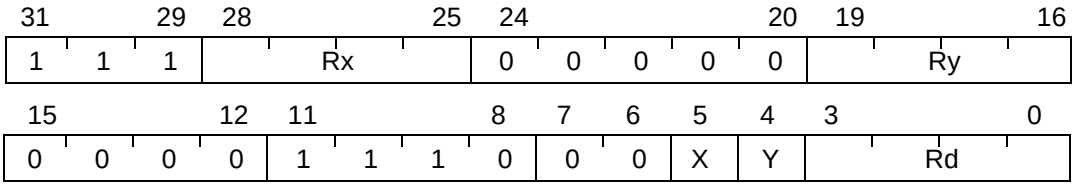
**V:** V ← (OP1[31] ∧ OP2[31] ∧ ¬RES[31]) ∨ (¬OP1[31] ∧ ¬OP2[31] ∧ RES[31])

**N:** N ← RES[31]

**Z:** Z ← (RES[31:0] == 0)

**C:** C ← OP1[31] ∧ OP2[31] ∨ OP1[31] ∧ ¬RES[31] ∨ OP2[31] ∧ ¬RES[31]

**Opcode:**




**Example:**

addhh.wR10, R2:t, R3:b
will perform R10 ← SE(R2[31:16]) + SE(R3[15:0])

## AND – Logical AND with optional logical shift

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical AND between the specified registers and stores the result in the destination register.

**Operation:**

I. Rd ← Rd ∧ Rs;
II. Rd ← Rx ∧ (Ry << sa5);
III. Rd ← Rx ∧ (Ry >> sa5);

**Syntax:**

| | | |
|---|---|---|
| I. | and | Rd, Rs |
| II. | and | Rd, Rx, Ry << sa |
| III. | and | Rd, Rx, Ry >> sa |

**Operands:**

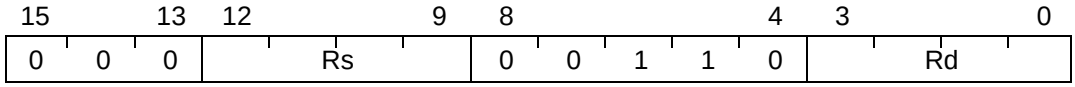
I. {d, s} ∈ {0, 1, …, 15}
II, III {d, x, y} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

**Status Flags**

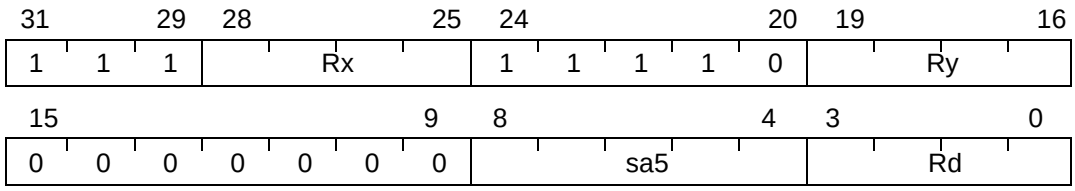
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode**

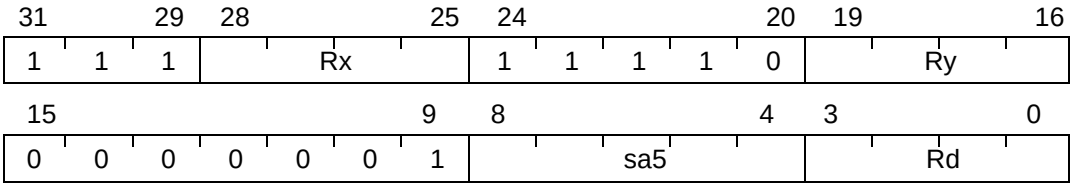
**Format I:**




**Format II:**



**Format III:**



## AND{cond4} – Conditional And

**Architecture revision:**
Architecture revision1 and higher.

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Performs a bitwise logical AND between the specified registers and stores the result in the destination register.

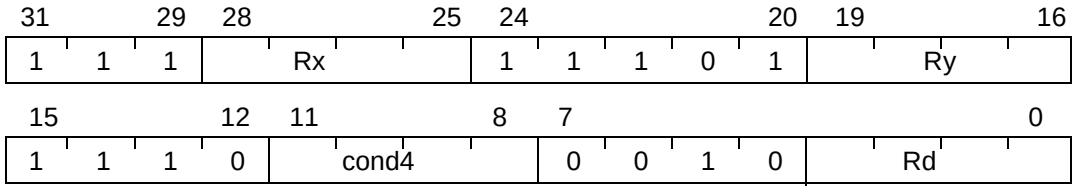
**Operation:**
I. if ( cond4)
Rd ← Rx ∧ Ry;

**Syntax:**
I. and{cond4}Rd, Rx, Ry

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## ANDH, ANDL – Logical AND into high or low half of register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical AND between the high or the low halfword in the specified register and a constant. The result is stored in the high or the low halfword of the destination register while the other bits remain unchanged. The Clear Other Half (COH) parameter allows the other half to be cleared.

**Operation:**

I. Rd[31:16] ← Rd[31:16] ∧ imm16;
II. Rd[31:16] ← Rd[31:16] ∧ imm16;
Rd[15:0] ← 0;
III. Rd[15:0] ← Rd[15:0] ∧ imm16;
IV. Rd[15:0] ← Rd[15:0] ∧ imm16;
Rd[31:16] ← 0;

**Syntax:**

I. andh Rd, imm
II. andh Rd, imm, COH
III. andl Rd, imm
IV. andl Rd, imm, COH

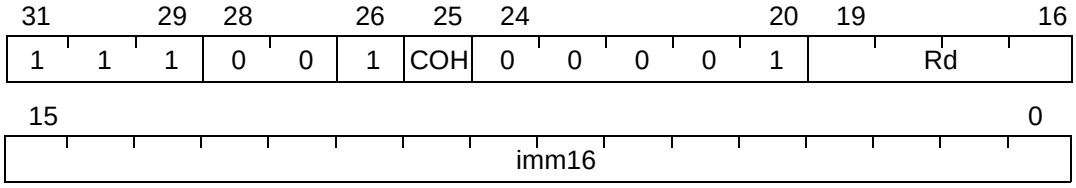
**Operands:**
I, II, III, IV.
d ∈ {0, 1, …, 15}
imm ∈ {0, 1, ..., 65535}

**Status Flags:**

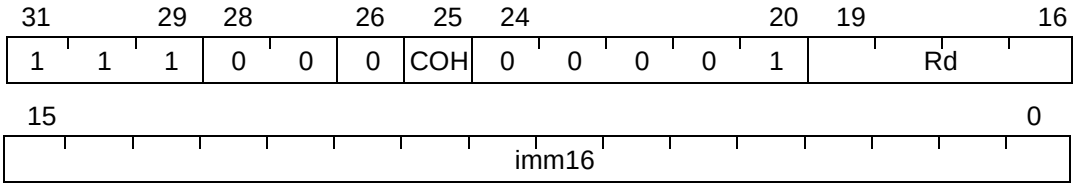
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode**

**Format I, II:**



**Format III, IV:**



## ANDN – Logical AND NOT

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical ANDNOT between the specified registers and stores the result in the destination register.

**Operation:**
I. Rd ← Rd ∧ ¬Rs;

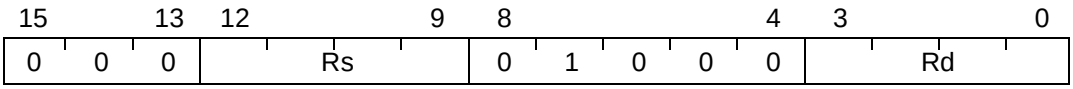
**Syntax:**
I. andn Rd, Rs

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | N ← RES[31] |
| **Z:** | Z ← (RES[31:0] == 0) |
| **C:** | Not affected |

**Opcode(s):**



## ASR – Arithmetic Shift Right

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Shifts all bits in a register to the right the amount of bits specified by the five least significant bits in Ry or an immediate while keeping the sign.

**Operation:**

I. Rd ← ASR(Rx, Ry[4:0]);
II. Rd ← ASR(Rd, sa5);
III. Rd ← ASR(Rs, sa5);

**Syntax:**

I. asr Rd, Rx, Ry
II. asr Rd, sa
III. asr Rd, Rs, sa

**Operands:**

I. d, x, y ∈ {0, 1, …, 15}
II. d ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}
III. {d,s} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

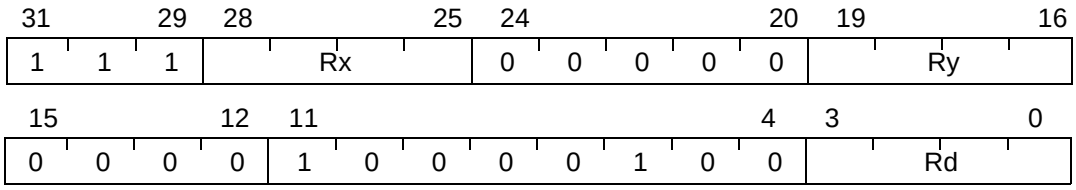
**Status Flags:**

**Format I: Shamt = Ry[4:0], Op = Rx**
**Format II: Shamt = sa5, Op = Rd**
**Format III: Shamt = sa5, Op = Rs**

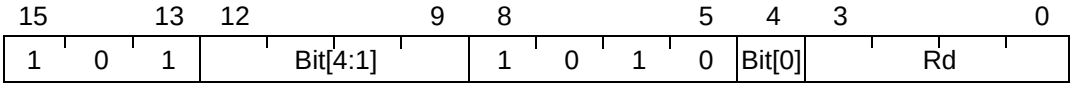
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:**
```
if (Shamt != 0) then
        C ← Op[Shamt-1]
else
        C ← 0
```

**Opcode**

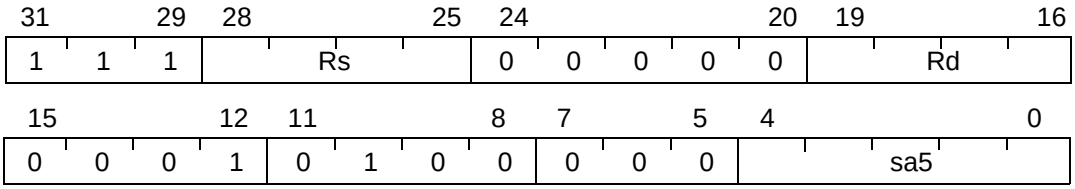
**Format I:**




**Format II:**




**Format III:**



## BFEXTS – Bitfield extract and sign-extend

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction extracts and sign-extends the w5 bits in Rs starting at bit-offset bp5 to Rd.

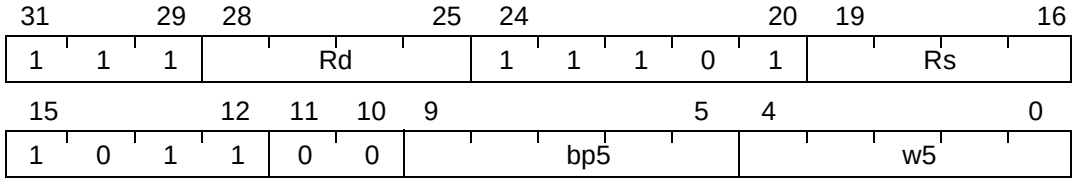
**Operation:**
I. Rd ← SE(Rs[bp5+w5-1:bp5]);

**Syntax:**
I. bfexts Rd, Rs, bp5, w5

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}
{bp5, w5} ∈ {0, 1, ..., 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← RES[31]

**Opcode:**
**Format I:**




**Note:**
If (w5 = 0) or if (bp5 + w5 > 32) the result is undefined.

## BFEXTU – Bitfield extract and zero-extend

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction extracts and zero-extends the w5 bits in Rs starting at bit-offset bp5 to Rd.

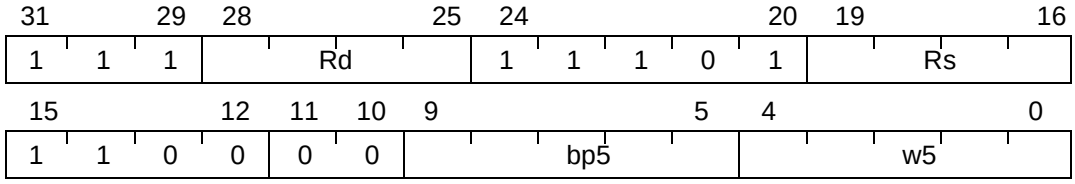
**Operation:**
I. Rd ← ZE(Rs[bp5+w5-1:bp5]);

**Syntax:**
I. bfextu Rd, Rs, bp5, w5

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}
{bp5, w5} ∈ {0, 1, ..., 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← RES[31]

**Opcode:**
**Format I:**




**Note:**
If (w5 = 0) or if (bp5 + w5 > 32) the result is undefined.

## BFINS – Bitfield insert

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction inserts the lower w5 bits of Rs in Rd at bit-offset bp5.

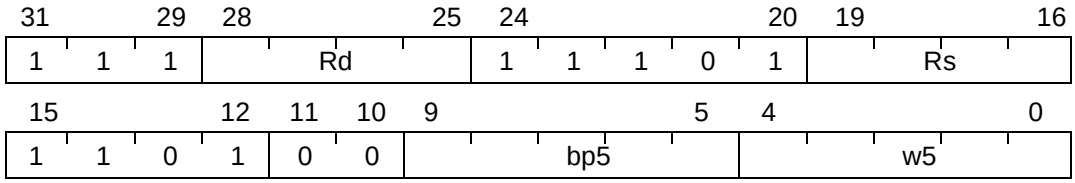
**Operation:**
I. Rd[bp5+w5-1:bp5] ← Rs[w5-1:0];

**Syntax:**
I. bfins Rd, Rs, bp5, w5

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}
{bp5, w5} ∈ {0, 1, ..., 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← RES[31]

**Opcode:**
**Format I:**




**Note:**
If (w5 = 0) or if (bp5 + w5 > 32) the result is undefined.

## BLD – Bit load from register to C and Z

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Copy an arbitrary bit in a register to C and Z.

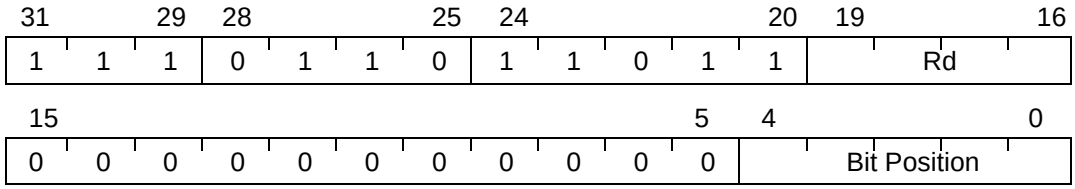
**Operation:**
I. C ← Rd[bp5];
Z ← Rd[bp5];

**Syntax:**
I. bld Rd, bp

**Operands:**
I. d ∈{0, 1, …, 15}
bp ∈ {0, 1, …, 31}

**Status Flags**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Z ← Rd[bp5]
**C:** C ← Rd[bp5]

**Opcode:**



## BR{cond} – Branch if Condition Satisfied

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Branch if the specified condition is satisfied.

**Operation:**

I.
```
if (cond3)
        PC ← PC + (SE(disp8) << 1);
else
        PC ← PC + 2;
```

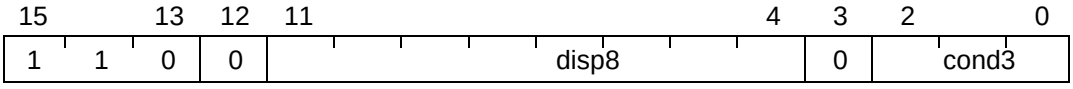
II.
```
if (cond4)
        PC ← PC + (SE(disp21) << 1);
else
        PC ← PC + 4;
```

**Syntax:**
I. br{cond3}disp
II. br{cond4}disp

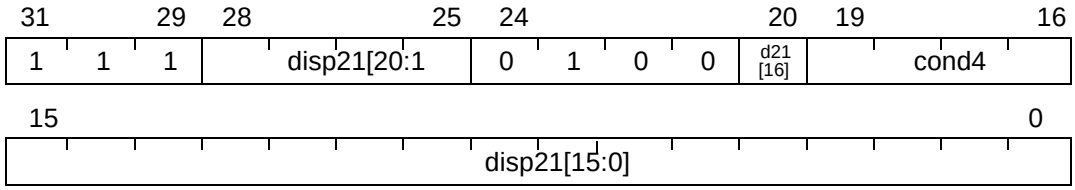
**Operands:**
I. cond3 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl}
disp ∈ {-256, -254, ..., 254}
II. cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
disp ∈ {-2097152, -2097150, ..., 2097150}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**
**Format I:**



**Format II:**


31
29
28
25
24
20
19
16
1
1
1
disp21[20:1
0
1
0
0
d21
[16]
cond4
15
0
disp21[15:0]

## BREAKPOINT – Software Debug Breakpoint

**Architecture revision:**
Architecture revision1 and higher.

**Description**
If the on chip debug system is enabled, this instruction traps a software breakpoint for debugging. The breakpoint instruction will enter debug mode disabling all interrupts and exceptions. If the on chip debug system is not enabled, this instruction will execute as a *nop*.

**Operation:**

```
I.      if (SR[DM]==0)
            RSR_DBG ← SR;
            RAR_DBG ← address of first non-completed instruction;
            SR[R] ← 1;
            SR[J] ← 1;
            SR[D] ← 1;
            SR[M2:M0] ← B'110;
            SR[DM] ← 1;
            SR[EM] ← 1;
            SR[GM] ← 1;
            PC ← EVBA+0x1C;
        else
            PC ← PC + 2;
```

**Syntax:**

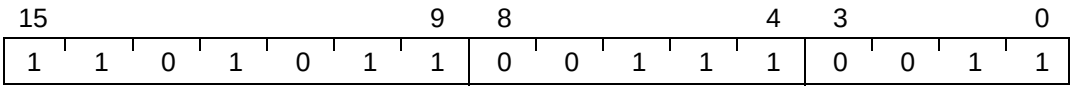
```
I.      breakpoint
```

**Operands:**
None

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
If no on chip debug system is implemented, this instruction will execute as a "NOP".

## BREV – Bit Reverse

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Bit-reverse the contents in the register.

**Operation:**
I. Rd[31:0] ← Rd[0:31];

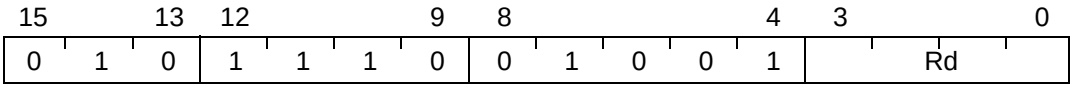
**Syntax:**
I. brev Rd

**Operands:**
I. d ∈{0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected.

**Opcode:**



## BST – Copy C to register bit

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Copy the C-flag to an arbitrary bit in a register.

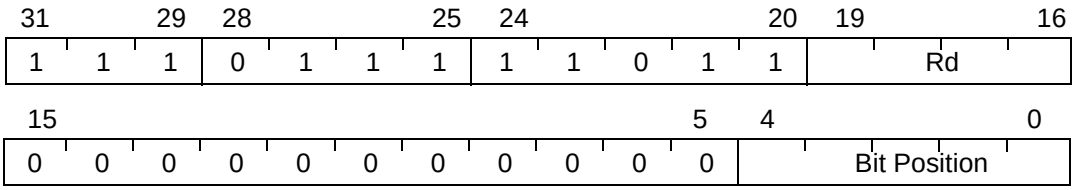
**Operation:**
I. Rd[bp5] ← C;

**Syntax:**
I. bst Rd, bp

**Operands:**
I. d ∈ {0, 1, …, 15}
bp ∈ {0, 1, …, 31}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## CACHE – Perform Cache control operation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Control cache operation.

**Operation:**
I. Issue a command to the cache

**Syntax:**
I. cache Rp[disp], Op5

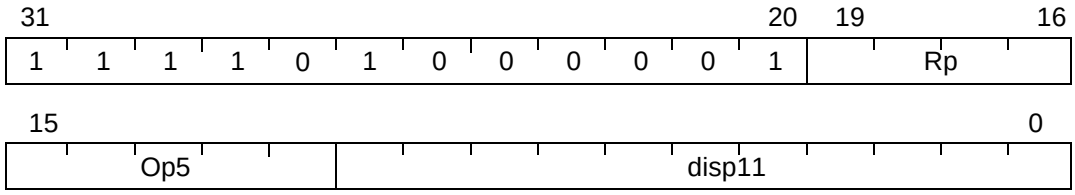
**Operands:**
I. disp ∈ {-1024, -1023, ..., 1023}
p ∈ {0, 1, …, 15}

| Op[4:3] | Semantic |
|---|---|
| 00 | Instruction Cache |
| 01 | Data Cache or unified cache |
| 10 | Secondary Cache |
| 11 | Tertiary Cache |

| Op[2:0] | Semantic |
|---|---|
| 000 | Implementation definedk |
| 001 | Implementation defined |
| 010 | Implementation defined |
| 011 | Implementation defined |
| 100 | Implementation defined |
| 101 | Implementation defined |
| 110 | Implementation defined |
| 111 | Implementation defined |

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**

This instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception.

## CASTS.{H,B} – Typecast to Signed Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sign extends the halfword or byte that is specified to word size. The result is stored back to the specified register.

**Operation:**
I. Rd[31:16] ← Rd[15];
II. Rd[31:8] ← Rd[7];

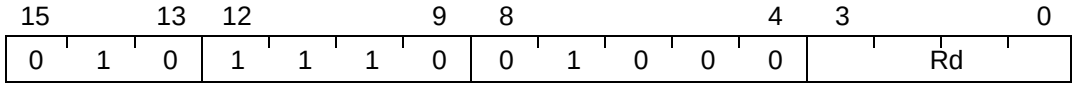
**Syntax:**
I. casts.h Rd
II. casts.b Rd

**Operands:**
I, II. d ∈ {0, 1, …, 15}

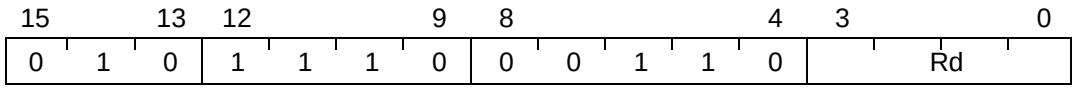
**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← RES[31]

**Opcode:**

**Format I:**




**Format II:**



## CASTU.{H,B} – Typecast to Unsigned Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Zero extends the halfword or byte that is specified to word size. The result is stored back to the specified register.

**Operation:**
I. Rd[31:16] ← 0;
II. Rd[31:8] ← 0:

**Syntax:**
I. castu.h Rd
II. castu.b Rd

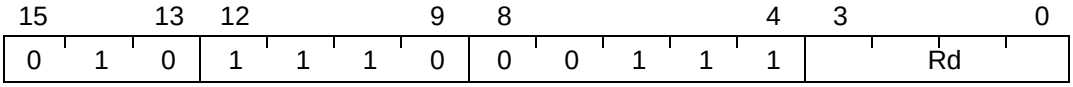
**Operands:**
I, II. d ∈ {0, 1, …, 15}

**Status Flags:**

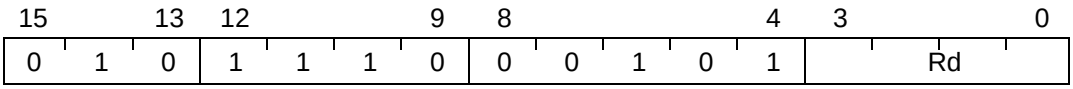
| | |
|---|---|
| **Q:** | Not affected. |
| **V:** | Not affected. |
| **N:** | N ← RES[31] |
| **Z:** | Z ← (RES[31:0] == 0) |
| **C:** | C ← RES[31] |

**Opcode:**

**Format I:**




**Format II:**



## CBR – Clear Bit in Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Clears a bit in the specified register. All other bits are unaffected.

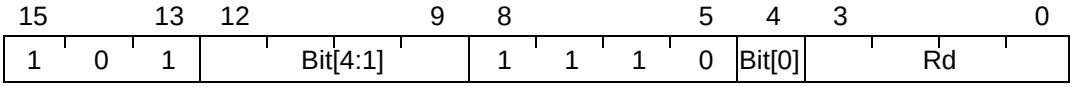
**Operation:**
I. Rd[bp5] ← 0;

**Syntax:**
I. cbr Rd, bp

**Operands:**
I. d ∈ {0, 1, …, 15}
bp ∈ {0, 1, …, 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode:**



## CLZ – Count Leading Zeros

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Counts the number of binary zero bits before the first binary one bit in a register value. The value returned from the operation can be used for doing normalize operations. If the operand is zero, the value 32 is returned.

**Operation:**

```
I.      temp ← 32;
        for (i = 31; i >= 0; i--)
                if (Rs[i] == 1) then
                        temp ← 31 - i;
                        break;
        Rd ← temp;
```

**Syntax:**

```
I.      clz     Rd, Rs
```

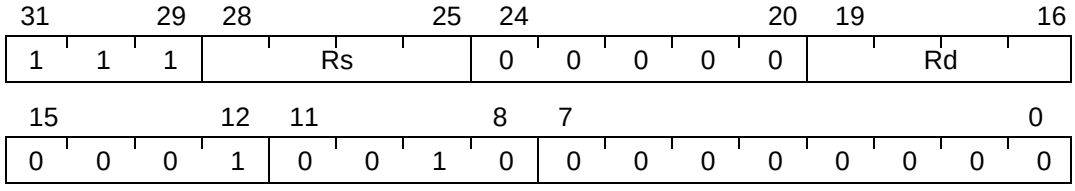
**Operands:**

I. {d, s} ∈ {0, 1, …, 15}

**Status Flags**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← (RES[31:0] == 32)

**Opcode:**



## COM – One's Compliment

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a one's complement of specified register.

**Operation:**
I. Rd ← ¬Rd;

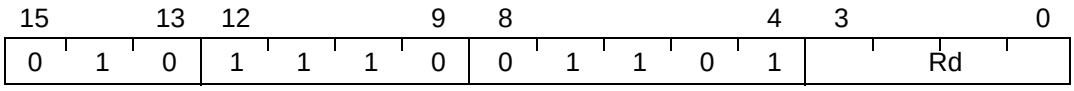
**Syntax:**
I. com Rd

**Operands:**
I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode:**



## COP – Coprocessor Operation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Addresses a coprocessor and performs the specified operation on the specified registers.

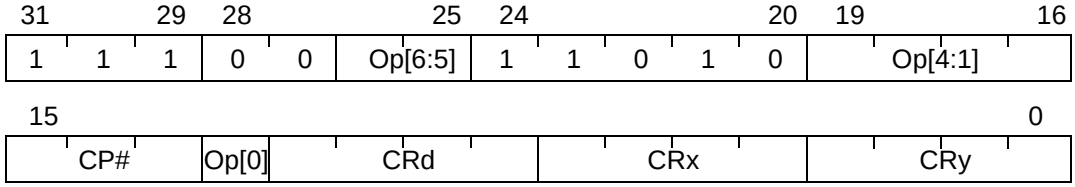
**Operation:**
I. CP#(CRd) ← CP#(CRx) Op CP#(CRy);

**Syntax:**
I. cop CP#, CRd, CRx, CRy, Op

**Operands:**
I. # ∈ {0, 1, …, 7}
Op ∈ {0, 1, …, 127}
{d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**
**Q:** Coprocessor-specific
**V:** Coprocessor-specific
**N:** Coprocessor-specific
**Z:** Coprocessor-specific
**C:** Coprocessor-specific

**Opcode:**




**Example:**
cop CP2, CR0, CR1, CR2, 0

## CP.B – Compare Byte

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a compare between the lowermost bytes in the two operands specified. The operation is implemented by doing a subtraction without writeback of the difference. The operation sets the status flags according to the result of the subtraction, but does not affect the operand registers.

**Operation:**
I. Rd[7:0] - Rs[7:0];

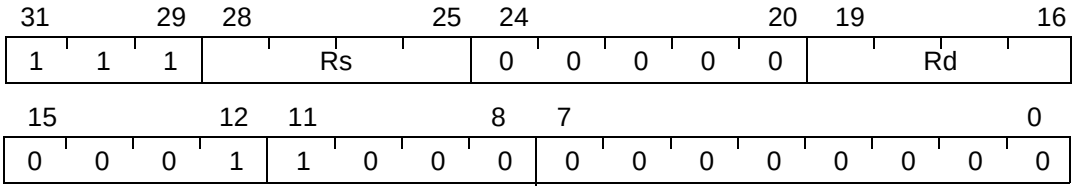
**Syntax:**
I. cp.b Rd, Rs

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** V ← (Rd[7] ∧ ¬Rs[7] ∧ ¬RES[7]) ∨ (¬Rd[7] ∧ Rs[7] ∧ RES[7])
**N:** N ← RES[7]
**Z:** Z ← (RES[7:0] == 0)
**C:** C ← ¬Rd[7] ∧ Rs[7] ∨ Rs[7] ∧ RES[7] ∨ ¬Rd[7] ∧ RES[7]

**Opcode**



## CP.H – Compare Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a compare between the lowermost halfwords in the two operands specified. The operation is implemented by doing a subtraction without writeback of the difference. The operation sets the status flags according to the result of the subtraction, but does not affect the operand registers.

**Operation:**
I. Rd[15:0] - Rs[15:0];

**Syntax:**
I. cp.h Rd, Rs

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}

**Status Flags:**

**Format I: OP1 = Rd, OP2 = Rs**

**Q:** Not affected

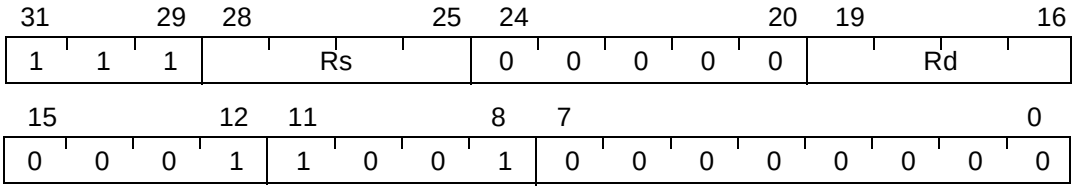
**V:** V ← (OP1[15] ∧ ¬OP2[15] ∧ ¬RES[15]) ∨ (¬OP1[15] ∧ OP2[15] ∧ RES[15])

**N:** N ← RES[15]

**Z:** Z ← (RES[15:0] == 0)

**C:** C ← ¬OP1[15] ∧ OP2[15] ∨ OP2[15] ∧ RES[15] ∨ ¬OP1[15] ∧ RES[15]

**Opcode**



## CP.W – Compare Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a compare between the two operands specified. The operation is implemented by doing a subtraction without writeback of the difference. The operation sets the status flags according to the result of the subtraction, but does not affect the operand registers.

**Operation:**
I. Rd - Rs;
II. Rd - SE(imm6);
III. Rd - SE(imm21);

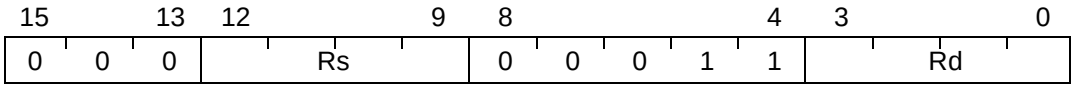
**Syntax:**
I. cp.w Rd, Rs
II. cp.w Rd, imm
III. cp.w Rd, imm

**Operands:**
I. {d, s} ∈ {0, 1, …, 15}
II. d ∈ {0, 1, …, 15}
imm ∈ {-32, -31, ..., 31}
III. d ∈ {0, 1, …, 15}
imm ∈ {-1048576, -104875, ..., 1048575}

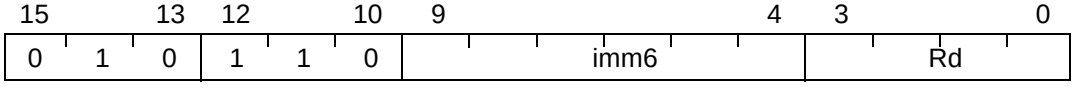
**Status Flags:**
**Format I: OP1 = Rd, OP2 = Rs**
**Format II: OP1 = Rd, OP2 = SE(imm6)**
**Format III:OP1 = Rd, OP2 = SE(imm21)**
**Q:** Not affected
**V:** V ← (OP1[31] ∧ ¬OP2[31] ∧ ¬RES[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← ¬OP1[31] ∧ OP2[31] ∨ OP2[31] ∧ RES[31] ∨ ¬OP1[31] ∧ RES[31]

**Opcode**

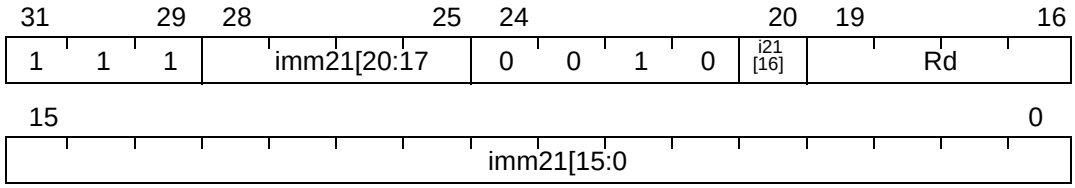
**Format I:**




**Format II:**



**Format III:**


31
29
28
25
24
20
19
16
1
1
1
imm21[20:17
0
0
1
0
i21
[16]
Rd
15
0
imm21[15:0

## CPC – Compare with Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a compare between the two registers specified. The operation is executed by doing a subtraction with carry (as borrow) without writeback of the difference. The operation sets the status flags according to the result of the subtraction, but does not affect the operand registers. Note that the zero flag status before the operation is included in the calculation of the new zero flag. This instruction allows large compares (64, 128 or more bits).

**Operation:**
I. Rd - Rs - C;
II. Rd - C;

**Syntax:**
I. cpc Rd, Rs
II. cpc Rd

**Operands:**
I. $\{d, s\} \in \{0, 1, \ldots, 15\}$
II. $d \in \{0, 1, \ldots, 15\}$

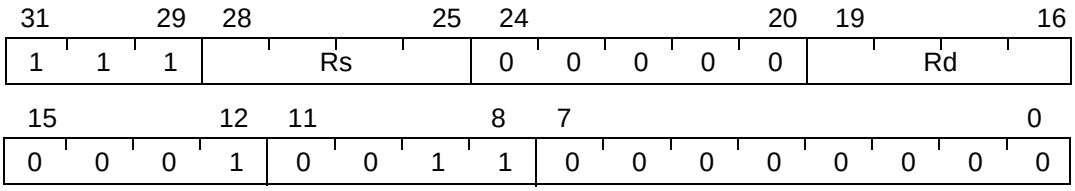
**Status Flags:**

**In format II, Rs referred to below equals zero.**

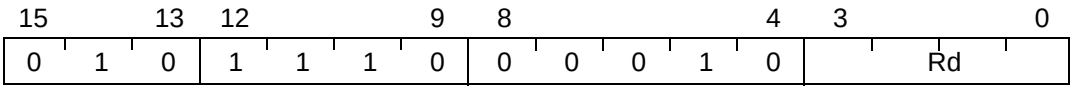
**Q:** Not affected
**V:** $V \leftarrow (Rd[31] \wedge \neg Rs[31] \wedge \neg RES[31]) \vee (\neg Rd[31] \wedge Rs[31] \wedge RES[31])$
**N:** $N \leftarrow RES[31]$
**Z:** $Z \leftarrow (RES[31:0] == 0) \wedge Z$
**C:** $C \leftarrow \neg Rd[31] \wedge Rs[31] \vee Rs[31] \wedge RES[31] \vee \neg Rd[31] \wedge RES[31]$

**Opcode:**

**Format I:**




**Format II:**



## CSRF – Clear Status Register Flag

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Clears the status register (SR) flag specified.

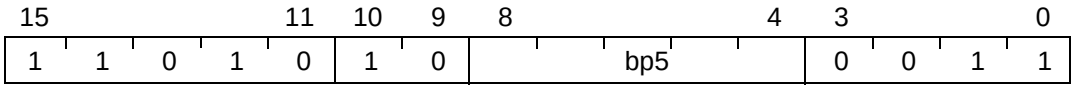
**Operation:**
I. SR[bp5] ← 0;

**Syntax:**
I. csrf bp

**Operands:**
I. bp ∈ {0, 1, …, 31}

**Status Flags:**
**SR[bp5] ← 0, all other flags unchanged.**

**Opcode:**




**Note:**
Privileged if bp5 > 15, ie. upper half of status register. An exception will be triggered if the upper half of the status register is attempted changed in user mode.

## CSRFCZ – Copy Status Register Flag to C and Z

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Copies the status register (SR) flag specified to C and Z.

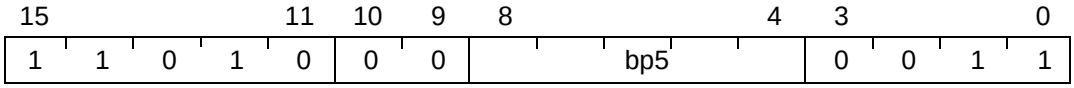
**Operation:**
I. C ← SR[bp5];
Z ← SR[bp5];

**Syntax:**
I. csrfcz bp

**Operands:**
I. bp ∈ {0, 1, …, 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Z ← SR[bp5]
**C:** C ← SR[bp5]

**Opcode:**




**Note:**
Privileged if bp5 > 15, ie. upper half of status register. A Privilege Violation exception will be triggered if the upper half of the status register is attempted read in user mode.

## DIVS – Signed divide

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a signed divide between the two 32-bit register specified. The quotient is returned in Rd, the remainder in Rd+1. No exceptions are taken if dividing by 0. Result in Rd and Rd+1 is UNDEFINED when dividing by 0. The sign of the remainder will be the same as the dividend, and the quotient will be negative if the signs of Rx and Ry are opposite.

**Operation:**
I. Rd ← Rx / Ry;
Rd+1 ← Rx % Ry;

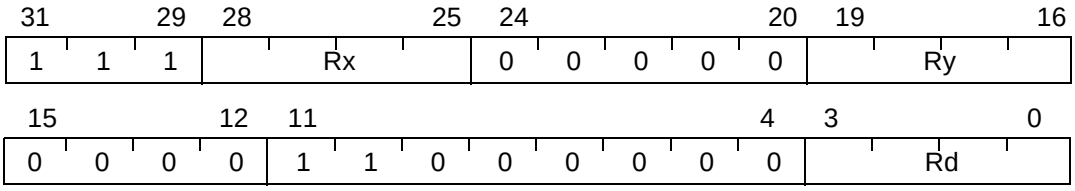
**Syntax:**
I. divs Rd, Rx, Ry

**Operands:**
I. d ∈ {0, 2, …, 14}
{x, y} ∈ {0, 1, …, 15}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**



## DIVU – Unsigned divide

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs an unsigned divide between the two 32-bit register specified. The quotient is returned in Rd, the remainder in Rd+1. No exceptions are taken if dividing by 0. Result in Rd and Rd+1 is UNDEFINED when dividing by 0.

**Operation:**

I. Rd ← Rx / Ry;
Rd+1 ← Rx % Ry;

**Syntax:**

I. divu Rd, Rx, Ry

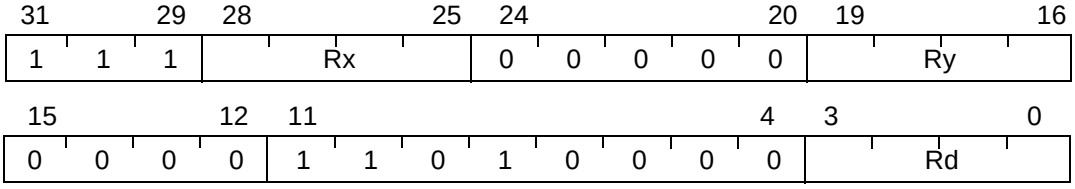
**Operands:**

I. d ∈ {0, 2, …, 14}
{x, y} ∈ {0, 1, …, 15}

**Status Flags**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## EOR – Logical Exclusive OR with optional logical shift

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical Exclusive-OR between the specified registers and stores the result in the destination register.

**Operation:**

I. Rd ← Rd ⊕ Rs;
II. Rd ← Rx ⊕ (Ry << sa5);
III. Rd ← Rx ⊕ (Ry >> sa5);

**Syntax:**

| | | |
|---|---|---|
| I. | eor | Rd, Rs |
| II. | eor | Rd, Rx, Ry << sa |
| III. | eor | Rd, Rx, Ry >> sa |

**Operands:**

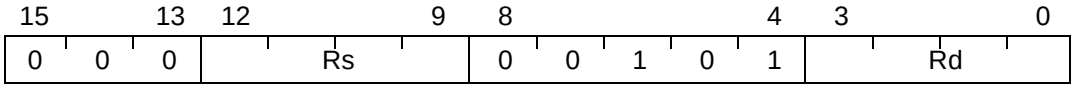
I. {d, s} ∈ {0, 1, …, 15}
II, III. {d, x, y} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

**Status Flags**

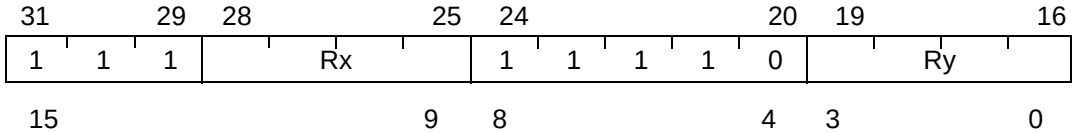
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

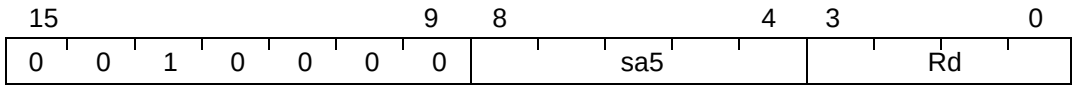
**Opcode:**

**Format I:**

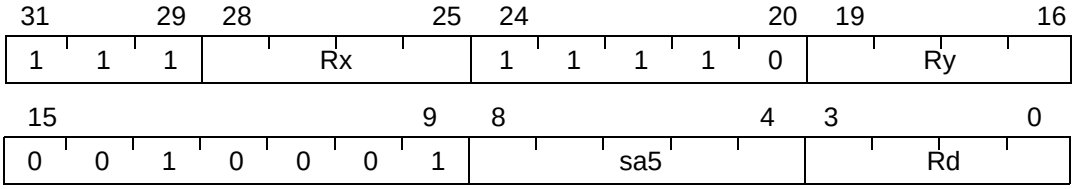



**Format II:**



**Format III:**



## EOR{cond4} – Conditional Logical EOR

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Performs a bitwise logical Exclusive-OR between the specified registers and stores the result in the destination register.

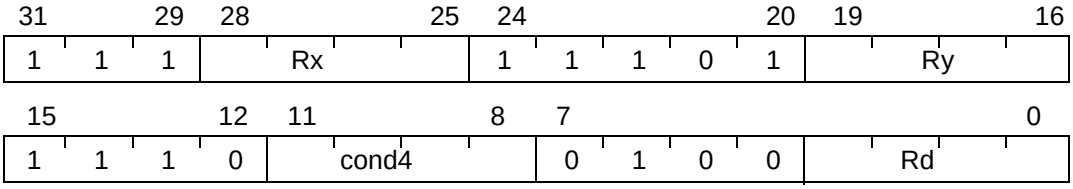
**Operation:**
I. if ( cond4)
Rd ← Rx ⊕ Ry;

**Syntax:**
I. eor{cond4} Rd, Rx, Ry

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## EORH, EORL – Logical EOR into high or low half of register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical Exclusive-OR between the high or low halfword in the specified register and a constant. The result is stored in the destination register.

**Operation:**

I. Rd[31:16] ← Rd[31:16] ⊕ imm16
II. Rd[15:0] ← Rd[15:0] ⊕ imm16

**Syntax:**

I. eorh Rd, imm
II. eorl Rd, imm

**Operands:**

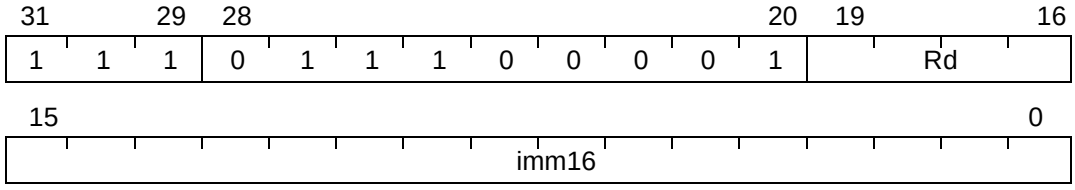
I, II. d ∈ {0, 1, …, 15}
imm ∈ {0, 1, ..., 65535}

**Status Flags:**

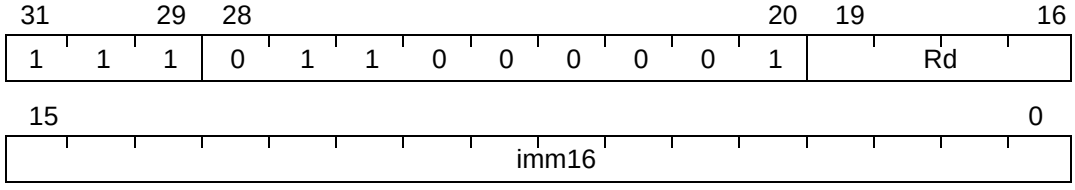
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode**

**Format I:**




**Format II:**



## FRS – Flush Return Stack

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Special instruction to invalidate the return address stack. This instruction is used when the user writes code that conflicts with the semantics required by the return address stack.

**Operation:**
I. Invalidate all entries in the return address stack.

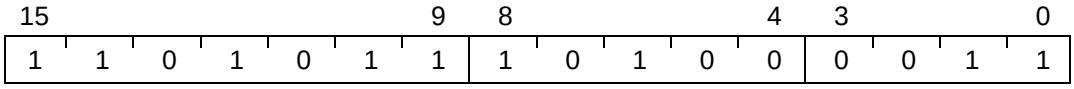
**Syntax:**
I. frs

**Operands:**
I. none

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**




**Note:**
On implementation without a return stack this instruction will execute as a "NOP".

## ICALL – Indirect Call to Subroutine

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Call to a subroutine pointed to by the pointer residing in Rp.

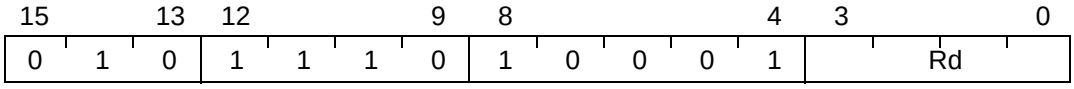
**Operation:**
I. LR ← PC + 2;
PC ← Rd;

**Syntax:**
I. icall Rd

**Operands:**
I. d ∈ {0, 1, …, 15}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## INCJOSP – Increment Java Operand Stack Pointer

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Increment the system register "Java Operand Stack Pointer" with value.

**Operation:**

```
I.      if ( JOSP[3:0] + imm < 0 )
            TRAP 4
        else if (JOSP[3:0] + imm > 8 )
            TRAP 3
        else
            JOSP ← JOSP + imm;
```

| imm3 | imm |
|---|---|
| 100 | -4 |
| 101 | -3 |
| 110 | -2 |
| 111 | -1 |
| 000 | 1 |
| 001 | 2 |
| 010 | 3 |
| 011 | 4 |

**Syntax:**
I. incjosp imm

**Operands:**
I. imm ∈ {-4, -3, -2, -1, 1, 2, 3, 4}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | imm3 | | | 0 | 0 | 1 | 1 |

**Note:**
When trapped, this instruction will destroy R12. It is the programmer's responsibility to keep the R12value if needed.

## LD.D – Load Doubleword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the doubleword memory location specified.

**Operation:**

I. Rd+1:Rd ← *(Rp);
   Rp ← Rp + 8;
II. Rp ← Rp - 8;
   Rd+1:Rd ← *(Rp);
III. Rd+1:Rd ← *(Rp);
IV. Rd+1:Rd ← *(Rp + (SE(disp16)));
V. Rd+1:Rd ← *(Rb + (Ri << sa2));

**Syntax:**

| | | |
|---|---|---|
| I. | ld.d | Rd, Rp++ |
| II. | ld.d | Rd, --Rp |
| III. | ld.d | Rd, Rp |
| IV. | ld.d | Rd, Rp[disp] |
| V. | ld.d | Rd, Rb[Ri<<sa] |

**Operands:**

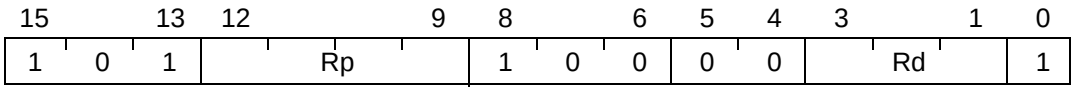
I-V. d ∈ {0, 2, 4, …, 14}
   p, b, i ∈ {0, 1, …, 15}
IV. disp ∈ {-32768, -32767, ..., 32767}
V. sa ∈ {0, 1, 2, 3}

**Status Flags:**

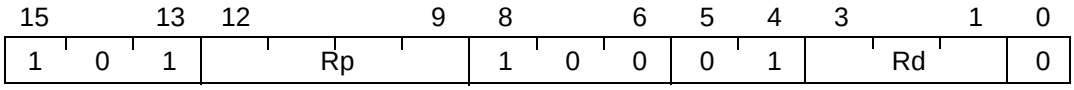
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

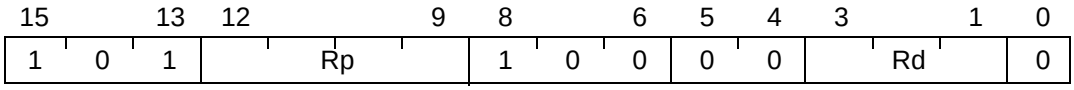
**Format I:**



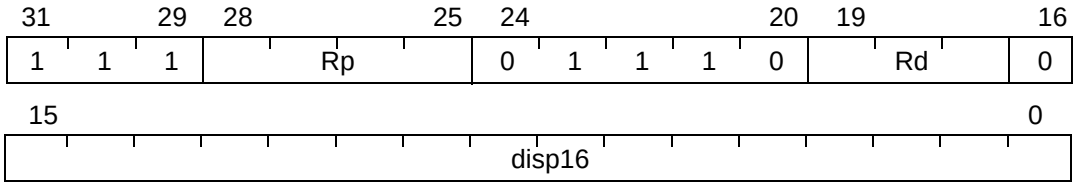
**Format II:**



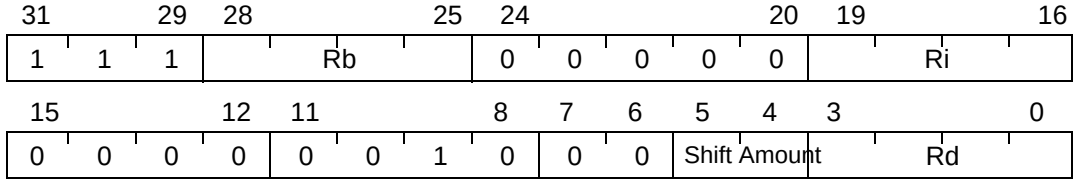

**Format III:**




**Format IV:**




**Format V:**




**Note:**

Format I and II: If Rd = Rp, the result is UNDEFINED.
If Rd = Rp+1, the result is UNDEFINED.

## LD.SB – Load Sign-extended Byte

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the byte memory location specified and sign-extends it.

**Operation:**
I. Rd ← SE( *(Rp + (SE(disp16))) );
II. Rd ← SE( *(Rb + (Ri << sa2)) );

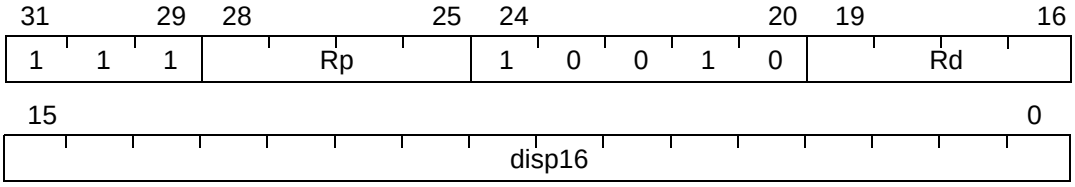
**Syntax:**
I. ld.sb Rd, Rp[disp]
II. ld.sb Rd, Rb[Ri<<sa]

**Operands:**
I. d, p ∈ {0, 1, …, 15}
disp ∈ {-32768, -32767, ..., 32767}
II. d, b, i ∈ {0, 1, …, 15}
sa ∈ {0, 1, 2, 3}

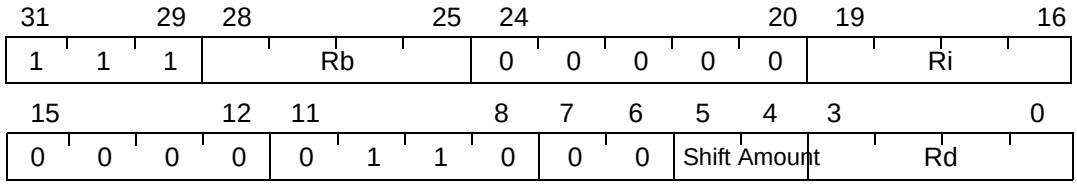
**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## LD.SB{cond4} – Conditionally Load Sign-extended Byte

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Reads the byte memory location specified and sign-extends it if the given condition is satisfied.

**Operation:**
I. if (cond4)
Rd ← SE( *(Rp + (ZE(disp9))) );

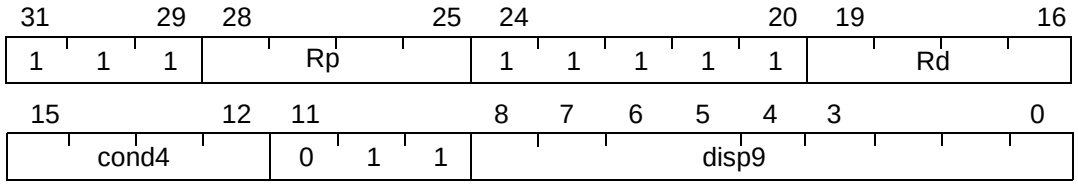
**Syntax:**
I. ld.sb{cond4} Rd, Rp[disp]

**Operands:**
I. d, p ∈ {0, 1, …, 15}
disp ∈ {0, 1, ..., 511}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected. |
| **V:** | Not affected. |
| **N:** | Not affected. |
| **Z:** | Not affected. |
| **C:** | Not affected. |

**Opcode:**



## LD.UB – Load Zero-extended Byte

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the byte memory location specified and zero-extends it.

**Operation:**

I. Rd ← ZE( *(Rp) );
   Rp ← Rp + 1;
II. Rp ← Rp - 1;
   Rd ← ZE( *(Rp) );
III. Rd ← ZE( *(Rp + (ZE(disp3))) );
IV. Rd ← ZE( *(Rp + (SE(disp16))) );
V. Rd ← ZE( *(Rb + (Ri << sa2)) );

**Syntax:**

| | | |
|---|---|---|
| I. | ld.ub | Rd, Rp++ |
| II. | ld.ub | Rd, --Rp |
| III. | ld.ub | Rd, Rp[disp] |
| IV. | ld.ub | Rd, Rp[disp] |
| V. | ld.ub | Rd, Rb[Ri<<sa] |

**Operands:**

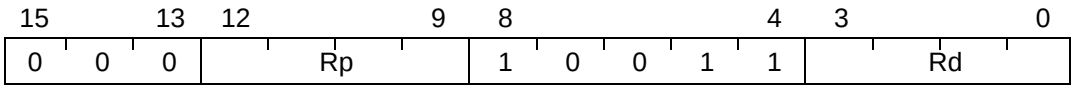
I-V. d, p, b, i ∈ {0, 1, …, 15}
III. disp ∈ {0, 1, ..., 7}
IV. disp ∈ {-32768, -32767, ..., 32767}
V. sa ∈ {0, 1, 2, 3}

**Status Flags:**

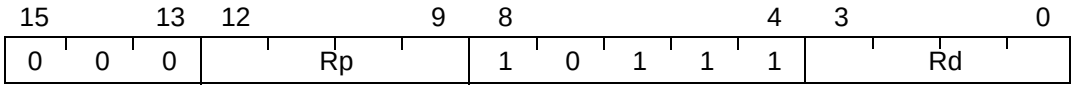
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

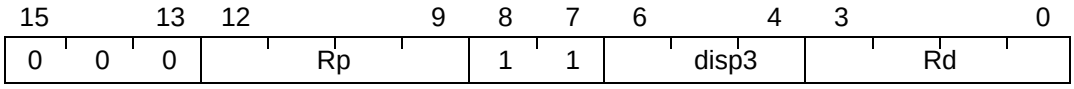
**Format I:**



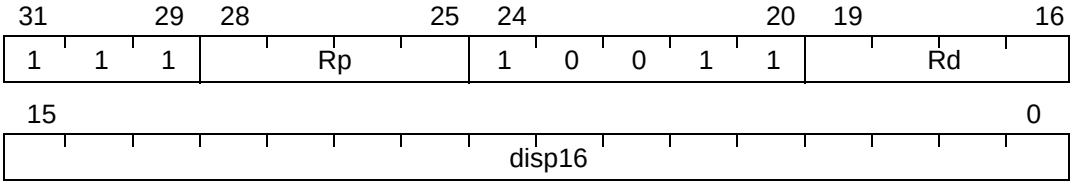
**Format II:**



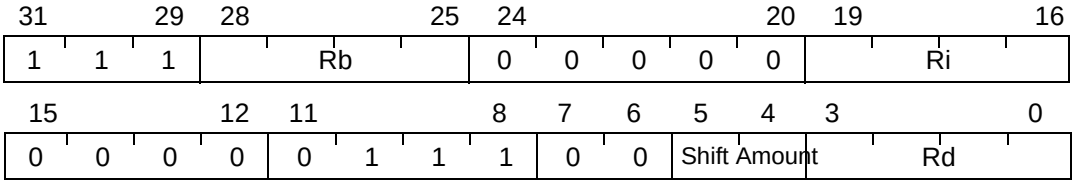

**Format III:**




**Format IV:**




**Format V:**




**Note:**
Format I and II: If Rd = Rp, the result is UNDEFINED.

## LD.UB{cond4} – Conditionally Load Zero-extended Byte

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Reads the byte memory location specified and zero-extends it if the given condition is satisfied.

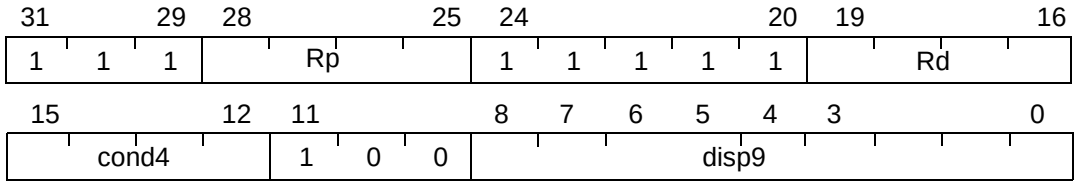
**Operation:**
I. if (cond4)
Rd ← ZE( *(Rp + (ZE(disp9))) );

**Syntax:**
I. ld.ub{cond4} Rd, Rp[disp]

**Operands:**
I. d, p ∈ {0, 1, …, 15}
disp ∈ {0, 1, ..., 511}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LD.SH – Load Sign-extended Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the halfword memory location specified and sign-extends it.

**Operation:**

I. Rd ← SE( *(Rp) );
   Rp ← Rp + 2;
II. Rp ← Rp - 2;
   Rd ← SE( *(Rp) );
III. Rd ← SE( *(Rp + (ZE(disp3) << 1)) );
IV. Rd ← SE( *(Rp + (SE(disp16)));
V. Rd ← SE( *(Rb + (Ri << sa2));

**Syntax:**

| | | |
|---|---|---|
| I. | ld.sh | Rd, Rp++ |
| II. | ld.sh | Rd, --Rp |
| III. | ld.sh | Rd, Rp[disp] |
| IV. | ld.sh | Rd, Rp[disp] |
| V. | ld.sh | Rd, Rb[Ri<<sa] |

**Operands:**

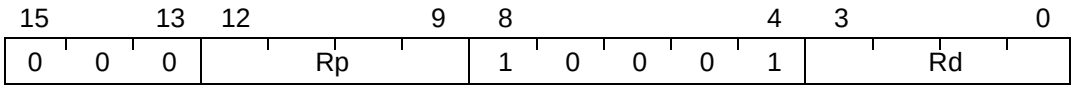
I-V. d, p, b, i ∈ {0, 1, …, 15}
III. disp ∈ {0, 2, ..., 14}
IV. disp ∈ {-32768, -32767, ..., 32767}
V. sa ∈ {0, 1, 2, 3}

**Status Flags:**

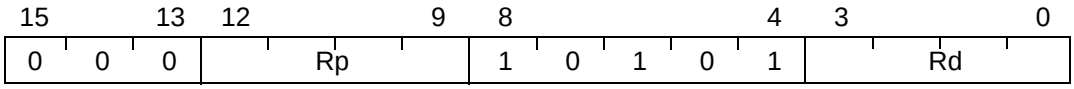
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

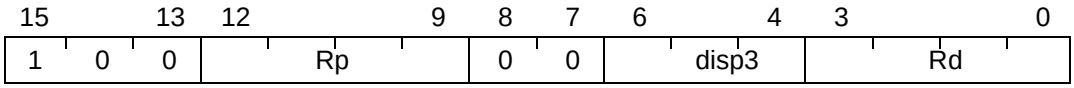
**Format I:**



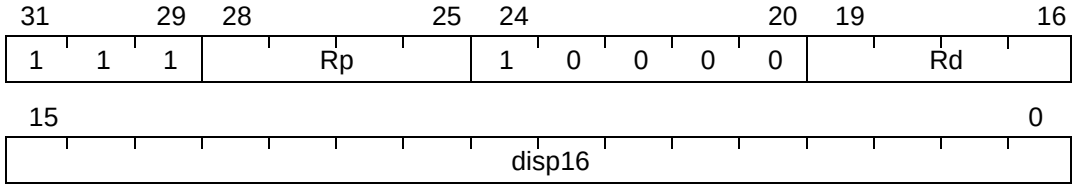
**Format II:**



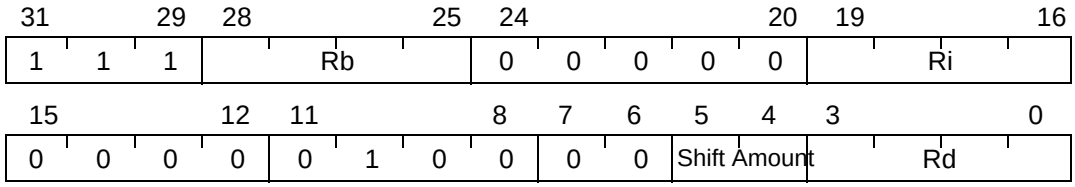

**Format III:**




**Format IV:**




**Format V:**




**Note:**
Format I and II: If Rd = Rp, the result is UNDEFINED.

## LD.SH{cond4} – Conditionally Load Sign-extended Halfword

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Reads the halfword memory location specified and sign-extends it if the given condition is satisfied.

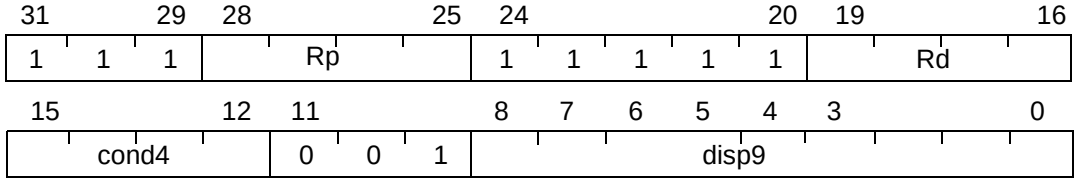
**Operation:**
I. if (cond4)
Rd ← SE( *(Rp + (ZE(disp9<<1))) );

**Syntax:**
I. ld.sh{cond4} Rd, Rp[disp]

**Operands:**
I. d, p ∈ {0, 1, …, 15}
disp ∈ {0, 2, ..., 1022}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LD.UH – Load Zero-extended Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the halfword memory location specified and zero-extends it.

**Operation:**

I. Rd ← ZE( *(Rp) );
   Rp ← Rp + 2;
II. Rp ← Rp - 2;
   Rd ← ZE( *(Rp) );
III. Rd ← ZE( *(Rp + (ZE(disp3) << 1)) );
IV. Rd ← ZE( *(Rp + (SE(disp16))) );
V. Rd ← ZE( *(Rb + (Ri << sa2)) );

**Syntax:**

| | | |
|---|---|---|
| I. | ld.uh | Rd, Rp++ |
| II. | ld.uh | Rd, --Rp |
| III. | ld.uh | Rd, Rp[disp] |
| IV. | ld.uh | Rd, Rp[disp] |
| V. | ld.uh | Rd, Rb[Ri<<sa] |

**Operands:**

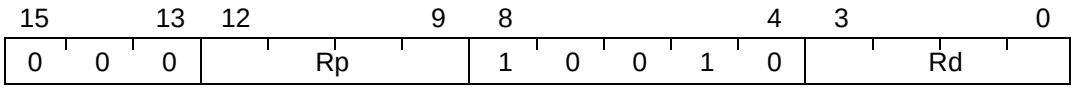
I-V. d, p, b, i ∈ {0, 1, …, 15}
III. disp ∈ {0, 2, ..., 14}
IV. disp ∈ {-32768, -32767, ..., 32767}
V. sa ∈ {0, 1, 2, 3}

**Status Flags:**

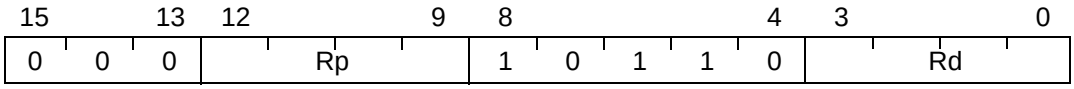
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

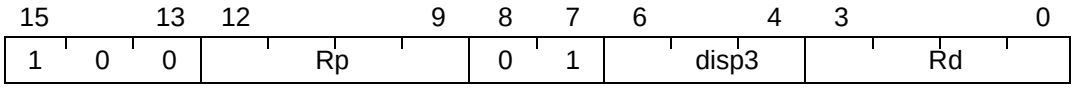
**Format I:**



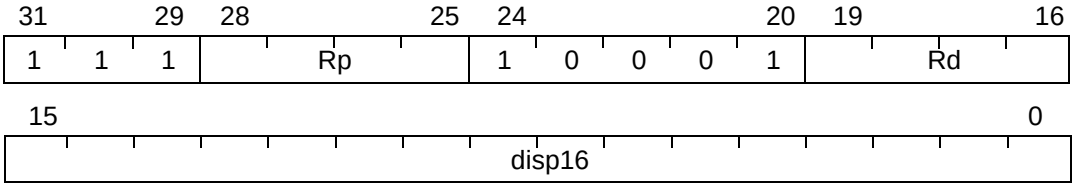
**Format II:**



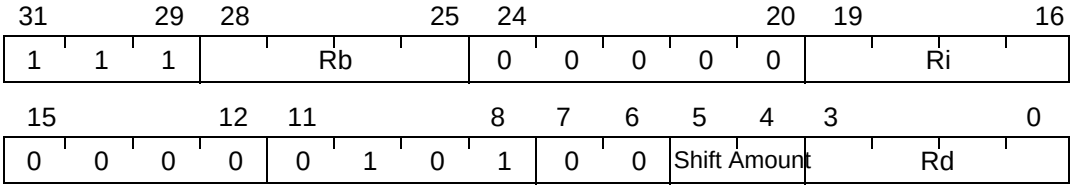

**Format III:**




**Format IV:**




**Format V:**




**Note:**
Format I and II: If Rd = Rp, the result is UNDEFINED.

## LD.UH{cond4} – Conditionally Load Zero-extended Halfword

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Reads the halfword memory location specified and zero-extends it if the given condition is satisfied.

**Operation:**

I. if (cond4)
Rd ← ZE( *(Rp + (ZE(disp9<<1))) );

**Syntax:**

I. ld.uh{cond4} Rd, Rp[disp]

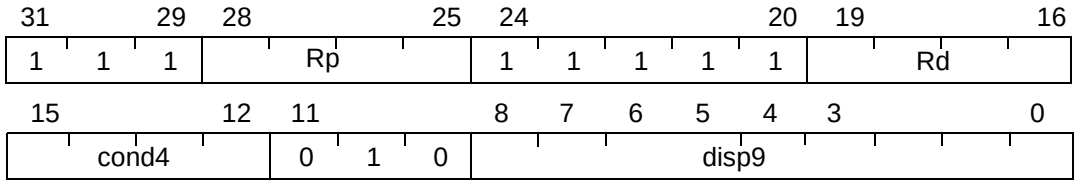
**Operands:**

I. d, p ∈ {0, 1, …, 15}
disp ∈ {0, 2, ..., 1022}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LD.W – Load Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Format I to V: Reads the word memory location specified.
Format VI: This instruction extracts a specified byte from Ri. This value is zero-extended, shifted left two positions and added to Rb to form an address. The contents of this address is loaded into Rd. The instruction is useful for indexing tables.

**Operation:**

```
I.      Rd ← *(Rp);
        Rp ← Rp + 4;
II.     Rp ← Rp - 4;
        Rd ← *(Rp);
III.    Rd ← *(Rp + (ZE(disp5) << 2));
IV.     Rd ← *(Rp + (SE(disp16)));
V.      Rd ← *(Rb + (Ri << sa2));
VI.     If (part == b)
                Rd ← *(Rb + (Ri[7:0] << 2) );
        else if (part == l)
                Rd ← *(Rb + (Ri[15:8] << 2) );
        else if (part == u)
                Rd ← *(Rb + (Ri[23:16] << 2) );
        else
                Rd ← *(Rb + (Ri[31:24] << 2) );
```

**Syntax:**

```
I.      ld.w    Rd, Rp++
II.     ld.w    Rd, --Rp
III.    ld.w    Rd, Rp[disp]
IV.     ld.w    Rd, Rp[disp]
V.      ld.w    Rd, Rb[Ri<<sa]
VI.     ld.w    Rd, Rb[Ri:<part> << 2]
```

**Operands:**

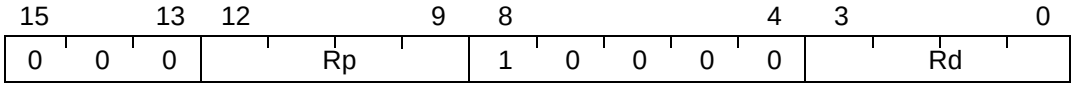
I-V. d, p, b, i ∈ {0, 1, …, 15}
III. disp ∈ {0, 4, ..., 124}
IV. disp ∈ {-32768, -32767, ..., 32767}
V. sa ∈ {0, 1, 2, 3}
VI. {d, b, i} ∈ {0, 1, …, 15}
part ∈ {t, u, l, b}

**Status Flags:**

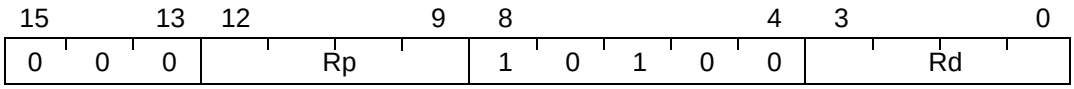
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

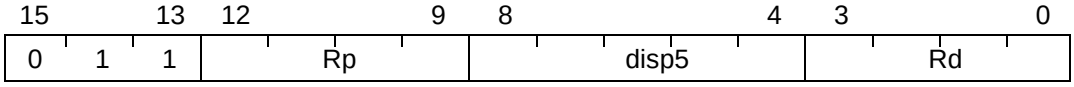
**Format I:**



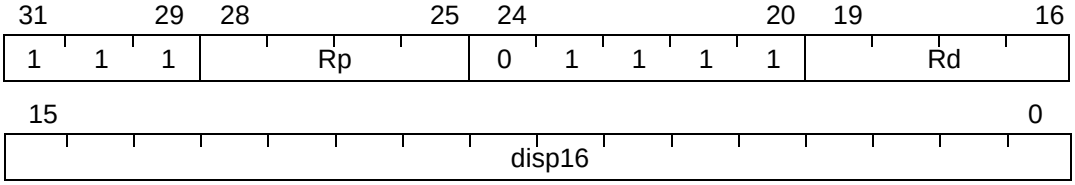

**Format II:**



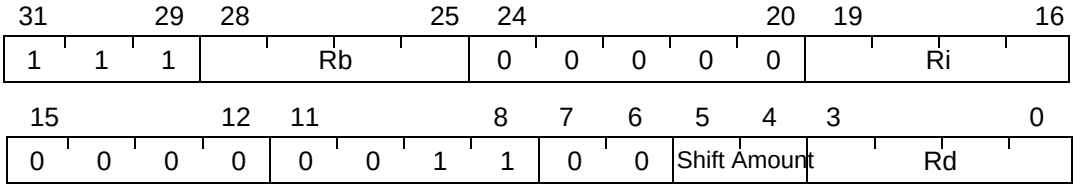

**Format III:**



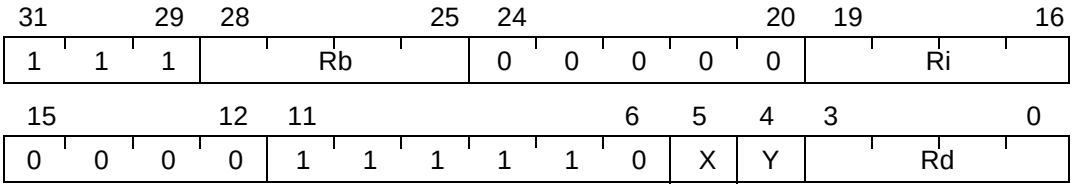

**Format IV:**




**Format V:**




**Format VI:**




**Note:**

Format I and II: If Rd = Rp, the result is UNDEFINED.

## LD.W{cond4} – Conditionally Load Word

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Reads the word memory location specified if the given condition is satisfied.

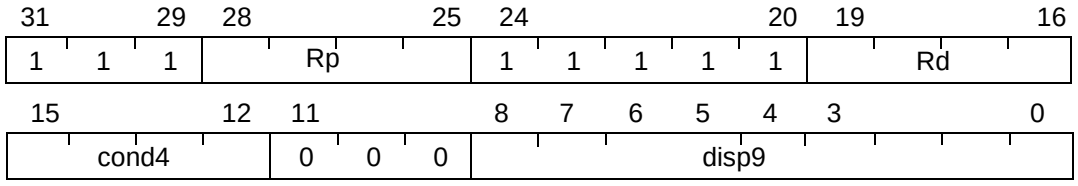
**Operation:**
I. if (cond4)
Rd ← *(Rp + (ZE(disp9<<2)));

**Syntax:**
I. ld.w{cond4} Rd, Rp[disp]

**Operands:**
I. d, p ∈ {0, 1, …, 15}
disp ∈ {0, 4, ..., 2044}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LDC.{D,W} – Load Coprocessor

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the memory location specified into the addressed coprocessor.

**Operation:**

I. CP#(CRd+1:CRd) ← *(Rp + (ZE(disp8) << 2));
II. Rp ← Rp-8;
CP#(CRd+1:CRd) ← *(Rp);
III. CP#(CRd+1:CRd) ← *(Rb + (Ri << sa2));
IV. CP#(CRd) ← *(Rp + (ZE(disp8) << 2));
V. Rp ← Rp-4;
CP#(CRd) ← *(Rp);
VI. CP#(CRd) ← *(Rb + (Ri << sa2));

**Syntax:**

I. ldc.d CP#, CRd, Rp[disp]
II. ldc.d CP#, CRd, --Rp
III. ldc.d CP#, CRd, Rb[Ri<<sa]
IV. ldc.w CP#, CRd, Rp[disp]
V. ldc.w CP#, CRd, --Rp
VI. ldc.w CP#, CRd, Rb[Ri<<sa]

**Operands:**

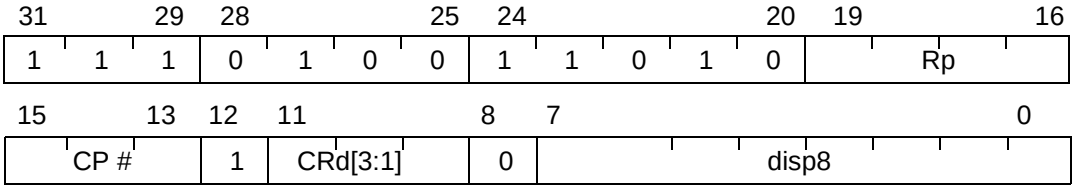
I-VI. # ∈ {0, 1, …, 7}
I-II, IV-V. p ∈ {0, 1, …, 15}
I-III. d ∈ {0, 2, …, 14}
I, IV. disp ∈ {0, 4, …, 1020}
III, VI. {b, i} ∈ {0, 1, …, 15}
III, VI. sa ∈ {0, 1, 2, 3}

**Status Flags:**

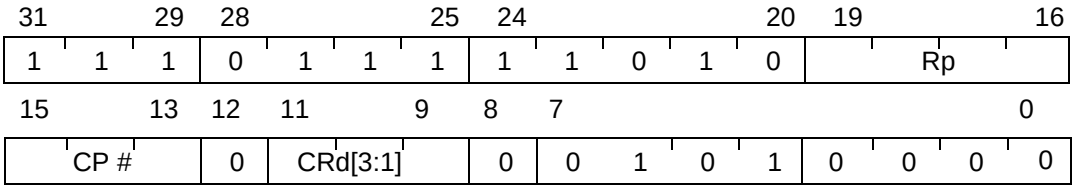
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

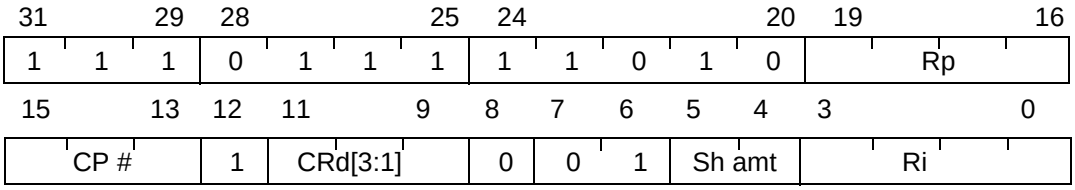
**Format I:**



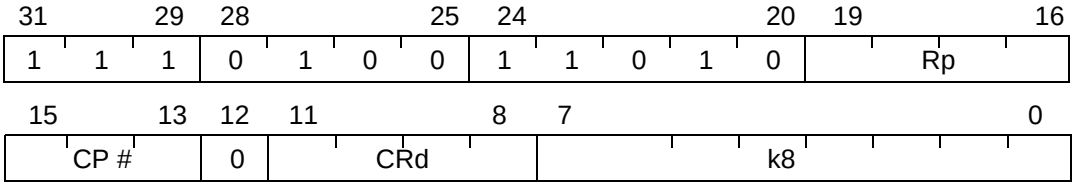

**Format II:**



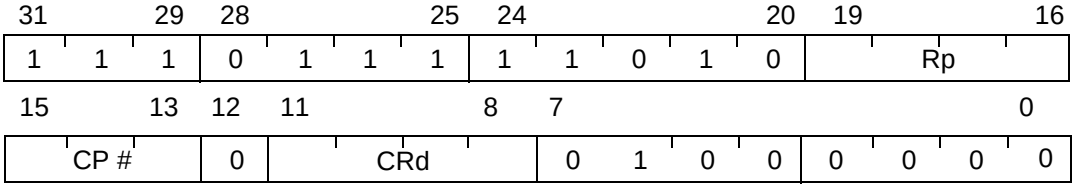

**Format III:**



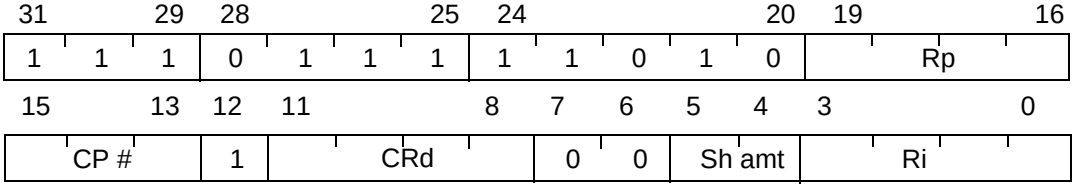

**Format IV:**




**Format V:**




**Format VI:**




**Example:**

```
ldc.d     CP2, CR0, R2[0]
```

## LDC0.{D,W} – Load Coprocessor 0

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the memory location specified into coprocessor 0.

**Operation:**
I. CP0(CRd+1:CRd) ← *(Rp + (ZE(disp12) << 2));
II. CP0(CRd) ← *(Rp + (ZE(disp12) << 2));

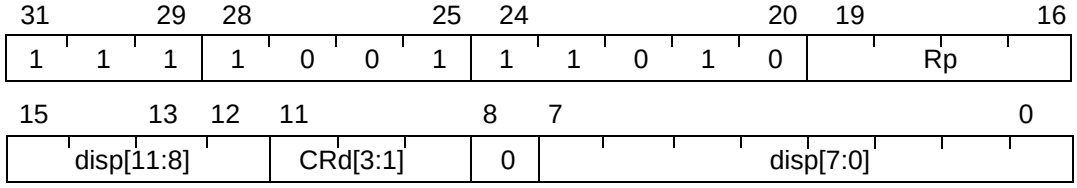
**Syntax:**
I. ldc0.d CRd, Rp[disp]
II. ldc0.w CRd, Rp[disp]

**Operands:**
I,II p ∈ {0, 1, …, 15}
I. d ∈ {0, 2, …, 14}
II. d ∈ {0, 1, …, 15}
I, II. disp ∈ {0, 4, …, 16380}

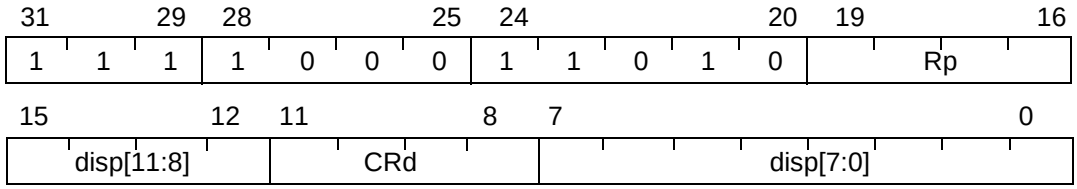
**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**




**Example:**
ldc0.d CR0, R2[0]

## LDCM.{D,W} – Load Coprocessor Multiple Registers

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the memory locations specified into the addressed coprocessor. The pointer register can optionally be updated after the operation.

**Operation:**

```
I.    Loadaddress ←Rp;
      for (i = 7 to 0)
            if ReglistCPD8[i] == 1 then
                  CP#(CR(2*i+1))  ←*(Loadaddress++);
                  CP#(CR(2*i))  ←*(Loadaddress++);
      if Opcode[++] == 1 then
            Rp  ←  Loadaddress;
II.   Loadaddress ←Rp;
      for (i = 7 to 0)
            if ReglistCPH8[i] == 1 then
                  CP#(CRi+8)  ←*(Loadaddress++);
      if Opcode[++] == 1 then
            Rp  ←  Loadaddress;
III.  Loadaddress ←Rp;
      for (i = 7 to 0)
            if ReglistCPL8[i] == 1 then
                  CP#(CRi)  ←*(Loadaddress++);
      if Opcode[++] == 1 then
            Rp  ←  Loadaddress;
```

**Syntax:**

```
I.    ldcm.d  CP#, Rp{++}, ReglistCPD8
II.   ldcm.w  CP#, Rp{++}, ReglistCPH8
III.  ldcm.w  CP#, Rp{++}, ReglistCPL8
```

**Operands:**

```
I-III.  # ∈ {0, 1, …, 7}
        p ∈ {0, 1, …, 15}
I.      ReglistCPD8 ∈ {CR0-CR1,CR2-CR3,CR4-CR5,CR6-CR7,CR8-CR9,
                       CR10-CR11,CR12-CR13,CR14-CR15}
II.     ReglistCPH8 ∈ {CR8, CR9, CR10, ..., CR15}
III.    ReglistCPL8 ∈ {CR0, CR1, CR2, ..., CR7}
```

**Status Flags:**

**Q:** Not affected.

**V:** Not affected.

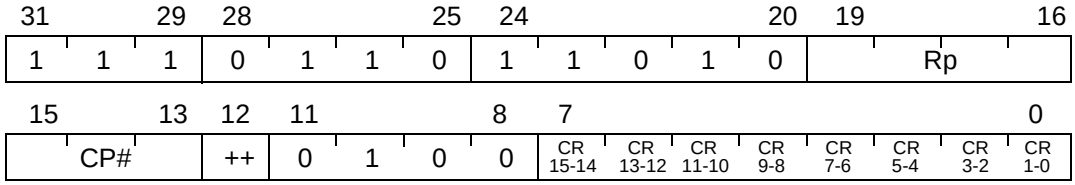
**N:** Not affected.

**Z:** Not affected.

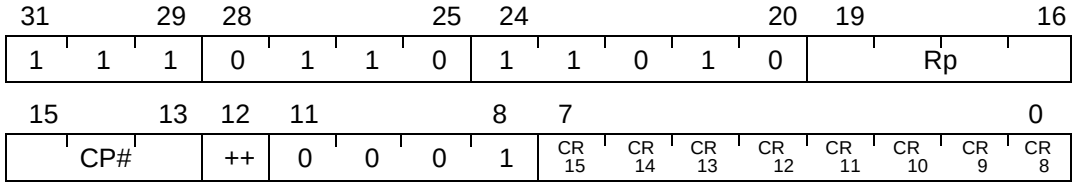
**C:** Not affected.

**Opcode:**

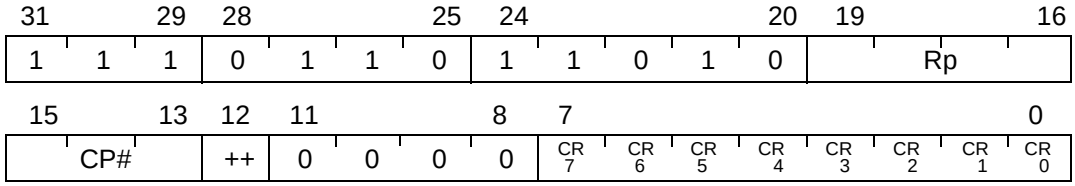
**Format I:**




**Format II:**




**Format III:**




**Example:**

ldcm.w CP2, SP++, CR2-CR5

**Note:**

Emtpy ReglistCPL8/ReglistCPL8/ReglistCPD8 gives UNDEFINED result.

## LDDPC – Load PC-relative with Displacement

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a PC relative load of a register

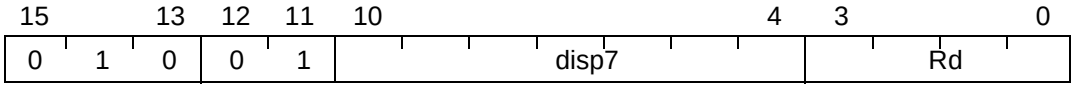
**Operation:**
I. Rd ← *( (PC && 0xFFFF_FFFC) + (ZE(disp7) << 2));

**Syntax:**
I. lddpc Rd, PC[disp]

**Operands:**
I. d ∈ {0, 1, …, 15}
disp ∈ {0, 4, …, 508}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LDDSP – Load SP-relative with Displacement

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads the value of a memory location referred to by the stack pointer register and a displacement.

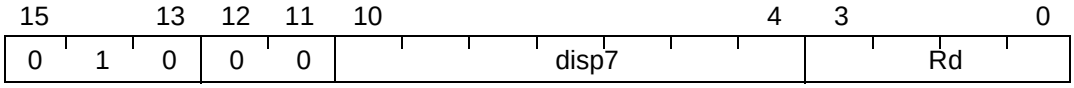
**Operation:**
I. Rd ← *( (SP && 0xFFFF_FFFC) + (ZE(disp7) << 2));

**Syntax:**
I. lddsp Rd, SP[disp]

**Operands:**
I. d ∈ {0, 1, …, 15}
disp ∈ {0, 4, …, 508}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## LDINS.{B,H} – Load and Insert Byte or Halfword into register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction loads a byte or a halfword from memory and inserts it into the addressed byte or halfword position in Rd. The other parts of Rd are unaffected.

**Operation:**

```
I.      If (part == b)
            Rd[7:0] ← *(Rp+SE(disp12));
        else if (part == l)
            Rd[15:8] ← *(Rp+SE(disp12));
        else if (part == u)
            Rd[23:16] ← *(Rp+SE(disp12));
        else
            Rd[31:24] ← *(Rp+SE(disp12));
II.     If (part == b)
            Rd[15:0] ← *(Rp+SE(disp12) << 1);
        else
            Rd[31:16] ← *(Rp+SE(disp12) << 1);
```

**Syntax:**

```
I.      ldins.b  Rd:<part>, Rp[disp]
II.     ldins.h  Rd:<part>, Rp[disp]
```

**Operands:**

I. $\{p, d\} \in \{0, 1, \ldots, 15\}$
$part \in \{t, u, l, b\}$
$disp \in \{-2048, -2047, ..., 2047\}$

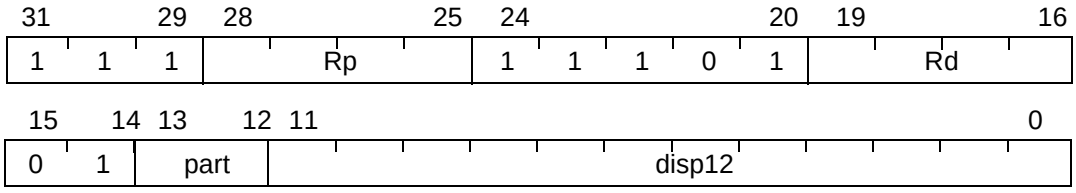
II. $\{p, d\} \in \{0, 1, \ldots, 15\}$
$part \in \{t, b\}$
$disp \in \{-4096, -4094, ..., 4094\}$

**Status Flags:**

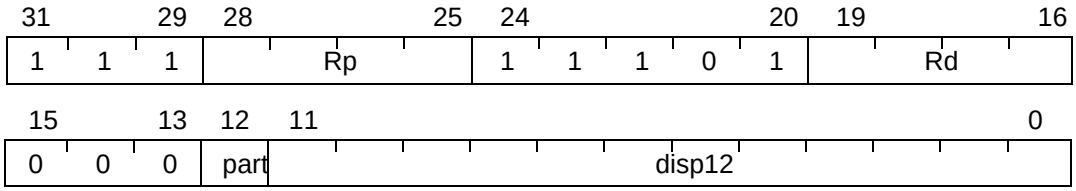
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

**Format I:**




**Format II:**



## LDM – Load Multiple Registers

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Loads the consecutive words pointed to by Rp into the registers specified in the instruction. The PC can be loaded, resulting in a jump to the loaded target address. If PC is loaded, the return value in R12 is tested and the flags are updated. The return value may optionally be set to -1, 0 or 1.

**Operation:**

```
I.      Loadaddress ← Rp;
        if Reglist16[PC] == 1 then
                if Rp == PC then
                        Loadaddress ← SP;
                PC ← *(Loadaddress++);
                if Rp == PC then
                        if Reglist16[LR,R12] == B'00
                                R12 ← 0;
                        else if Reglist16[LR,R12] == B'01
                                R12 ← 1;
                        else
                                R12 ← –1;
                        Test R12 and update flags;
                else
                        if Reglist16[LR] == 1
                                LR ← *(Loadaddress++);
                        if Reglist16[SP] == 1
                                SP ← *(Loadaddress++);
                        if Reglist16[R12] == 1
                                R12 ← *(Loadaddress++);
                        Test R12 and update flags;
        else
                if Reglist16[LR] == 1
                        LR ← *(Loadaddress++);
                if Reglist16[SP] == 1
                        SP ← *(Loadaddress++);
                if Reglist16[R12] == 1
                        R12 ← *(Loadaddress++);
        for (i = 11 to 0)
                if Reglist16[i] == 1 then
                        Ri ← *(Loadaddress++);
        if Opcode[++] == 1 then
                if Rp == PC then
                        SP ← Loadaddress;
                else
                        Rp ← Loadaddress;
```

**Syntax:**

I. ldm Rp{++}, Reglist16

**Operands:**

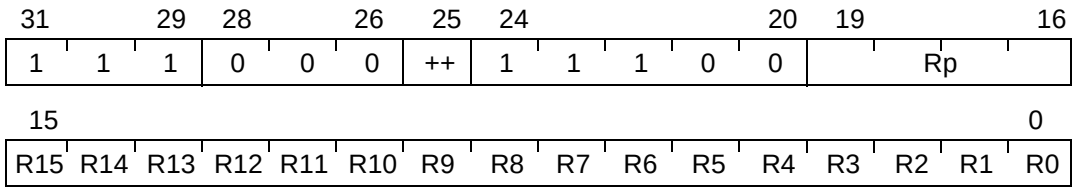
I. Reglist16 ∈ {R0, R1, R2, ..., R12, LR, SP, PC}
p ∈ {0, 1, …, 15}

**Status Flags:**

**Flags are only updated if Reglist16[PC] == 1.**
**They are set as the result of the operation cp R12, 0.**

**Q:** Not affected
**V:** V ← 0
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← 0

**Opcode:**




**Note:**

Emtpy Reglist16 gives UNDEFINED result.
If Rp is in Reglist16 and pointer is written back the result is UNDEFINED.
The R bit in the status register has no effect on this instruction.

## LDMTS – Load Multiple Registers for Task Switch

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Loads the consecutive words pointed to by Rp into the registers specified in the instruction.The target registers reside in the User Register Context, regardless of which context the instruction is called from.

**Operation:**

```
I.      Loadaddress ←Rp;
        for (i = 15 to 0)
                if Reglist16[i] == 1 then
                        Ri USER ←*(Loadaddress++);
        if Opcode[++] == 1 then
                Rp  ←  Loadaddress;
```

**Syntax:**
I. ldmts Rp{++}, Reglist16

**Operands:**
I. Reglist16 ∈ {R0, R1, R2, ..., R12, LR, SP}
p ∈ {0, 1, …, 15}

**Status Flags:**
Not affected.

**Opcode:**

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | ++ | 1 | 1 | 1 | 0 | 0 | Rp | | | |

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R15 | R14 | R13 | R12 | R11 | R10 | R9 | R8 | R7 | R6 | R5 | R4 | R3 | R2 | R1 | R0 |

**Note:**
This instruction is intended for performing task switches.
Emtpy Reglist16 gives UNDEFINED result.
PC in Reglist16 gives UNDEFINED result.

## LDSWP.{SH, UH, W} – Load and Swap

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction loads a halfword or a word from memory. If a halfword load is performed, the loaded value is zero- or sign-extended. The bytes in the loaded value are shuffled and the result is written back to Rd. The instruction can be used for performing loads from memories of different endianness.

**Operation:**

I. temp[15:0] ← *(Rp+SE(disp12) << 1);
Rd ← SE(temp[7:0], temp[15:8]);

II. temp[15:0] ← *(Rp+SE(disp12) << 1);
Rd ← ZE(temp[7:0], temp[15:8]);

III. temp ← *(Rp+SE(disp12) << 2);
Rd ← (temp[7:0], temp[15:8], temp[23:16], temp[31:24]);

**Syntax:**

I. ldswp.shRd, Rp[disp]
II. ldswp.uhRd, Rp[disp]
III. ldswp.wRd, Rp[disp]

**Operands:**

I, II. {d, p} ∈ {0, 1, …, 15}
disp ∈ {-4096, -4094, ..., 4094}

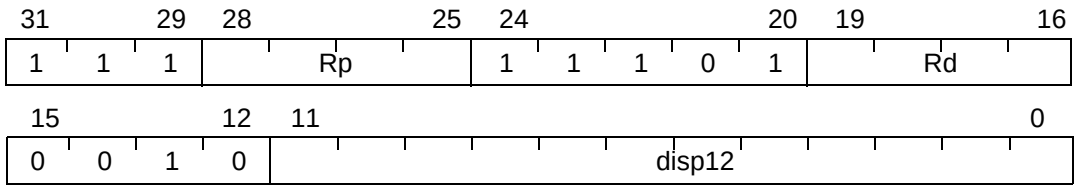
III. {d, p} ∈ {0, 1, …, 15}
disp ∈ {-8192, -8188, ..., 8188}

**Status Flags:**

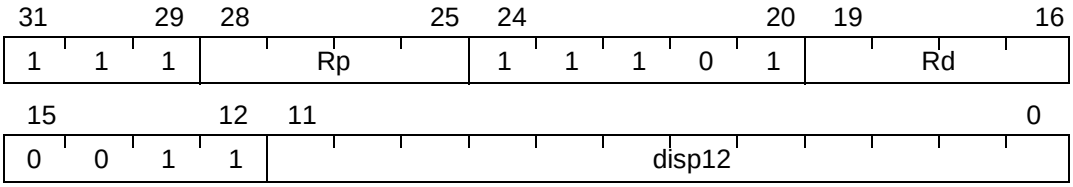
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

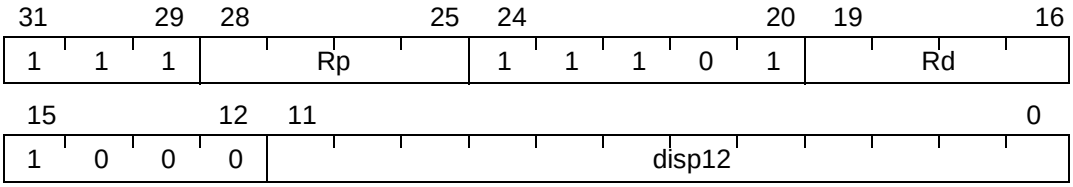
**Format I:**



**Format II:**




**Format III:**



## LSL – Logical Shift Left

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Shifts all bits in a register the amount of bits specified to the left. The shift amount can reside in a register or be specified as an immediate. Zeros are shifted into the LSBs. The last bit that is shifted out is placed in C.

**Operation:**

I. Rd ← LSL(Rx, Ry[4:0]);
II. Rd ← LSL(Rd, sa5);
III. Rd ← LSL(Rs, sa5);

**Syntax:**

| | | |
|---|---|---|
| I. | lsl | Rd, Rx, Ry |
| II. | lsl | Rd, sa |
| III. | lsl | Rd, Rs, sa |

**Operands:**

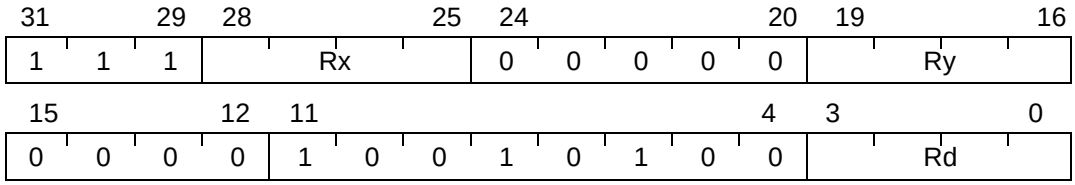
I. {d, x, y} ∈ {0, 1, …, 15}
II. d ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}
III. {d,s} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

**Status Flags:**

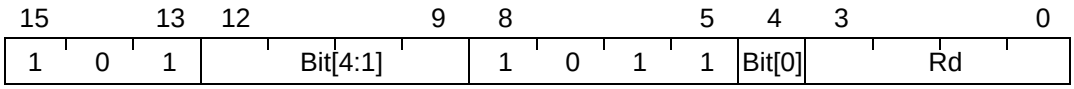
**Format I: Shamt = Ry[4:0], Op = Rx**
**Format II: Shamt = sa5, Op = Rd**
**Format III: Shamt = sa5, Op = Rs**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** if Shamt != 0
C ← Op[32-Shamt]
else
C ← 0

**Opcode:**

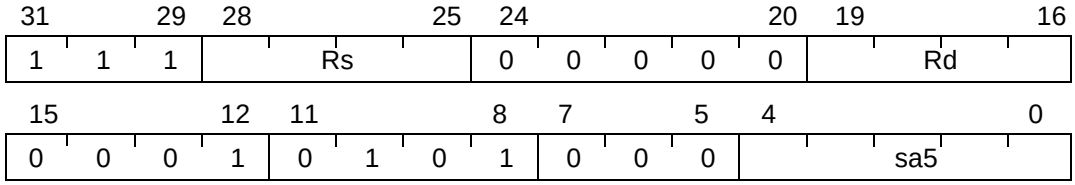
**Format I:**




**Format II:**




**Format III:**



## LSR – Logical Shift Right

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Shifts all bits in a register the amount specified to the right. The shift amount may be specified by a register or an immediate. Zeros are shifted into the MSB.

**Operation:**
I. Rd ← LSR(Rx, Ry[4:0]);
II. Rd ← LSR(Rd, sa5);
III. Rd ← LSR(Rs, sa5);

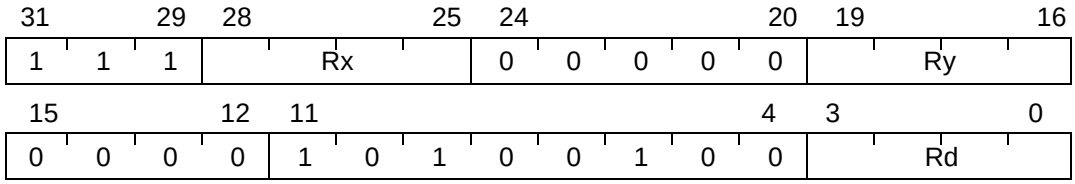
**Syntax:**
I. lsr Rd, Rx, Ry
II. lsr Rd, sa
III. lsr Rd, Rs, sa

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
II. d ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}
III. {d,s} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

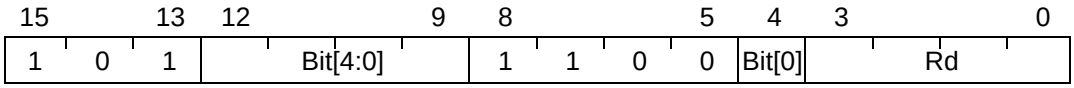
**Status Flags:**
**Format I: Shamt = Ry[4:0], Op = Rx**
**Format II: Shamt = sa5, Op = Rd**
**Format III: Shamt = sa5, Op = Rs**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** if Shamt != 0
C ← Op[Shamt-1]
else
C ← 0

**Opcode:**

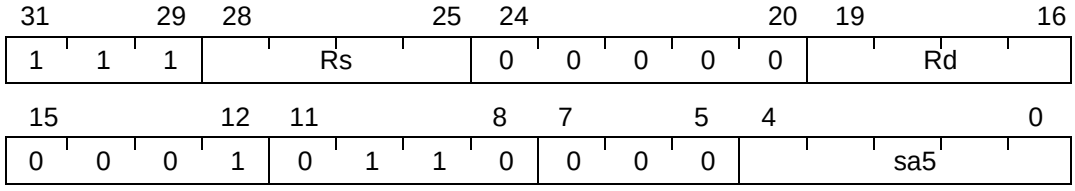
**Format I:**




**Format II:**




**Format III:**



## MAC – Multiply Accumulate

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a Multiply-Accumulate operation and stores the result into the destination register.

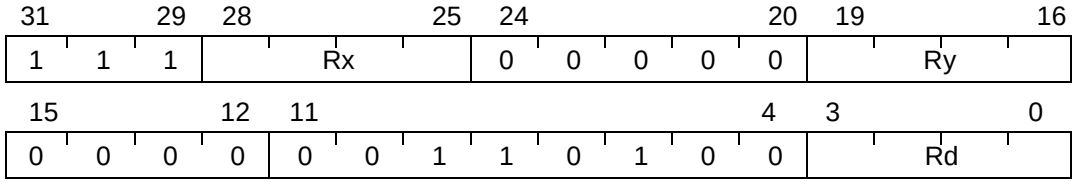
**Operation:**
I. Rd ← (Rx × Ry) + Rd;

**Syntax:**
I. mac Rd, Rx, Ry

**Operands:**
{d, x, y} ∈ {0, 1, …, 15}

**Status Flags**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MACHH.D – Multiply Halfwords and Accumulate in Doubleword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified and adds the result to the specified doubleword-register. Only the 48 highest of the 64 possible bits in the doubleword accumulator are used. The 16 lowest bits are cleared. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
(Rd+1:Rd)[63:16] ← (operand1 × operand2)[31:0] + (Rd+1:Rd)[63:16];
Rd[15:0] ← 0;

**Syntax:**

I. machh.d Rd, Rx:<part>, Ry:<part>

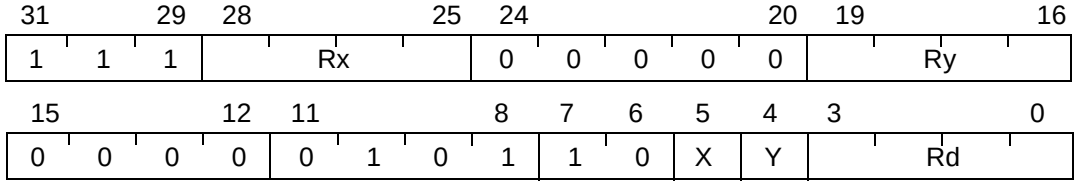
**Operands:**

I. d ∈ {0, 2, 4, …, 14}
{x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

machh.d R10, R2:t, R3:b will perform
(R11 : R10)[63:16] ← ( SE(R2[31:16]) × SE(R3[15:0]) ) + (R11 : R10)[63:16]
R10[15:0] ← 0

## MACHH.W – Multiply Halfwords and Accumulate in Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified and adds the result to the specified word-register. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
Rd ← (operand1 × operand2) + Rd;

**Syntax:**

I. machh.w Rd, Rx:<part>, Ry:<part>

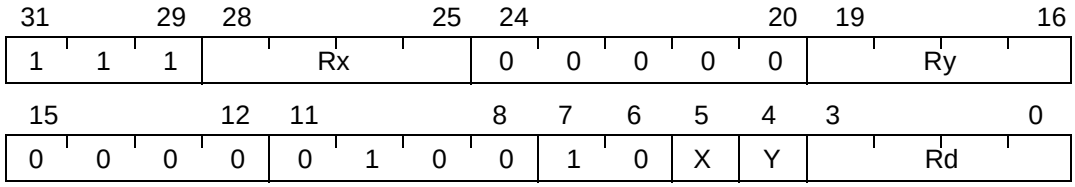
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

machh.w R10, R2:t, R3:b
will perform R10 ← ( SE(R2[31:16]) × SE(R3[15:0]) ) + R10

## MACS.D – Multiply Accumulate Signed

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a Multiply-Accumulate operation with signed numbers and stores the result into the destination registers.

**Operation:**

I.
```
acc ← (Rd+1:Rd);
prod ← (Rx × Ry);
res ← prod + acc;
(Rd+1:Rd) ← res;
```

**Syntax:**

I. `macs.d Rd, Rx, Ry`

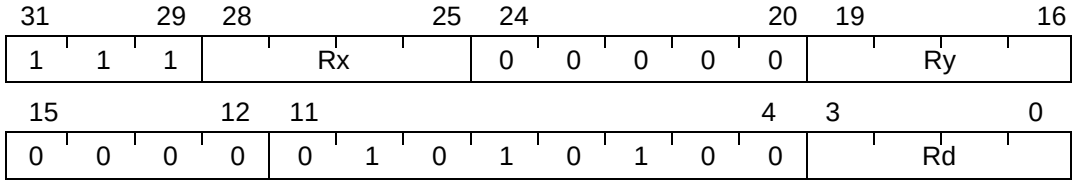
**Operands:**

I. $d \in \{0, 2, 4, \ldots, 14\}$
$\{x, y\} \in \{0, 1, \ldots, 15\}$

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MACSATHH.W – Multiply-Accumulate Halfwords with Saturation into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified, shifts the results one position to the left and stores the result as a temporary word-sized product. If the two operands equals -1, the product is saturated to the largest positive 32-bit fractional number. The halfword registers are selected as either the high or low part of the operand registers. The temporary product is added with saturation to Rd.

**Operation:**

I.
```
If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
If (operand1 == operand2 == 0x8000)
        product ← 0x7FFF_FFFF;
else
        product ← (operand1 × operand2) << 1;
Rd ← Sat(product + Rd);
```

**Syntax:**

I. macsathh.w Rd, Rx:<part>, Ry:<part>

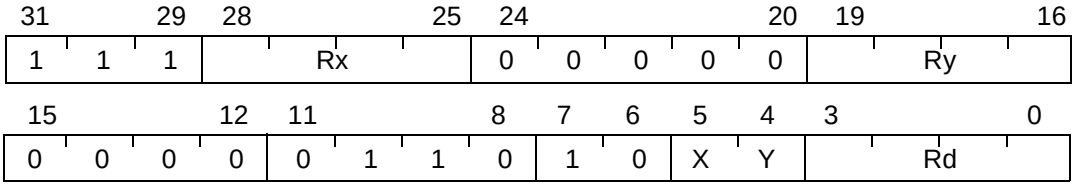
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or if the accumulation overflows, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

```
macsathh.wR10, R2:t, R3:b
will perform R10 ← Sat (Sat(( SE(R2[31:16])  × SE(R3[15:0]) ) << 1) + R10)
```

## MACU.D – Multiply Accumulate Unsigned

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a Multiply-Accumulate operation with unsigned numbers and stores the result into the destination registers.

**Operation:**

I.
```
acc ← (Rd+1:Rd);
prod ← (Rx × Ry);
res ← prod + acc;
(Rd+1:Rd) ← res;
```

**Syntax:**

I. macu.d Rd, Rx, Ry

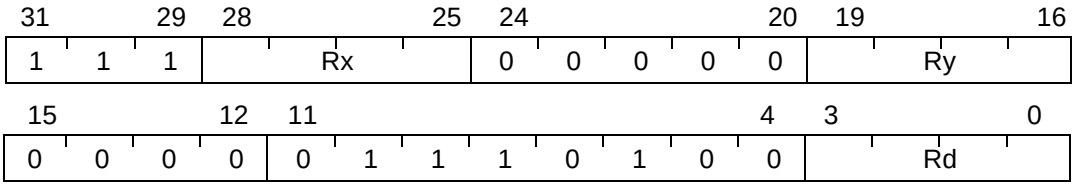
**Operands:**

I. d ∈ {0, 2, 4, …, 14}
{x, y} ∈ {0, 1, …, 15}

**Status Flags**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MACWH.D – Multiply Word with Halfword and Accumulate in Doubleword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the word and halfword register specified and adds the result to the specified doubleword-register. The halfword register is selected as either the high or low part of Ry. Only the 48 highest of the 64 possible bits in the doubleword accumulator are used. The 16 lowest bits are cleared.

**Operation:**

I. operand1 = Rx;
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
(Rd+1:Rd)[63:16] ← (operand1 × operand2)[47:0] + (Rd+1:Rd)[63:16];
Rd[15:0] ← 0;

**Syntax:**

I. macwh.d Rd, Rx, Ry:<part>

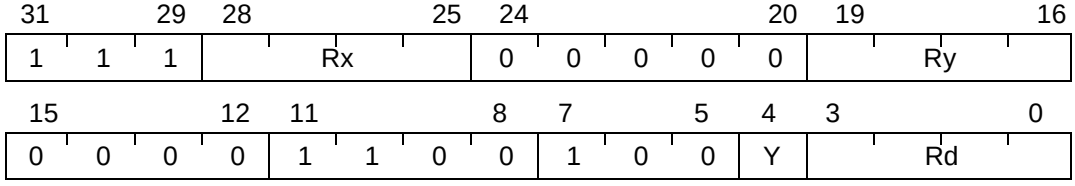
**Operands:**

I. d ∈ {0, 2, …, 14}
{x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

macwh.dR10, R2, R3:bwill perform
(R11:R10)[63:16] ← (R2 × SE(R3[15:0])) + (R11:R10)[63:16]
R10[15:0] ← 0

## MAX – Return Maximum Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets Rd equal to the signed maximum of Rx and Ry.

**Operation:**

```
I.    If Rx > Ry
          Rd ← Rx;
      else
          Rd ← Ry;
```

**Syntax:**

```
I.    max    Rd, Rx, Ry
```

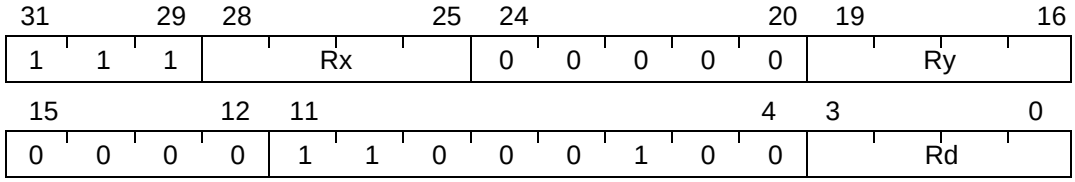
**Operands:**

d, x, y ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MCALL – Subroutine Call

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subroutine call to a call destination specified in a location residing in memory.

**Operation:**

I. LR ← PC + 4

PC ← *((Rp & 0xFFFFFFFC) + (SE(disp16) << 2))

**Syntax:**

I. mcall Rp[disp]

**Operands:**

p ∈ {0, 1, …, 15}

disp ∈ {-131072, -131068,…, 131068}

**Status Flags:**

**Q:** Not affected.

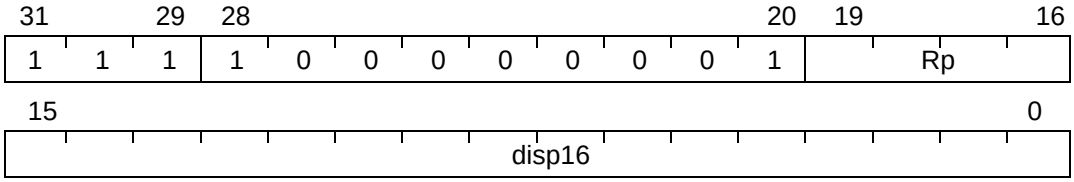
**V:** Not affected.

**N:** Not affected.

**Z:** Not affected.

**C:** Not affected.

**Opcode:**



## MEMC – Clear bit in memory

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a read-modify-write operation to clear an arbitrary bit in memory. The word to modify is pointed to by a signed 17-bit address. This allows the instruction to address the upper 64KB and lower 64KB of memory. This instruction is part of the optional RMW instruction set.

**Operation:**

I. *(SE(imm15<<2)[bp5]) ← 0

**Syntax:**

I. memc imm, bp5

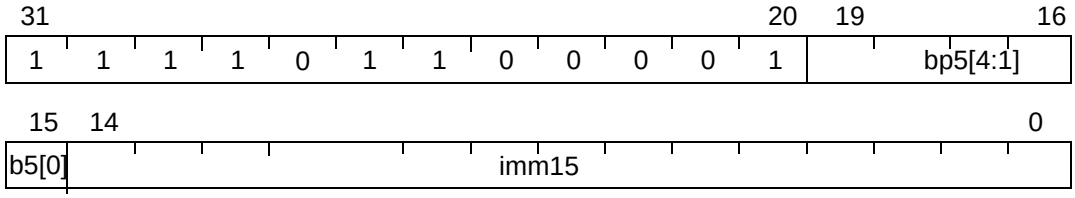
**Operands:**

bp5 ∈ {0, 1, …, 31}
imm ∈ {-65536, -65532,…, 65532}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MEMS – Set bit in memory

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a read-modify-write operation to set an arbitrary bit in memory. The word to modify is pointed to by a signed 17-bit address. This allows the instruction to address the upper 64KB and lower 64KB of memory. This instruction is part of the optional RMW instruction set.

**Operation:**

I. *(SE(imm15<<2)[bp5]) ← 1

**Syntax:**

I. mems imm, bp5

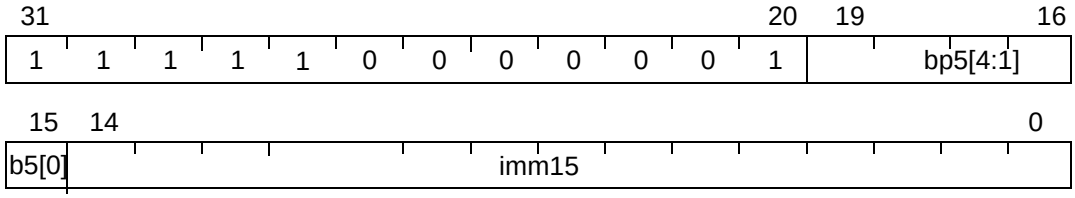
**Operands:**

bp5 ∈ {0, 1, …, 31}
imm ∈ {-65536, -65532,…, 65532}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MEMT – Toggle bit in memory

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a read-modify-write operation to toggle an arbitrary bit in memory. The word to modify is pointed to by a signed 17-bit address. This allows the instruction to address the upper 64KB and lower 64KB of memory. This instruction is part of the optional RMW instruction set.

**Operation:**

I. *(SE(imm15<<2)[bp5]) ← ¬*(SE(k15<<2)[bp5])

**Syntax:**

I. memt imm, bp5

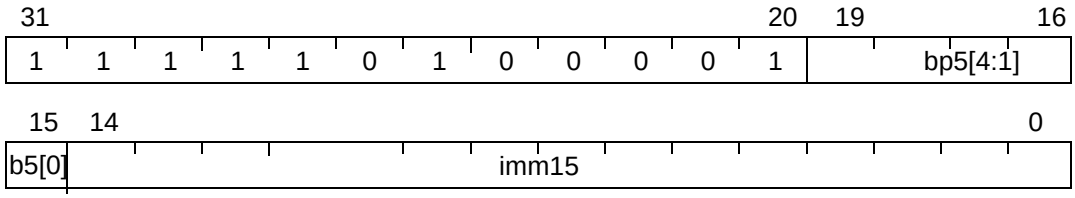
**Operands:**

bp5 ∈ {0, 1, …, 31}
imm ∈ {-65536, -65532,…, 65532}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MFDR – Move from Debug Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the value in the specified debug register to the specified register in the register file. Note that special timing concerns must be considered when operating on the debug registers, see the Pipeline Chapter for details.

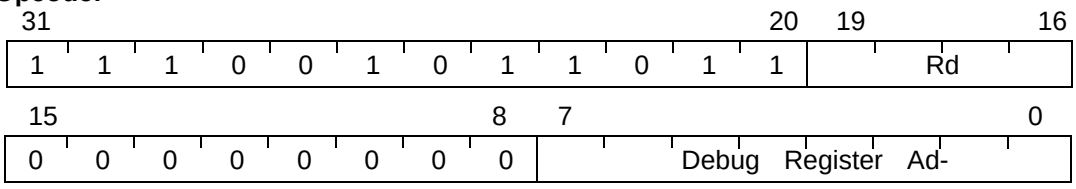
**Operation:**
I. Rd ← DebugRegister[DebugRegisterAddress << 2];

**Syntax:**
I. mfdr Rd, DebugRegisterNo

**Operands:**
I. DebugRegisterNo ∈ {0, 4, 8, ..., 1020}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
Debug registers are implementation defined. If accessing a debug register that does not exist, the result is UNDEFINED.

This instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception.

## MFSR – Move from System Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the value in the specified system register to the specified register in the register file. Note that special timing concerns must be considered when operating on the system registers, see the Pipeline Chapter for details.

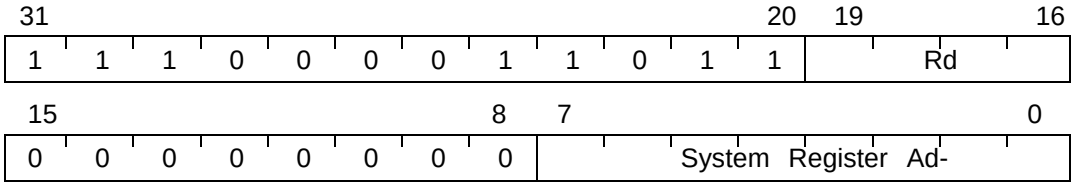
**Operation:**
I. Rd ← SystemRegister[SystemRegisterAddress << 2];

**Syntax:**
I. mfsr Rd, SystemRegisterAddress

**Operands:**
I. SystemRegisterAddress ∈ {0, 4, 8, ..., 1020}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
Some system registers are implementation defined. If accessing a system register that does not exist, the result is UNDEFINED.

With the exception of accessing the JECR and JOSP system registers, this instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception.

JECR and JOSP can be accessed from all modes with this instruction.

## MIN – Return Minimum Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets Rd equal to the signed minimum of Rx and Ry.

**Operation:**

```
I.    If Rx < Ry
          Rd ← Rx;
      else
          Rd ← Ry;
```

**Syntax:**

```
I.    min     Rd, Rx, Ry
```

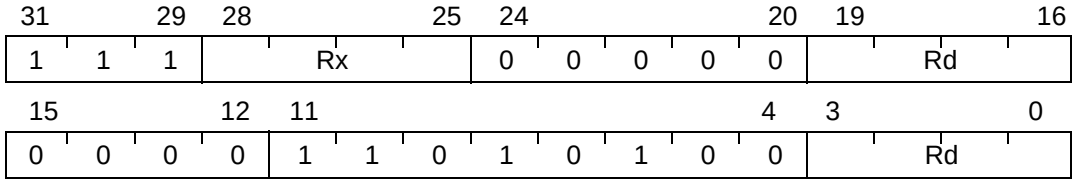
**Operands:**

d, x, y ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MOV – Move Data Into Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Moves a value into a register. The value may be an immediate or the contents of another register. Note that Rd may specify PC, resulting in a jump. All flags are unchanged.

**Operation:**

I. Rd ← SE(imm8);
II. Rd ← SE(imm21);
III. Rd ← Rs;

**Syntax:**

I. mov Rd, imm
II. mov Rd, imm
III. mov Rd, Rs

**Operands:**

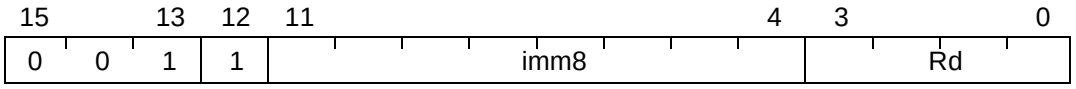
I. d ∈ {0, 1, …, 15}
imm ∈ {-128, -127, ..., 127}
II. d ∈ {0, 1, …, 15}
imm ∈ {-1048576, -104875, ..., 1048575}
III. d, s ∈ {0, 1, …, 15}

**Status Flags:**

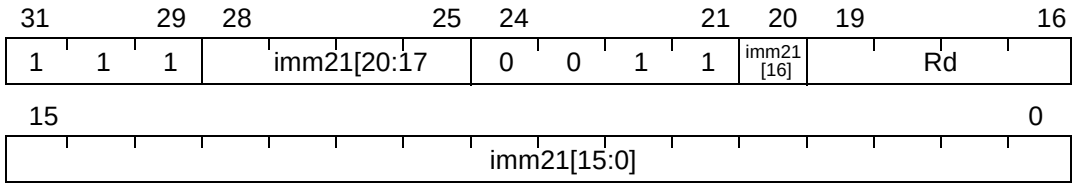
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

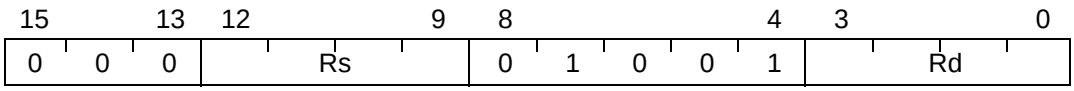
**Format I:**




**Format II:**



**Format III:**



## MOV{cond4} – Conditional Move Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Copies the contents of the source register or immediate to the destination register. The source register is unchanged. All flags are unchanged.

**Operation:**

I. if ( cond4)
Rd ← Rs;

II. if ( cond4)
Rd ← SE(imm8);

**Syntax:**

I. mov{cond4} Rd, Rs

II. mov{cond4} Rd, imm

**Operands:**

I. {d, s} ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

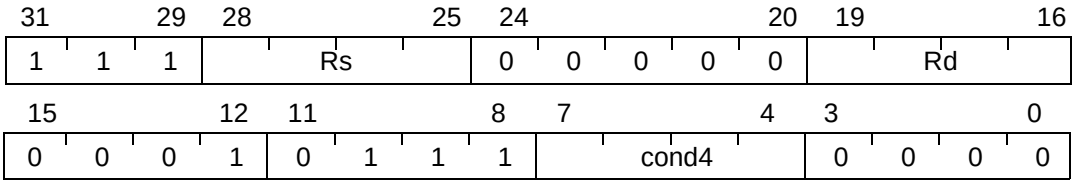
II. d ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
imm ∈ {-128, -127, ..., 127}

**Status Flags:**

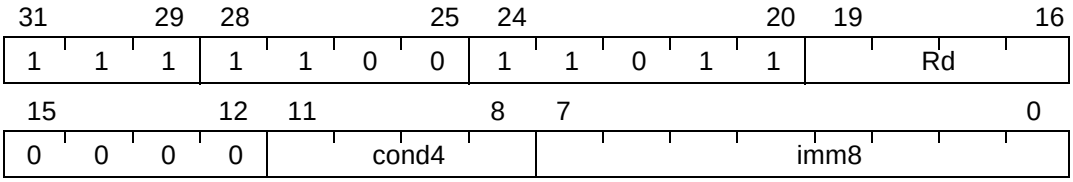
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**


31 29 28 25 24 20 19 16
1 1 1 1 1 0 0 1 1 0 1 1 Rd
15 12 11 8 7 0
0 0 0 0 cond4 imm8

## MOVH – Move Data Into High Halfword of Register

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Moves a value into the high halfword of a register. The low halfword is cleared. All flags are unchanged.

**Operation:**

I. Rd ← imm16<<16;

**Syntax:**

I. movh Rd, imm

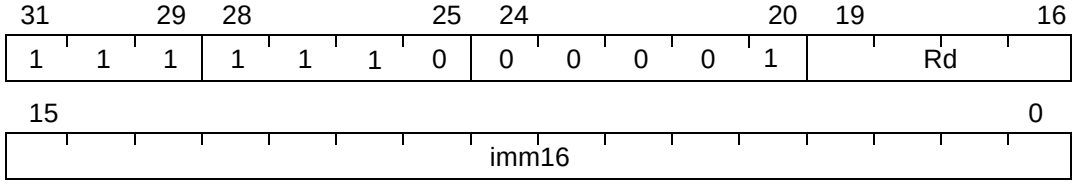
**Operands:**

I. d ∈ {0, 1, …, 15}
imm ∈ {0, 1, ..., 65535}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MTDR – Move to Debug Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the value in the specified register to the specified debug register. Note that special timing concerns must be considered when operating on the system registers, see the Pipeline Chapter for details.

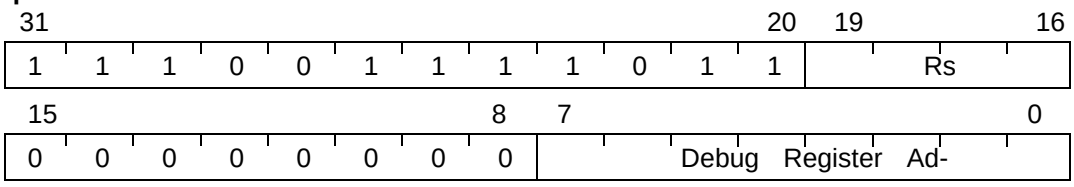
**Operation:**
I. DebugRegister[DebugRegisterAddress << 2] ← Rs;

**Syntax:**
I. mtdr DebugRegisterAddress, Rs

**Operands:**
I. DebugRegisterAddress ∈ {0, 4, 8, ..., 1020}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
The debug registers are implementation defined, and updates of these registers are handled in an implementation specific way.

This instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception.

## MTSR – Move to System Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the value in the specified register to the specified system register. Note that special timing concerns must be considered when operating on the system registers, see the Implementation Manual for details.

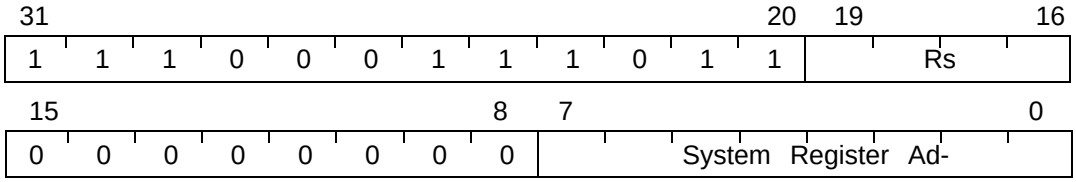
**Operation:**
I. SystemRegister[SystemRegisterAddress << 2] ← Rs;

**Syntax:**
I. mtsr SystemRegisterAddress, Rs

**Operands:**
I. SystemRegisterAddress ∈ {0, 4, 8, ..., 1020}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
Some system registers are implementation defined. If writing a system register that does not exist, or to a register that is read only, the instruction is executed but no registers are updated.

With the exception of accessing the JECR and JOSP system registers, this instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception. JECR and JOSP can be accessed from all modes with this instruction.

The instruction mtsr JOSP, Rx must be used with care. The programmer must ensure that no change of flow instruction nor an INCJOSP instruction follows mtsr JOSP, Rx within a number of instructions. This number of cycles is implementation defined. It should also be noted, that this is true even if the instructions are not to be executed. For instance the sequence

```
mtsr JOSP, Rx
retj
incjosp
```

will execute with an incorrect result. In practice this warning will only affect programmers writing their own Java Virtual Machine based on the AVR32 Java Extension module.

## MUL – Multiply

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the specified operands and stores the result in the destination register.

**Operation:**

I. Rd ← Rd × Rs;
II. Rd ← Rx × Ry;
III. Rd ← Rs × SE(imm8)

**Syntax:**

| | | |
|---|---|---|
| I. | mul | Rd, Rs |
| II. | mul | Rd, Rx, Ry |
| III. | mul | Rd, Rs, imm |

**Operands:**

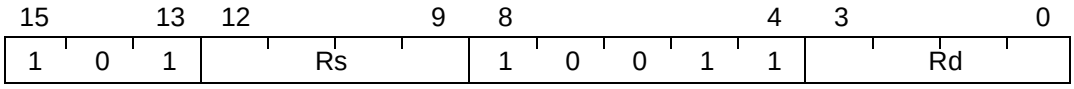
I. {d, s} ∈ {0, 1, …, 15}
II. {d, x, y} ∈ {0, 1, …, 15}
III. {d, s} ∈ {0, 1, …, 15}
imm ∈ {-128, -127, ..., 127}

**Status Flags:**

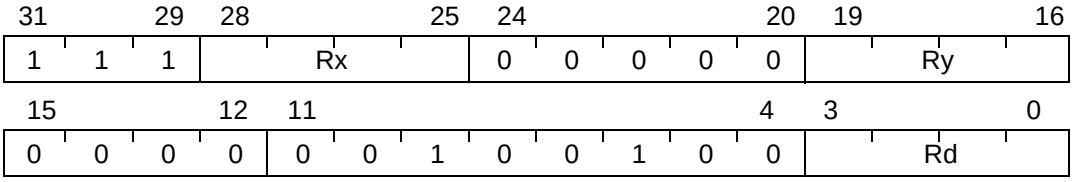
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

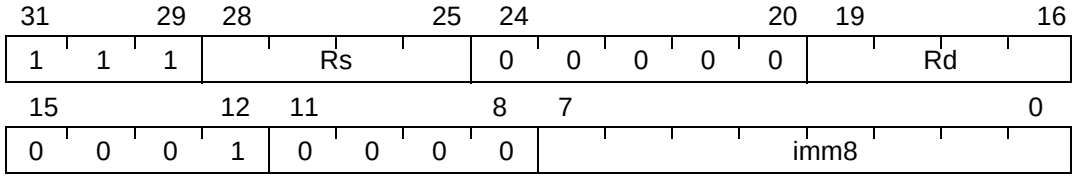
**Format I:**




**Format II:**



**Format III:**



## MULHH.W – Multiply Halfword with Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified and stores the result in the destination word-register. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
Rd ← operand1 × operand2;

**Syntax:**

I. mulhh.w Rd, Rx:<part>, Ry:<part>

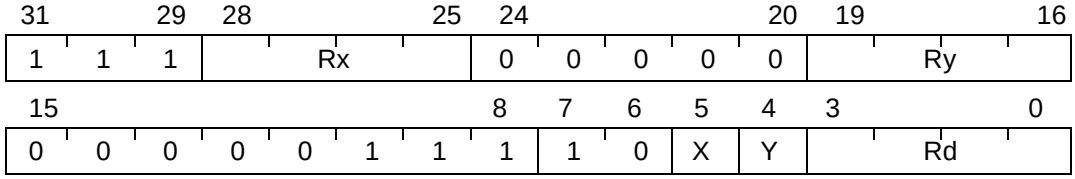
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

mulhh.wR10, R2:t, R3:b
will perform R10 ← SE(R2[31:16]) × SE(R3[15:0])

## MULNHH.W – Multiply Halfword with Negated Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified and stores the result in the destination word-register. The halfword registers are selected as either the high or low part of the operand registers. The result is negated.

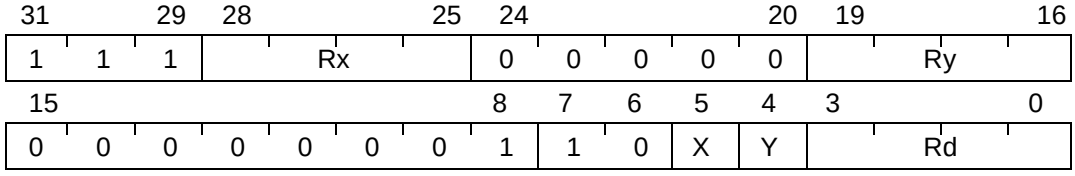
**Operation:**
I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
Rd ← - (operand1 × operand2);

**Syntax:**
I. mulnhh.w Rd, Rx:<part>, Ry:<part>

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MULNWH.D – Multiply Word with Negated Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the word register with the halfword register specified and stores the negated result in the destination register pair. The halfword register is selected as either the high or low part of Ry. Since the most significant part of the product is stored, no overflow will occur.

**Operation:**

I. operand1 = Rx;
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
(Rd+1:Rd)[63:16] ← - (operand1 × operand2);
Rd[15:0] ← 0;

**Syntax:**

I. mulnwh.d Rd, Rx, Ry:<part>

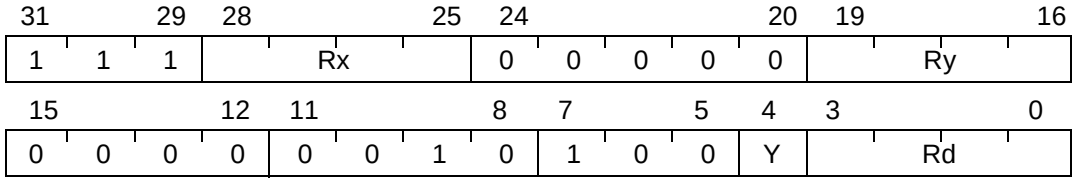
**Operands:**

I. d ∈ {0, 2, 4, …, 14}
{x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MULS.D – Multiply Signed

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two registers specified and stores the result in the destination registers.

**Operation:**
I. Rd+1:Rd ← Rx × Ry;

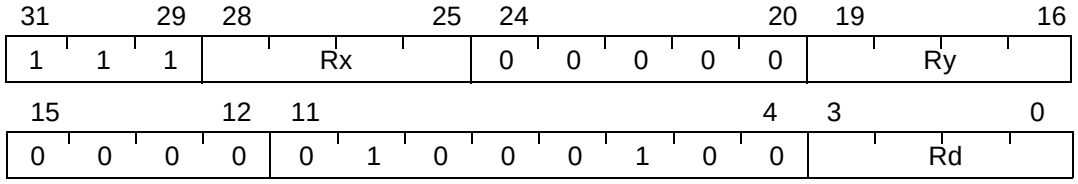
**Syntax:**
I. muls.d Rd, Rx, Ry

**Operands:**
I. d ∈ {0, 2, 4, …, 14}
{x, y} ∈ {0, 1, …, 15}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected. |
| **V:** | Not affected. |
| **N:** | Not affected. |
| **Z:** | Not affected. |
| **C:** | Not affected. |

**Opcode:**



## MULSATHH.H – Multiply Halfwords with Saturation into Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified, shifts the results one position to the left and stores the sign-extended high halfword of the result in the destination word-register. If the two operands equals -1, the result is saturated to the largest positive 16-bit fractional number. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I.
```
If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
If (operand1 == operand2 == 0x8000)
        Rd ← 0x7FFF;
else
        Rd ← SE(  (operand1 × operand2) >> 15  );
```

**Syntax:**

I. mulsathh.h Rd, Rx:<part>, Ry:<part>

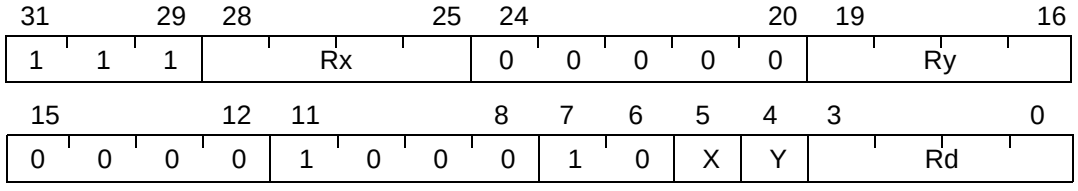
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

```
mulsathh.h R10, R2:t, R3:b
will perform R10 ← SE( Sat(SE(R2[31:16])  × SE(R3[15:0]) )  >> 15 )
```

## MULSATHH.W – Multiply Halfwords with Saturation into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified, shifts the results one position to the left and stores the result in the destination word-register. If the two operands equals -1, the result is saturated to the largest positive 32-bit fractional number. The halfword registers are selected as either the high or low part of the operand registers.

**Operation:**

I.
```
If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
If (operand1 == operand2 == 0x8000)
        Rd ← 0x7FFF_FFFF;
else
        Rd ← (operand1 × operand2) << 1;
```

**Syntax:**

I. mulsathh.w Rd, Rx:<part>, Ry:<part>

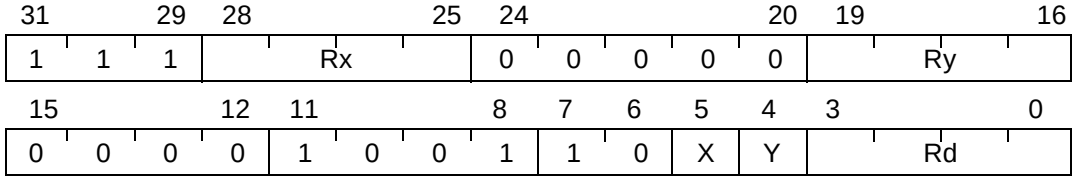
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

```
mulsathh.w R10, R2:t, R3:b
will perform R10 ← Sat( (SE(R2[31:16])  × SE(R3[15:0] )) << 1)
```

## MULSATRNDHH.H – Multiply Halfwords with Saturation and Rounding into Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two halfword registers specified, shifts the results one position to the left and stores the result in the destination word-register. If the two operands equal -1, the result is saturated to the largest positive 16-bit fractional number. The halfword registers are selected as either the high or low part of the operand registers. The product is rounded.

**Operation:**

I.
```
If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
If (operand1 == operand2 == 0x8000)
        Rd ← 0x7FFF;
else
        Rd ← SE( ((operand1 × operand2) + 0x4000 ) >> 15 );
```

**Syntax:**

I. mulsatrndhh.h Rd, Rx:<part>, Ry:<part>

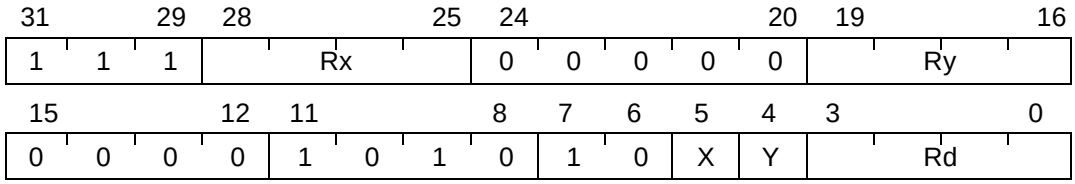
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

```
mulsatrndhh.h R10, R2:t, R3:b
will perform R10 ← SE( Sat( SE(R2[31:16])  × SE(R3[15:0]) ) + 0x4000) >> 15)
```

## MULSATRNDWH.W – Multiply Word and Halfword with Saturation and Rounding into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the word register with the halfword register specified, rounds the upper 32 bits of the result and stores it in the destination word-register. The halfword register is selected as either the high or low part of Ry. Since the most significant part of the product is stored, no overflow will occur. If the two operands equals -1, the result is saturated to the largest positive 32-bit fractional number.

**Operation:**

I. operand1 = Rx;
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
If ((operand1 == 0x8000_0000) && (operand2 == 0x8000))
Rd ← 0x7FFF_FFFF;
else
Rd ← SE( ((operand1 × operand2) + 0x4000 ) >> 15 );

**Syntax:**

I. mulsatrndwh.w Rd, Rx, Ry:<part>

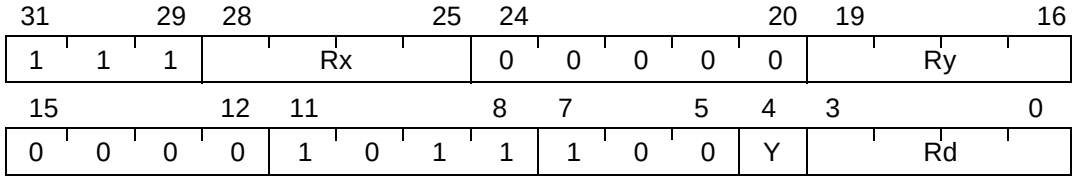
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

mulsatrndwh.w R10, R2, R3b will perform R10 ← (Sat( R2[31:16] × SE(R3[15:0]) ) + 0x4000) >> 15

## MULSATWH.W – Multiply Word and Halfword with Saturation into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the word register with the halfword register specified and stores the upper 32 bits of the result in the destination word-register. The halfword register is selected as either the high or low part of Ry. Since the most significant part of the product is stored, no overflow will occur. If the two operands equal -1, the result is saturated to the largest positive 32-bit fractional number.

**Operation:**

I.
```
operand1 = Rx;
If (Ry-part == t) then operand2 = SE(Ry[31:16])  else operand2 = SE(Ry[15:0]);
If ((operand1 == 0x8000_0000) && (operand2 == 0x8000))
        Rd ← 0x7FFF_FFFF;
else
        Rd ← (operand1 × operand2) >> 15;
```

**Syntax:**

I. `mulsatwh.w  Rd, Rx, Ry:<part>`

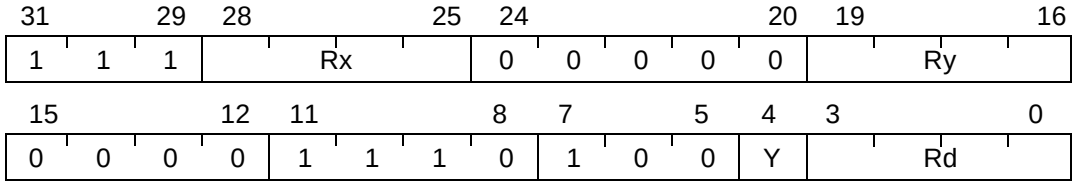
**Operands:**

I. $\{d, x, y\} \in \{0, 1, \ldots, 15\}$
part $\in$ {t,b}

**Status Flags:**

**Q:** Set if saturation occurred, or previously set.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Example:**

```
mulsatwh.wR10, R2, R3:b
will perform R10 ← Sat( R2  × SE(R3[15:0]))  >> 15
```

## MULU.D – Multiply Unsigned

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the two registers specified and stores the result in the destination registers.

**Operation:**
I. Rd+1:Rd ← Rx × Ry;

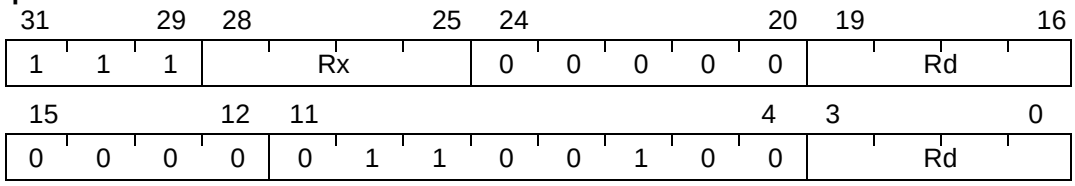
**Syntax:**
I. mulu.d Rd, Rx, Ry

**Operands:**
I. d ∈ {0, 2, 4, …, 14}
{x, y} ∈ {0, 1, …, 15}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected. |
| **V:** | Not affected. |
| **N:** | Not affected. |
| **Z:** | Not affected. |
| **C:** | Not affected. |

**Opcode:**



## MULWH.D – Multiply Word with Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Multiplies the word register with the halfword register specified and stores result in the destination register pair. The halfword register is selected as either the high or low part of Ry. Since the most significant part of the product is stored, no overflow will occur.

**Operation:**

I.
```
operand1 = Rx;
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
(Rd+1:Rd)[63:16] ← operand1 × operand2;
Rd[15:0] ← 0;
```

**Syntax:**

I. `mulwh.d Rd, Rx, Ry:<part>`

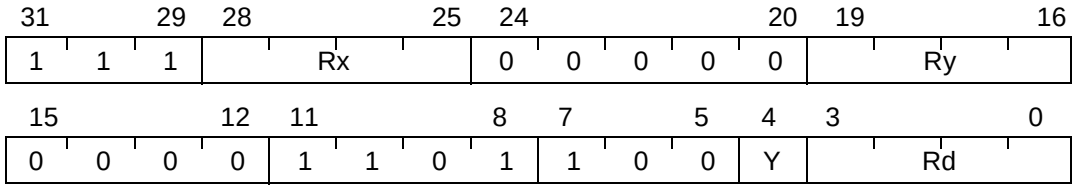
**Operands:**

I. $d \in \{0, 2, 4, \ldots, 14\}$
$\{x, y\} \in \{0, 1, \ldots, 15\}$
part $\in$ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MUSFR – Copy Register to Status Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the lower 4 bits of the register Rs to the lower 4 bits of the status register.

**Operation:**
I. SR[3:0] ← Rs[3:0];

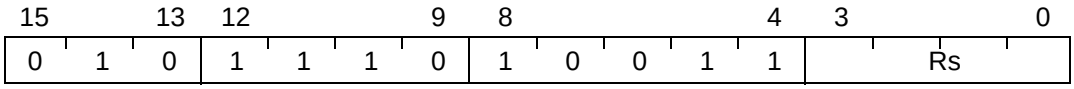
**Syntax:**
I. musfr Rs

**Operands:**
I. s ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## MUSTR – Copy Status Register to Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The instruction copies the value of the 4 lower bits of the status register into the register Rd. The value is zero extended.

**Operation:**

I. Rd ← ZE(SR[3:0]);

**Syntax:**

I. mustr Rd

**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

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

## MVCR.{D,W} – Move Coprocessor Register to Register file

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Addresses a coprocessor and moves the specified registers into the register file.

**Operation:**

I. (Rd+1:Rd) ← CP#(CRs+1:CRs);

II. Rd ← CP#(CRs);

**Syntax:**

I. mvcr.d CP#, Rd, CRs

II. mvcr.w CP#, Rd, CRs

**Operands:**

I. # ∈ {0, 1, …, 7}
{d, s} ∈ {0, 2, 4, …, 14}

II. # ∈ {0, 1, …, 7}
{d, s} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

Format I:

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Rd | | | 0 |

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP# | | | 0 | CRs | | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

Format II:

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Rd | | | |

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP# | | | 0 | CRs | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Example:**

mvcr.d CP2, R0, CR2

## MVRC.{D,W} – Move Register file Register to Coprocessor Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Moves the specified register into the addressed coprocessor.

**Operation:**
I. CP#(CRd+1:CRd) ← Rs+1:Rs;
II. CP#(CRd) ← Rs;

**Syntax:**
I. mvrc.d CP#, CRd, Rs
II. mvrc.w CP#, CRd, Rs

**Operands:**
I. # ∈ {0, 1, …, 7}
{d, s} ∈ {0, 2, 4, …, 14}
I. # ∈ {0, 1, …, 7}
{d, s} ∈ {0, 1, …, 15}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**
Format I:

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Rs | | | 0 |

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP# | | | 0 | CRd | | | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

Format II:

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Rs | | | |

| 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP# | | | 0 | CRd | | | | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

**Example:**
mvrc.d CP2, CR0, R2

## NEG – Two's Complement

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a two's complement of specified register.

**Operation:**
I. Rd ← 0 -Rd;

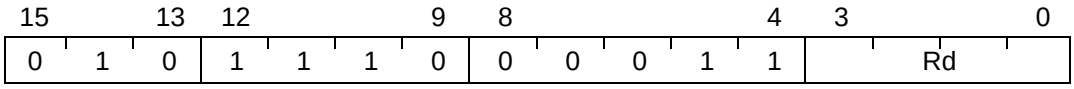
**Syntax:**
I. neg Rd

**Operands:**
I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** V ← Rd[31] ∧ RES[31]
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← Rd[31] ∨ RES[31]

**Opcode:**



## NOP – No Operation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Special instructions for "no operation" that does not create data depencencies in the pipeline

**Operation:**
I. none

**Syntax:**
I. nop

**Operands:**
I. none

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**

| 15 | | | | | | 9 | 8 | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

## OR – Logical OR with optional logical shift

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical OR between the specified registers and stores the result in the destination register.

**Operation:**

I. Rd ← Rd ∨ Rs;
II. Rd ← Rx ∨ (Ry << sa5);
III. Rd ← Rx ∨ (Ry >> sa5);

**Syntax:**

| | | |
|---|---|---|
| I. | or | Rd, Rs |
| II. | or | Rd, Rx, Ry << sa |
| III. | or | Rd, Rx, Ry >> sa |

**Operands:**

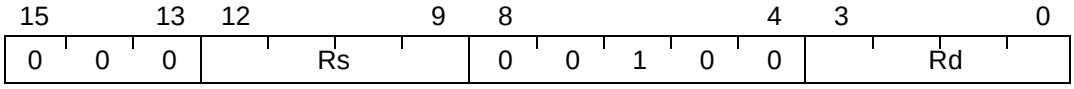
I. {d, s} ∈ {0, 1, …, 15}
II, III. {d, x, y} ∈ {0, 1, …, 15}
sa ∈ {0, 1, …, 31}

**Status Flags:**

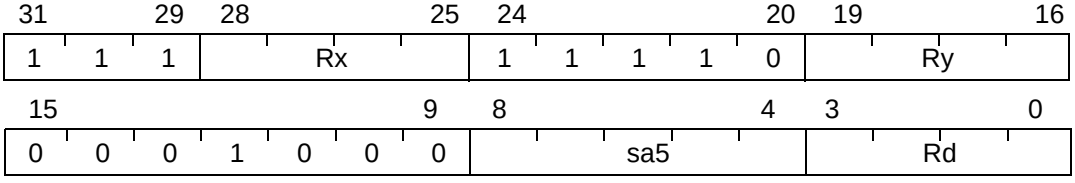
**Q:** Not affected.
**V:** Not affected.
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected.

**Opcode:**

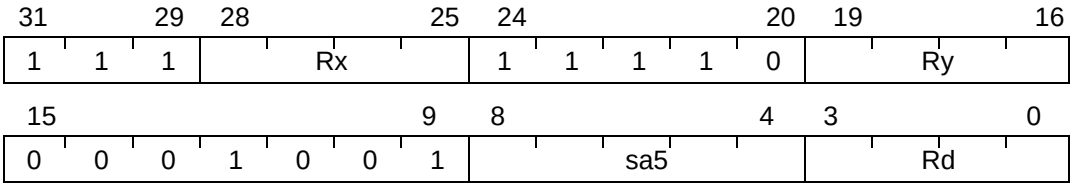
**Format I:**




**Format II:**



**Format III:**



## OR{cond4} – Conditional logical OR

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Performs a bitwise logical OR between the specified registers and stores the result in the destination register.

**Operation:**

I. if ( cond4)
Rd ← Rx ∨ Ry;

**Syntax:**

I. or{cond4} Rd, Rx, Ry

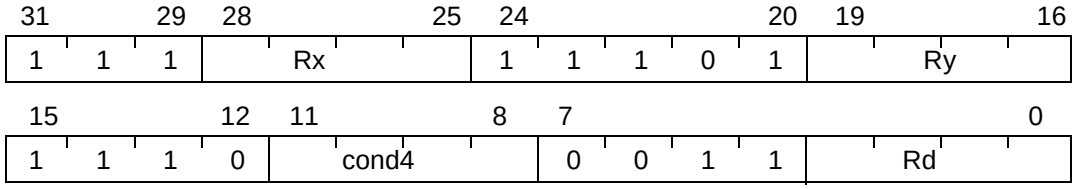
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## ORH, ORL – Logical OR into high or low half of register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a bitwise logical OR between the high or low word in the specified register and a constant. The result is stored in the destination register.

**Operation:**
I. Rd[31:16] ← Rd[31:16] ∨ imm16;
II. Rd[15:0] ← Rd[15:0] ∨ imm16;

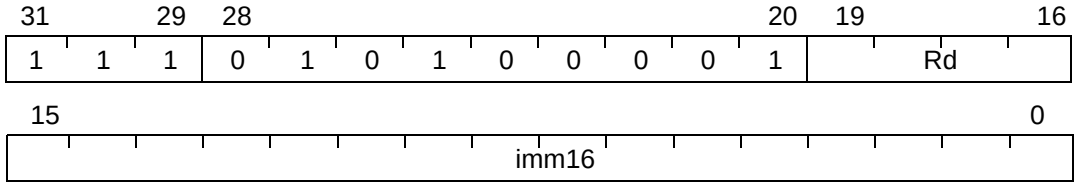
**Syntax:**
I. orh Rd, imm
II. orl Rd, imm

**Operands:**
I, II. d ∈ {0, 1, …, 15}
imm ∈ {0, 1, ..., 65535}

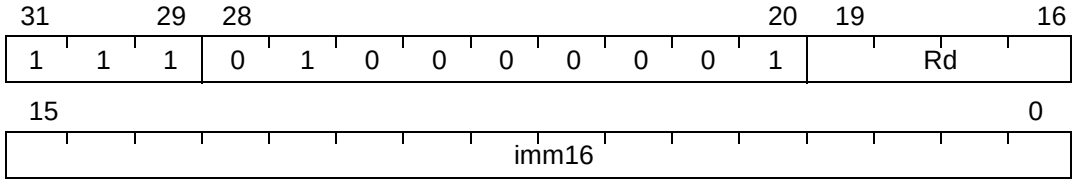
**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** Not affected

**Opcode**

**Format I:**




**Format II:**



## PABS.{SB/SH} – Packed absolute value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Compute the absolute values of four packed signed bytes (pabs.sb) or two packed signed halfwords (pabs.sh) from the source register and store the results as packed bytes or halfwords in the destination register.

**Operation:**

I. Rd[31:24] ← | Rs[31:24] |; Rd[23:16] ← | Rs[23:16] |;
Rd[15:8] ← | Rs[15:8] |; Rd[7:0] ← | Rs[7:0] |;

II. Rd[31:16] ← | Rs[31:16] |;
Rd[15:0] ← | Rs[15:0] |;

**Syntax:**

| | | |
|---|---|---|
| I. | pabs.sb | Rd, Rs |
| II. | pabs.sh | Rd, Rs |

**Operands:**

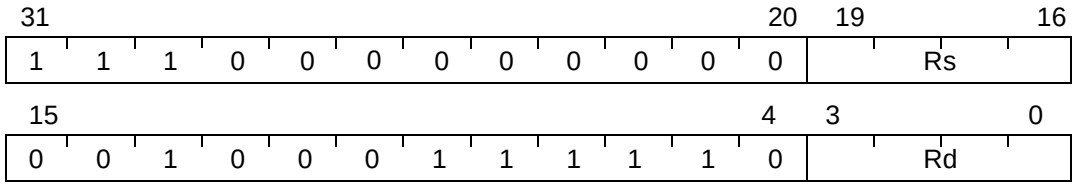
I, II. {d, s} ∈ {0, 1, …, 15}

**Status Flags:**

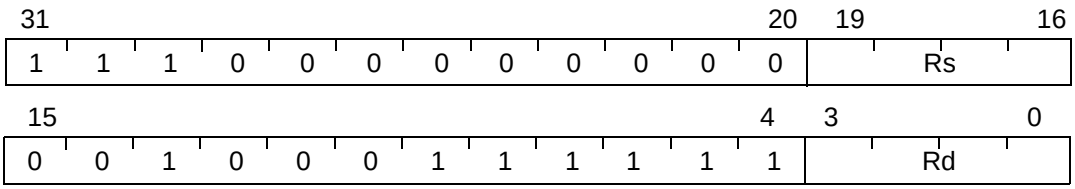
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PACKSH.{UB/SB} – Pack Signed Halfwords to Bytes

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Pack the four signed halfwords located in the two source registers into four bytes in the destination register. Each of the signed halfwords are saturated to unsigned (packsh.ub) or signed bytes (packsh.sb).

**Operation:**

I. Rd[31:24] ← SATSU(Rx[31:16], 8); Rd[23:16] ← SATSU(Rx[15:0], 8);
Rd[15:8] ← SATSU(Ry[31:16], 8); Rd[7:0] ← SATSU(Ry[15:0], 8);

II. Rd[31:24] ← SATS(Rx[31:16], 8); Rd[23:16] ← SATS(Rx[15:0], 8);
Rd[15:8] ← SATS(Ry[31:16], 8); Rd[7:0] ← SATS(Ry[15:0], 8);

**Syntax:**

I. packsh.ub Rd, Rx, Ry
II. packsh.sb Rd, Rx, Ry

**Operands:**

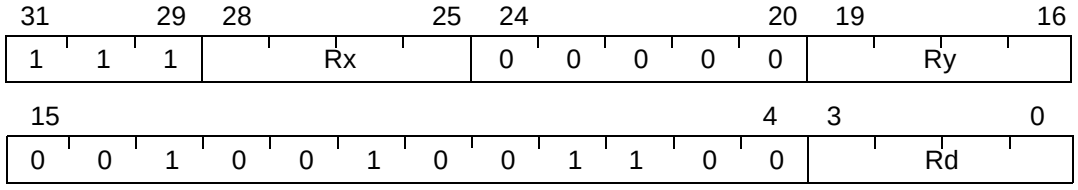
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

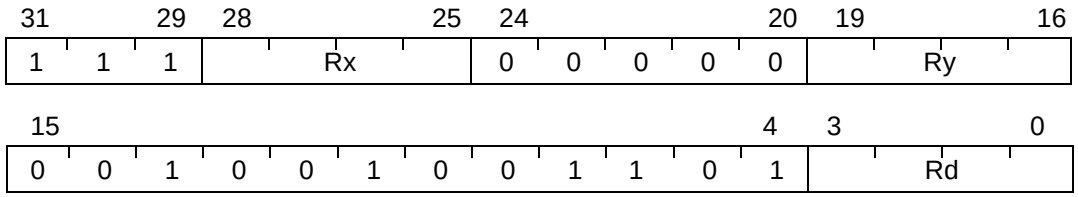
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PACKW.SH – Pack Words to Signed Halfwords

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Pack the two words given in the source registers into two halfwords in the destination register. Each of the words are saturated to signed halfwords before being packed.

**Operation:**

I. Rd[31:16] ← SATS(Rx, 16);
Rd[15:0] ← SATS(Ry, 16);

**Syntax:**

I. packw.sh Rd, Rx, Ry

**Operands:**

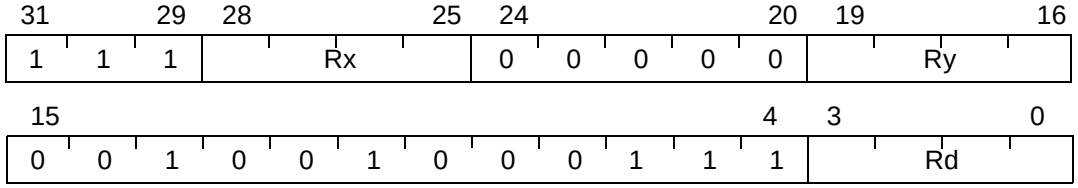
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PADD.{B/H} – Packed Addition

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform addition of four pairs of packed bytes (padd.b) or two pairs of halfwords (padd.h). Upon overflow any additional bits are discarded and the result is wrapped around.

**Operation:**

I. Rd[31:24] ← Rx[31:24] + Ry[31:24]; Rd[23:16] ← Rx[23:16] + Ry[23:16];
Rd[15:8] ← Rx[15:8] + Ry[15:8]; Rd[7:0] ← Rx[7:0] + Ry[7:0];

II. Rd[31:16] ← Rx[31:16] + Ry[31:16];
Rd[15:0] ← Rx[15:0] + Ry[15:0];

**Syntax:**

| | | |
|---|---|---|
| I. | padd.b | Rd, Rx, Ry |
| II. | padd.h | Rd, Rx, Ry |

**Operands:**

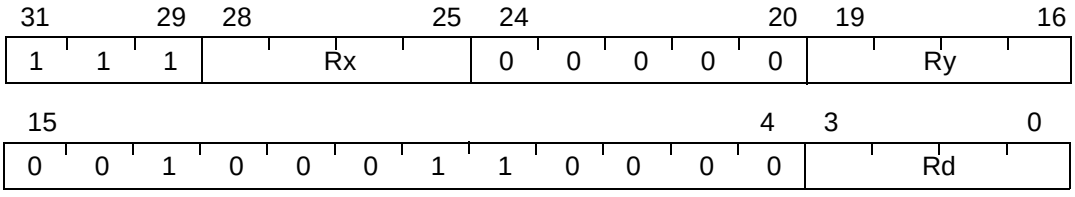
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

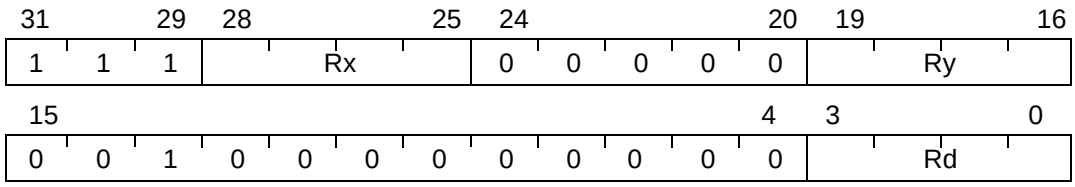
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PADDH.{UB/SH} – Packed Addition with Halving

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform addition of four pairs of packed unsigned bytes (paddh.ub) or two pairs of packed signed halfwords (paddh.sh) with a halving of the result to prevent any overflows from occuring.

**Operation:**

I. Rd[31:24] ← LSR(ZE(Rx[31:24], 9) + ZE(Ry[31:24], 9), 1) ;
Rd[23:16] ← LSR(ZE(Rx[23:16], 9) + ZE(Ry[23:16], 9), 1);
Rd[15:8] ← LSR(ZE(Rx[15:8], 9) + ZE(Ry[15:8], 9), 1);
Rd[7:0] ← LSR(ZE(Rx[7:0], 9) + ZE(Ry[7:0], 9), 1);

II. Rd[31:16] ← ASR(SE(Rx[31:16], 17) + SE(Ry[31:16], 17), 1);
Rd[15:0] ← ASR(SE(Rx[15:0], 17) + SE(Ry[15:0], 17), 1);

**Syntax:**

| | | |
|---|---|---|
| I. | paddh.ub | Rd, Rx, Ry |
| II. | paddh.sh | Rd, Rx, Ry |

**Operands:**

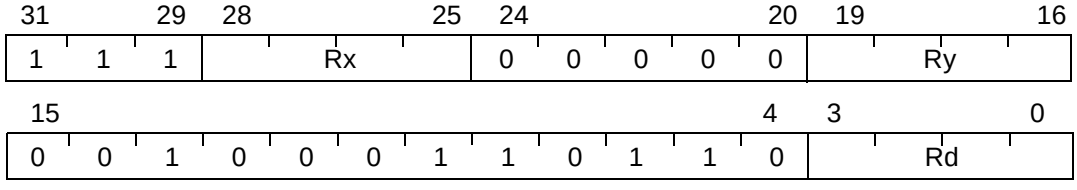
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

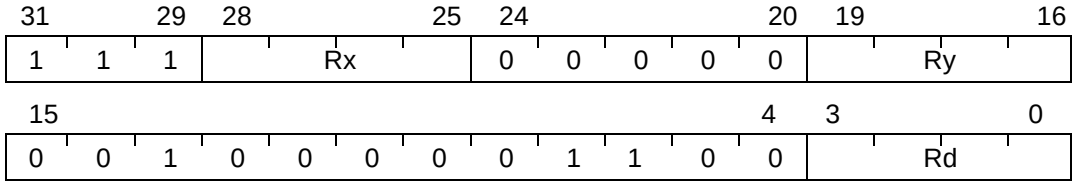
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PADDS.{UB/SB/UH/SH} – Packed Addition with Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform addition of four pairs of packed bytes or two pairs of halfwords. The result is saturated to either unsigned bytes (padds.ub), signed bytes (padds.sb), unsigned halfwords (padds.uh) or signed halfwords (padds.sh).

**Operation:**

I. Rd[31:24] ← SATU(ZE(Rx[31:24], 9) + ZE(Ry[31:24], 9), 8) ;
Rd[23:16] ← SATU(ZE(Rx[23:16], 9) + ZE(Ry[23:16], 9), 8);
Rd[15:8] ← SATU(ZE(Rx[15:8], 9) + ZE(Ry[15:8], 9), 8);
Rd[7:0] ← SATU(ZE(Rx[7:0], 9) + ZE(Ry[7:0], 9), 8);

II. Rd[31:24] ← SATS(SE(Rx[31:24], 9) + SE(Ry[31:24], 9), 8);
Rd[23:16] ← SATS(SE(Rx[23:16], 9) + SE(Ry[23:16], 9), 8);
Rd[15:8] ← SATS(SE(Rx[15:8], 9) + SE(Ry[15:8], 9), 8);
Rd[7:0] ← SATS(SE(Rx[7:0], 9) + SE(Ry[7:0], 9), 8);

III. Rd[31:16] ← SATU(ZE(Rx[31:16], 17) + ZE(Ry[31:16], 17), 16);
Rd[15:0] ← SATU(ZE(Rx[15:0], 17) + ZE(Ry[15:0], 17), 16);

IV. Rd[31:16] ← SATS(SE(Rx[31:16], 17) + SE(Ry[31:16], 17), 16);
Rd[15:0] ← SATS(SE(Rx[15:0], 17) + SE(Ry[15:0], 17), 16);

**Syntax:**

| | | |
|---|---|---|
| I. | padds.ub | Rd, Rx, Ry |
| II. | padds.sb | Rd, Rx, Ry |
| III. | padds.uh | Rd, Rx, Ry |
| IV. | padds.sh | Rd, Rx, Ry |

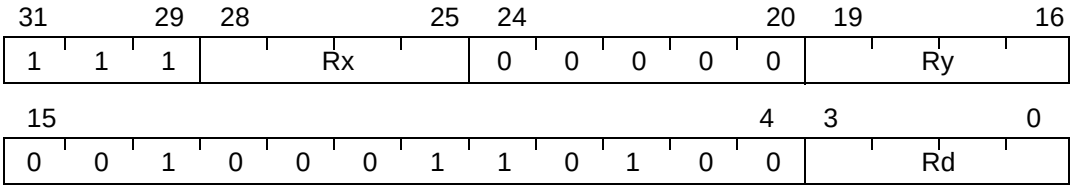
**Operands:**
I, II, III, IV.{d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

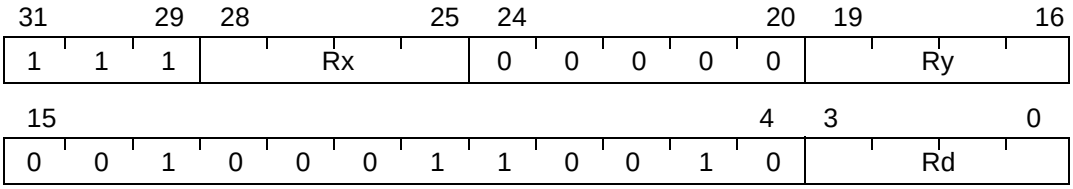
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

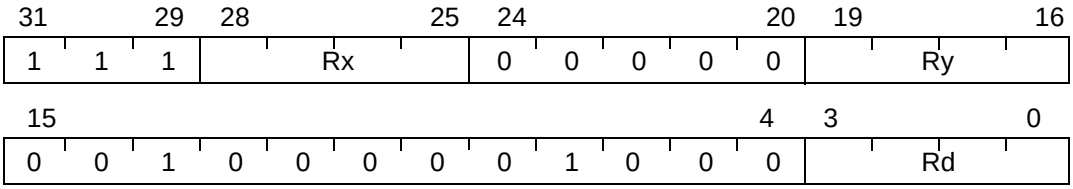
**Format I:**



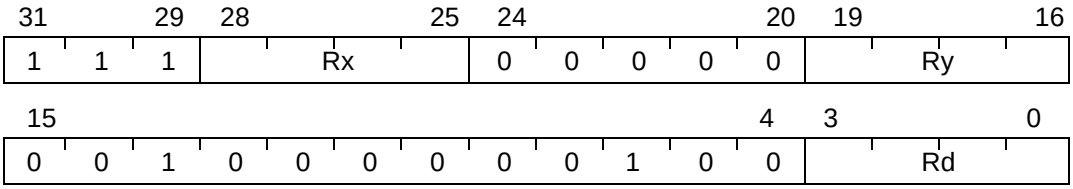

**Format II:**




**Format III:**




**Format IV:**



## PADDSUB.H – Packed Halfword Addition and Subtraction

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform an addition and subtraction on the same halfword operands which are selected from the source registers. The two halfword results are packed into the destination register without performing any saturation.

**Operation:**

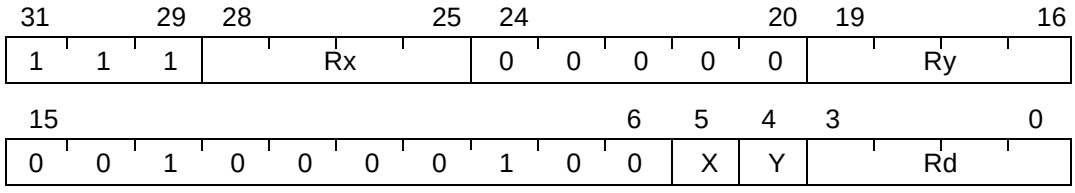
I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← operand1 + operand2;
Rd[15:0] ← operand1 - operand2;

**Syntax:**
I. paddsub.h Rd, Rx:<part>, Ry:<part>

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**
**Format I:**



## PADDSUBH.SH – Packed Halfword Addition and Subtraction with Halving

### Description

Perform an addition and subtraction on the same signed halfword operands which are selected from the source registers. The halfword results are halved in order to prevent any overflows from occuring

### Operation:

I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← ASR(SE(operand1, 17) + SE(operand2, 17), 1);
Rd[15:0] ← ASR(SE(operand1, 17) - SE(operand2, 17), 1);

### Syntax:

I. paddsubh.sh Rd, Rx:<part>, Ry:<part>

### Operands:

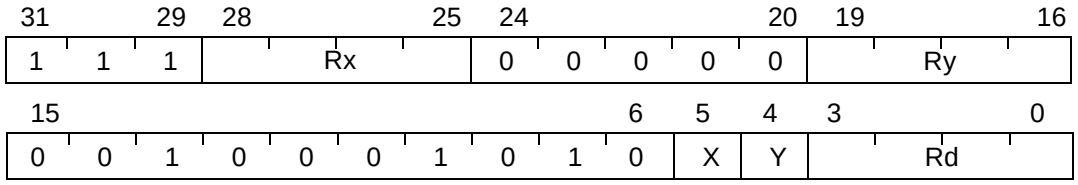
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

### Status Flags:

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

### Opcode:

**Format I:**



## PADDSUBS.{UH/SH} – Packed Halfword Addition and Subtraction with Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform an addition and subtraction on the same halfword operands which are selected from the source registers. The resulting halfwords are saturated to unsigned halfwords (paddsubs.uh) or signed halfwords (paddsubs.sh) and then packed together in the destination register.

**Operation:**

I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← SATU(ZE(operand1, 17) + ZE(operand2, 17), 16);
Rd[15:0] ← SATSU(ZE(operand1, 17) - ZE(operand2, 17), 16);

II. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← SATS(SE(operand1, 17) + SE(operand2, 17), 16);
Rd[15:0] ← SATS(SE(operand1, 17) - SE(operand2, 17), 16);

**Syntax:**

I. paddsubs.uh Rd, Rx:<part>, Ry:<part>
II. paddsubs.sh Rd, Rx:<part>, Ry:<part>

**Operands:**

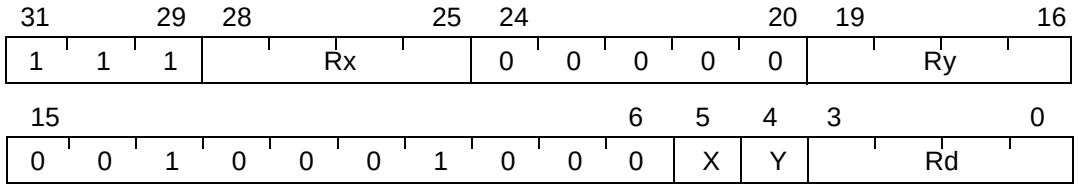
I,II. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

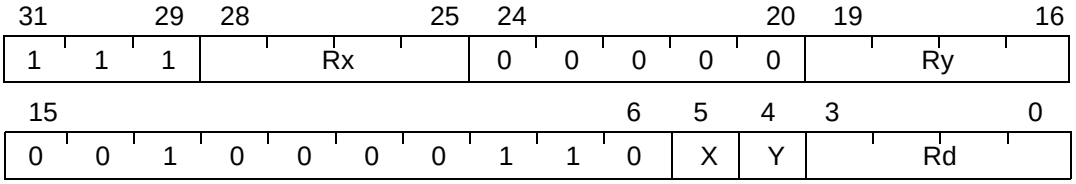
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PADDX.H – Packed Halfword Addition with Crossed Operand

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Add together the top halfword of Rx with the bottom halfword of Ry and the bottom halfword of Rx with the top halfword of Ry. The resulting halfwords are packed together in the destination register without performing any saturation.

**Operation:**

I. Rd[31:16] ← Rx[31:16] + Ry[15:0] ;
Rd[15:0] ← Rx[15:0] + Ry[31:16];

**Syntax:**

I. paddx.h Rd, Rx, Ry

**Operands:**

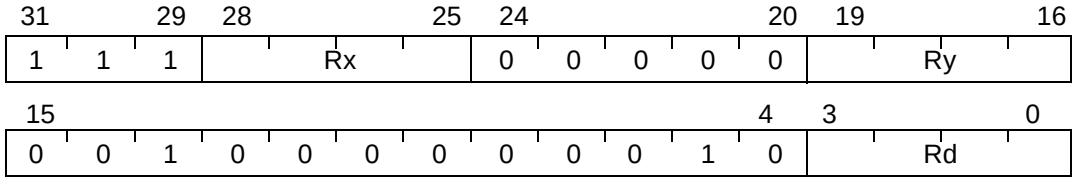
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PADDXH.SH – Packed Signed Halfword Addition with Crossed Operand and Halving

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Add together the top halfword of Rx with the bottom halfword of Ry and the bottom halfword of Rx with the top halfword of Ry. The resulting halfwords are halved in order to avoid any overflow and then packed together in the destination register.

**Operation:**

I. Rd[31:16] ← ASR(SE(Rx[31:16], 17) + SE(Ry[15:0], 17), 1);
Rd[15:0] ← ASR(SE(Rx[15:0], 17) + SE(Ry[31:16], 17), 1);

**Syntax:**

I. paddxh.sh Rd, Rx, Ry

**Operands:**

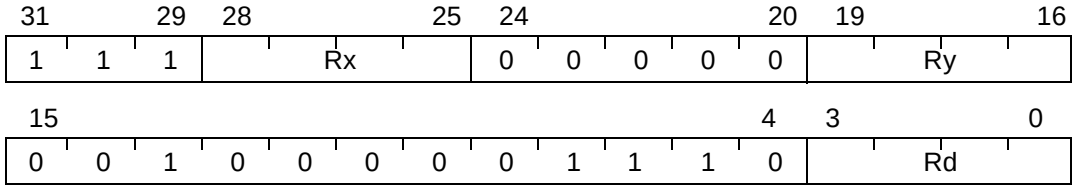
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PADDXS.{UH/SH} – Packed Halfword Addition with Crossed Operand and Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Add together the top halfword of Rx with the bottom halfword of Ry and the bottom halfword of Rx with the top halfword of Ry. The resulting halfwords are saturated to unsigned halfwords (paddxh.uh) or signed halfwords (paddxh.sh) and then packed together in the destination register.

**Operation:**

I. Rd[31:16] ← SATU(ZE(Rx[31:16], 17) + ZE(Ry[15:0], 17), 16) ;
Rd[15:0] ← SATU(ZE(Rx[15:0], 17) + ZE(Ry[31:16], 17), 16);

II. Rd[31:16] ← SATS(SE(Rx[31:16], 17) + SE(Ry[15:0], 17), 16) ;
Rd[15:0] ← SATS(SE(Rx[15:0], 17) + SE(Ry[31:16], 17), 16);

**Syntax:**

| | | |
|---|---|---|
| I. | paddxs.uh | Rd, Rx, Ry |
| II. | paddxs.sh | Rd, Rx, Ry |

**Operands:**

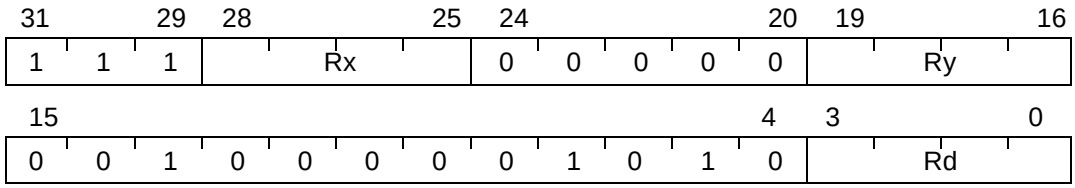
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

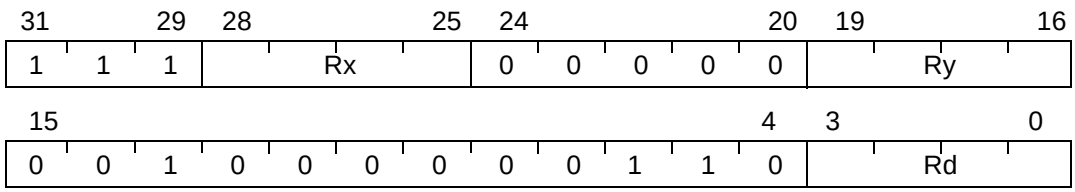
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PASR.{B/H} – Packed Arithmetic Shift Right

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform an arithmetic shift right on each of the packed bytes or halfwords in the source register.

**Operation:**

I. Rd[31:24] ← ASR(Rs[31:24], sa3);
Rd[23:16] ← ASR(Rs[23:16], sa3);
Rd[15:8] ← ASR(Rs[15:8], sa3);
Rd[7:0] ← ASR(Rs[7:0], sa3);

II. Rd[31:16] ← ASR(Rs[31:16], sa4);
Rd[15:0] ← ASR(Rs[15:0], sa4);

**Syntax:**

| | | |
|---|---|---|
| I. | pasr.b | Rd, Rs, sa |
| II. | pasr.h | Rd, Rs, sa |

**Operands:**

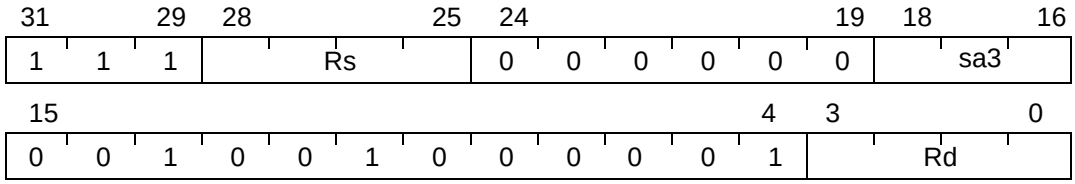
I, II. {d, s} ∈ {0, 1, …, 15}
I. sa ∈ {0, 1, …, 7}
II. sa ∈ {0, 1, …, 15}

**Status Flags:**

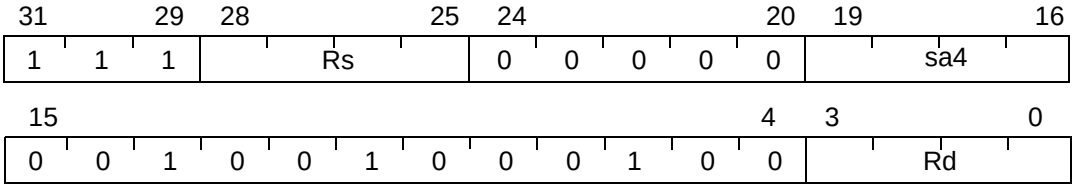
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PAVG.{UB/SH} – Packed Average

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Computes the average of pairs of packed unsigned bytes (pavg.ub) or packed signed halfwords (pavg.sh). The averages are computed by adding two values together while also adding in a rounding factor in the least significant bit. The result is then halved by shifting it one position to the right.

**Operation:**

I. Rd[31:24] ← LSR(ZE(Rx[31:24], 9) + ZE(Ry[31:24], 9) + 1, 1);
Rd[23:16] ← LSR(ZE(Rx[23:16], 9) + ZE(Ry[23:16], 9) + 1, 1);
Rd[15:8] ← LSR(ZE(Rx[15:8], 9) + ZE(Ry[15:8], 9) + 1, 1);
Rd[7:0] ← LSR(ZE(Rx[7:0], 9) + ZE(Ry[7:0], 9) + 1, 1);

II. Rd[31:16] ← ASR(SE(Rx[31:16], 17) + SE(Ry[31:16], 17) + 1, 1);
Rd[15:0] ← ASR(SE(Rx[15:0], 17) + SE(Ry[15:0], 17) + 1, 1);

**Syntax:**

| | | |
|---|---|---|
| I. | pavg.ub | Rd, Rx, Ry |
| II. | pavg.sh | Rd, Rx, Ry |

**Operands:**

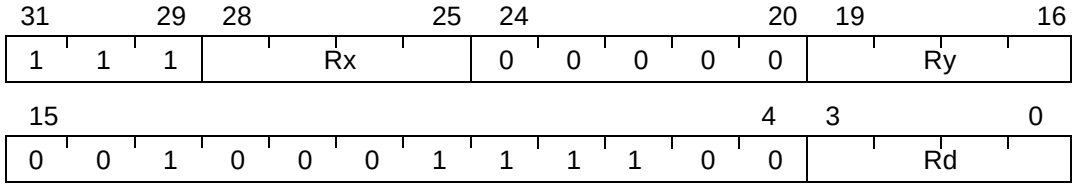
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

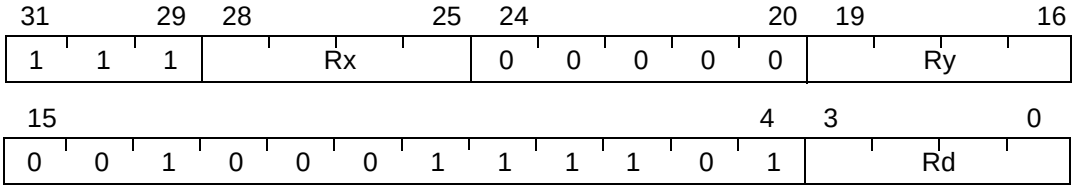
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PLSL.{B/H} – Packed Logical Shift Left

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a logical shift left on each of the packed bytes or halfwords in the source register and store the result to the destination register.

**Operation:**

I. Rd[31:24] ← LSL(Rs[31:24], sa3);
Rd[23:16] ← LSL(Rs[23:16], sa3);
Rd[15:8] ← LSL(Rs[15:8], sa3);
Rd[7:0] ← LSL(Rs[7:0], sa3);

II. Rd[31:16] ← LSL(Rs[31:16], sa4);
Rd[15:0] ← LSL(Rs[15:0], sa4);

**Syntax:**

| | | |
|---|---|---|
| I. | plsl.b | Rd, Rs, sa |
| II. | plsl.h | Rd, Rs, sa |

**Operands:**

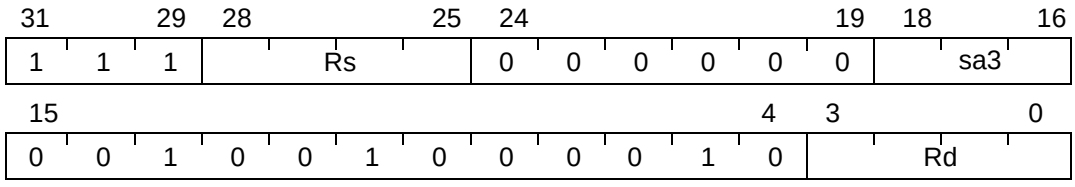
I, II. {d, s} ∈ {0, 1, …, 15}
I. sa ∈ {0, 1, …, 7}
II. sa ∈ {0, 1, …, 15}

**Status Flags:**

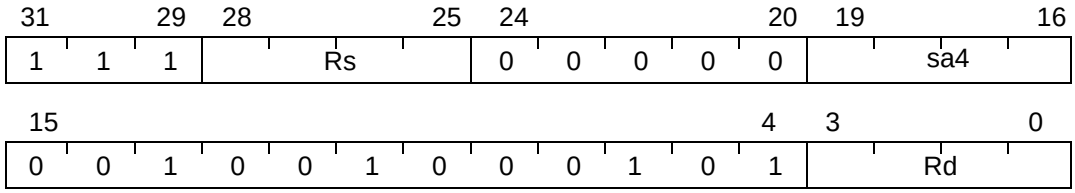
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PLSR.{B/H} – Packed Logical Shift Right

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a logical shift right on each of the packed bytes or halfwords in the source register and store the result to the destination register.

**Operation:**

I. Rd[31:24] ← LSR(Rs[31:24], sa3);
Rd[23:16] ← LSR(Rs[23:16], sa3);
Rd[15:8] ← LSR(Rs[15:8], sa3);
Rd[7:0] ← LSR(Rs[7:0], sa3);

II. Rd[31:16] ← LSR(Rs[31:16], sa4);
Rd[15:0] ← LSR(Rs[15:0], sa4);

**Syntax:**

| | | |
|---|---|---|
| I. | plsr.b | Rd, Rs, sa |
| II. | plsr.h | Rd, Rs, sa |

**Operands:**

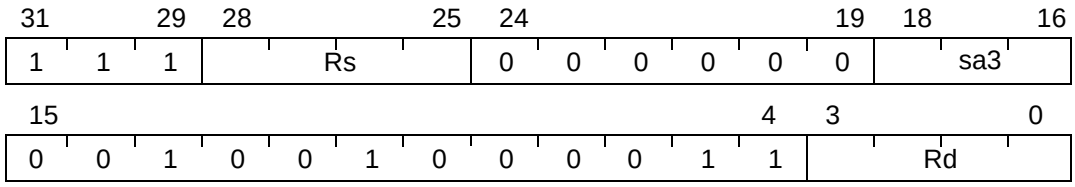
I, II. {d, s} ∈ {0, 1, …, 15}
I. sa ∈ {0, 1, …, 7}
II. sa ∈ {0, 1, …, 15}

**Status Flags:**

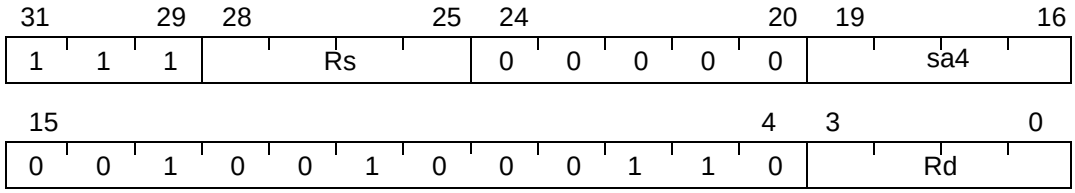
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PMAX.{UB/SH} – Packed Maximum Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Compute the maximum values of pairs of packed unsigned bytes (pmax.ub) or packed signed halfwords (pmax.sh).

**Operation:**

I. If ( Rx[31:24] > Ry[31:24] ) then Rd[31:24] ← Rx[31:24] else Rd[31:24] ← Ry[31:24] ;
If ( Rx[23:16] > Ry[23:16] ) then Rd[23:16] ← Rx[23:16] else Rd[23:16] ← Ry[23:16] ;
If ( Rx[15:8] > Ry[15:8] ) then Rd[15:8] ← Rx[15:8] else Rd[15:8] ← Ry[15:8] ;
If ( Rx[7:0] > Ry[7:0] ) then Rd[7:0] ← Rx[7:0] else Rd[7:0] ← Ry[7:0] ;

II. If ( Rx[31:16] > Ry[31:16] ) then Rd[31:16] ← Rx[31:16] else Rd[31:16] ← Ry[31:16] ;
If ( Rx[15:0] > Ry[15:0] ) then Rd[15:0] ← Rx[15:0] else Rd[15:0] ← Ry[15:0] ;

**Syntax:**

I. pmax.ub Rd, Rx, Ry
II. pmax.sh Rd, Rx, Ry

**Operands:**

I, II. {d, x, y} ∈ {0, 1, …, 15}

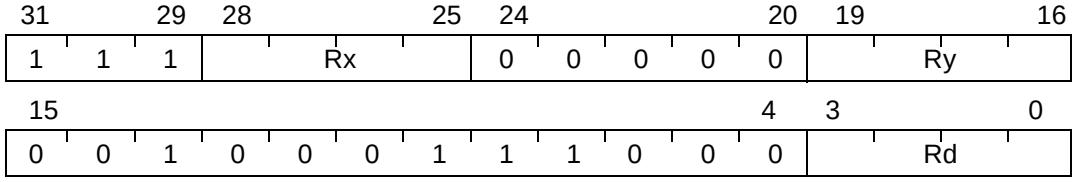
**Status Flags:**

**Format I:**
**Q:** Not affected.
**V:** ( Rx[7:0] > Ry[7:0] )
**N:** ( Rx[15:8] > Ry[15:8] )
**Z:** ( Rx[23:16] > Ry[23:16] )
**C:** ( Rx[31:24] > Ry[31:24] )

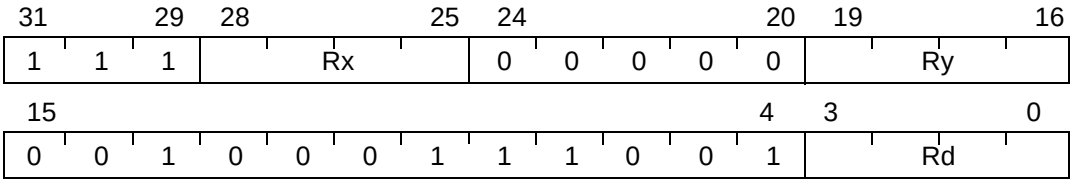
**Format II:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** ( Rx[15:0] > Ry[15:0] )
**C:** ( Rx[31:16] > Ry[31:16] )

**Opcode:**

**Format I:**



**Format II:**



## PMIN.{UB/SH} – Packed Minimum Value

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Compute the minimum values of pairs of packed unsigned bytes (pmin.ub) or packed signed halfwords (pmin.sh).

**Operation:**

I. If ( Rx[31:24] < Ry[31:24] ) then Rd[31:24] ← Rx[31:24] else Rd[31:24] ← Ry[31:24] ;
If ( Rx[23:16] < Ry[23:16] ) then Rd[23:16] ← Rx[23:16] else Rd[23:16] ← Ry[23:16] ;
If ( Rx[15:8] < Ry[15:8] ) then Rd[15:8] ← Rx[15:8] else Rd[15:8] ← Ry[15:8] ;
If ( Rx[7:0] < Ry[7:0] ) then Rd[7:0] ← Rx[7:0] else Rd[7:0] ← Ry[7:0] ;

II. If ( Rx[31:16] < Ry[31:16] ) then Rd[31:16] ← Rx[31:16] else Rd[31:16] ← Ry[31:16] ;
If ( Rx[15:0] < Ry[15:0] ) then Rd[15:0] ← Rx[15:0] else Rd[15:0] ← Ry[15:0] ;

**Syntax:**

| | | |
|---|---|---|
| I. | pmin.ub | Rd, Rx, Ry |
| II. | pmin.sh | Rd, Rx, Ry |

**Operands:**

I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Format I:**

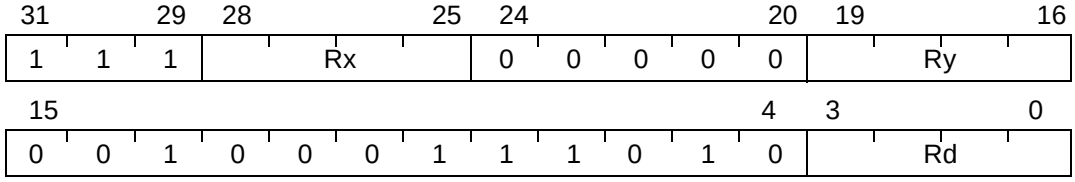
**Q:** Not affected.
**V:** ( Rx[7:0] < Ry[7:0] )
**N:** ( Rx[15:8] < Ry[15:8] )
**Z:** ( Rx[23:16] < Ry[23:16] )
**C:** ( Rx[31:24] < Ry[31:24] )

**Format II:**

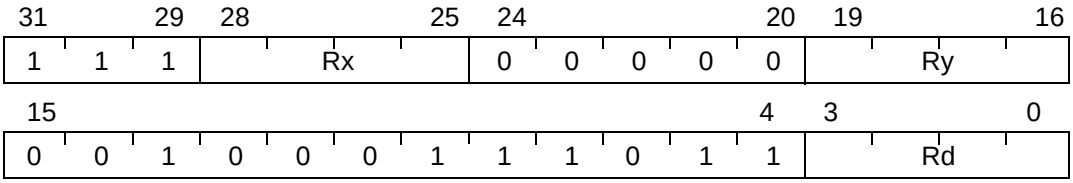
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** ( Rx[15:0] < Ry[15:0] )
**C:** ( Rx[31:16] < Ry[31:16] )

**Opcode:**

**Format I:**



**Format II:**



## POPJC – Pop Java Context from Frame

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Fetch the system registers LV0 to LV7 used in Java state from the current method frame. The register FRAME (equal to R9) is used as pointer register.

**Operation:**

I.
```
temp ←FRAME;
JAVA_LV0 ←*(temp--);
JAVA_LV1 ←*(temp--);
JAVA_LV2 ←*(temp--);
JAVA_LV3 ←*(temp--);
JAVA_LV4 ←*(temp--);
JAVA_LV5 ←*(temp--);
JAVA_LV6 ←*(temp--);
JAVA_LV7 ←*(temp--);
```

**Syntax:**

I. popjc

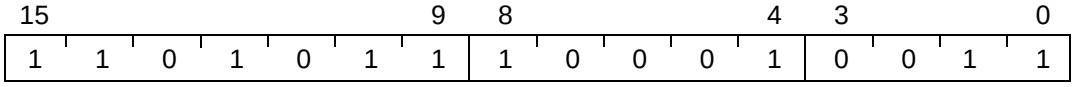
**Operands:**

I. none

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## POPM – Pop Multiple Registers from Stack

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Loads the consecutive words pointed to by SP into the registers specified in the instruction. The PC can be loaded, resulting in a jump to the loaded value. If PC is popped, the return value in R12 is tested and the flags are updated. R12 can optionally be updated with -1, 0 or 1. The k bit in the instruction coding is used to optionally let the POPM instruction update the return register R12 with the values -1, 0 or 1.

**Operation:**

```
I.      if Reglist8[PC] ∧ k == B'1
            PC  ← *(SP++)
            if Reglist8[LR:R12] == B'00
                R12  ←  0;
            else if Reglist8[LR:R12] == B'01
                R12  ←  1;
            else
                R12  ←  −1;
            Test R12 and update flags;
        else
            if Reglist8[PC] == 1 then
                PC  ← *(SP++);
            if Reglist8[LR] == 1 then
                LR  ← *(SP++);
            if Reglist8[R12] == 1 then
                R12  ←*(SP++);
            if Reglist8[PC] == 1 then
                Test R12 and update flags;

        if Reglist8[5] == 1 then
            R11  ←*(SP++);
        if Reglist8[4] == 1 then
            R10  ←*(SP++);
        if Reglist8[3] == 1 then
            R9  ← *(SP++);
            R8  ← *(SP++);
        if Reglist8[2] == 1 then
            R7  ← *(SP++);
            R6  ← *(SP++);
            R5  ← *(SP++);
            R4  ← *(SP++);
        if Reglist8[1] == 1 then
            R3  ← *(SP++);
```

R2 ← *(SP++);
R1 ← *(SP++);
R0 ← *(SP++);

**Syntax:**

I. popm Reglist8 {, R12 = {-1, 0, 1}}
If the optional R12 = {-1, 0, 1} parameter is specified, PC must be in Reglist8.
If the optional R12 = {-1, 0, 1} parameter is specified, LR should NOT be in Reglist8.

**Operands:**

I. Reglist8 ∈ {R0- R3, R4-R7, R8-R9, R10,R11, R12, LR, PC}

**Status Flags:**

**Flags are only updated if Reglist8[PC] == 1.**
**They are set as the result of the operation cp R12, 0**

**Q:** Not affected
**V:** V ← 0
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← 0

**Opcode:**

| 15 | | | | | | | | | | | | 3 | 2 | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | PC | LR | 12 | 11 | 10 | 9-8 | 7-4 | 3-0 | k | 0 | 1 | 0 |

**Note:**

Emtpy Reglist8 gives UNDEFINED result.
The R bit in the status register has no effect on this instruction.

## PREF – Cache Prefetch

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction allows the programmer to explicitly state that the cache should prefetch the specified line. The memory system treats this instruction in an implementation-dependent manner, and implementations without cache treats the instruction as a NOP. A prefetch instruction never reduces the performance of the system. If the prefetch instruction performs an action that would lower the system performance, it is treated as a NOP. For example, if the prefetch instruction is about to generate an addressing exception, the instruction is cancelled and no exception is taken.

**Operation:**
I. Prefetch cache line containing the address (Rp + SE(disp16)).

**Syntax:**

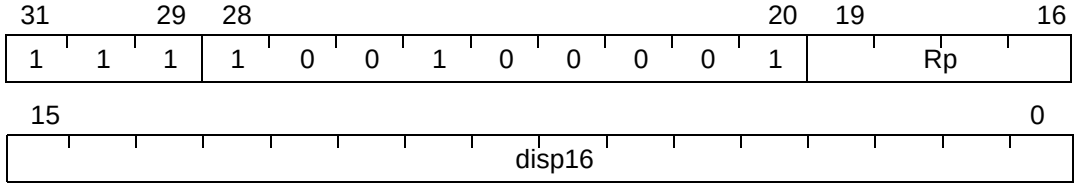
```
pref    Rp[disp]
```

**Operands:**
I. $p \in \{0, 1, \ldots, 15\}$
$disp \in \{-32768, -32767, ..., 32767\}$

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## PSAD – Packed Sum of Absolute Differences

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Compute the Sum of Absolute Differences (SAD) of four pairs of packed unsigned bytes from the source registers and store the result in the destination register.

**Operation:**

I. Rd ← | Rx[31:24] - Ry[31:24] | + | Rx[23:16] - Ry[23:16] | +
| Rx[15:8] - Ry[15:8] | + | Rx[7:0] - Ry[7:0] |;

**Syntax:**

I. psad Rd, Rx, Ry

**Operands:**

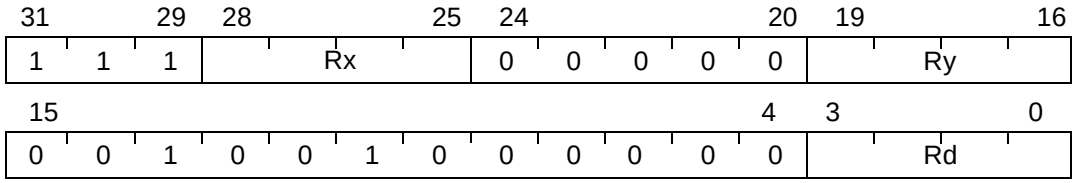
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PSUB.{B/H} – Packed Subtraction

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform subtraction of four pairs of packed bytes (psub.b) or two pairs of halfwords (psub.h). Upon overflow any additional bits are discarded and the result is wrapped around.

**Operation:**

I. Rd[31:24] ← Rx[31:24] - Ry[31:24]; Rd[23:16] ← Rx[23:16] - Ry[23:16];
Rd[15:8] ← Rx[15:8] - Ry[15:8]; Rd[7:0] ← Rx[7:0] - Ry[7:0];

II. Rd[31:16] ← Rx[31:16] - Ry[31:16];
Rd[15:0] ← Rx[15:0] - Ry[15:0];

**Syntax:**

| | | |
|---|---|---|
| I. | psub.b | Rd, Rx, Ry |
| II. | psub.h | Rd, Rx, Ry |

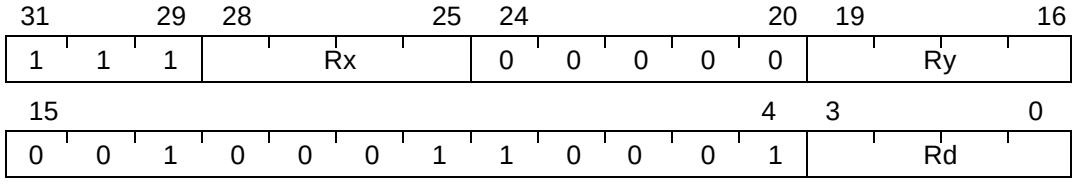
**Operands:**
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

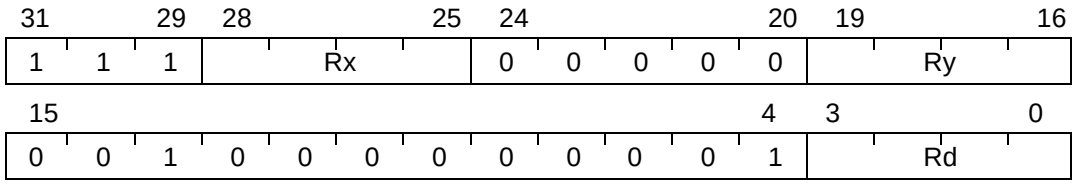
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PSUBADD.H – Packed Halfword Subtraction and Addition

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform an subtraction and addition on the same halfword operands which are selected from the source registers. The two halfword results are packed into the destination register without performing any saturation.

**Operation:**

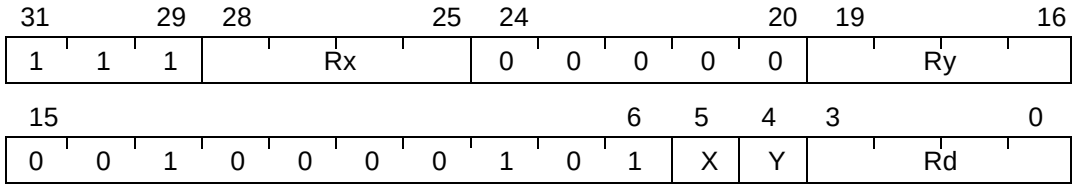
I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← operand1 - operand2;
Rd[15:0] ← operand1 + operand2;

**Syntax:**
I. psubadd.h Rd, Rx:<part>, Ry:<part>

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**
**Format I:**



## PSUBADDH.SH – Packed Signed Halfword Subtraction and Addition with Halving

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a subtraction and addition on the same halfword operands which are selected from the source registers. The halfword results are halved in order to prevent any overflows from occuring

**Operation:**

I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← ASR(SE(operand1, 17) - SE(operand2, 17), 1);
Rd[15:0] ← ASR(SE(operand1, 17) + SE(operand2, 17), 1);

**Syntax:**
I. psubaddh.sh Rd, Rx:<part>, Ry:<part>

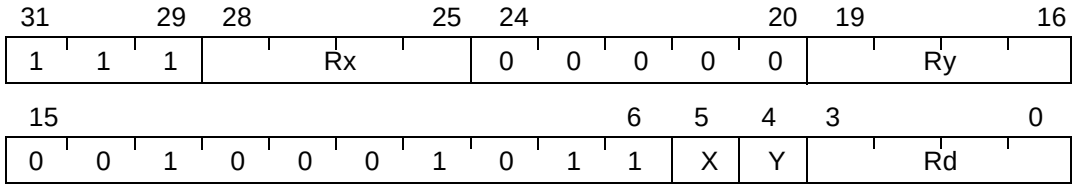
**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PSUBADDS.{UH/SH} – Packed Halfword Subtraction and Addition with Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform a subtraction and addition on the same halfword operands which are selected from the source registers. The resulting halfwords are saturated to unsigned halfwords (psubadds.uh) or signed halfwords (psubadds.sh) and then packed together in the destination register.

**Operation:**

I. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← SATSU(ZE(operand1, 17) - ZE(operand2, 17), 16);
Rd[15:0] ← SATU(ZE(operand1, 17) + ZE(operand2, 17), 16);

II. If (Rx-part == t) then operand1 = Rx[31:16] else operand1 = Rx[15:0];
If (Ry-part == t) then operand2 = Ry[31:16] else operand2 = Ry[15:0];
Rd[31:16] ← SATS(SE(operand1, 17) - SE(operand2, 17), 16 );
Rd[15:0] ← SATS(SE(operand1, 17) + SE(operand2, 17), 16);

**Syntax:**

I. psubadds.uh Rd, Rx:<part>, Ry:<part>
II. psubadds.sh Rd, Rx:<part>, Ry:<part>

**Operands:**

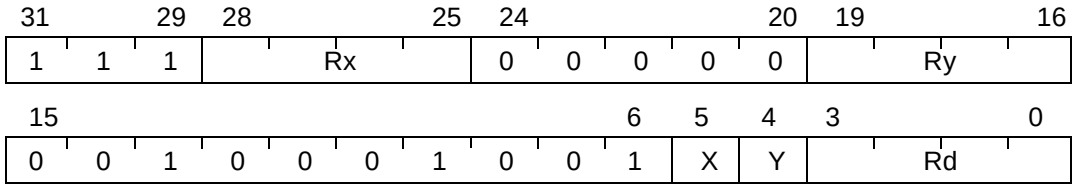
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**

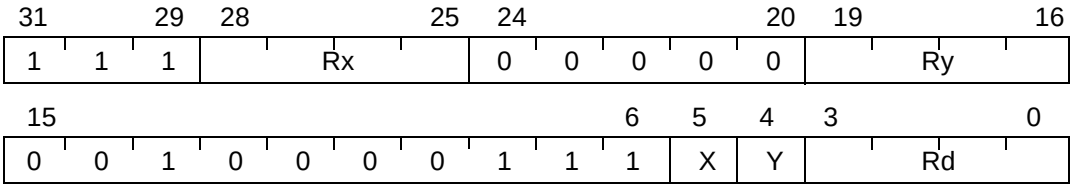
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PSUBH.{UB/SH} – Packed Subtraction with Halving

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform subtraction of four pairs of packed unsigned bytes (psub.ub) or two pairs of signed half-words (psub.sh) with a halfing of the result to prevent any overflows from occuring.

**Operation:**

I. Rd[31:24] ← LSR(ZE(Rx[31:24], 9) - ZE(Ry[31:24], 9), 1);
Rd[23:16] ← LSR(ZE(Rx[23:16], 9) - ZE(Ry[23:16], 9), 1);
Rd[15:8] ← LSR(ZE(Rx[15:8], 9) - ZE(Ry[15:8], 9), 1);
Rd[7:0] ← LSR(ZE(Rx[7:0], 9) - ZE(Ry[7:0], 9), 1);

II. Rd[31:16] ← ASR(SE(Rx[31:16], 17) - SE(Ry[31:16], 17), 1);
Rd[15:0] ← ASR(SE(Rx[15:0], 17) - SE(Ry[15:0], 17), 1);

**Syntax:**

| | | |
|---|---|---|
| I. | psubh.ub | Rd, Rx, Ry |
| II. | psubh.sh | Rd, Rx, Ry |

**Operands:**

I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | Rx | | | | 0 | 0 | 0 | 0 | 0 | Ry | | | |

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

**Format II:**

| 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | Rx | | | | 0 | 0 | 0 | 0 | 0 | Ry | | | |

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

## PSUBS.{UB/SB/UH/SH} – Packed Subtraction with Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Perform subtraction of four pairs of packed bytes or two pairs of halfwords. The result is saturated to either unsigned bytes (psubs.ub), signed bytes (psubs.sb), unsigned halfwords (psubs.uh) or signed halfwords (psubs.sh).

**Operation:**

I. Rd[31:24] ← SATSU(ZE(Rx[31:24], 9) - ZE(Ry[31:24], 9), 8) ;
Rd[23:16] ← SATSU(ZE(Rx[23:16], 9) - ZE(Ry[23:16], 9), 8);
Rd[15:8] ← SATSU(ZE(Rx[15:8], 9) - ZE(Ry[15:8], 9), 8);
Rd[7:0] ← SATSU(ZE(Rx[7:0], 9) - ZE(Ry[7:0], 9), 8);

II. Rd[31:24] ← SATS(SE(Rx[31:24], 9) - SE(Ry[31:24], 9), 8);
Rd[23:16] ← SATS(SE(Rx[23:16], 9) - SE(Ry[23:16], 9), 8);
Rd[15:8] ← SATS(SE(Rx[15:8], 9) - SE(Ry[15:8], 9), 8);
Rd[7:0] ← SATS(SE(Rx[7:0], 9) - SE(Ry[7:0], 9), 8);

III. Rd[31:16] ← SATSU(ZE(Rx[31:16], 17) - ZE(Ry[31:16], 17), 16);
Rd[15:0] ← SATSU(ZE(Rx[15:0], 17) - ZE(Ry[15:0], 17), 16);

IV. Rd[31:16] ← SATS(SE(Rx[31:16], 17) - SE(Ry[31:16], 17), 16);
Rd[15:0] ← SATS(SE(Rx[15:0], 17) - SE(Ry[15:0], 17), 16);

**Syntax:**

| | | |
|---|---|---|
| I. | psubs.ub | Rd, Rx, Ry |
| II. | psubs.sb | Rd, Rx, Ry |
| III. | psubs.uh | Rd, Rx, Ry |
| IV. | psubs.sh | Rd, Rx, Ry |

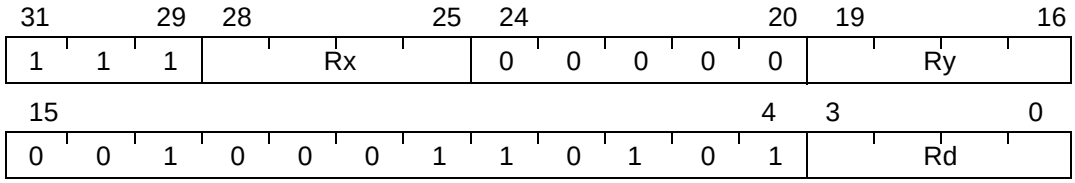
**Operands:**
I, II, III, IV.{d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

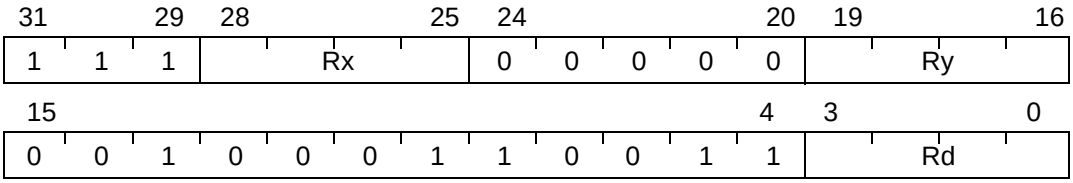
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

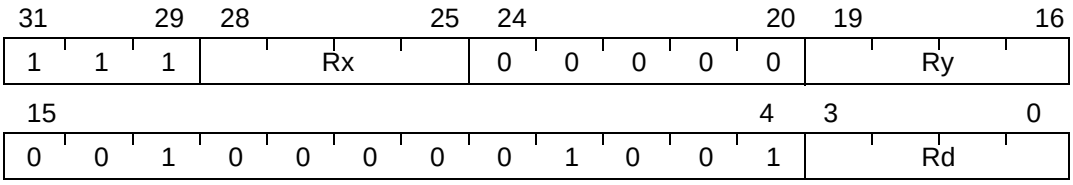
**Format I:**



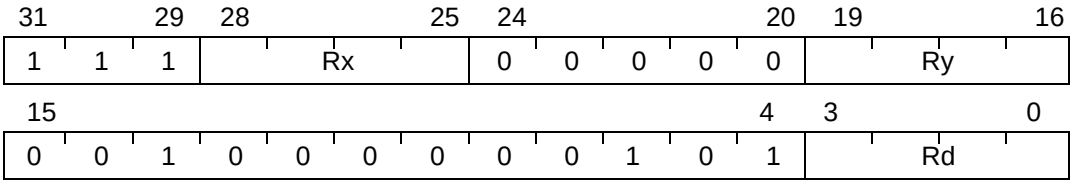
**Format II:**




**Format III:**




**Format IV:**



## PSUBX.H – Packed Halfword Subtraction with Crossed Operand

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtract the bottom halfword of Ry from the top halfword of Rx and the top halfword of Ry from the bottom halfword of Rx. The resulting halfwords are packed together in the destination register without performing any saturation.

**Operation:**

I. Rd[31:16] ← Rx[31:16] - Ry[15:0] ;
Rd[15:0] ← Rx[15:0] - Ry[31:16];

**Syntax:**

I. psubx.h Rd, Rx, Ry

**Operands:**

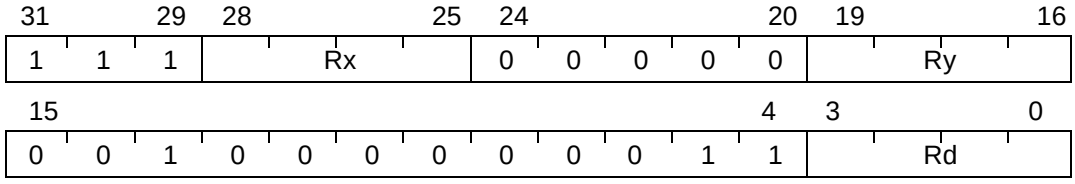
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PSUBXH.SH – Packed Signed Halfword Subtraction with Crossed Operand and Halving

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtract the bottom halfword of Ry from the top halfword of Rx and the top halfword of Ry from the bottom halfword of Rx. The resulting halfwords are halved in order to avoid any overflow and then packed together in the destination register.

**Operation:**

I. Rd[31:16] ← ASR(SE(Rx[31:16], 17) - SE(Ry[15:0], 17), 1);
Rd[15:0] ← ASR(SE(Rx[15:0], 17) - SE(Ry[31:16], 17), 1);

**Syntax:**

I. psubxh.sh Rd, Rx, Ry

**Operands:**

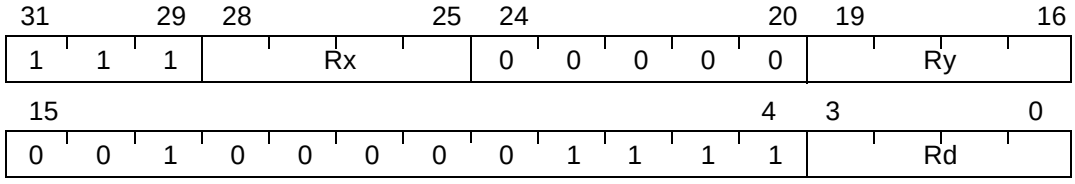
I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



## PSUBXS.{UH/SH} – Packed Halfword Subtraction with Crossed Operand and Saturation

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtract the bottom halfword of Ry from the top halfword of Rx and the top halfword of Ry from the bottom halfword of Rx. The resulting halfwords are saturated to unsigned halfwords (psubxh.uh) or signed halfwords (psubxh.sh) and then packed together in the destination register.

**Operation:**

I. Rd[31:16] ← SATSU(ZE(Rx[31:16], 17) - ZE(Ry[15:0], 17), 16) ;
Rd[15:0] ← SATSU(ZE(Rx[15:0], 17) - ZE(Ry[31:16], 17), 16);

II. Rd[31:16] ← SATS(SE(Rx[31:16], 17) - SE(Ry[15:0], 17), 16) ;
Rd[15:0] ← SATS(SE(Rx[15:0], 17) - SE(Ry[31:16], 17), 16);

**Syntax:**

| | | |
|---|---|---|
| I. | psubxs.uh | Rd, Rx, Ry |
| II. | psubxs.sh | Rd, Rx, Ry |

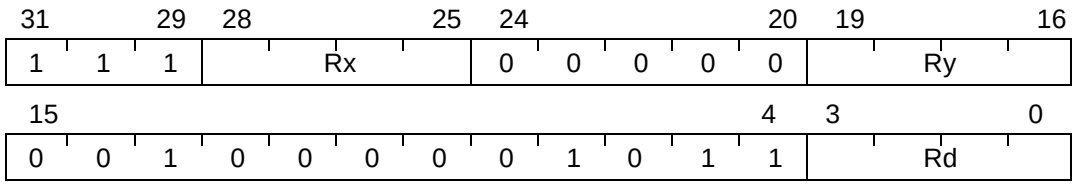
**Operands:**
I, II. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

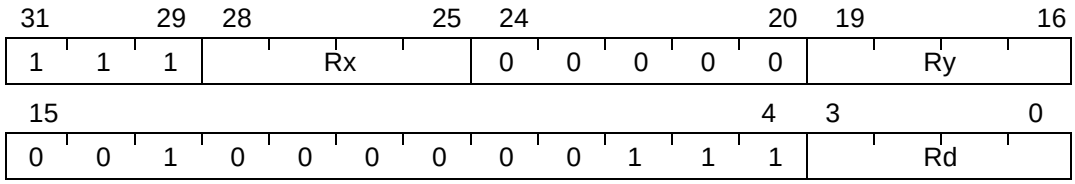
**Q:** Flag set if saturation occured in one or more of the partial operations.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## PUNPCK{SB/UB}.H – Unpack bytes to halfwords

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Unpack two unsigned bytes (punpckub.h) or two signed bytes (punpcksb.h) from the source register to two packed halfwords in the destination register.

**Operation:**

I. If ( Rs-part == top ) then
Rd[31:16] ← ZE(Rs[31:24], 16); Rd[15:0] ← ZE(Rs[23:16], 16);
else
Rd[31:16] ← ZE(Rs[15:8], 16); Rd[15:0] ← ZE(Rs[7:0], 16);

II. If ( Rs-part == top ) then
Rd[31:16] ← SE(Rs[31:24], 16); Rd[15:0] ← SE(Rs[23:16], 16);
else
Rd[31:16] ← SE(Rs[15:8], 16); Rd[15:0] ← SE(Rs[7:0], 16);

**Syntax:**

I. punpckub.h Rd, Rs:<part>
II. punpcksb.h Rd, Rs:<part>

**Operands:**

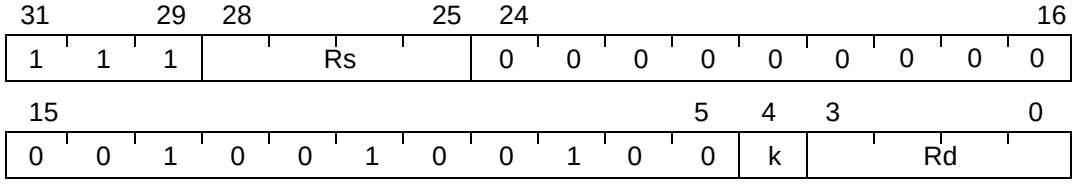
I, II. {d, s} ∈ {0, 1, …, 15}
part ∈ {t, b}

**Status Flags:**

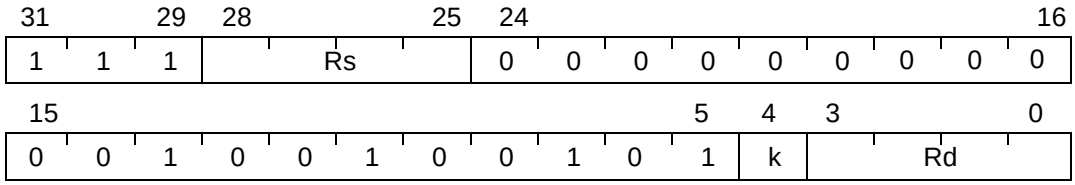
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**



## PUSHJC – Push Java Context to Frame

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the system registers LV0 to LV7 used in Java state to designated place on the current method frame. FRAME (equal to R9) is used as pointer register.

**Operation:**

I. temp ←FRAME;
*(temp--) ←JAVA_LV0;
*(temp--) ←JAVA_LV1;
*(temp--) ←JAVA_LV2;
*(temp--) ←JAVA_LV3;
*(temp--) ←JAVA_LV4;
*(temp--) ←JAVA_LV5;
*(temp--) ←JAVA_LV6;
*(temp--) ←JAVA_LV7;

**Syntax:**

I. pushjc

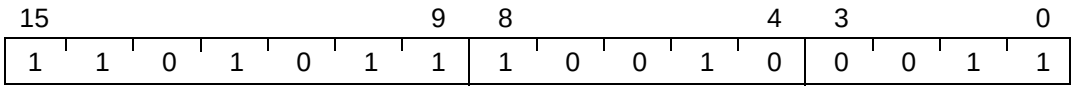
**Operands:**

I. none

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## PUSHM – Push Multiple Registers to Stack

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the registers specified in the instruction into consecutive words pointed to by SP.

**Operation:**

```
I.      if Reglist8[0] == 1 then
            *(--SP) ←R0;
            *(--SP) ←R1;
            *(--SP) ←R2;
            *(--SP) ←R3;
        if Reglist8[1] == 1 then
            *(--SP) ←R4;
            *(--SP) ←R5;
            *(--SP) ←R6;
            *(--SP) ←R7;
        if Reglist8[2] == 1 then
            *(--SP) ←R8;
            *(--SP) ←R9;
        if Reglist8[3] == 1 then
            *(--SP) ←R10;
        if Reglist8[4] == 1 then
            *(--SP) ←R11;
        if Reglist8[5] == 1 then
            *(--SP) ←R12;
        if Reglist8[6] == 1 then
            *(--SP) ←LR;
        if Reglist8[7] == 1 then
            *(--SP) ←PC;
```

**Syntax:**

```
I.      pushm  Reglist8
```

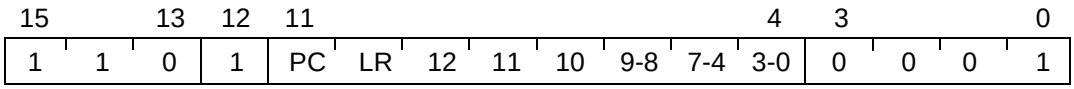
**Operands:**

I. Reglist8 ∈ {R0- R3, R4-R7, R8-R9, R10,R11, R12, LR, PC}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



| 15 | | 13 | 12 | 11 | | | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | PC | LR | 12 | 11 | 10 | 9-8 | 7-4 | 3-0 | 0 | 0 | 0 | 1 |

**Note:**

Emtpy Reglist8 gives UNDEFINED result.

The R bit in the status register has no effect on this instruction.

## RCALL – Relative Subroutine Call

**Architecture revision:**
Architecture revision1 and higher.

**Description**
PC-relative call of subroutine

**Operation:**

I. LR ← PC + 2
PC ← PC + (SE(disp10)<<1)

II. LR ← PC + 4
PC ← PC + (SE(disp21)<<1)

**Syntax:**

I. rcall PC[disp]

II. rcall PC[disp]

**Operands:**

I. disp ∈ {-1024, -1022, ..., 1022}

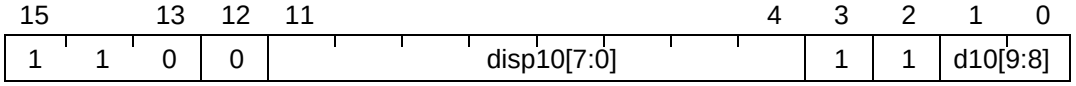
II. disp ∈ {-2097152, -2097150, ..., 2097150}

**Status Flags**

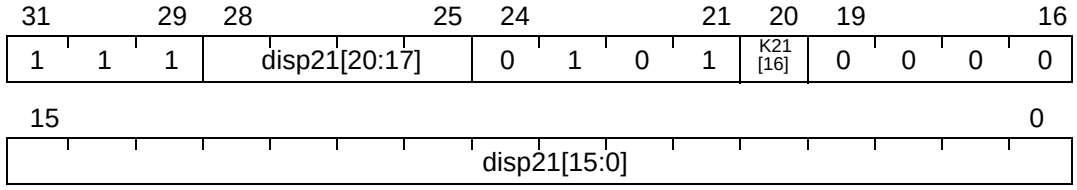
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**




**Format II:**



## RET{cond4} – Conditional Return from Subroutine

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Return from subroutine if the specified condition is true. Values are moved into the return register, the return value is tested, and flags are set.

**Operation:**

```
I.      If (cond4)
            If (Rs != {LR, SP, PC})
                R12 ← Rs;
            else if (Rs == LR)
                R12 ← -1;
            else if (Rs == SP)
                R12 ← 0;
            else
                R12 ← 1;
            Test R12 and set flags;
            PC ← LR;
```

**Syntax:**

```
I.      ret{cond4} Rs
```

**Operands:**

```
I.      cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
        s ∈{0, 1, …, 15}
```

**Status Flags:**

**Flags are set as result of the operation CP R12, 0.**

**Q:** Not affected
**V:** V ← 0
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← 0

**Opcode:**

| 15 | | | 13 | 12 | | | 9 | 8 | 7 | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | | 1 | 1 | 1 | 1 | 0 | cond4 | | | | Rs | | | |

## RETD – Return from Debug mode

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Return from debug mode.

**Operation:**
I. SR ← RSR_DBG
PC ← RAR_DBG

**Syntax:**
I. retd

**Operands:**
None

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode**:

| 15 | | | | | | | 9 | 8 | | | | 4 | 3 | | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | |

**Note:**

This instruction can only be executed in a privileged mode. Execution from any other mode will trigger a Privilege Violation exception.

## RETE – Return from event handler

**Architecture revision:**

Architecture revision1 and higher.

**Description**

Returns from an exception or interrupt. SREG[L] is cleared to support atomical memory access with the *stcond* instruction. This instruction can only be executed in INT0-INT3, EX and NMI modes. Execution in Application or Supervisor modes will trigger a Privilege Violation exception.

**Operation:**

```
I.    If (microarchitecture == AVR32A)
            SR ← *(SP_SYS++)
            PC ← *(SP_SYS++)
            If ( SR[M2:M0] == {B'010, B'011, B'100, B'101} )
                  LR ← *(SP_SYS++)
                  R12 ← *(SP_SYS++)
                  R11 ← *(SP_SYS++)
                  R10 ← *(SP_SYS++)
                  R9 ← *(SP_SYS++)
                  R8 ← *(SP_SYS++)
            SREG[L] ← 0;
      else
            SR ← RSR_Current Context
            PC ← RAR_Current Context
            SREG[L] ← 0;
```

**Syntax:**

I RETE

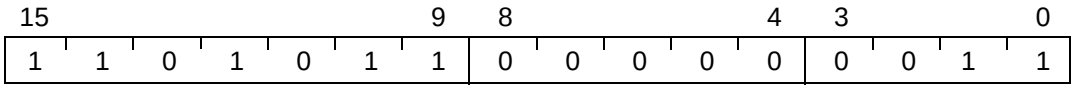
**Operands:**

None

**Status Flags**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## RETJ – Return from Java trap

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Returns from a Java trap.

**Operation:**

```
I.      PC ← LR;
        J ← 1;
        R ← 0;
        if ( SR[M2:M0] == B'001 )
                GM ← 0;
```

**Syntax:**

```
I       retj
```

**Operands:**
None

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

| 15 | | | | | | | 9 | 8 | | | | 4 | 3 | | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | |

## RETS – Return from supervisor call

**Architecture revision:**
Architecture revision1 and higher.

**Description**

Returns from a supervisor call.

**Operation:**

I. If ( SR[M2:M0] == B'000 )
    Issue Privilege Violation Exception;
  else if ( SR[M2:M0] == B'001 )
    If (microarchitecture == AVR32A)
      SR ← *($SP_{SYS}$++)
      PC ← *($SP_{SYS}$++)
    else
      SR ← $RSR_{SUP}$;
      PC ← $RAR_{SUP;}$
  else
    PC ← $LR_{Current\ Context}$

**Syntax:**

I RETS

**Operands:**

None

**Status Flags**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

| 15 | | | | | | | 9 | 8 | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |

## RETSS – Return from Secure State

**Architecture revision:**
Architecture revision 3 and higher.

**Description**

Returns from Secure State.

**Operation:**

```
I.      If ( SR[SS] == 0 )
            Issue Privilege Violation Exception;
        else
            SR ← SS_RSR
            PC ← SS_RAR
```

**Syntax:**

```
I       RETSS
```

**Operands:**

None

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**

| 15 | | | | | | | 9 | 8 | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | |

## RJMP – Relative Jump

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Jump the specified amount relative to the Program Counter .

**Operation:**
I. PC ← PC + (SE(disp10)<<1);

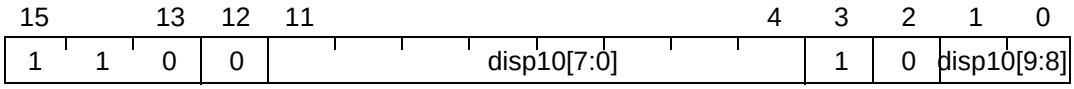
**Syntax:**
I. rjmp PC[disp]

**Operands:**
I. disp ∈ {-1024, -1022, ..., 1022}

**Status Flags**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**



## ROL – Rotate Left through Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Shift all bits in Rd one place to the left. The C flag is shifted into the LSB. The MSB is shifted into the C flag.

**Operation:**

I.
$C' \leftarrow Rd[31];$
$Rd \leftarrow Rd << 1;$
$Rd[0] \leftarrow C;$
$C \leftarrow C';$

**Syntax:**

I. rol Rd

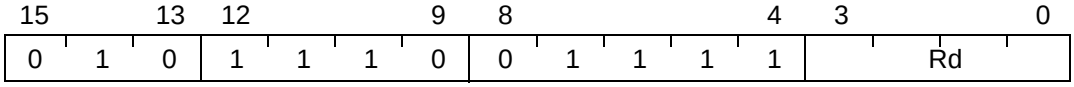
**Operands:**

I. $d \in \{0, 1, \ldots, 15\}$

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** $N \leftarrow Res[31]$
**Z:** $Z \leftarrow (RES[31:0] == 0)$
**C:** $C \leftarrow Rd[31]$

**Opcode:**



## ROR – Rotate Right through Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Shift all bits in Rd one place to the right. The C flag is shifted into the MSB. The LSB is shifted into the C flag.

**Operation:**

I.
```
C´ ← Rd[0];
Rd ← Rd >> 1;
Rd[31] ← C;
C ← C´;
```

**Syntax:**

I. `ror Rd`

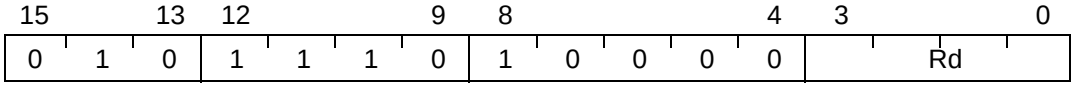
**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** N ← Res[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← Rd[0]

**Opcode:**



## RSUB – Reverse Subtract

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a subtraction and stores the result in destination register. Similar to sub, but the minuend and subtrahend are interchanged.

**Operation:**

I. Rd ← Rs - Rd;

II. Rd ← SE(imm8) - Rs;

**Syntax:**

I. rsub Rd, Rs

II. rsub Rd, Rs, imm

**Operands:**

I. {d, s} ∈ {0, 1, …, 15}

II. {d, s} ∈ {0, 1, …, 15}
imm ∈ {-128, -127, ..., 127}

**Status Flags:**

**Format I: OP1 = Rs, OP2 = Rd**
**Format II: OP1 = SE(imm8), OP2 = Rs**

**Q:** Not affected

**V:** V ← (OP1[31] ∧ ¬OP2[31] ∧ ¬RES[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ RES[31])

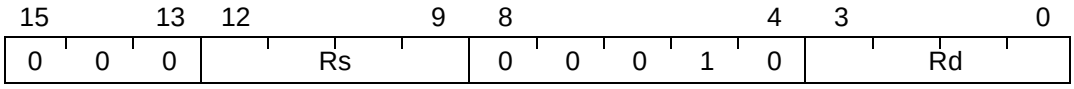
**N:** N ← RES[31]

**Z:** Z ← (RES[31:0] == 0)

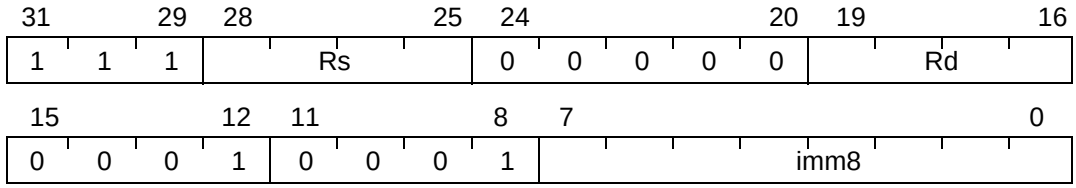
**C:** C ← ¬OP1[31] ∧ OP2[31] ∨ OP2[31] ∧ RES[31] ∨ ¬OP1[31] ∧ RES[31]

**Opcode:**

**Format I:**




**Format II:**



## RSUB{cond4} – Conditional Reverse Subtract

**Architecture revision:**
Architecture revision1 and higher.

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
Performs a subtraction and stores the result in destination register. Similar to sub, but the minuend and subtrahend are interchanged.

**Operation:**

I. if ( cond4)
Rd ← SE(imm8) - Rd;

**Syntax:**

I. rsub{cond4} Rd, imm

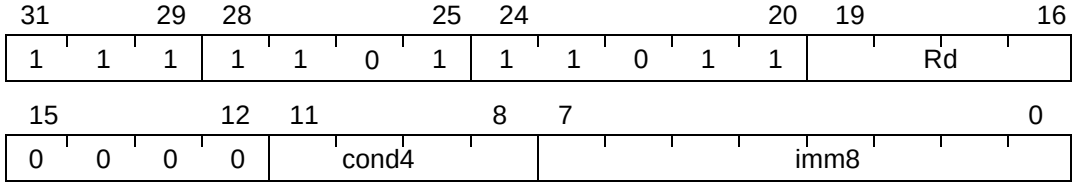
**Operands:**

I. d ∈ {0, 1, …, 15}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
imm ∈ {-128, -127, ..., 127}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## SATADD.H – Saturated Add of Halfwords

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds the two halfword registers specified and stores the result in destination register. The result is saturated if it overflows the range representable with 16 bits. If saturation occurs, the Q flag is set.

**Operation:**

```
I.      temp ← ZE(Rx[15:0]) + ZE(Ry[15:0]));
        if (Rx[15] ∧ Ry[15] ∧ ¬temp[15]) ∨ (¬Rx[15] ∧ ¬Ry[15] ∧ temp[15]) then
                if Rx[15] == 0 then
                        Rd ← 0x00007fff;
                else
                        Rd ← 0xffff8000;
        else
                Rd ← SE(temp[15:0]);
```

**Syntax:**

```
I.      satadd.hRd, Rx, Ry
```

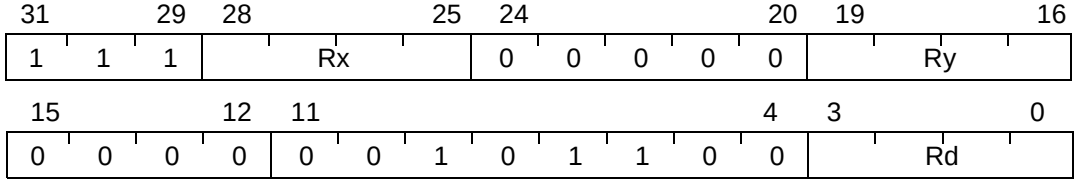
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

- **Q:** Q ← (Rx[15] ∧ Ry[15] ∧ ¬temp[15]) ∨ (¬Rx[15] ∧ ¬Ry[15] ∧ temp[15]) ∨ Q
- **V:** V ← (Rx[15] ∧ Ry[15] ∧ ¬temp[15]) ∨ (¬Rx[15] ∧ ¬Ry[15] ∧ temp[15])
- **N:** N ← Rd[15]
- **Z:** Z ← if (Rd[15:0] == 0)
- **C:** C ← 0

**Opcode:**



## SATADD.W– Saturated Add of Words

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Adds the two registers specified and stores the result in destination register. The result is saturated if a two's complement overflow occurs. If saturation occurs, the Q flag is set.

**Operation:**

I.
```
temp ← Rx + Ry;
if (Rx[31] ∧ Ry[31] ∧ ¬temp[31]) ∨ (¬Rx[31] ∧ ¬Ry[31] ∧ temp[31]) then
        if Rx[31] == 0 then
                Rd ← 0x7fffffff;
        else
                Rd ← 0x8000000;
else
        Rd ← temp;
```

**Syntax:**

I. satadd.wRd, Rx, Ry

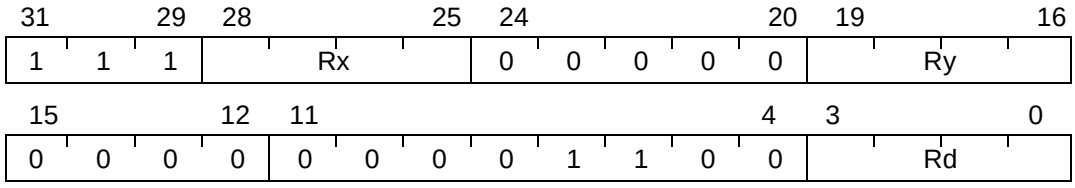
**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Q ← (Rx[31] ∧ Ry[31] ∧ ¬temp[31]) ∨ (¬Rx[31] ∧ ¬Ry[31] ∧ temp[31]) ∨ Q
**V:** V ← (Rx[31] ∧ Ry[31] ∧ ¬temp[31]) ∨ (¬Rx[31] ∧ ¬Ry[31] ∧ temp[31])
**N:** N ← Rd[31]
**Z:** Z ← (Rd[31:0] == 0)
**C:** C ← 0

**Opcode:**



## SATRNDS – Saturate with Rounding Signed

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction considers the value in (Rd>>sa)[bp-1:0] as a signed value. Rounding is performed after the shift. If the value in (Rd>>sa)[31:bp] is not merely a sign-extention of this value, overflow has occurred and saturation is performed to the maximum signed positive or negative value. If saturation occurs, the Q flag is set. An arithmetic shift is performed on Rd. If bp equals zero, no saturation is performed.

**Operation:**

I.
```
Temp ← Rd >> sa
if (sa != 0)
        Rnd = Rd[sa-1]
        Temp = Temp + Rnd;
if ((Temp == SE( Temp[bp-1:0])) || (bp == 0) )
        Rd ← Temp;
else
        if (Temp[31] == 1)
                Rd ← -2^(bp-1);
        else
                Rd ← 2^(bp-1) - 1;
```

**Syntax:**

I. `satrnds Rd >> sa, bp`

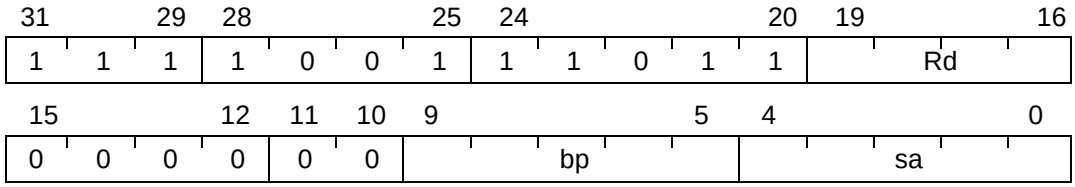
**Operands:**

I. $d \in \{0, 1, \ldots, 15\}$
$\{sa, bp\} \in \{0, 1, \ldots, 31\}$

**Status Flags:**

**Q:** Set if saturation occurred or Q was already set, cleared otherwise.
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## SATRNDU – Saturate with Rounding Unsigned

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction considers the value in (Rd>>sa)[bp-1:0] as a unsigned value. Rounding is performed after the shift. If the value in (Rd>>sa)[31:bp] is not merely a zero extention of this value, overflow has occurred and saturation is performed to the maximum unsigned positive value or zero. If saturation occurs, the Q flag is set. An arithmetic shift is performed on Rd. If bp equals zero, no saturation is performed.

**Operation:**

```
I.      Temp  ← Rd >> sa
        if (sa != 0)
                Rnd = Rd[sa-1]
                Temp = Temp + Rnd;
        If ((Temp == ZE( Temp[bp-1:0]))  || (bp == 0) )
                Rd ← Temp;
        else
                if (Temp[31] == 1)
                        Rd ← 0x0000_0000;
                else
                        Rd ← 2^bp - 1;
```

**Syntax:**

```
I.      satrndu Rd >> sa, bp
```

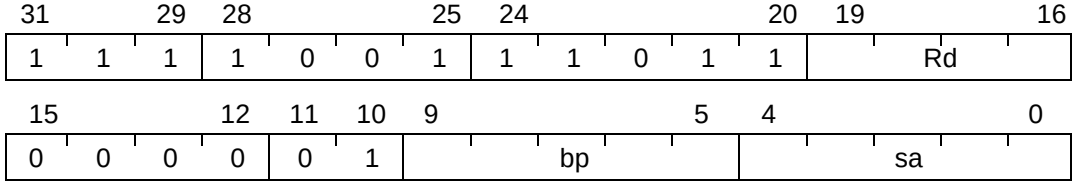
**Operands:**

```
I.      d ∈ {0, 1, …, 15}
        {sa, bp} ∈ {0, 1, …, 31}
```

**Status Flags:**

**Q:** Set if saturation occurred or Q was already set, cleared otherwise.
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## SATS – Saturate Signed

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction considers the value in (Rd>>sa)[bp-1:0] as a signed value. If the value in (Rd>>sa)[31:bp] is not merely a sign-extention of this value, overflow has occurred and saturation is performed to the maximum signed positive or negative value. If saturation occurs, the Q flag is set. An arithmetic shift is performed on Rd. If bp equals zero, no saturation is performed.

**Operation:**

```
I.      Temp ← Rd >> sa
        If ((Temp == SE( Temp[bp-1:0])) || (bp == 0))
                Rd ← Temp;
        else
                if (Temp[31] == 1)
                        Rd ← -2^(bp-1);
                else
                        Rd ← 2^(bp-1) - 1;
```

**Syntax:**

```
I.      sats    Rd >> sa, bp
```

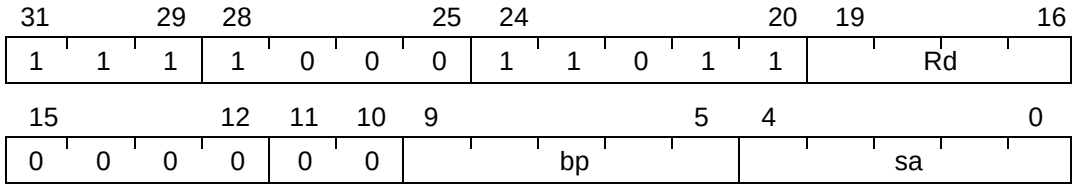
**Operands:**

I. $d \in \{0, 1, \ldots, 15\}$
$\{sa, bp\} \in \{0, 1, \ldots, 31\}$

**Status Flags:**

- **Q:** Set if saturation occurred or Q was already set, cleared otherwise.
- **V:** Not affected
- **N:** Not affected
- **Z:** Not affected
- **C:** Not affected

**Opcode:**



## SATSUB.H – Saturated Subtract of Halfwords

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a subtraction of the specified halfwords and stores the result in destination register. The result is saturated if it overflows the range representable with 16 bits. If saturation occurs, the Q flag is set.

**Operation:**

```
I.      temp ← ZE(Rx[15:0]) - ZE(Ry[15:0]) ;
        if (Rx[15] ∧ ¬Ry[15] ∧ ¬temp[15]) ∨ (¬Rx[15] ∧ Ry[15] ∧ temp[15]) then
                if Rx[15]==0 then
                        Rd ← 0x00007fff;
                else
                        Rd ← 0xffff8000;
        else
                Rd ← SE(temp[15:0]);
```

**Syntax:**

```
I.      satsub.hRd, Rx, Ry
```

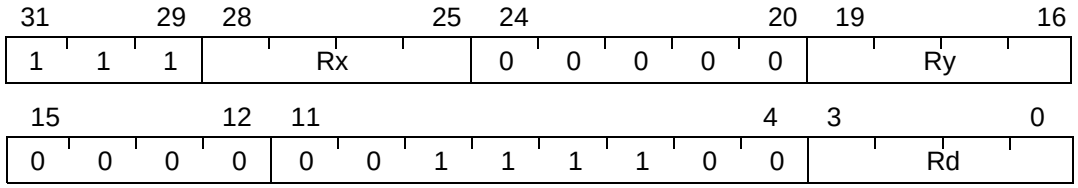
**Operands:**

I. $\{d, s\} \in \{0, 1, \ldots, 15\}$

**Status Flags:**

**Q:** $Q \leftarrow (Rx[15] \wedge \neg Ry[15] \wedge \neg temp[15]) \vee (\neg Rx[15] \wedge Ry[15] \wedge temp[15]) \vee Q$
**V:** $V \leftarrow (Rx[15] \wedge \neg Ry[15] \wedge \neg temp[15]) \vee (\neg Rx[15] \wedge Ry[15] \wedge temp[15])$
**N:** $N \leftarrow Rd[15]$
**Z:** $Z \leftarrow (Rd[15:0] == 0)$
**C:** $C \leftarrow 0$

**Opcode:**



## SATSUB.W – Saturated Subtract of Words

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a subtraction and stores the result in destination register. The result is saturated if a two's complement overflow occurs. If saturation occurs, the Q flag is set.

**Operation:**

I. temp ← Rx - Ry;

II. temp ← Rs - SE(imm16));

**Format I: OP1 = Rx, OP2 = Ry**
**Format II: OP1 = Rs, OP2 = SE(imm16)**

```
if (OP1[31] ∧ ¬OP2[31] ∧ ¬temp[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ temp[31]) then
        if(OP1[31]==0) then
                Rd ← 0x7fffffff;
        else
                Rd ← 0x80000000;
else
        Rd ← temp
```

**Syntax:**

I. satsub.w Rd, Rx, Ry

II. satsub.w Rd, Rs, imm

**Operands:**

I. {d, x, y} ∈ {0, 1, …, 15}

II. {d, s} ∈ {0, 1, …, 15}
imm ∈ {-32768, -32767, ..., 32767}

**Status Flags:**

**Format I: OP1 = Rx, OP2 = Ry**
**Format II: OP1 = Rs, OP2 = SE(imm16)**

**Q:** Q ← (OP1[31] ∧ ¬OP2[31] ∧ ¬temp[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ temp[31]) ∨ Q

**V:** V ← (OP1[31] ∧ ¬OP2[31] ∧ ¬temp[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ temp[31])

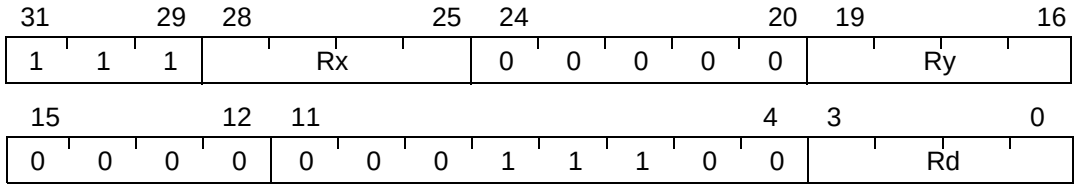
**N:** N ← Rd[31]

**Z:** Z ← (Rd[31:0] == 0)

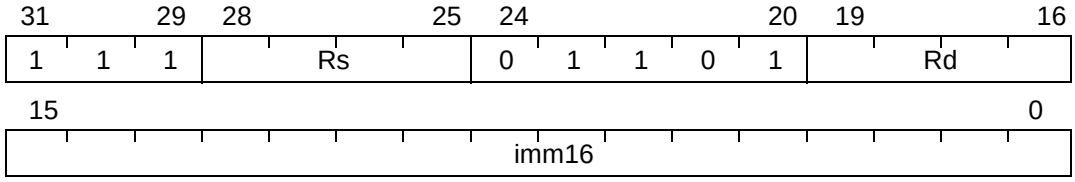
**C:** C ← 0

**Opcode:**

**Format I:**




**Format II:**



## SATU – Saturate Unsigned

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction considers the value in (Rd>>sa)[bp-1:0] as a unsigned value. If the value in (Rd>>sa)[31:bp] is not merely a zero extention of this value, overflow has occurred and saturation is performed to the maximum unsigned positive value or zero. If saturation occurs, the Q flag is set. An arithmetic shift is performed on Rd. If bp equals zero, no saturation is performed.

**Operation:**

```
I.      Temp ← Rd >> sa
        If ((Temp == ZE( Temp[bp-1:0])) || (bp == 0) )
                Rd ← Temp;
        else
                if (Temp[31] == 1)
                        Rd ← 0x0000_0000;
                else
                        Rd ← 2^bp - 1;
```

**Syntax:**

```
I.      satu    Rd >> sa, bp
```

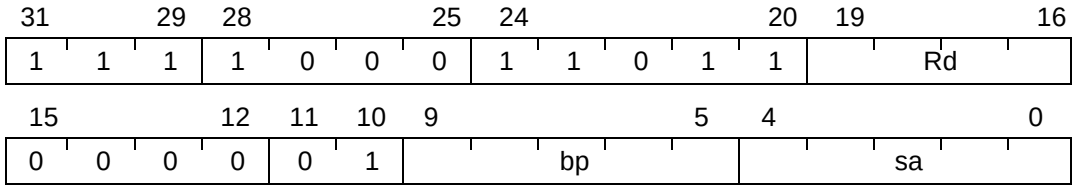
**Operands:**

I. $d \in \{0, 1, \ldots, 15\}$
$\{sa, bp\} \in \{0, 1, \ldots, 31\}$

**Status Flags:**

**Q:** Set if saturation occurred or Q was already set, cleared otherwise.
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## SBC – Subtract with Carry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtracts a specified register and the value of the carry bit from a destination register and stores the result in the destination register.

**Operation:**
I. Rd ← Rx - Ry - C;

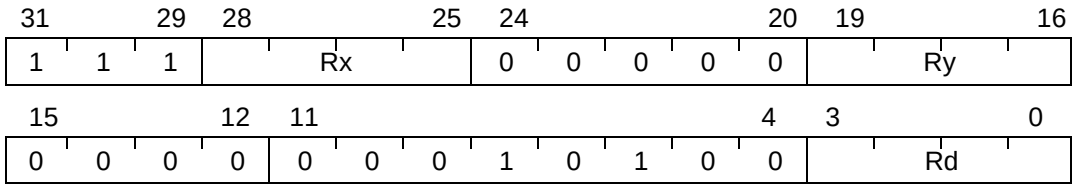
**Syntax:**
I. sbc Rd, Rx, Ry

**Operands:**
I. {x, y, d} ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** V ← (Rx[31] ∧ ¬Ry[31] ∧ ¬RES[31]) ∨ (¬Rx[31] ∧ Ry[31] ∧ RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0) ∧ Z
**C:** C ← ¬Rx[31] ∧ Ry[31] ∨ Ry[31] ∧ RES[31] ∨ ¬Rx[31] ∧ RES[31]

**Opcode:**



## SBR – Set Bit in Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets a bit in the specified  register. All other bits are unaffected.

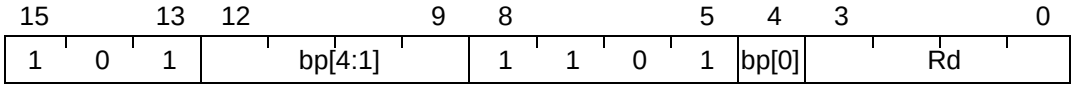
**Operation:**
I. Rd[bp5] ← 1;

**Syntax:**
I. sbr Rd, bp

**Operands:**
I. d ∈ {0, 1, …, 15}
bp ∈ {0, 1, …, 31}

**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Z ← 0
**C:** Not affected

**Opcode:**



## SCALL – Supervisor Call

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The *scall* instruction performs a supervisor routine call. The behaviour of the instruction is dependent on the mode it is called from, allowing *scall* to be executed from all contexts. *Scall* jumps to a dedicated entry point relative to EVBA. *Scall* can use the same call convention as regular subprogram calls.

**Operation:**

```
I.    If ( SR[M2:M0] == {B'000 or B'001} )
          If (microarchitecture == AVR32A)
              *(--SP_SYS) ← PC + 2;
              *(--SP_SYS) ← SR;
              PC ← EVBA + 0x100;
              SR[M2:M0] ← B'001;
          else
              RAR_SUP ← PC + 2;
              RSR_SUP ← SR;
              PC ← EVBA + 0x100;
              SR[M2:M0] ← B'001;
      else
          LR_Current Context ← PC + 2;
          PC ← EVBA + 0x100;
```

**Syntax:**
I. scall

**Operands:**
I. none

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**

| 15 | | | | | | | 9 | 8 | | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | | 1 | 0 | 0 | 1 | 1 | | 0 | 0 | 1 | 1 |

## SCR – Subtract Carry from Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtracts carry from the specified destination register.

**Operation:**
I. Rd ← Rd - C;

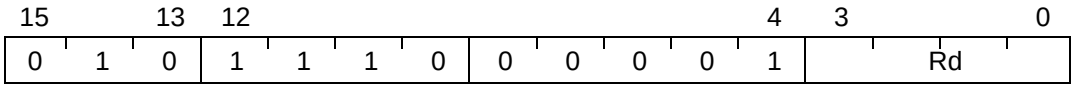
**Syntax:**
I. scr Rd

**Operands:**
I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected
**V:** V ← (Rd[31] ∧ ¬RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0) ∧ Z
**C:** C ← ¬Rd[31] ∧ RES[31]

**Opcode:**




**Example**

```
; Subtract a 32-bit variable (R0) from a 64-bit variable (R2:R1)
sub     R1, R0
scr     R2
```

## SLEEP – Set CPU Activity Mode

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets the system in the sleep mode specified by the implementation defined Op8 operand. The semantic of Op8 is IMPLEMENTATION DEFINED. If bit 7 in Op8 is one, SR[GM] will be cleared when entering sleep mode.

**Operation:**
I. Set the system in the specified sleep mode.

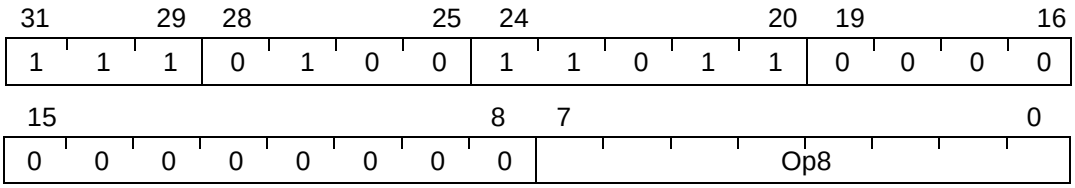
**Syntax:**
I. sleep Op8

**Operands:**
I. Op8 ∈ {0, 1, …, 255}

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**




**Note:**
The sleep instruction is a privileged instruction, and will trigger a Privilege Violation exception if executed in user mode.

## SR{cond4} – Set Register Conditionally

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets the register specified to 1 if the condition specified is true, clear the register otherwise.

**Operation:**

I.
```
if (cond4)
        Rd ← 1;
else
        Rd ← 0;
```

**Syntax:**

I. sr{cond4} Rd

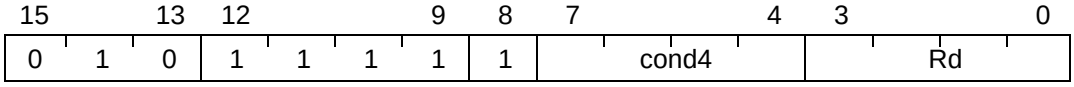
**Operands:**

I. cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
d ∈ {0, 1, ..., 15}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## SSCALL – Secure State Call

**Architecture revision:**
Architecture revision 3 and higher.

**Description**
The *sscall* instruction performs a secure state call. *Sscall* can use the same call convention as regular subprogram calls.

**Operation:**

I.

```
SS_RAR ← PC;
SS_RSR ←  SR;
If (microarchitecture == AVR32A)
        PC ← 0x8000_0004;
else)
        PC ← 0xA000_0004;
SR[SS] ← 1;
SR[GM] ← 1;
if (SR[M2:M0] == 0)
        SR[M2:M0] ← 001;
```

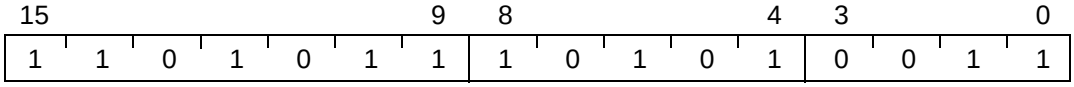
**Syntax:**
I. sscall

**Operands:**
I. none

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**



## SSRF – Set Status Register Flag

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Sets the status register (SR) flag specified.

**Operation:**
I. SR[bp5] ← 1;

**Syntax:**
I. ssrf bp

**Operands:**
I. bp ∈ {0, 1, …, 31}

**Status Flags:**
**SR[bp5] ← 1, all other flags unchanged.**

**Opcode:**

| 15 | | | | | 11 | 10 | 9 | 8 | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | | 0 | 1 | | | bp5 | | | 0 | 0 | 1 | 1 |

**Note:**
Privileged if bp5 > 15, ie. upper half of status register. An exception will be triggered if the upper half of the status register is attempted changed in user mode.

## ST.B – Store Byte

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The source register is stored to the byte memory location referred to by the pointer address.

**Operation:**

I. *(Rp) ← Rs[7:0];
Rp ← Rp + 1;
II. Rp ← Rp - 1;
*(Rp) ← Rs[7:0];
III. *(Rp + ZE(disp3)) ← Rs[7:0];
IV. *(Rp + SE(disp16)) ← Rs[7:0];
V. *(Rb + (Ri << sa2)) ← Rs[7:0];

**Syntax:**

| | | |
|---|---|---|
| I. | st.b | Rp++, Rs |
| II. | st.b | --Rp, Rs |
| III. | st.b | Rp[disp], Rs |
| IV. | st.b | Rp[disp], Rs |
| V. | st.b | Rb[Ri << sa], Rs |

**Operands:**

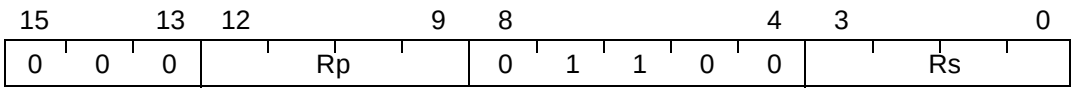
I, II. {s , p} ∈ {0, 1, …, 15}
III. {s , p} ∈ {0, 1, …, 15}
disp ∈ {0, 1, ..., 7}
IV. {s , p} ∈ {0, 1, …, 15}
disp ∈ {-32768, -32767, ..., 32767}
V. {b, i, s} ∈ {0, 1, …, 15}
sa ∈ {0, 1, 2, 3}

**Status Flags:**

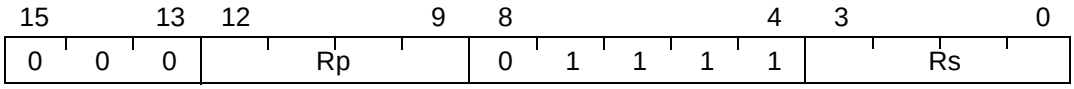
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

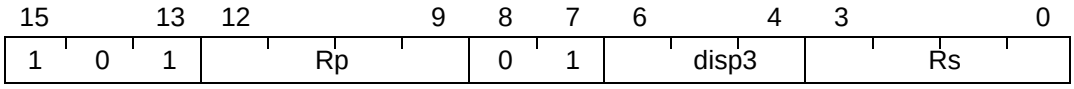
**Format I:**



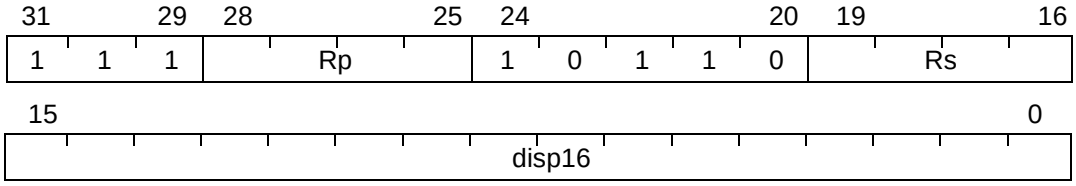
**Format II:**



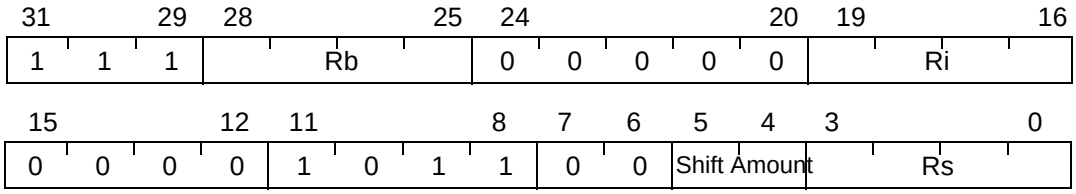

**Format III:**




**Format IV:**




**Format V:**




**Note:**
For formats I. and II., if Rp = Rs the result will be UNDEFINED.

## ST.B{cond4} – Conditionally Store Byte

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
The source register is stored to the byte memory location referred to by the pointer address if the given condition is satisfied.

**Operation:**

I. if (cond4)
*(Rp + ZE(disp9)) ← Rs[7:0];

**Syntax:**

I. st.b{cond4} Rp[disp], Rs

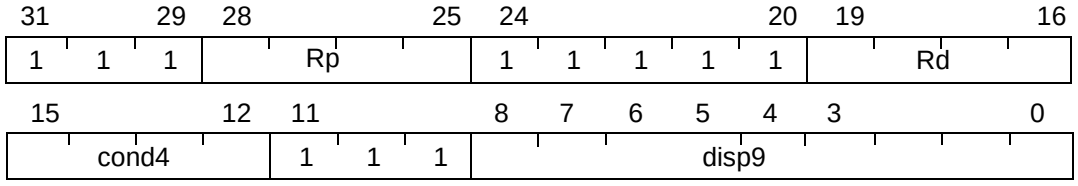
**Operands:**

I. s, p ∈ {0, 1, …, 15}
disp ∈ {0, 1, ..., 511}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## ST.D – Store Doubleword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The source registers are stored to the doubleword memory location referred to by the pointer address.

**Operation:**

I. *(Rp) ← Rs+1:Rs;
Rp ← Rp + 8;
II. Rp ← Rp - 8;
*(Rp) ← Rs+1:Rs;
III. *(Rp) ← Rs+1:Rs;
IV. *(Rp + SE(disp16)) ← Rs+1:Rs;
V. *(Rb + (Ri << sa2)) ← Rs+1:Rs;

**Syntax:**

| | | |
|---|---|---|
| I. | st.d | Rp++, Rs |
| II. | st.d | --Rp, Rs |
| III. | st.d | Rp, Rs |
| IV. | st.d | Rp[disp], Rs |
| V. | st.d | Rb[Ri << sa], Rs |

**Operands:**

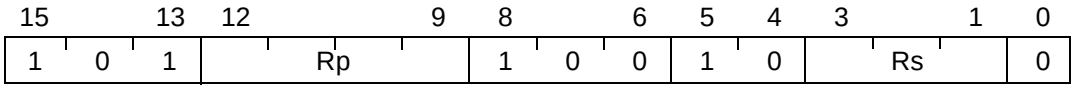
I, II, III. p ∈ {0, 1, …, 15}
s ∈ {0, 2, …, 14}
IV. p ∈ {0, 1, …, 15}
s ∈ {0, 2, …, 14}
disp ∈ {-32768, -32767, ..., 32767}
V. {b, i} ∈ {0, 1, …, 15}
s ∈ {0, 2, …, 14}
sa ∈ {0, 1, 2, 3}

**Status Flags:**

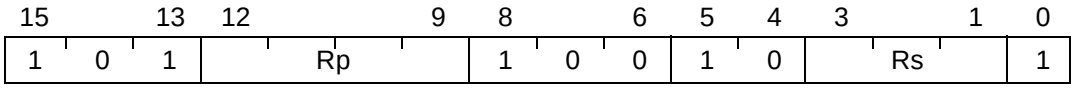
| | |
|---|---|
| **Q:** | Not affected. |
| **V:** | Not affected. |
| **N:** | Not affected. |
| **Z:** | Not affected. |
| **C:** | Not affected. |

**Opcode:**

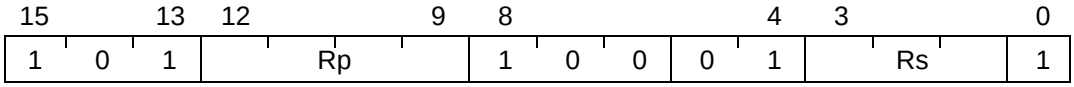
**Format I:**



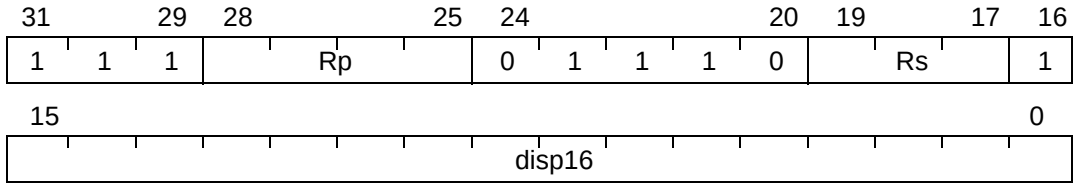

**Format II:**



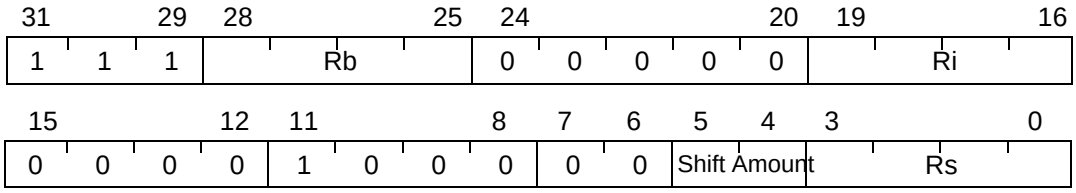

**Format III:**




**Format IV:**




**Format V:**




**Note:**

For formats I. and II., if Rp == Rs the result will be UNDEFINED.

## ST.H – Store Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The source register is stored to the halfword memory location referred to by the pointer address.

**Operation:**

I. *(Rp) ← Rs[15:0];
   Rp ← Rp + 2;
II. Rp ← Rp - 2;
   *(Rp) ← Rs[15:0];
III. *(Rp + ZE(disp3 << 1)) ← Rs[15:0];
IV. *(Rp + SE(disp16)) ← Rs[15:0];
V. *(Rb + (Ri << sa2)) ← Rs[15:0];

**Syntax:**

| | | |
|---|---|---|
| I. | st.h | Rp++, Rs |
| II. | st.h | --Rp, Rs |
| III. | st.h | Rp[disp], Rs |
| IV. | st.h | Rp[disp], Rs |
| V. | st.h | Rb[Ri << sa], Rs |

**Operands:**

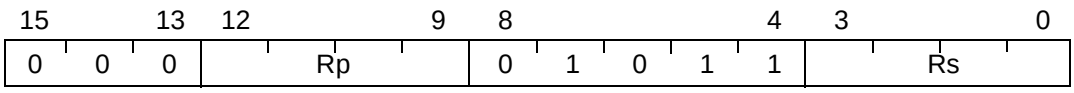
I, II. {s , p} ∈ {0, 1, …, 15}
III. {s , p} ∈ {0, 1, …, 15}
   disp ∈ {0, 2, ..., 14}
IV. {s , p} ∈ {0, 1, …, 15}
   disp ∈ {-32768, -32767, ..., 32767}
V. {b, i, s} ∈ {0, 1, …, 15}
   sa ∈ {0, 1, 2, 3}

**Status Flags:**

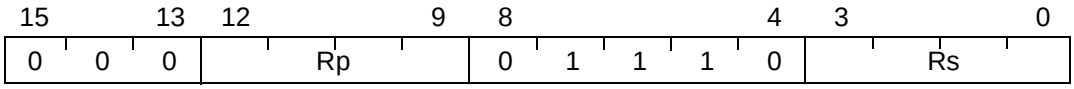
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

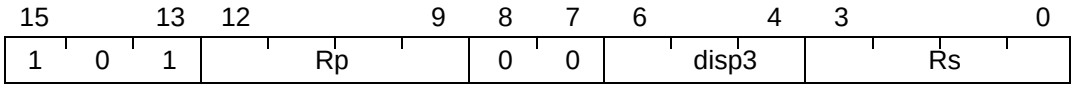
**Format I:**



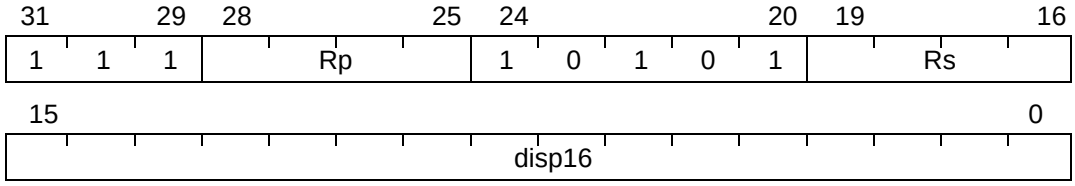
**Format II:**



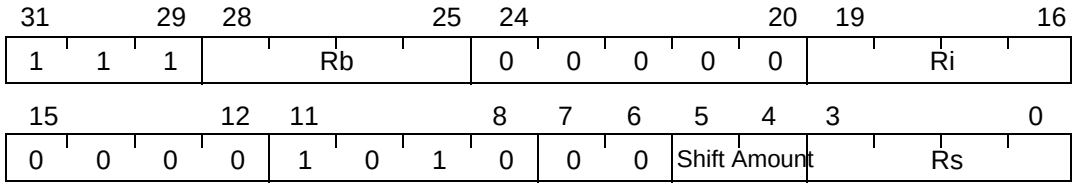

**Format III:**




**Format IV:**




**Format V:**




**Note:**
For formats I. and II., if Rp == Rs the result will be UNDEFINED.

## ST.H{cond4} – Conditionally Store Halfword

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
The source register is stored to the halfword memory location referred to by the pointer address if the given condition is satisfied.

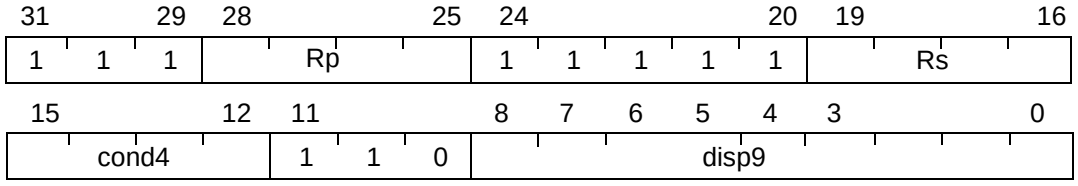
**Operation:**
I. if (cond4)
*(Rp + ZE(disp9<<1)) ← Rs[15:0];

**Syntax:**
I. st.h{cond4} Rp[disp], Rs

**Operands:**
I. s, p ∈ {0, 1, …, 15}
disp ∈ {0, 2, ..., 1022}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## ST.W – Store Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The source register is stored to the word memory location referred to by the pointer address.

**Operation:**

I. *(Rp) ← Rs;
Rp ← Rp + 4;
II. Rp ← Rp - 4;
*(Rp) ← Rs;
III. *(Rp + ZE(disp4 << 2)) ← Rs;
IV. *(Rp + SE(disp16)) ← Rs;
V. *(Rb + (Ri << sa2)) ← Rs;

**Syntax:**

| | | |
|---|---|---|
| I. | st.w | Rp++, Rs |
| II. | st.w | --Rp, Rs |
| III. | st.w | Rp[disp], Rs |
| IV. | st.w | Rp[disp], Rs |
| V. | st.w | Rb[Ri << sa], Rs |

**Operands:**

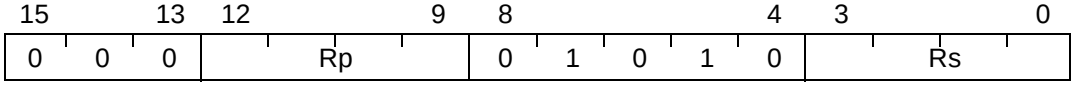
I, II. {s , p} ∈ {0, 1, …, 15}
III. {s , p} ∈ {0, 1, …, 15}
disp ∈ {0, 4, ..., 60}
IV. {s , p} ∈ {0, 1, …, 15}
disp ∈ {-32768, -32767,…, 32767}
V. {b, i, s} ∈ {0, 1, …, 15}
sa ∈ {0, 1, 2, 3}

**Status Flags:**

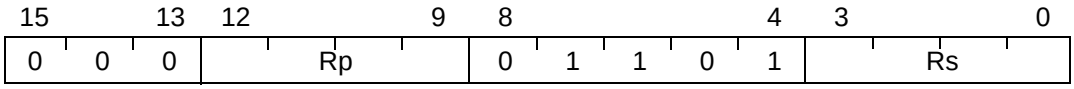
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

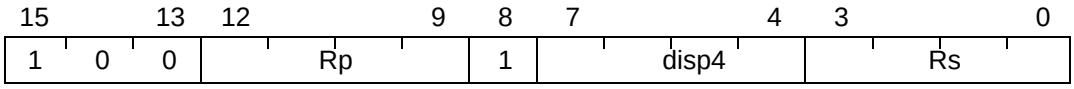
**Format I:**



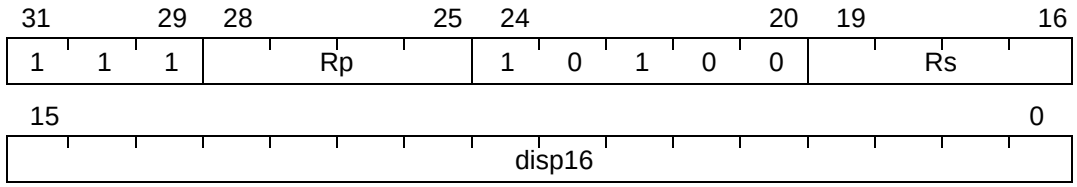
**Format II:**



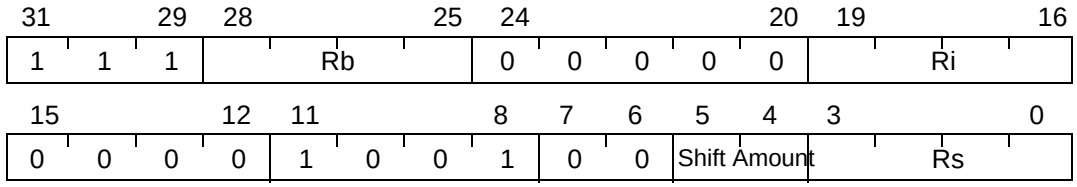

**Format III:**




**Format IV:**




**Format V:**




**Note:**
For formats I. and II., if Rp == Rs the result will be UNDEFINED.

## ST.W{cond4} – Conditionally Store Word

**Architecture revision:**
Architecture revision 2 and higher.

**Description**
The source register is stored to the word memory location referred to by the pointer address if the given condition is satisfied.

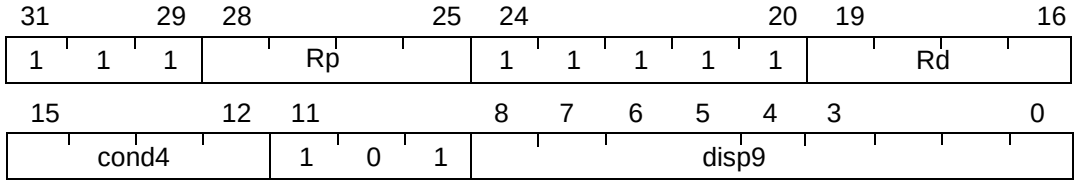
**Operation:**
I. if (cond4)
*(Rp + ZE(disp9<<2)) ← Rs;

**Syntax:**
I. st.w{cond4} Rp[disp], Rs

**Operands:**
I. s, p ∈ {0, 1, …, 15}
disp ∈ {0, 4, ..., 2044}
cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}

**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## STC.{D,W} – Store Coprocessor

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the source register value to the location specified by the addressing mode.

**Operation:**

I. *(Rp + (ZE(disp8) << 2)) ← CP#(CRd+1:CRd);
II. *(Rp) ← CP#(CRd+1:CRd);
Rp ← Rp+8;
III. *(Rb + (Ri << sa2)) ← CP#(CRd+1:CRd);
IV. *(Rp + (ZE(disp8) << 2)) ← CP#(CRd);
V. *(Rp) ← CP#(CRd);
Rp ← Rp+4;
VI. *(Rb + (Ri << sa2)) ← CP#(CRd);

**Syntax:**

| | | |
|---|---|---|
| I. | stc.d | CP#, Rp[disp], CRs |
| II. | stc.d | CP#, Rp++, CRs |
| III. | stc.d | CP#, Rb[Ri<<sa], CRs |
| IV. | stc.w | CP#, Rp[disp], CRs |
| V. | stc.w | CP#, Rp++, CRs |
| VI. | stc.w | CP#, Rb[Ri<<sa], CRs |

**Operands:**

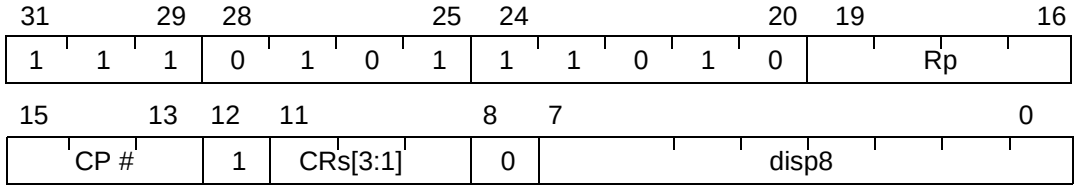
I-VI. # ∈ {0, 1, …, 7}
I-II, IV-V. s ∈ {0, 1, …, 15}
I-III. s ∈ {0, 2, …, 14}
I, IV. disp ∈ {0, 4, …, 1020}
III, VI. {b, i} ∈ {0, 1, …, 15}
III, VI. sa ∈ {0, 1, 2, 3}

**Status Flags:**

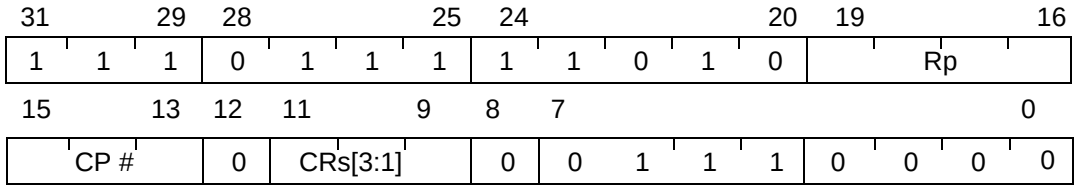
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

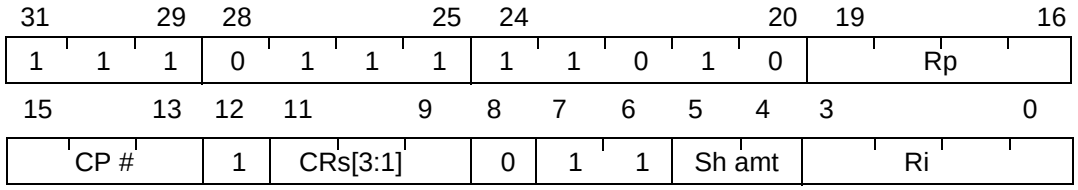
**Format I:**



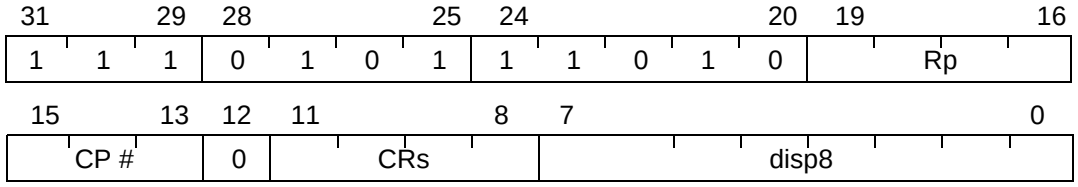

**Format II:**



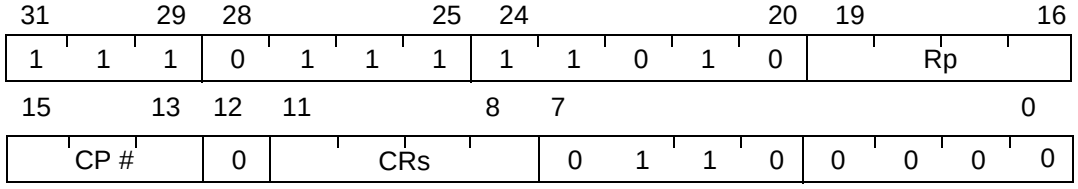

**Format III:**



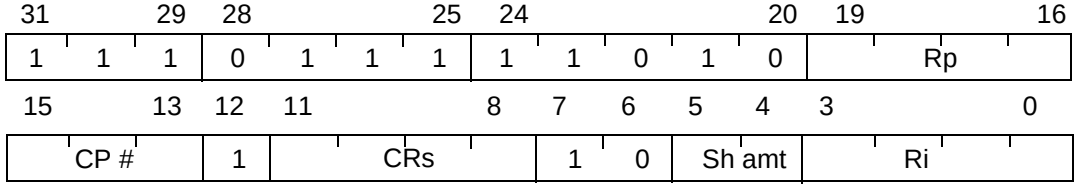

**Format IV:**




**Format V:**




**Format VI:**




**Example:**

```
stc.d     CP2, R2[0], CR0
```

## STC0.{D,W} – Store Coprocessor 0 Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the coprocessor 0 source register value to the location specified by the addressing mode.

**Operation:**
I. *(Rp + (ZE(disp12) << 2)) ← CP#(CRd+1:CRd);
II. *(Rp + (ZE(disp12) << 2)) ← CP#(CRd);

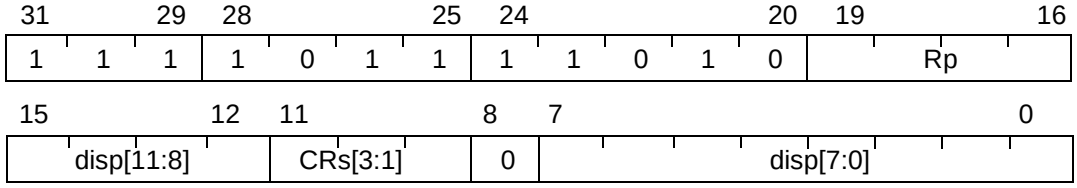
**Syntax:**
I. stc0.d Rp[disp], CRs
II. stc0.w Rp[disp], CRs

**Operands:**
I-II. p ∈ {0, 1, …, 15}
I. s ∈ {0, 2, …, 14}
II. s ∈ {0, 1, …, 15}
I, IV. disp ∈ {0, 4, …, 16380}

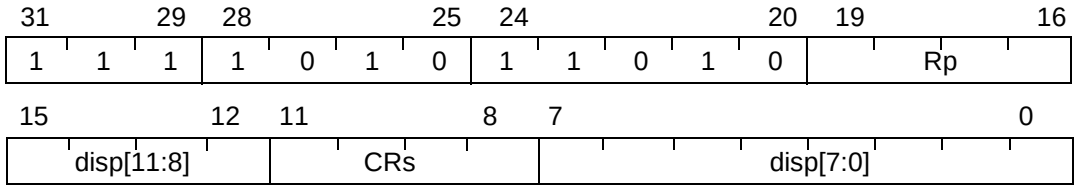
**Status Flags:**
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

**Format I:**




**Format II:**




**Example:**
stc0.d R2[0], CR0

## STCM.{D,W} – Store Coprocessor Multiple Registers

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Writes multiple registers in the addressed coprocessor into the specified memory locations.

**Operation:**

```
I.      Storeaddress ←Rp;
        if Opcode[--] == 1 then
                for (i = 0 to 7)
                        if ReglistCPD8[i] == 1 then
                                *(--Storeaddress)  ←CP#(CR(2*i));
                                *(--Storeaddress)  ←CP#(CR(2*i+1));
                Rp  ←  Storeaddress;
        else
                for (i = 7 to 0)
                        if ReglistCPD8[i] == 1 then
                                *(Storeaddress++)  ←CP#(CR(2*i+1));
                                *(Storeaddress++)  ←CP#(CR(2*i));

II      Storeaddress ←Rp;
        if Opcode[--] == 1 then
                for (i = 0 to 7)
                        if ReglistCPH8[i] == 1 then
                                *(--Storeaddress)  ←CP#(CRi+8);
                Rp  ←  Storeaddress;
        else
                for (i = 7 to 0)
                        if ReglistCPH8[i] == 1 then
                                *(Storeaddress++)  ←CP#(CRi+8);
III     Storeaddress ←Rp;
        if Opcode[--] == 1 then
                for (i = 0 to 7)
                        if ReglistCPL8[i] == 1 then
                                *(--Storeaddress)  ←CP#(CRi);
                Rp  ←  Storeaddress;
        else
                for (i = 7 to 0)
                        if ReglistCPL8[i] == 1 then
                                *(Storeaddress++)  ←CP#(CRi);
```

**Syntax:**

I. stcm.d CP#, {--}Rp, ReglistCPD8
II. stcm.w CP#, {--}Rp, ReglistCPH8
III. stcm.w CP#, {--}Rp, ReglistCPL8

**Operands:**

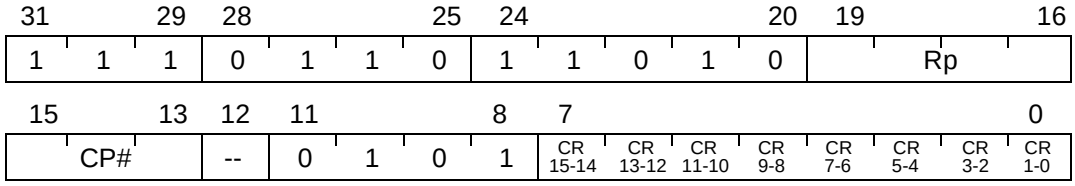
I-III. # ∈ {0, 1, …, 7}
p ∈ {0, 1, …, 15}
I. ReglistCPD8 ∈ {CR0-CR1,CR2-CR3,CR4-CR5,CR6-CR7,CR8-CR9, CR10-CR11,CR12-CR13,CR14-CR15}
II. ReglistCPH8 ∈ {CR8, CR9, CR10, ..., CR15}
III. ReglistCPL8 ∈ {CR0, CR1, CR2, ..., CR7}

**Status Flags:**

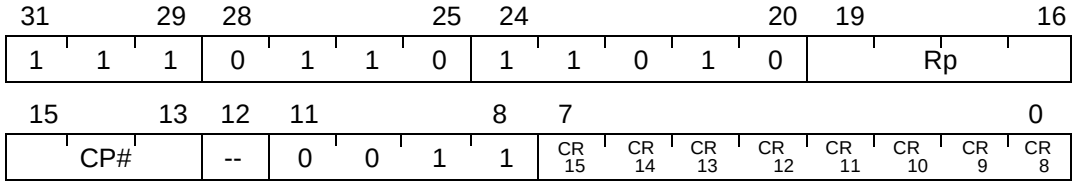
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

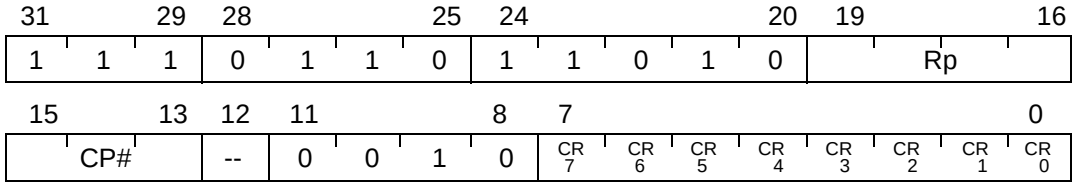
**Format I:**




**Format II:**




**Format III:**




**Example:**

stcm.w CP2, --SP, CR2-CR5

**Note:**

Emtpy ReglistCPH8/ReglistCPL8/ReglistCPD8 gives UNDEFINED result.

## STCOND – Store Word Conditionally

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The source register is stored to the word memory location referred to by the pointer address if SREG[L] is set. Also, SREG[L] is copied to SREG[Z] to indicate a success or failure of the operation. This instruction is used for atomical memory access.

**Operation:**

```
I.      SREG[Z] ← SREG[L];
        If SREG[L]
                *(Rp + SE(disp16)) ← Rs;
```

**Syntax:**

```
I.      stcond  Rp[disp], Rs
```

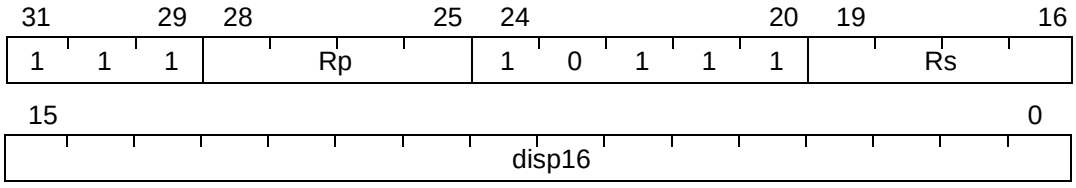
**Operands:**

```
I.      {s , p} ∈ {0, 1, …, 15}
        disp ∈ {-32768, -32767, ..., 32767}
```

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** SREG[Z] ← SREG[L].
**C:** Not affected.

**Opcode:**




**Note:**

## STDSP – Store Stack-Pointer Relative

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the source register value to the memory location referred to specified by the Stack Pointer and the displacement.

**Operation:**
I. *( (SP && 0xFFFF_FFFC) + (ZE(disp7) << 2) ) ← Rs;

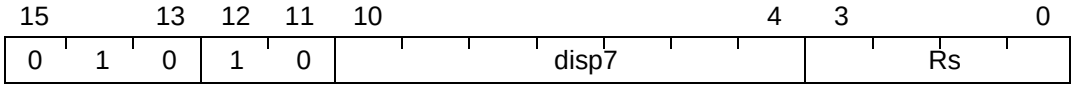
**Syntax:**
I. stdsp SP[disp], Rs

**Operands:**
I. disp ∈ {0, 4, ..., 508}
s ∈ {0, 1, …, 15}

**Status Flags:**

| | |
|---|---|
| **Q:** | Not affected |
| **V:** | Not affected |
| **N:** | Not affected |
| **Z:** | Not affected |
| **C:** | Not affected |

**Opcode:**



## STHH.W – Store Halfwords into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
The selected halfwords of the source registers are combined and stored to the word memory location referred to by the pointer address.

**Operation:**
If (Rx-part == t) then high-part = Rx[31:16] else high-part = Rx[15:0];
If (Ry-part == t) then low-part = Ry[31:16] else low-part = Ry[15:0];

I. *(Rp + ZE(disp8 << 2)) ← {high-part, low-part};
II. *(Rb + (Ri << sa2)) ← {high-part, low-part};

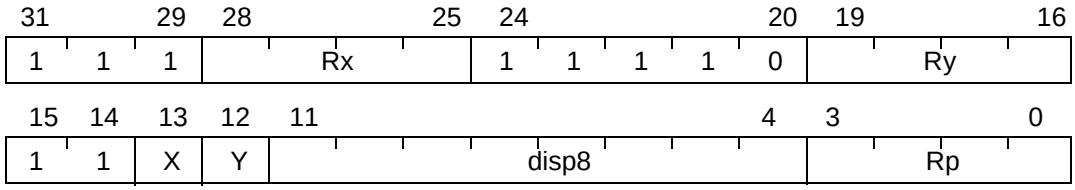
**Syntax:**
I. sthh.w Rp[disp], Rx:<part>, Ry:<part>
II. sthh.w Rb[Ri << sa], Rx:<part>, Ry:<part>

**Operands:**
I. {p, x, y} ∈ {0, 1, …, 15}
disp ∈ {0, 4, ..., 1020}
part ∈ {b,t}
II. {b, i, x, y} ∈ {0, 1, …, 15}
sa ∈ {0, 1, 2, 3}
part ∈ {b,t}

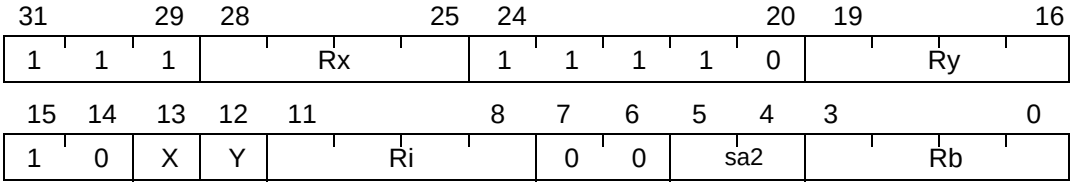
**Status Flags:**
**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

**Format I:**



**Format II:**


31 29 28 25 24 20 19 16
1 1 1 Rx 1 1 1 1 0 Ry
15 14 13 12 11 8 7 6 5 4 3 0
1 0 X Y Ri 0 0 sa2 Rb

## STM – Store Multiple Registers

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the registers specified to the consecutive memory locations pointed to by Rp. Both registers in the register file and some of the special-purpose registers can be stored.

```
I.      Storeaddress ← Rp;
        if Opcode[--] == 1 then
                for (i = 0 to 15)
                        if Reglist16[i] == 1 then
                                *(--Storeaddress) ←Ri;
                Rp ← Storeaddress;
        else
                for (i = 15 to 0)
                        if Reglist16[i] == 1 then
                                *(Storeaddress++) ←Ri;
```

**Syntax:**

```
I.      stm     {--}Rp, Reglist16
```

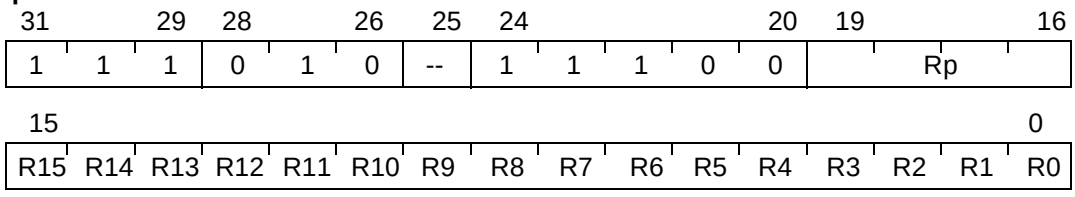
**Operands:**

I. Reglist16 ∈ {R0, R1, R2, ..., R12, LR, SP, PC}
p ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**

Emtpy Reglist16 gives UNDEFINED result.

If Rp is in Reglist16 and pointer is written back the result is UNDEFINED

The R bit in the status register has no effect on this instruction.

## STMTS – Store Multiple Registers for Task Switch

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Stores the registers specified to the consecutive memory locations pointed to by Rp. The registers specified all reside in the application context.

```
I.      Storeaddress ← Rp;
        if Opcode[--] == 1 then
                for (i = 0 to 15)
                        if Reglist16[i] == 1 then
                                *(--Storeaddress) ←Ri_App;
                Rp ← Storeaddress;
        else
                for (i = 15 to 0)
                        if Reglist16[i] == 1 then
                                *(Storeaddress++) ←Ri_App;
```

**Syntax:**

```
I.      stmts   {--}Rp, Reglist16
```

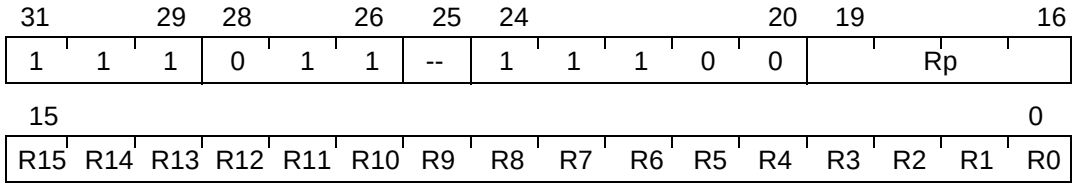
**Operands:**

```
I.      Reglist16 ∈ {R0, R1, R2, ..., R12, LR, SP}
        p ∈ {0, 1, …, 15}
```

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
Emtpy Reglist16 gives UNDEFINED result.
PC in Reglist16 gives UNDEFINED result.

## STSWP.{H, W} – Swap and Store

**Architecture revision:**
Architecture revision1 and higher.

**Description**
This instruction swaps the bytes in a halfword or a word in the register file and stores the result to memory. The instruction can be used for performing stores to memories of different endianness.

**Operation:**

I. temp[15:0] ← (Rs[7:0], Rs[15:8]);
*(Rp+SE(disp12) << 1) ← temp[15:0];

II. temp[31:0] ← (Rs[7:0], Rs[15:8], Rs[23:16], Rs[31:24]);
*(Rp+SE(disp12) << 2) ← temp[31:0];

**Syntax:**

I. stswp.h Rp[disp], Rs

II. stswp.w Rp[disp], Rs

**Operands:**

I. {s, p} ∈ {0, 1, …, 15}
disp ∈ {-4096, -4094, ..., 4094}

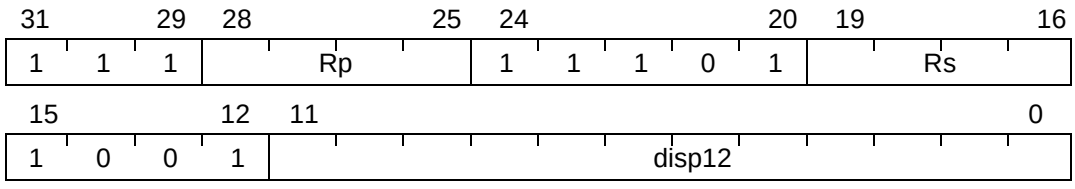
II. {s, p} ∈ {0, 1, …, 15}
disp ∈ {-8192, -8188 ..., 8188}

**Status Flags:**

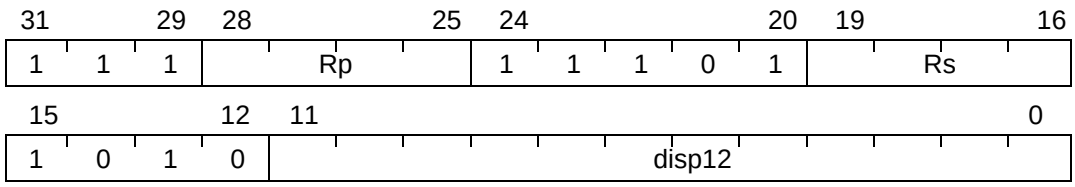
**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**

**Format I:**




**Format II:**



## SUB – Subtract (without Carry)

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Performs a subtraction and stores the result in destination register.

**Operation:**

```
I.    Rd ← Rd - Rs;
II.   Rd ← Rx - (Ry << sa2);
III.  if (Rd == SP)
          Rd ← Rd - SE(imm8 << 2);
      else
          Rd ← Rd - SE(imm8);
IV.   Rd ← Rd - SE(imm21);
V.    Rd ← Rs - SE(imm16);
```

**Syntax:**

```
I.    sub   Rd, Rs
II.   sub   Rd, Rx, Ry << sa
III.  sub   Rd, imm
IV.   sub   Rd, imm
V.    sub   Rd, Rs, imm
```

**Operands:**

```
I-V.  {d, s, x, y} ∈ {0, 1, …, 15}
II.   sa ∈ {0, 1, 2, 3}
III.  if (Rd == SP)
          imm ∈{-512, -508, ..., 508}
      else
          imm ∈{-128, -127, ..., 127}
IV.   imm ∈{-1048576, -104875, ..., 1048575}
V.    imm ∈ {-32768, -32767, ..., 32767}
```

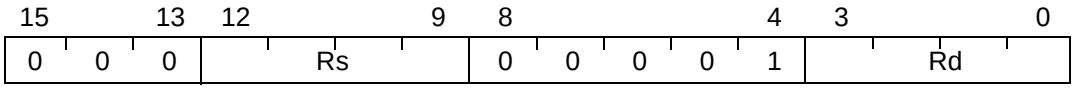
**Status Flags:**

**Format I: OP1 = Rd, OP2 = Rs**
**Format II:OP1 = Rx, OP2 = Ry << sa2**
**Format III: OP1 = Rd, if (Rd==SP) OP2 = SE(imm8<<2) else OP2 = SE(imm8)**
**Format IV: OP1 = Rd, OP2 = SE(imm21)**
**Format V: OP1 = Rs, OP2 = SE(imm16)**

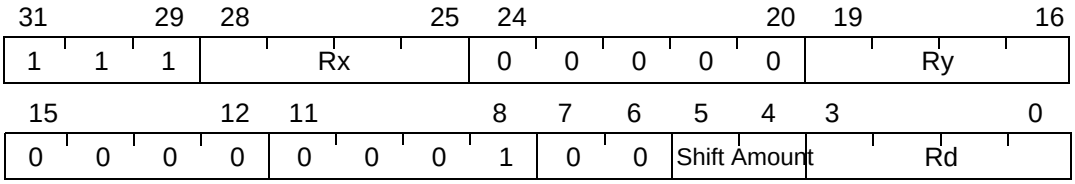
**Q:** Not affected
**V:** $V \leftarrow (OP1[31] \wedge \neg OP2[31] \wedge \neg RES[31]) \vee (\neg OP1[31] \wedge OP2[31] \wedge RES[31])$
**N:** $N \leftarrow RES[31]$
**Z:** $Z \leftarrow (RES[31:0] == 0)$
**C:** $C \leftarrow \neg OP1[31] \wedge OP2[31] \vee OP2[31] \wedge RES[31] \vee \neg OP1[31] \wedge RES[31]$

**Opcode:**

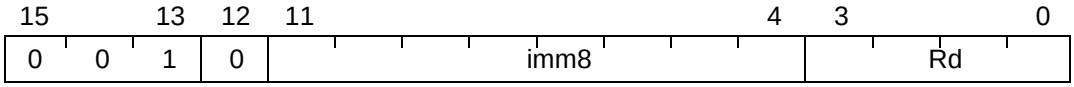
**Format I:**



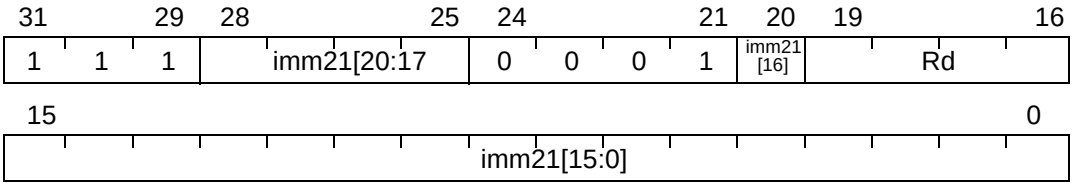

**Format II:**



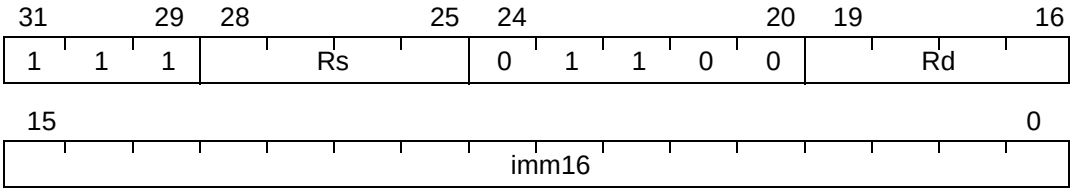

**Format III:**




**Format IV:**




**Format V:**



## SUB{cond4} – Conditional Subtract

**Architecture revision:**
Format I in Architecture revision1 and higher.
Format II in Architecture revision 2 and higher.

**Description**
Subtracts a value from a given register and stores the result in destination register if cond4 is true.

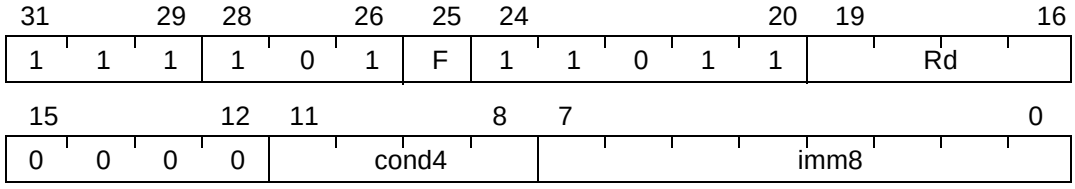
**Operation:**
I. If (cond4) then
Rd ← Rd - imm8;
Update flags if opcode[f] field is cleared
II. If (cond4) then
Rd ← Rx - Ry;

**Syntax:**
I. sub{f}{cond4} Rd, imm
II. sub{cond4} Rd, Rx, Ry

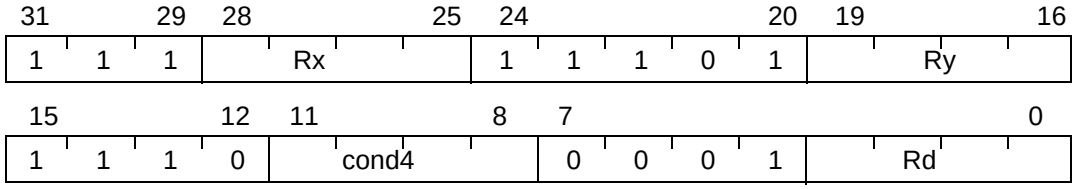
**Operands:**
I. cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
d ∈ {0, 1, …, 15}
imm ∈ {-128, -127, ..., 127}
II. cond4 ∈ {eq, ne, cc/hs, cs/lo, ge, lt, mi, pl, ls, gt, le, hi, vs, vc, qs, al}
{d, x, y} ∈ {0, 1, …, 15}

**Status Flag**:
**K = SE(imm8)**
**Flags only affected if format I and (cond4) is true and F parameter is given**
**Q:** Not affected
**V:** V ← (Rd[31] ∧ ¬K[31] ∧ ¬RES[31]) ∨ (¬Rd[31] ∧ K[31] ∧ RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← ¬Rd[31] ∧ K[31] ∨ K[31] ∧ RES[31] ∨ RES[31] ∧ ¬Rd[31]

**Opcode:**
**Format I:I**



**Format II:**




**Example:**

subfeq R3, 5 performs R3 ← R3 - 5 and sets flags accordingly if Z flag set.

subeq R5, 7 performs R5 ← R5 - 5 if Z flag set. Flags are not affected.

## SUBHH.W– Subtract Halfwords into Word

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Subtracts the two halfword registers specified and stores the result in the destination word-register. The halfword registers are selected as either the high or low part of the operand registers.

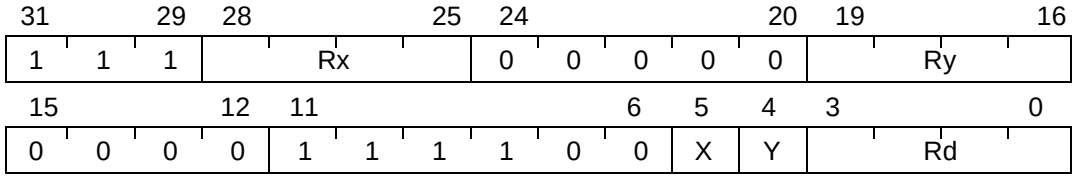
**Operation:**
I. If (Rx-part == t) then operand1 = SE(Rx[31:16]) else operand1 = SE(Rx[15:0]);
If (Ry-part == t) then operand2 = SE(Ry[31:16]) else operand2 = SE(Ry[15:0]);
Rd ← operand1 - operand2;

**Syntax:**
I. subhh.wRd, Rx:<part>, Ry:<part>

**Operands:**
I. {d, x, y} ∈ {0, 1, …, 15}
part ∈ {t,b}

**Status Flags:**
**OP1 = operand1, OP2 = operand2**
**Q:** Not affected
**V:** V ← (OP1[31] ∧ ¬OP2[31] ∧ ¬RES[31]) ∨ (¬OP1[31] ∧ OP2[31] ∧ RES[31])
**N:** N ← RES[31]
**Z:** Z ← (RES[31:0] == 0)
**C:** C ← ¬OP1[31] ∧ OP2[31] ∨ OP2[31] ∧ RES[31] ∨ ¬OP1[31] ∧ RES[31]

**Opcode:**




**Example:**
subhh.wR10, R2:t, R3:b
will perform R10 ← SE(R2[31:16]) - SE(R3[15:0])

## SWAP.B – Swap Bytes

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Swaps different parts of a register.

**Operation:**

I.
```
Temp ← Rd;
Rd[31:24] ← Temp[7:0];
Rd[23:16] ← Temp[15:8];
Rd[15:8] ← Temp[23:16];
Rd[7:0] ← Temp[31:24];
```

**Syntax:**

I. `swap.b Rd`

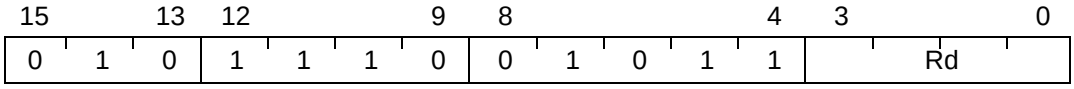
**Operands:**

I. $d \in \{0, 1, \ldots, 15\}$

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## SWAP.BH – Swap Bytes in Halfword

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Swaps different parts of a register.

**Operation:**

I.
```
Temp ← Rd;
Rd[31:24] ← Temp[23:16];
Rd[23:16] ← Temp[31:24];
Rd[15:8] ← Temp[7:0];
Rd[7:0] ← Temp[15:8];
```

**Syntax:**

I. swap.bhRd

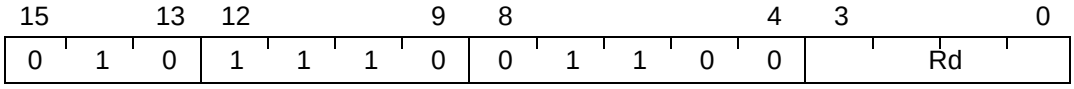
**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## SWAP.H – Swap Halfwords

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Swaps different parts of a register.

**Operation:**

I. Temp ← Rd;
Rd[31:16] ← Temp[15:0];
Rd[15:0] ← Temp[31:16];

**Syntax:**

I. swap.h Rd

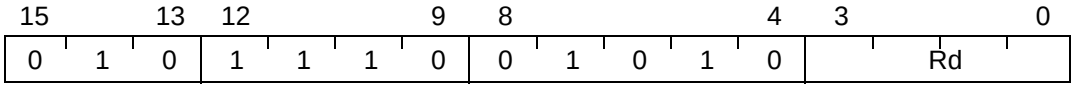
**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## SYNC – Synchronize memory

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Finish all pending memory accesses and empties write buffers. The semantic of Op8 is IMPLEMENTATION DEFINED.

**Operation:**
I. Finishes all pending memory operations.

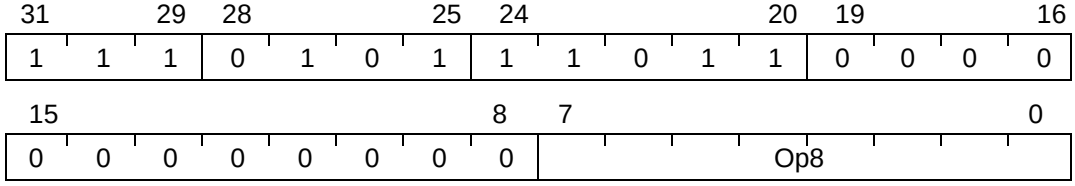
**Syntax:**
I. sync Op8

**Operands:**
I. $0 \leq Op8 \leq 255$

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**



## TLBR – Read TLB Entry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Read the contents of the addressed ITLB or DTLB Entry into TLBEHI and TLBELO.

**Operation:**

```
I.      if (TLBEHI[I] == 1)
            {TLBEHI, TLBELO} ←ITLB[MMUCR[IRP]];
        else
            {TLBEHI, TLBELO} ←DTLB[MMUCR[DRP]];
```

**Syntax:**

```
I.      tlbr
```

**Operands:**
None

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**

| 15 | | | | | | | 9 | 8 | | | | 4 | 3 | | | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |

**Note:**
This instruction can only be executed in a privileged mode.

## TLBS – Search TLB For Entry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Search the addressed TLB for an entry matching TLB Entry High and Low (TLBEHI/TLBELO) registers. Return a pointer to the entry in MMUCR[IRP] or MMUCR[DRP] if a match found, otherwise set the Not Found bit in the MMU control register, MMUCR[N].

**Operation:**

```
I.  MMUCR[N]   ←1;
    if (TLBEHI[I] == 1)
        TlbToSearch   ←ITLB;
    else
        TlbToSearch  ←DTLB;
    endif;

    for (i = 0 to TLBToSearchEntries-1)
        if ( Compare(TlbToSearch[i]VPN, VA, TlbToSearch[i]SZ, TlbToSearch[i]V) )
        // VPN and VA matches for the given page size and entry valid
            if ( SharedVMM or
                (PrivateVMM and ( TlbToSearch[i]G or (TlbToSearch[i]ASID==TLBEHI[ASID]) ) ) )
                ptr ← i;
                MMUCR[N]   ←0;
            endif;
        endif;
    endfor;
    if (TLBEHI[I] == 1)
        MMUCR[IRP]   ←ptr;
    else
        MMUCR[DRP]   ←ptr;
    endif;
```

**Syntax:**

I. tlbs

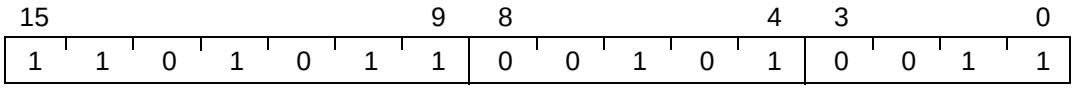
**Operands:**

None

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
This instruction can only be executed in a privileged mode.

## TLBW – Write TLB Entry

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Write the contents of the TLB Entry High and Low (TLBEHI/TLBELO) registers into the addressed TLB entry.

**Operation:**

```
I.      if (TLBEHI[I] == 1)
            ITLB[MMUCR[IRP]] ← {TLBEHI, TLBELO};
        else
            ITLB[MMUCR[DRP]] ← {TLBEHI, TLBELO};
```

**Syntax:**

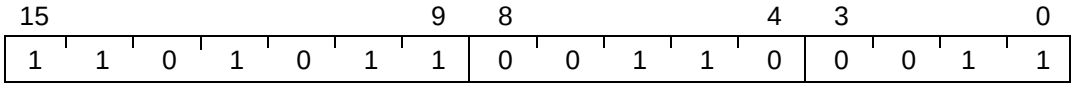
```
I.      tlbw
```

**Operands:**
None

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Not affected.
**C:** Not affected.

**Opcode:**




**Note:**
This instruction can only be executed in a privileged mode.

## TNBZ – Test if No Byte is Equal to Zero

**Architecture revision:**
Architecture revision1 and higher.

**Description**
If any of the bytes 0,1,2,3 in the word is zero, the SR[Z] flag is set.

**Operation:**

```
I.      if (Rd[31:24] == 0 ∨
            Rd[23:16] == 0 ∨
            Rd[15:8] == 0 ∨ Rd[7:0] == 0 )
          SR[Z] ← 1;
        else
          SR[Z] ← 0;
```

**Syntax:**

```
I.      tnbz    Rd
```

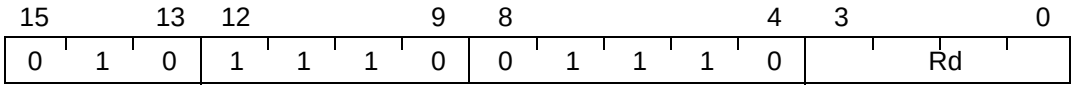
**Operands:**

I. d ∈ {0, 1, …, 15}

**Status Flags:**

**Q:** Not affected.
**V:** Not affected.
**N:** Not affected.
**Z:** Z ← (Rd[31:24] == 0 ∨ Rd[23:16] == 0 ∨ Rd[15:8] == 0 ∨ Rd[7:0] == 0 )
**C:** Not affected.

**Opcode:**



## TST – Test Register

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Test register. Used to check if a subset of a register includes one or more set bits. No writeback of the result is performed, but the flags are set.

**Operation:**
I. Rd $\wedge$ Rs;

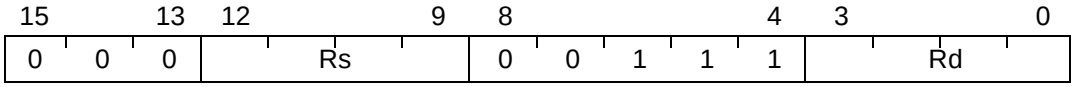
**Syntax:**
I. tst Rd, Rs

**Operands**:
I. {d,s} $\in$ {0, 1, …, 15}

**Status Flags**

**Q:** Not affected
**V:** Not affected
**N:** N $\leftarrow$ RES[31]
**Z:** Z $\leftarrow$ (RES[31:0] == 0)
**C:** Not affected

**Opcode(s)**



## XCHG – Exchange Register and Memory

**Architecture revision:**
Architecture revision1 and higher.

**Description**
Reads a word from memory pointed to by Rx into register Rd, and writes the value of register Ry to memory. This instruction can be used to implement binary semaphores (mutexes). The *stcond* instruction should be used to implement counting semaphores.

**Operation:**

I.
```
Temp ← *(Rx);
*(Rx) ← Ry;
Rd ← Temp;
```

**Syntax:**

I. `xchg Rd, Rx, Ry`

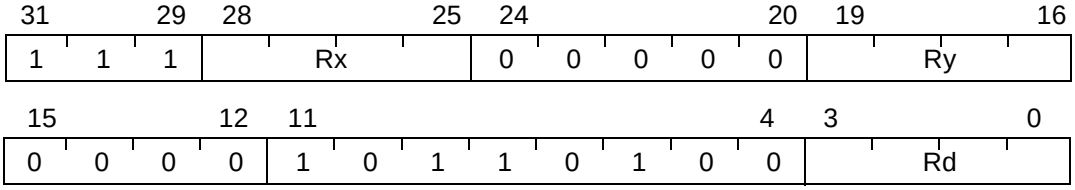
**Operands:**

I. {d,x,y} ∈ {0, 1, …, 14}

**Status Flags:**

**Q:** Not affected
**V:** Not affected
**N:** Not affected
**Z:** Not affected
**C:** Not affected

**Opcode:**




**Note:**

If R15 is used as Rd, Rx or Ry, the result is UNDEFINED.
If Rd = Ry, the result is UNDEFINED.
If Rd = Rx, the result is UNDEFINED.

# 10. Revision History

## 10.1 Rev. 32000A-02/2006

1. Initial version.

## 10.2 Rev. 32000B-11/2007

1. Improved description of RETE in Instruction Set Chapter.
2. Corrected description of STC.D in Instruction Set Chapter.
3. Added micro-TLB miss performance counting.
4. Added clear-on-compare functionality to COUNT system register
5. Updated MPU description to match implementation
6. Added new architecture revision 2 instructions

## 10.3 Rev. 32000C-08/2009

1. Corrected typos in the MOVH instruction description.
2. Corrected Reset address typo in chapter 7.3.1.1
3. Corrected typos in RETE, DIVS and DIVU detailed instruction set descriptions.
4. Described new architecture revision 3 secure execution state.
5. Automatic clear of COUNT on COMPARE match can now be overridden, usually by writing a bit in the implementation's CPUCR register.

## 10.4 Rev. 32000D-04/2011

1. FlashVault™ description added
2. Instruction syntax: Each Ri<part> has been replaced by Ri:<part> in the instruction set summary and descriptions
3. Added description of bit 7 in Op8 in sleep instruction
4. Parantheses added to shift instruction descriptions to clarify the order of the operations
5. Added cond4 to ld.sb, ld.ub, ld.sh, ld.uh, ld.w, st.b, st.h, st.w instruction description syntax
6. SE replaced by ZE in st.w{cond4} in the Instruction Set Summary table

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