# FT64

# Overview

FT64 is a two-way superscalar processing core capable of executing up to two instructions per clock cycle. The core features register renaming to avoid data hazards. This implementation originated from the RiSC-16 core by Dr. Bruce L. Jacob. The core has the following features:

* register renaming
* speculative loading
* 32 bit fixed instruction format
* 64 bit data width
* immediate prefix instructions for large immediates
* powerful branch prediction
* return address prediction
* bus interface unit
* instruction and data caches
* dual result busses
* dual ALU’s, one flow control unit, one memory unit, one floating point unit

## Goals

One of the primary goals for the development of this core was the implementation of a register renaming mechanism. The author also wanted a stream-lined core as a starting place. One goal was to implement many features of the Thor core using a fixed 32 bit instruction set. Easy implementation of a compiler was also a goal.

## Register Set

There are 32 general purpose registers in the architecture. R0 always has the value zero.

|  |  |  |
| --- | --- | --- |
| Register | Description / Suggested Usage | Saver |
| r0 | always reads as zero |  |
| r1-r2 | return values / exception | caller |
| r3-r10 | temporaries | caller |
| r11-r17 | register variables | callee |
| r18-r23 | function arguments | caller |
| r24 | type number / function argument | caller |
| r25 | class pointer / function argument | caller |
| r26 | thread pointer | callee |
| r27 | global pointer |  |
| r28 | exception link register | caller |
| r29 | return address / link register | caller |
| r30 | base / frame pointer | callee |
| r31 | stack pointer (hardware) | callee |

The register file has six read ports and two write ports.

## Program Counter

The program counter identifies which instruction to execute. The program counter increments by four with the least significant two bits always zero. The increment may be overridden using one of the flow control instructions. The program counter typically addresses 32 bit instruction parcels.

|  |  |
| --- | --- |
| 63 2 | 1 0 |
| Address[63..2] | 02 |

## Caches

The core has both instruction and data caches in order to improve performance.

The instruction cache is a two level cache (L1, L2) allowing better performance. The first level cache is fully associative, the second level cache is four-way set associative. L1 is 2kB in size and made from distributed ram in order to get single cycle performance. L1 is organized as 64 lines of 32 bytes. L2 is 16kB in size implemented with block ram. L2 is organized as 512 lines of 32 bytes. The instruction cache is dual ported to allow two instructions to be fetched at one time.

The data cache is organized as 512 lines of 32 bytes (16kB) and implemented with block ram. Access to the data cache is multicycle. The data cache has three read ports allowing three load operations to be in progress at the same time. Stores write through to memory. There is only a single write port on the data cache.

### Uncached Data Area

The address range $FFDxxxxx is an uncached data area. This area is reserved for I/O devices. The data cache may also be disabled in control register zero.

## Branch Predictor

The branch predictor is a (2, 2) correlating predictor. The branch history is maintained in a 512 entry history table. It has four read ports for predicting branch outcomes, one port for each instruction in the fetch buffer. The branch predictor may be disabled by a bit in control register zero. When disabled all branches are predicted as not taken.

## Branch Target Buffer (BTB)

The core has a 1k entry branch target buffer for predicting the target address of flow control instructions where the address is calculated and potentially unknown at time of fetch. Instructions covered by the BTB include long call instructions, jump-and-link, interrupt return and breakpoint instructions and branches to targets contained in a register.

## Return Address Stack Predictor (RSB)

There is an address predictor for return addresses which can in some cases can eliminate the flushing of the instruction queue when a return instruction is executed. The RET instruction is detected in the fetch stage of the core and a predicted return address used to fetch instructions following the return. The return address stack predictor has a stack depth of 16 entries. On stack overflow or underflow the prediction will be wrong, however performance will be no worse than not having a predictor. The return address stack predictor checks the address of the instruction queued following the RET against the address fetched for the RET instruction to make sure that the address corresponds.

## Operating Levels

The core has eight operating levels. The highest operating level is operating level zero which is called the machine operating level. Operating level zero has complete access to the machine. Other operating levels may have more restricted access. When an interrupt occurs the operating level is set to the machine level. The core vectors to an address depending on the current operating level.

|  |  |  |
| --- | --- | --- |
| Operating Level | Privilege Level | Moniker |
| 7 | 7 to 255 | user |
| 6 | 6 | supervisor |
| 5 | 5 | supervisor |
| 4 | 4 | supervisor |
| 3 | 3 | supervisor |
| 2 | 2 | supervisor |
| 1 | 1 | hypervisor |
| 0 | 0 | machine |

### Switching Operating Levels

The operating level is automatically switched to the machine level when an interrupt occurs. The BRK instruction may be used to switch operating levels. The REX instruction may also be used by an interrupt handler to switch the operating level to a lower level. The RTI instruction will switch the operating level back to what it was prior to the interrupt.

## Privilege Levels

The core supports a 256 level privilege level system. Privilege level zero is assigned to operating mode zero. Privilege level one is assigned to operating level one. Privilege levels 2 to 6 are assigned to their corresponding operating level. The remaining privilege levels are assigned to operating level seven.

## Control and Status Registers

### Control Register Zero (CSR #000)

This register contains a bit to enable protected mode.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 63 | 62 33 32 30 9 6 1 | | | | | | | | | 0 |
| D | ~ |  |  | TXE | bpe | dce |  | ~ |  | Pe |

D: debug mode status. this bit is set during an interrupt routine if the processor was in debug mode when the interrupt occurred.

PE: Protected Mode enable: 1 = enabled, 0 = disabled.

DCE: data cache enable: 1=enabled, 0 = disabled

bpe: branch predictor enable: 1=enabled, 0=disabled

TXE: call target exception enable: 1= enabled, 0 = disabled

Disabling the data cache is useful for some codes with large data sets to prevent cache loading of values that are used infrequently. The instruction cache may not be disabled.

Disabling branch prediction will significantly affect the cores performance, but may be useful for debugging. Disabling branch prediction causes all branches to be predicted as not-taken (unless determined otherwise by the instruction). No entries will be updated in the branch history table if the branch predictor is disabled.

This register supports bit set / clear CSR instructions.

TXE: see the TGT instruction

### HARTID (0x001)

This register contains a number that is externally supplied on the hartid\_i input bus to represent the hardware thread id or the core number.

### TICK (0x002)

This register contains a tick count of the number of clock cycles that have passed since the last reset.

### PCR Paging Control (CSR 0x003)

This register controls the paged memory management unit. A more detailed description is available under the section on memory management.

### AEC Arithmetic Exception Control (CSR 0x004)

This register has controls to enable arithmetic exceptions and status bits to indicate the occurrence of exception conditions.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Exception Occurrence | | | | | | Exception Enable | | | | | |
| 63 37 | 36 | 35 | 34 | 33 | 32 | 31 5 | 4 | 3 | 2 | 1 | 0 |
|  | DIV | MUL | ASL | SUB | ADD |  | DIV | MUL | ASL | SUB | ADD |

### CAUSE (0x006)

This register contains a code indicating the cause of an exception or interrupt. The break handler will examine this code in order to determine what to do. Only the low order 16 bits are implemented. The high order bits read as zero and are not updateable.

### BADADDR (CSR 0x007)

This register contains the effective address for a load / store operation that caused a memory management exception or a bus error. Note that the address of the instruction causing the exception is available in the EPC register.

### PCR2 Paging Control (CSR 0x008)

This register controls the paged memory management unit. A more detailed description is available under the section on memory management.

### SEMA (CSR 0x00C) Semaphores

This register is available for system semaphore or flag use. The least significant bit is tied to the reservation address status input (rb\_i). It will be set if a SWC instruction was successful. The least significant bit is also cleared automatically when an interrupt (BRK) or interrupt return (RTI) instruction is executed. Any one of the remaining bits may also be cleared by an RTI instruction. This could be a busy status bit for the interrupt routine. Bits in this CSR may be set or cleared with one of the CSRxx instructions. This register has individual bit set / clear capability.

### FSTAT (CSR 0x014) Floating Point Status and Control Register

The floating point status and control register may be read using the CSR instruction. Unlike other CSR’s the control register has its own dedicated instructions for update. See the section on floating point instructions for more information.

|  |  |  |  |
| --- | --- | --- | --- |
| Bit |  | Symbol | Description |
| 31:29 | **RM** | rm | rounding mode |
| 28 | **E5** | inexe | - inexact exception enable |
| 27 | **E4** | dbzxe | - divide by zero exception enable |
| 26 | **E3** | underxe | - underflow exception enable |
| 25 | **E2** | overxe | - overflow exception enable |
| 24 | **E1** | invopxe | - invalid operation exception enable |
| 23 | **NS** | ns | - non standard floating point indicator |
| **Result Status** | | | |
| 22 |  | fractie | - the last instruction (arithmetic or conversion) rounded intermediate result (or caused a disabled overflow exception) |
| 21 | **RA** | rawayz | rounded away from zero (fraction incremented) |
| 20 | **SC** | C | denormalized, negative zero, or quiet NaN |
| 19 | **SL** | neg < | the result is negative (and not zero) |
| 18 | **SG** | pos > | the result is positive (and not zero) |
| 17 | **SE** | zero = | the result is zero (negative or positive) |
| 16 | **SI** | inf ? | the result is infinite or quiet NaN |
| **Exception Occurrence** | | | |
| 15 | **X6** | swt | {reserved} - set this bit using software to trigger an invalid operation |
| 14 | **X5** | inerx | - inexact result exception occurred (sticky) |
| 13 | **X4** | dbzx | - divide by zero exception occurred |
| 12 | **X3** | underx | - underflow exception occurred |
| 11 | **X2** | overx | - overflow exception occurred |
| 10 | **X1** | giopx | - global invalid operation exception – set if any invalid operation exception has occurred |
| 9 | **GX** | gx | - global exception indicator – set if any enabled exception has happened |
| 8 | **SX** | sumx | - summary exception – set if any exception could occur if it was enabled  - can only be cleared by software |
| **Exception Type Resolution** | | | |
| 7 | **X1T** | cvt | - attempt to convert NaN or too large to integer |
| 6 | **X1T** | sqrtx | - square root of non-zero negative |
| 5 | **X1T** | NaNCmp | - comparison of NaN not using unordered comparison instructions |
| 4 | **X1T** | infzero | - multiply infinity by zero |
| 3 | **X1T** | zerozero | - division of zero by zero |
| 2 | **X1T** | infdiv | - division of infinities |
| 1 | **X1T** | subinfx | - subtraction of infinities |
| 0 | **X1T** | snanx | - signaling NaN |

### DBADx (CSR 0x018 to 0x01B) Debug Address Register

These registers contain addresses of instruction or data breakpoints.

|  |
| --- |
| 63 0 |
| Address 63..0 |

### DBCR (CSR 0x01C) Debug Control Register

This register contains bits controlling the circumstances under which a debug interrupt will occur.

|  |  |  |  |
| --- | --- | --- | --- |
| bits |  |  |  |
| 3 to 0 | Enables a specific debug address register to do address matching. If the corresponding bit in this register is set and the address (instruction or data) matches the address in the debug address register then a debug interrupt will be taken. |  |  |
| 17, 16 | This pair of bits determine what should match the debug address register zero in order for a debug interrupt to occur.   |  |  |  | | --- | --- | --- | | 17:16 |  |  | | 00 | match the instruction address |  | | 01 | match a data store address |  | | 10 | reserved |  | | 11 | match a data load or store address |  | |  |  |
| 19, 18 | This pair of bits determine how many of the address bits need to match in order to be considered a match to the debug address register. These bits are ignored when matching instruction addresses, which are always half-word aligned.   |  |  |  | | --- | --- | --- | | 19:18 |  | Size | | 00 | all bits must match | byte | | 01 | all but the least significant bit should match | char | | 10 | all but the two LSB’s should match | half | | 11 | all but the three LSB’s should match | word | |  |  |
| 23 to 20 | Same as 16 to 19 except for debug address register one. |  |  |
| 27 to 24 | Same as 16 to 19 except for debug address register two. |  |  |
| 31 to 28 | Same as 16 to 19 except for debug address register three. |  |  |
| 55 to 62 | These bits are a history stack for single stepping mode. An exception will automatically disable single stepping mode and record the single step mode state on stack. Returning from an exception pops the single step mode state from the stack. |  |  |
| 63 | This bit enables SSM (single stepping mode) |  |  |

### DBSR (CSR 0x01D) - Debug Status Register

This register contains bits indicating which addresses matched. These bits are set when an address match occurs, and must be reset by software.

|  |  |
| --- | --- |
| bit |  |
| 0 | matched address register zero |
| 1 | matched address register one |
| 2 | matched address register two |
| 3 | matched address register three |
| 63 to 4 | not used, reserved |

### CAS (CSR 0x02C) Compare and Swap

This register is to support the compare and swap (CAS) instruction. If the value in the addressed memory location identified by the CAS instruction is equal to the value in the CAS register, then the source register is written to the memory location, and the source register is loaded with the value 1. Otherwise if the value in the addressed memory location doesn’t match the value in this register, then value at the memory location is loaded into the CAS register, and the source register is set to zero. No write to memory occurs if the match fails.

|  |
| --- |
| 63 0 |
| Value 63..0 |

### TVEC (0x030 to 0x037)

These registers contain the address of the exception handling routine for a given operating level. TVEC[0] (0x030) is used directly by hardware to form an address of the interrupt routine. The lower eight bits of TVEC[0] are not used. The lower bits of the interrupt address are determined from the operating level. For the other registers the two low order bits of the address must be zero in order to keep the program counter aligned on a half-word address. TVEC[1] to TVEC[7] are used by the REX instruction.

### EPC (0x040)

This register contains the address of the interrupted or exceptioned code.

### STATUSL (0x044)

This register contains the interrupt mask, operating level, and privilege level stack. When an exception or interrupt occurs this register is shifted to the left and the current status copied to the low order bits, when an RTI instruction is executed this register is shifted to the right and the status bits copied from the low order bits of the register.

|  |  |  |  |
| --- | --- | --- | --- |
| 63 14 | 13 6 | 5 3 | 2 0 |
| Stack area | PL8 | OL3 | IM3 |

### STATUSH (0x045)

This register contains the interrupt mask, operating level, and privilege level stack. When an exception or interrupt occurs the stack area of this register is shifted to the left when an RTI instruction is executed the stack area is shifted to the right. Note that the privilege level, operating level, and interrupt mask are set to 0, 0, and 7 respectively on a stack underflow. An exception is also triggered on a stack underflow.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 63 | 6261 | 60 56 | 55 | 5452 | 5150 | 4948 | 47 0 |
| SD1 | ~2 | VM5 | MPRV1 | ~3 | XS2 | FS2 | Stack area |

#### VM5

These bits control virtual memory options. Note that multiple options may be present at the same time. At reset all the bits are set to zero.

|  |  |  |
| --- | --- | --- |
| Bit | Indicates |  |
| 0 | 1 = single bound |  |
| 1 | 1 = separate program and data bounds |  |
| 2 | 1 = lot protection system |  |
| 3 | 1 = simplified paged unit |  |
| 4 | 1 = paging unit |  |

#### MPRV

This bit when true (1) causes memory operations to use the first stack privilege level when evaluating privilege and protection rules. (Bits 0 to 13 in the status reg).

#### FS2

These two bits can be used to keep track of the floating point register state.

#### XS2

These two bits can be used to keep track of an additional core extension state.

### CODEBUF (0x080 to 0x0BF)

This register range is for access to 64 adaptable code buffers. The code buffers are used by the EXEC instruction in order to execute code which may change at run-time.

### INFO (0x7F0 to 0x7FF)

This set of registers contains general information about the core including the manufacturer name, cpu class and name, and model number.

# Exceptions

## External Interrupts

There is very little difference between an externally generated exception and an internally generated one. An externally caused exception will force a BRK instruction into the instruction stream. The BRK instruction contains a cause code identifying the external interrupt source.

## Effect on Machine Status

The operating mode is always switched to the machine mode on exception. It’s up to the machine mode code to redirect the exception to a lower operating mode when desired. Further exceptions at the same or lower interrupt level are disabled automatically. Machine mode code must enable interrupts at some point. This can be done automatically when the exception is redirected to a lower level by the REX instruction. The RTI instruction will also automatically enable further machine level exceptions.

## Exception Stack

The program counter and status bits are pushed onto an internal stack when an exception occurs. This stack is only eight entries deep as that is the maximum amount of nesting that can occur. Further nesting of exceptions can be achieved by saving the state contained in the exception registers.

## Exception Vectoring

Exceptions are handled through a vector table. The vector table has eight entries, one for each operating level the core may be running at. The location of the vector table is determined by TVEC[0]. If the core is operating at level four for instance and an interrupt occurs vector table address number four is used for the interrupt handler. Note that the interrupt automatically switches the core to operating level zero, privilege level zero. An exception handler at the machine level may redirect exceptions to a lower level handler identified in one of the vector registers. More specific exception information is supplied in the cause register.

|  |  |  |
| --- | --- | --- |
| Operating Level | Address (If TVEC[0] contains $FFFC0000) |  |
| 0 | $FFFC0000 | Handler for operating level zero interrupt |
| 1 | $FFFC0020 |  |
| 2 | $FFFC0040 |  |
| 3 | $FFFC0060 |  |
| 4 | $FFFC0080 |  |
| 5 | $FFFC00A0 |  |
| 6 | $FFFC00C0 |  |
| 7 | $FFFC00E0 | handler for operating level seven interrupt |

## Reset

The core begins executing instructions at address $FFFC0100. All registers are in an undefined state.

## Exception Cause Codes

The following table outlines the cause code for a given purpose. These codes are specific to FT64. Under the HW column an ‘x’ indicates that the exception is internally generated by the processor; the cause code is hard-wired to that use. An ‘e’ indicates an externally generated interrupt, the usage may vary depending on the system.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Cause Code |  | HW | Description |  |
| 0 |  |  |  |  |
| 1 |  |  |  |  |
| 2 |  |  | FMTK Scheduler |  |
| 432 |  | e |  |  |
| 433 | KRST | e | Keyboard reset interrupt |  |
| 434 | MSI | e | Millisecond Interrupt |  |
| 435 | TICK | e | FMTK Tick Interrupt |  |
| … |  |  |  |  |
| 463 | KBD | e | Keyboard interrupt |  |
| 480 | SSM | x | single step |  |
| 481 | DBG | x | debug exception |  |
| 482 | TGT | x | call target exception |  |
| 483 | MEM | x | memory fault |  |
| 484 | IADR | x | bad instruction address |  |
| 485 | UNIMP | x | unimplemented instruction |  |
| 486 | FLT |  | floating point exception |  |
| 487 | CHK |  | bounds check exception |  |
| 488 | DBZ | x | divide by zero |  |
| 489 | OFL | x | overflow |  |
| 493 | FLT | x | floating point exception |  |
| 497 | EXF | x | Executable fault |  |
| 498 | DWF | x | Data write fault |  |
| 499 | DRF | x | data read fault |  |
| 500 | SGB | x | segment bounds violation |  |
| 501 | PRIV | x | privilege level violation |  |
|  |  |  |  |  |
|  |  |  |  |  |
| 504 | STF | x | stack fault |  |
| 505 | CPF | x | code page fault |  |
| 506 | DPF | x | data page fault |  |
| 508 | DBE | x | data bus error |  |
| 509 | IBE | x | instruction bus error |  |
| 510 | NMI | x | Non-maskable interrupt |  |
|  |  |  |  |  |

# Simplified Paged Memory Management Unit

## Overview

The memory management unit is a simplified paged memory management unit. Memory management by the MMU includes virtual to physical address mapping and read/write/execute permissions. The MMU divides memory into 64kB or 4MiB pages depending on the setting in PCR2.

64kiB pages

Processor address bits 16 to 25 are used as a ten bit index into a mapping table to find the physical page. The MMU remaps the ten address bits into a sixteen bit value used as address bits 16 to 31 when accessing a physical address. The lower sixteen bits of the address pass through the MMU unchanged. The maximum amount of memory that may be mapped in the MMU is 64MiB per map out of a pool of 4GiB. Addresses with the most significant six bits set are not mapped.

4MiB pages

Some tasks require a lot of memory and a 64MB map isn’t sufficient. For instance, while in machine mode the core requires access to the entire address range. A memory page size of 4MiB may be selected by setting the bit corresponding to the memory map in PCR2.

Processor address bits 22 to 31 are used as a ten bit index into a mapping table to find the physical page. The MMU remaps the ten address bits into a ten bit value used as address bits 22 to 31 when accessing a physical address. The lower 22 bits of the address pass through the MMU unchanged. The maximum amount of memory that may be mapped in the MMU is 4GiB per map out of a pool of 4GiB. Addresses with the most significant six bits set are not mapped.

## Map Tables

The mapping tables for memory management are stored directly in the MMU rather than being stored in main memory as is commonly done. The MMU supports up to 64 independent mapping tables. Only a single mapping table may be active at one time. The active mapping table is set in the paging control register (CSR #3) bits 0 to 5 – called the operate key. Mapping tables may be shared between tasks.

## Map Caching / TLB

There isn’t a need for a TLB or ATC as the entire mapping table is contained in the MMU. A TLB isn’t required. Address mapping is still only two cycles.

## Operate Key

The operate key controls which mapping table is actively mapping the memory space. The operate key is located in CSR #3 bits 0 to 5. The operate key is similar to an ASID (address space identifier). The operate key is also used as part of the cores cache tags. When the operate key changes due to a task switch, the cache does not have to be invalidated.

## Access Key

The MMU mapping tables are present at I/O address $FFDC4000 to $FFDC4FFF. All the mapping tables share the same I/O space. Only one mapping table is visible in the address space at one time. Which table is visible is controlled by an access key. The access key is located in the paging control register (CSR #3) bits 8 to 13.

## Address Pass-through

Addresses pass through the MMU unaltered until the mapping enable bit is set. Until mapping is enabled, the physical address will match the virtual address. Additionally address bits 0 to 15 pass through the MMU unaltered.

## Mapping Table Layout

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | D20 | D19 | D18 | D17 | D16 | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |  |
| 000 | S1 | S0 | W | R | X | PA31 | PA30 | PA29 | PA28 | PA27 | PA26 | PA25 | PA24 | PA23 | PA22 | PA21 | PA20 | PA19 | PA18 | PA17 | PA16 |  |
| 004 | S1 | S0 | W | R | X | PA31 | PA30 | PA29 | PA28 | PA27 | PA26 | PA25 | PA24 | PA23 | PA22 | PA21 | PA20 | PA19 | PA18 | PA17 | PA16 |  |
|  |  |  | … | | | | | | | | | | | | | | | | | | |  |
| FFC | S1 | S0 | W | R | X | PA31 | PA30 | PA29 | PA28 | PA27 | PA26 | PA25 | PA24 | PA23 | PA22 | PA21 | PA20 | PA19 | PA18 | PA17 | PA16 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

PAnn = physical address

X = executable page indicator.

W = writeable data page indicator.

R = readable data page indicator.

Note the low order six bits are not used for 4MiB pages.

S1,S0 = two bits for program use

## PCR- Paging Control Register Layout

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 | 30 14 | 13 8 | 7 6 | 5 0 |
| PE | ~18 | AKey6 | ~ | OKey6 |

PE = Paging Enable (1=enabled, 0 = disabled)

AKey = Access Key

OKey = Operate Key

## PCR2 – Page Size

This register controls the memory page size. Each bit in the register corresponds to a memory map. Memory may be paged in either 64kiB or 4MiB pages. All pages in a map have the same size.

## Latency

The address map operation when enabled has two cycles of latency. In the case of instructions address translation only takes place on a cache miss when the cache needs to be loaded from main memory.

# Instruction Set Description

## Formats

Instructions have a fixed 32 bit format. Immediate constants may be extended using prefix instructions. There are only a handful of different instruction formats.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Immed16 | | | | | | | Rt5 | | Ra5 | Opcode6 | RI |
| Funct6 | | | ~3 | Sz2 | Rt5 | | Rb5 | | Ra5 | Opcode6 | RR |
| Immed16 | | | | | | P2 | | Cond3 | Ra5 | 01h6 | B |
| Op2 | OL3 | Regno11 | | | | Rt5 | | | Ra5 | 0Eh6 | CSR |

## Operation Sizes

Many instructions have an option to process data in sub-word data sizes including bytes, chars, and half-words. Typically sized operations are supported only with register-register instructions. Sized instructions sign extend the result to 64 bits. Instructions using immediate values always operate on whole words.

## Arithmetic Operations

Arithmetic operations include addition, subtraction, comparison, multiplication and division.

## Logical Operations

Logical operations include bitwise and, or, and exclusive or.

## Memory Operations

Memory operations include loads and stores of bytes, words or half-words. There isn’t yet a full complement of memory operations in order to keep the size of the core smaller. Notably missing are instructions to load / store 16 bit quantities. The core can perform loads and stores using indexed addressing.

## Control Flow Instructions

Control flow instructions include call, return, jumps and branches, breakpoint and return instructions.

## Clock cycles

The clock cycles indicated are only approximate. The core hasn’t under gone significant timing measurements.

## ABS – Absolute Value

**Description:**

This instruction takes the absolute value of a register and places the result in a target register.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 016 | 45 | ~3 | Sz2 | Rt5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 only

**Operation:**

If Ra < 0

Rt = -Ra

else

Rt = Ra

Exceptions: none

Notes:

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

## ADD - Addition

Description:

Add two values. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction. When the operation is less than a word in size the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 04h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 046 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 1

Exceptions:

The immediate form of the instruction will not cause an exception. The registered form of the instruction may cause an overflow exception if enabled in the AEC register.

Notes:

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

## AND – Bitwise And

Description:

Perform a bitwise and operation between two operands. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 08h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 086 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

Clock Cycles: 1

Exceptions: none

## ASL – Arithmetic Shift Left

Description:

Bits from the source register Ra are shifted left by the amount in register Rb or an immediate value. A zero is shifted into bit zero. The difference between this instruction and a SHL instruction is that ASL may cause an arithmetic overflow exception. SHL will never cause an exception.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 24 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | A4 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions:

An overflow exception may result if the bits shifted out from the MSB are not the same as the resulting sign bit and the exception is enabled in the AEC register. Exceptions are only caused by a word size operation.

## ASR – Arithmetic Shift Right

Description:

Bits from the source register Ra are shifted right by the amount in register Rb or an immediate value. The sign bit is shifted into the most significant bits.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 34 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | B4 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## BBC –Branch if Bit Clear

Description:

If the specified bit in a register is clear then an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 11 | | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 13 | Bitno6 | Ra5 | 13h5 | D1 |

Operation:

if (Ra[bitno]=0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BBS –Branch if Bit Set

Description:

If the specified bit in a register is set then an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 11 | | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 03 | Bitno6 | Ra5 | 13h5 | D1 |

Operation:

if (Ra[bitno]=1)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## Bcc – Conditional Branch

Description:

If the branch condition is true, an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The immediate value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | Cond4 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | Cond4 | Rc5 | Rb5 | Ra5 | 03h6 |

|  |  |  |
| --- | --- | --- |
| Cond3 | Mne. |  |
| 0 | BEQ | Ra = Rb signed |
| 1 | BNE | Ra <> Rb |
| 2 | BLT | Ra < Rb |
| 3 | BGE | Ra >= Rb |
| 4 | BLTU | Ra < Rb (unsigned) |
| 5 | BGEU | RA >= Rb (unsigned) |
| 6 |  | reserved |
| 7 |  | reserved |
| 8 | FBEQ | Ra = Rb |
| 9 | FBNE | Ra != Rb |
| 10 | FBLT | Ra < Rb |
| 11 | FBGE | Ra >= Rb |
| 12 |  | reserved |
| 13 |  | reserved |
| 14 |  | reserved |
| 15 | FBUN | register Ra contains unordered floating point constant |

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

Clock Cycles:

Typically 1 with correct branch outcome and target prediction.

## BCDADD - Register-Register

**Description:**

Adds two registers using BCD arithmetic and places the result in a target register. Only the low order byte of the register is used. The result is an eight bit BCD number. The result is zero extended to 64 bits.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 006 | 05 | Rt5 | Rb5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 only

**Operation:**

Rt = Ra + Rb

**Exceptions:** none

## BCDMUL - Register-Register

**Description:**

Multiplies two registers using BCD arithmetic and places the result in a target register. Only the low order byte of the register is used. The result is a 16 bit BCD value. The result is zero extended to 64 bits.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 006 | 25 | Rt5 | Rb5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 Only

**Operation:**

Rt = Ra \* Rb

**Exceptions:** none

## BCDSUB - Register-Register

**Description:**

Subtracts two registers using BCD arithmetic and places the result in a target register. Only the low order byte of the register is used. The result is an eight bit BCD number. The result is zero extended to 64 bits.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 006 | 15 | Rt5 | Rb5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 only

**Operation:**

Rt = Ra - Rb

**Exceptions:** none

## BEQ –Branch if Equal

Description:

If two registers are equal an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 04 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 04 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra <> 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

Clock Cycles: Typically 1 with correct branch outcome and target prediction.

## BEQI –Branch if Equal Immediate

Description:

If a register is equal to a nine bit sign extended value then an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction. This instruction is useful for implementing case statements based on small values.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | Immed9 | Ra5 | 19h5 | D1 |

Operation:

if (Ra = Immediate)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

Clock Cycles: Typically 1 with correct branch outcome and target prediction.

## BFCHG – Bit-Field Change

Description:

The bit-field change instruction inverts all the bits in a bit-field.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 25 | | Rt5 | | ~5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFCLR – Bit-Field Clear

Description:

The bit-field clear instruction zeros out all the bits in a bit-field.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 15 | | Rt5 | | ~5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFEXT – Bit-Field Extract

Description:

Extracts a bitfield from register Ra located between the mask begin (mb) and mask end (me) bits and places the sign extended result into the target register. This instruction may be used to sign extend a value beginning at any bit.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 55 | | Rt5 | | ~5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFEXTU – Bit-Field Extract Unsigned

Description:

Extracts a bitfield from register Ra located between the mask begin (mb) and mask end (me) bits and places the zero extended result into the target register.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 65 | | Rt5 | | ~5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFINS – Bit-Field Insert

Description:

The bit-field insert instruction inserts the contents of Rb into a bit-field.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 35 | | Rt5 | | Rb5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFINSI – Bit-Field Insert Immediate

Description:

The bit-field insert immediate instruction inserts an immediate value into a bit-field. The constant is a maximum of fifteen bits and is zero extended to the width of the bit-field.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Imm[14..5] | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 45 | | Rt5 | | Imm[4..0] | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BFSET – Bit-Field Set

Description:

Sets the bits to one of the bitfield in Ra located between the mask begin (mb) and mask end (me) bits and stores the result in the target register.

Instruction Format:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ~10 | | ~2 | | me6 | | ~2 | mb6 | | 1Ah6 |
| 026 | 05 | | Rt5 | | ~5 | | | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

## BGE –Branch if Greater or Equal

Description:

If register Ra is greater than or equal to register Rb then an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The immediate value may not be extended with a prefix instruction. This instruction may also be used to branch on less than or equal by swapping the registers around.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 34 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 34 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra < 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BGEU –Branch if Greater or Equal Unsigned

Description:

If register Ra is greater than or equal to register Rb then an eleven bit sign extended value is shifted left twice and added to the program counter. The values are treated as unsigned numbers. The branch is relative to the address of the instruction directly following the branch. The immediate value may not be extended with a prefix instruction. This instruction may also be used to branch on less than or equal by swapping the registers around.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 54 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 54 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra < 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BLT –Branch if Less Than

Description:

If register Ra is less than register Rb then an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The immediate value may not be extended with a prefix instruction. This instruction may also be used to branch on greater than by swapping the registers around.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 24 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 24 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra < 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BLTU –Branch if Less Than Unsigned

Description:

If register Ra is less than register Rb then an eleven bit sign extended value is shifted left twice and added to the program counter. The values are treated as unsigned numbers. The branch is relative to the address of the instruction directly following the branch. The immediate value may not be extended with a prefix instruction. This instruction may also be used to branch on greater than by swapping the registers around.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 44 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 44 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra < 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BNE –Branch if Not Equal

Description:

If two registers are unequal an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 14 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 14 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra <> 0)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## BRK – Hardware / Software Breakpoint

Description:

Invoke the break handler routine. The break handler routine handles all the hardware and software exceptions in the core. A cause code is loaded into the CAUSE CSR register. The break handler should read the CAUSE code to determine what to do. The break handler is located by TVEC[0]. This address should contain a jump to the break handler. Note the reset address is $FFFC0100.

Instruction Format:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 19 | 18 16 | 15 | 14 6 | 5 0 |
| Immed13 | L3 | S | Cause Code9 | 00h6 |

S = 1 = software interrupt – return address is next instruction

S = 0 = hardware interrupt – return address is current instruction

L3 = the priority level of the hardware interrupt, the priority level at time of interrupt is recorded in the instruction, the interrupt mask will be set to this level when the instruction commits. This field is not used for software interrupts and should be zero.

Cause Code = numeric code associated with the cause of the interrupt.

## CACHE – Cache Command

## CACHEX –

CACHE Cmd, d(Rn)

CACHE Cmd, d(Ra + Rb \* scale)

**Description:**

This instruction commands the cache controller to perform an operation. Commands are summarized in the command table below.

Instruction Formats:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Displacement16 | | | | Cmd5 | Ra5 | 1Eh6 | CACHE Cmd,d16(Rn) |
| 1Eh6 | ~3 | Sc2 | Cmd5 | Rb5 | Ra5 | 02h6 | CACHE Cmd,d(Ra+Rb\*sc) |

**Commands:**

|  |  |  |
| --- | --- | --- |
| Cmd5 | Mne. | Operation |
| 00h |  | reserved |
| 01h |  | reserved |
| 02h | inviline | invalidate instruction cache line |
| 03h | invic | invalidate entire instruction cache (address is ignored) |
| 10h | disabledc | disable data cache |
| 11h | enabledc | enable data cache |
| 12h |  | invalidate data cache line |
| 13h | invdc | invalidate entire data cache (address is ignored) |
|  |  |  |

Operation:

Register Indirect with Displacement Form

Line = round32(sign extend(memory[displacement + Ra]))

Register-Register Form

Line = round32(sign extend(memory[Ra + Rb \* scale]))

Notes:

The displacement constant may be extended up to 64 bits.

|  |  |
| --- | --- |
| Sc2 Code | Multiply By |
| 0 | 1 |
| 1 | 2 |
| 2 | 4 |
| 3 | 8 |

## CALL – Call Subroutine

Description:

Call subroutine. This instruction first decrements the stack pointer then stores the address of the next instruction on the stack. Finally a jump is made to the address specified in the instruction. Note that if the call target exception is enabled the instruction at the target address must be a call target (TGT) instruction or an exception will occur.

Instruction Format:

The format first shifts the address field of the instruction by two bits to the left then modifies only PC bits 0 to 27. The high order PC bits are not affected. This allows accessing a subroutine within a 256MB region of memory. Note that with the use of a mmu this address range is often sufficient.

|  |  |
| --- | --- |
| Address[27..2] | 19h6 |

Clock Cycles: 1 + 1 memory access

The change of address takes place during the fetch stage of the core. This makes the instruction faster than other alternatives.

Instruction Format:

This instruction format loads the program counter with a constant value specified in the instruction. The constant value is sign extended to 64 bits. This instruction format may be used with constant prefixes in order to extend the range.

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | 1Fh5 | 1Fh5 | 2Bh6 |

42 bit call target

|  |  |  |  |
| --- | --- | --- | --- |
| Immediate[41..16] | | | 1Ah6 |
| Immed16 | 1Fh5 | 1Fh5 | 2Bh6 |

Clock Cycles: 7 (max) + 1 memory access

## CAS – Compare and Swap

**Description:**

If the contents of the addressed memory cell is equal to the contents of CAS register then a sixty-four bit value is stored to memory from the source register Rst and Rst is set equal to one. Otherwise Rst is set to zero and the contents of the memory cell is loaded into the CAS register. The memory address is the sum of the sign extended displacement and register Ra. The compare and swap operation is an atomic operation; the bus is locked during the load and potential store operation. This operation assumes that the addressed memory location is part of the volatile region of memory and bypasses the data cache. Note that the memory system must support bus locks in order for this instruction to work as expected.

This instruction is typically used to implement semaphores. The LWR and SWC may also be used to perform a similar function where the memory system does not support bus locks, but support address reservations instead.

**Instruction Format:**

|  |  |  |  |
| --- | --- | --- | --- |
| Disp16 | Rst5 | Ra5 | 25h6 |

**Operation:**

if memory[Ra+displacement] = casreg

memory[Ra + displacement] = Rst

Rst = 1

else

casreg = memory [Ra + displacement]

Rst = 0

**Assembler:**

CAS Rt, displacement[Ra]

## CLI – Clear Interrupt Mask

Description:

The interrupt level mask is set to zero enabling all interrupts. This is an alternate mnemonic for the SEI instruction where the mask level to set is set to zero by the assembler.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 306 | ~5 | ~5 | 05 | 05 | 02h6 |

Clock Cycles: 0.5

## CMOVEQ – Conditional Move Equal

Description:

The conditional move if equal instruction moves the contents of register Rb to the target register Rt if Ra is zero. Otherwise the contents of register Rc are moved to the target register.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 28h6 | Rt5 | Rc5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

## CMOVNE – Conditional Move Not Equal

Description:

The conditional move if not equal instruction moves the contents of register Rb to the target register Rt if Ra is non-zero. Otherwise the contents of register Rc are moved to the target register.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 29h6 | Rt5 | Rc5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

## CMP – Signed Comparison

Description:

The compare instruction places a 1, 0 or -1 in the target register based on the relationship between the two source operands. If they are equal a zero is placed in the target register, if register Ra is less than the second operand then a -1 is placed in the target register, otherwise a 1 is placed in the target register. The values are treated as signed operands.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 06h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 066 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

## CMPU – Unsigned Comparison

Description:

The compare instruction places a 1, 0 or -1 in the target register based on the relationship between the two source operands. If they are equal a zero is placed in the target register, if register Ra is less than the second operand then a -1 is placed in the target register, otherwise a 1 is placed in the target register. The values are treated as unsigned operands.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 07h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 076 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

## CNTLO – Count Leading Ones

Description:

Count the number of leading ones (starting at the MSB) and place the count in the target register.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 016 | 15 | ~3 | Sz2 | Rt5 | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## CNTLZ – Count Leading Zeros

Description:

Count the number of leading zeros (starting at the MSB) and place the count in the target register.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 016 | 05 | ~3 | Sz2 | Rt5 | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## CNTPOP – Count Population

Description:

Count the number of ones and place the count in the target register.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 016 | 25 | ~3 | Sz2 | Rt5 | Ra5 | 02h6 |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## CSR – Control and Status Access

Description:

The CSR instruction group provides access to control and status registers in the core. For the read-write operation the current value of the CSR is placed in the target register Rt then the CSR is updated from register Ra.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Op2 | OL3 | Regno11 | Rt5 | Ra5 | 0Eh6 |

|  |  |  |
| --- | --- | --- |
| Op2 |  | Operation |
| 0 | CSRRD | Only read the CSR, no update takes place, Ra should be 0. |
| 1 | CSRRW | Both read and write the CSR |
| 2 | CSRRS | Read CSR then set CSR bits |
| 3 | CSRRC | Read CSR then clear CSR bits |

CSRRS and CSRRC operations are only valid on registers that support the capability.

The OL3 field is reserved to specify the operating level. Note that registers cannot be accessed by a lower operating level.

|  |  |  |  |
| --- | --- | --- | --- |
| Regno12 |  | Access | Description |
| 001 | HARTID | R | hardware thread identifier (core number) |
| 002 | TICK | R | tick count, counts every cycle from reset |
| 030-037 | TVEC | RW | trap vector handler address |
| 040 | EPC | RW | exceptioned pc, pc value at point of exception |
| 044 | STATUSL | RWSC | status register, contains interrupt mask, operating level |
| 045 | STATUSH | RW | status register bits 64 to 127 |
| 080-0BF | CODE | RW | code buffers |
| 7F0 | INFO | R | Manufacturer name |
| 7F1 | “ | R | “ |
| 7F2 | “ | R | cpu class |
| 7F3 | “ | R | “ |
| 7F4 | “ | R | cpu name |
| 7F5 | “ | R | “ |
| 7F6 | “ | R | model number |
| 7F7 | “ | R | serial number |
| 7F8 | “ | R | cache sizes instruction (bits 32 to 63), data (bits 0 to 31) |

Clock Cycles: 0.5

## DEMUX – De-Multiplex

Description:

The DEMUX instruction performs a bit-by-bit copy of a bit of Rb to one of two target registers. If the corresponding bit in Ra is set a bit form Rb is copied to the corresponding bit in Rt2. Otherwise the bit from Rb is copied to the corresponding bit in Rt1.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2Bh6 | Rt25 | Rt15 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 1

Exceptions: none

## DIV – Signed Division

Description:

Compute the quotient. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The operands are treated as signed values and the result is a signed result. Note that for the registered form of the instruction both the quotient and remainder may be calculated at the same time.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 3Eh6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3E6 | Rtr5 | Rtq5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exceptions: A divide by zero exception may occur if enabled in the AEC register.

## DIVSU – Signed-Unsigned Division

Description:

Compute the quotient value. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The first operand is treated as a signed value. The second operand is an unsigned value. The result is a signed result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 3Dh6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3D6 | 05 | Rtq5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exception: A divide by zero exception may occur if enabled in the AEC register.

## DIVU – Unsigned Division

Description:

Compute the quotient value. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The operands are treated as unsigned values and the result is an unsigned result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 3Ch6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3C6 | 05 | Rtq5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exceptions: none

## EXEC – Execute Code Buffer

Description:

Execute code from code buffer. The N6 field specifies the code buffer to use. Code buffers allow code to be adapted at run-time. This is useful as an alternative to self-modifying code when code has to change.

Instruction Format:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ~10 | N6 | ~5 | ~5 | 0Fh6 |

Clock Cycles: Minimum 0.5 – depends on the instruction in the code buffer

## IMM – Immediate Prefix

Description:

The immediate prefix instruction extends the immediate constant of the following instruction. Immediate constants up to 64 bits may be formed by using two immediate constant prefixes in succession. If using two prefixes the low order prefix should appear first in the instruction stream. The assembler will automatically emit prefix instructions where needed.

Instruction Format:

|  |  |
| --- | --- |
| Immediate[41..16] | 1Ah6 |

|  |  |  |
| --- | --- | --- |
| ~4 | Immediate[63..42] | 1Bh6 |

ADD with 64 bit constant

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Immediate[41..16] | | | | 1Ah6 |
| ~4 | Immediate[63..42] | | | 1Bh6 |
| Immed16 | | Rt5 | Ra5 | 04h6 |

XOR with 42 bit sign extended constant

|  |  |  |  |
| --- | --- | --- | --- |
| Immediate[41..16] | | | 1Ah6 |
| Immed16 | Rt5 | Ra5 | 0Ah6 |

Clock Cycles: 0.5

## JAL – Jump-And-Link

Description:

This instruction loads the program counter with the sum of a register and a constant value specified in the instruction. In addition the address of the instruction following the JAL is stored in the specified target register. This instruction may be used to implement subroutine calls and returns.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 18h6 |

Clock Cycles:

## JMP – Jump to Address

Description:

A jump is made to the address specified in the instruction. The format first shifts the address field of the instruction by two bits to the left then modifies only PC bits 0 to 27. The high order PC bits are not affected. This allows accessing code within a 256MB region of memory. Note that with the use of a mmu this address range is often sufficient. If a larger address range is required the JAL instruction must be used.

Instruction Format:

|  |  |
| --- | --- |
| Address[27..2] | 28h6 |

Clock Cycles: 1

The jump instruction executes immediately during the fetch stage of the core. This makes it much faster than a JAL.

## LB – Load Byte

Description:

This instruction loads a byte (8 bit) value from memory. The value is sign extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 13h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 13h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LB – Load Byte with Increment

Description:

Loads a byte (8 bit) value from memory and increments the pointer register. If the increment amount is positive it takes place after the load operation. If the amount is negative it takes place before the load operation. The value is sign extended to 64 bits when placed in the target register. The increment amount should be +1, 0, or -1.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1Ah6 | 1h5 | Ra5 | Rt5 | Ra5 | 02h6 |

Assembler:

lb r1,[r2]+

Clock Cycles: 4 minimum depending on memory access time

## LBU – Load Unsigned Byte

Description:

This instruction loads a byte (8 bit) value from memory. The value is zero extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 23h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 23h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LC – Load Char (16 bits)

Description:

This instruction loads a char (16 bit) value from memory. The value is sign extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 20h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 20h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LCU – Load Unsigned Char (16 bits)

Description:

This instruction loads a char (16 bit) value from memory. The value is zero extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 21h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 21h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LH – Load Half-Word (32 bits)

Description:

This instruction loads a half-word (32 bit) value from memory. The memory address must be half-word aligned. The value is sign extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 10h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 10h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LHU – Load Half-Word (32 bits)

Description:

This instruction loads a half-word (32 bit) value from memory. The memory address must be half-word aligned. The value is zero extended to 64 bits when placed in the target register.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 11h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 11h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LINK – Link Stack

**Description:**

The specified base pointer register Rb (usually r30) is pushed onto the stack, the stack pointer is loaded into register Rb and then is adjusted by the amount specified. Normally the immediate value is a negative number in order to allocate stack space. It must include eight to account for the push of Rb.

**Instruction Format:**

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | 1Fh5 | 2Ah6 |

**Clock Cycles:** 4 minimum (one memory access)

**Execution Units:** All ALU’s / Memory

**Operation:**

memory[SP-8] = Rt

Rt = SP - 8

SP = SP + immediate

## LW – Load Word (64 bits)

Description:

This instruction loads a word (64 bit) value from memory. The memory address must be word aligned.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 12h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 12h6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LW – Load Word with Increment

Description:

Loads a word (64 bit) value to memory and increments the pointer register. The increment of the pointer register takes place after the load operation. If the increment amount is positive it takes place after the load operation. If the amount is negative it takes place before the load operation.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1Ah6 | 8h5 | Ra5 | Rt5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## LWR – Load Word and Reserve Address

Description:

This instruction loads a word (64 bit) value from memory and places a reservation on the address. The memory address must be word aligned. This instruction activates the sr\_o signal output by the core. It relies on external hardware to implement the address reservation. This instruction performs an un-cached load operation.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 1Dh6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 1Dh6 | ~3 | Sc2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## MAX – Maximum Value

**Description:**

Determines the maximum of three values in registers Ra, Rb, and Rc and places the result in the target register Rt.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2Dh6 | Rt5 | Rc5 | Rb5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 only

**Operation:**

IF Ra > Rb and Ra > Rc

Rt = Ra

else if Rb > Rc

Rt = Rb

else

Rt = Rc

## MEMDB –Memory Data Barrier

Description:

All memory instructions before the MEMDB are completed and committed to the architectural state before memory instructions after the MEMDB are issued. This instruction is used to ensure that the memory state is valid before subsequent instructions are executed.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 346 | ~5 | ~5 | ~5 | ~5 | 02h6 |

Clock Cycles: varies depending on queue contents

## MEMSB –Memory Synchronization Barrier

Description:

This instruction is similar to the SYNC instruction except that it applies only to memory operations. All instructions before the MEMSB are completed and committed to the architectural state before memory instructions after the MEMSB are issued. This instruction is used to ensure that the memory state is valid before subsequent instructions are executed.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 356 | ~5 | ~5 | ~5 | ~5 | 02h6 |

Clock Cycles: varies depending on queue contents

## MIN – Minimum Value

**Description:**

Determines the minimum of three values in registers Ra, Rb, and Rc and places the result in the target register Rt. To determine the minimum of two values use the same register twice.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2Ch6 | Rt5 | Rc5 | Rb5 | Ra5 | 02h6 |

**Clock Cycles:** 1

**Execution Units:** ALU #0 only

**Operation:**

IF Ra < Rb and Ra < Rc

Rt = Ra

else if Rb < Rc

Rt = Rb

else

Rt = Rc

## MOD – Signed Modulus

Description:

Compute the modulus (remainder) value. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The operands are treated as signed values and the result is a signed result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 2Eh6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3E6 | Rtm5 | 05 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exceptions: A divide by zero exception may occur if enabled in the AEC register.

## MODSU – Signed-Unsigned Modulus

Description:

Compute the modulus (remainder) value. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The first operand is treated as a signed value. The second operand is an unsigned value. The result is a signed result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 2Dh6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3D6 | Rtm5 | 05 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exceptions: A divide by zero exception may occur if enabled in the AEC register.

## MODU – Unsigned Modulus

Description:

Compute the modulus (remainder) value. The first operand must be in a register. The second operand may be in either a register or an immediate value specified in the instruction. The operands are treated as unsigned values and the result is an unsigned result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 2Ch6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3C6 | Rtm5 | 05 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 67

ALU Support: ALU #0 Only

Exceptions: none

## MUL – Signed Multiply

Description:

Multiply two values. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction. Both the operands are treated as signed values, the result is a signed result. For the registered form of the instruction both the high order and low order halves of the result are available. For the immediate form of the instruction, only the low order half (bits 0 to 63) of the product is available.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 3Ah6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3A6 | Rth5 | Rtl5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 8

## MULSU – Signed-Unsigned Multiply

Description:

Multiply two values. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction. The first operand is treated as a signed value. The second operand is treated as an unsigned value. The result is a signed result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 39h6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 396 | Rth5 | Rtl5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 8

## MULU – Unsigned Multiply

Description:

Multiply two values. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction. Both the operands are treated as unsigned values. The result is an unsigned result.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 38h6 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 386 | Rth5 | Rtl5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 8

Exceptions: none

## MUX – Multiplex

Description:

The MUX instruction performs a bit-by-bit copy of a bit of Rb to the target register if the corresponding bit in Ra is set, or a copy of a bit from Rc if the corresponding bit in Ra is clear.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2Ah6 | Rt5 | Rc5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

Exceptions: none

## NAND – Bitwise Nand

Description:

Perform a bitwise and operation between two operands then invert the result. Both operands must be in registers.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 0Ch6 | ~5 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

Exceptions: none

## NEG - Negate

Description:

This is an alternate mnemonic for the SUB instruction where the first register operand is R0.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 056 | ~5 | Rt5 | Rb5 | 05 | 02h6 |

Clock Cycles: 0.5

## NOP – No Operation

Description:

The NOP instruction doesn’t perform any operation. NOP’s are detected in the instruction fetch stage of the core and are not enqueued by the core. They do not occupy queue slots. Because NOPs don’t occupy queue slots they may not be used to synchronize operations between instructions.

Instruction Format:

|  |  |
| --- | --- |
| Immediate26 | 1Ch6 |

## NOR – Bitwise Nor

Description:

Perform a bitwise or operation between two operands then invert the result. Both operands must be in registers.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 0Dh6 | ~5 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

Exceptions: none

## OR – Bitwise Or

Description:

Perform a bitwise or operation between two operands. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 09h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 096 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

## POP – Pop Register from Stack

Description:

Loads a word (64 bit) value from memory and increment the stack pointer register. The increment of the stack pointer register takes place after the load operation. This is an alternate mnemonic for the load word with increment / decrement instruction.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1Ah6 | 8h5 | 1Fh5 | Rt5 | 1Fh5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## PUSH – Push Register on Stack

Description:

Stores a word (64 bit) value to memory and decrements the stack pointer register. The decrement of the stack pointer register takes place before the store operation. This is an alternate mnemonic for the store word with increment / decrement instruction.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 19h6 | 18h5 | 1Fh5 | Rb5 | 1Fh5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## RET – Return

Description:

Return from subroutine. The return address is popped from the stack and the stack pointer adjusted by the amount specified in the instruction. This amount must include eight for the return address and must be a multiple of eight.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | 1Fh5 | 1Fh5 | 29h6 |

Clock Cycles: 1 typ. 8 max + 1 memory access

Because there is a return address predictor the number of clock cycles taken by the RET instruction may be as low as 1 for a correctly predicted address. Otherwise the timing involves a memory load operation and a pipeline flush.

## REX – Redirect Exception

Description:

This instruction redirects an exception from an operating level to a lower operating level and privilege level. If the target operating level is hypervisor then the hypervisor privilege level (1) is set. If the target operating level is supervisor then one of the supervisor privilege levels must be chosen (2 to 6). This instruction if successful jumps to the target exception handler and does not return. If this instruction fails execution will continue with the next instruction.

This instruction may fail if exceptions are not enabled at the target level.

When redirecting the target privilege level is set to the bitwise ‘or’ of an immediate constant specified in the instruction and register Ra. One of these two values should be zero. The result should be a value in the range 0 to 255.

The location of the target exception handler is found in the trap vector register for that operating level (tvec[xx]).

The cause (cause) and bad address (badaddr) registers of the originating level are copied to the corresponding registers in the target level.

The REX instruction automatically enables exceptions for operating levels higher (numerically lower than) than the target level.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 1514 | 13 11 | 10 6 | 5 0 |
| ~8 | PL8 | ~2 | Tgt3 | Ra5 | 0Dh6 |

|  |  |
| --- | --- |
| Tgt2 |  |
| 0 | not used |
| 1 | redirect to hypervisor level |
| 2 | redirect to supervisor level |
| 3 | redirect to supervisor level |
| 4 | redirect to supervisor level |
| 5 | redirect to supervisor level |
| 6 | redirect to supervisor level |
| 7 | not used |

Clock Cycles: 3

Example:

|  |
| --- |
| REX 5,12,r0 ; redirect to supervisor handler, privilege level two  ; If the redirection failed, exceptions were likely disabled at the target level.  ; Continue processing so the target level may complete it’s operation.  RTI ; redirection failed (exceptions disabled ?) |

Notes:

Since all exceptions are initially handled at the machine level the machine level handler must check for disabled lower level exceptions.

## ROL – Rotate Left

Description:

Bits from the source register Ra are shifted left by the amount in register Rb or an immediate value. The most significant bit is shifted into bit zero.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 44 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | C4 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## ROR – Rotate Right

Description:

Bits from the source register Ra are shifted right by the amount in register Rb or an immediate value. The bit zero is shifted into the most significant bits.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 54 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | D4 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## RTI – Return from Interrupt

Description:

Return from an interrupt subroutine. The exceptioned program counter is loaded into the program counter register. The internal exception stack is popped and the operating level, privilege level and interrupt mask level are reset to values before the interrupt occurred. Optionally a semaphore bit in the semaphore register is cleared. The least significant bit of the semaphore register (the reservation status bit) is always cleared by this instruction.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 32h6 | ~4 | Sema6 | ~5 | ~5 | 02h6 |

Clock Cycles:

## SB – Store Byte

Description:

This instruction stores a byte (8 bit) value to memory.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | Ra5 | 15h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 15h6 | ~3 | Sc2 | Rc5 | Rb5 | Ra5 | 02h6 |

Operation:

Memory8[Ra + immediate] = Rb

Clock Cycles: 4 minimum depending on memory access time

## SC – Store Char (16 bits)

Description:

This instruction stores a char (16 bit) value to memory. The memory address must be char (16 bit) aligned.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | Ra5 | 23h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 23h6 | ~3 | Sc2 | Rc5 | Rb5 | Ra5 | 02h6 |

Operation:

Memory16[Ra + immediate] = Rb

Clock Cycles: 4 minimum depending on memory access time

## SEI – Set Interrupt Mask

SEI #3

Description:

The interrupt level mask is set to the value specified by the instruction. The value used is the bitwise or of the contents of register Ra and an immediate (M3) supplied in the instruction. The assembler assumes a mask value of seven, masking all interrupts, if no mask value is specified. Usually either M3 or Ra should be zero.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 306 | ~5 | ~5 | ~2 | M3 | Ra5 | 02h6 |

Operation:

im = M3 | Ra

## SGN – Get Sign

Description:

The SGN instruction places a 1, 0 or -1 in the target register depending on the sign of the source operand. This instruction is an alternate mnemonic for the compare instruction where the value is compared to zero.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 066 | ~3 | Sz2 | Rt5 | 05 | Ra5 | 02h6 |

Clock Cycles: 0.5

|  |  |
| --- | --- |
| Sz2 |  |
| 0 | Byte |
| 1 | Char |
| 2 | Half |
| 3 | Word |

## SH – Store Half-Word (32 bits)

Description:

This instruction stores a half-word (32 bit) value to memory. The memory address must be half-word aligned.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | Ra5 | 14h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 14h6 | ~3 | Sc2 | Rc5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## SHL – Shift Left

Description:

Bits from the source register Ra are shifted left by the amount in register Rb or an immediate value. Zeros are shifted into the least significant bits.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 04 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 84 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## SHR – Shift Right

Description:

Bits from the source register Ra are shifted right by the amount in register Rb or an immediate value. Zeros are shifted into the most significant bits.

For the sub-word forms the result is sign extended to 64 bits.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 14 | ~ | Rt5 | Rb5 | Ra5 | 02h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Func6 | 94 | I1 | Rt5 | Imm5 | Ra5 | 02h6 |

|  |  |
| --- | --- |
| Func6 | Op Size |
| 03h | word |
| 1Fh | byte |
| 2Fh | char |
| 3Fh | half |

Clock Cycles: 1

ALU Support: ALU #0 Only

Exceptions: none

## SUB - Subtract

Description:

Subtract two values. Both operands must be in a register.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 056 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

Exceptions:

The registered form of the instruction may cause an overflow exception if enabled in the AEC register.

## SW – Store Word (64 bits)

Description:

This instruction stores a word (64 bit) value to memory. The memory address must be word aligned.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | Ra5 | 16h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 16h6 | ~3 | Sc2 | Rc5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 4 minimum depending on memory access time

## SW – Store Word with Decrement

Description:

Stores a word (64 bit) value to memory and increments or decrements the pointer register Ra. This instruction may be used to implement a stack push operation. The amount should be +8, 0, or -8. If the increment amount is positive it takes place after the store operation. If the amount is negative it takes place before the store operation.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 19h6 | Amt5 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

## SWC – Store Word and Clear Reservation

Description:

This instruction conditionally stores a word (64 bit) value to memory and clears any memory reservation that was previously set at the address. If the memory address was reserved at the time of the store the store will succeed, otherwise the data is not stored. The previous status of the reservation is copied to the least significant bit of the semaphore register. This instruction depends on external hardware to implement the reservation. The instruction activates the cr\_o signal output by the core. The memory address must be word aligned. This instruction should be both preceded and succeeded by SYNC instructions to ensure that the reservation status bit is updated correctly in the semaphore CSR.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rb5 | Ra5 | 17h6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 17h6 | ~3 | Sc2 | Rc5 | Rb5 | Ra5 | 02h6 |

Side Effect: the reservation status bit (bit 0) in the semaphore register is set accordingly.

Clock Cycles: 4 minimum depending on memory access time

## SYNC -Synchronize

Description:

All instructions before the SYNC are completed and committed to the architectural state before instructions after the SYNC are issued. This instruction is used to ensure that the machine state is valid before subsequent instructions are executed.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 366 | 05 | ~5 | ~5 | ~5 | 02h6 |

Clock Cycles: varies depending on queue contents

## TGT – Jump / Call Target

**Description:**

This instruction identifies the location of a jump or call target. This should be the first instruction of a subroutine. If the target exception is enabled the core will generate an exception if the destination of a call or jump operation doesn’t contain the TGT instruction. The TGT instruction is treated as a NOP. The use of the TGT instruction is to help prevent the use of random jumps or calls into the middle of code.

The TGT instruction contains a constant field which indicates the index into the indirect call table for the target. Each TGT instruction should have a program unique index. When the call target moves in memory the operating system will reset the value in the target address table.

**Instruction Formats**:

|  |  |  |
| --- | --- | --- |
| TAT Index26 | 0Ch6 | TGT |

**Operation**:

Exceptions: target exception

Notes:

## UNLINK – Unlink Stack

**Description:**

The specified base pointer register Rb is loaded into the stack pointer, then register Rb is popped from the stack.

**Instruction Format:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1Bh6 | ~5 | 1Fh5 | Rb5 | 1Fh5 | 02h6 |

**Clock Cycles:** 4 (one memory access)

**Execution Units:** All ALU’s / Memory

**Operation:**

SP = Rb

Rb = memory[SP]

SP = SP + 8

## WAIT – Wait For Signal

**Description:**

This instruction causes the core to pause execution during the execute phase of the instruction until an external signal is true. Note that instructions already in the queue before the wait will continue to execute to completion. Also additional instructions may be fetched after the wait instruction however they will not be able to update the state of the machine until the wait is done.

The signal to wait for is specified as the union of register Ra and an immediate value. Either Ra or the immediate value should be zero.

A timeout for the wait may be specified in register Rb. If a timeout is not desired use R0 for Rb and the instruction will wait indefinitely.

**Instruction Formats**:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 316 | ~5 | Imm5 | Rb5 | Ra5 | 02h6 |

**Operation**:

if (no signal)

delay instruction

else

mark instruction done

Notes:

This instruction waits for a signal to occur before proceeding.

## XCHG – Exchange Registers

Description:

Swap the contents of two registers.

Instruction Format:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2Eh6 | ~5 | Rb5 | Ra5 | ~5 | 02h6 |

Clock Cycles: 1

Exceptions: none

## XOR – Bitwise Exclusive Or

Description:

Perform a bitwise exclusive or operation between two operands. The first operand must be in a register. The second operand may be in a register or may be an immediate value specified in the instruction.

Instruction Format:

|  |  |  |  |
| --- | --- | --- | --- |
| Immed16 | Rt5 | Ra5 | 0Ah6 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 0A6 | ~3 | Sz2 | Rt5 | Rb5 | Ra5 | 02h6 |

Clock Cycles: 0.5

# Floating Point Instruction Set

## Overview

The floating point unit provides basic floating point operations including addition, subtraction, multiplication, division and float to integer and integer to float conversions. The core contains only a single floating point unit. Only double precision floating point operations are supported.

The precision field (prec2) should be set to 1.

The rounding mode is normally specified by the rounding mode bits in the floating point control and status register. However it may be overridden by specification of a rounding mode in the instruction.

**Representation**

The floating point format is an IEEE-754 representation for double precision. Briefly,

**Double Precision Format:**

|  |  |  |  |
| --- | --- | --- | --- |
| 63 | 62 | 61 52 | 51 0 |
| SM | SE | Exponent | Mantissa |

SM – sign of mantissa

SE – sign of exponent

The exponent and mantissa are both represented as two’s complement numbers, however the sign bit of the exponent is inverted.

|  |  |
| --- | --- |
| SeEEEEEEEEEE |  |
| 11111111111 | Maximum exponent |
| …. |  |
| 01111111111 | exponent of zero |
| …. |  |
| 00000000000 | Minimum exponent |

The exponent ranges from -1024 to +1023 for double precision numbers

## Instruction Format

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| Func6 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

Not all instructions required the Rb5 field. If not required Rb should be set to zero.

## FABS – Floating Absolute Value

**Description:**

Take the absolute value of the floating point number in registers Ra and place the result into target register Rt. The sign bit (bit 63) of the register is set to zero. No rounding of the number occurs.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 15h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FADD – Floating point addition

**Description:**

Add two floating point numbers in registers Ra and Rb and place the result into target register Rt.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 046 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

**Clock Cycles: 10**

**Execution Units:** Floating Point

## FBEQ –Branch if Equal

Description:

If two registers are equal an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction. Note that positive and negative zero are treated as equal.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 84 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 84 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra = Rb)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## FBGE –Branch if Greater than or Equal

Description:

If register Ra is greater than or equal to register Rb an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction. A branch on less than or equal may be achieved by swapping registers.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | Bh4 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | Bh4 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra >= Rb)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## FBLT –Branch if Less Than

Description:

If register Ra is less than register Rb an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction. A branch on greater than may be achieved by swapping the registers.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | Ah4 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | Ah4 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra < Rb)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## FBNE –Branch if Not Equal

Description:

If two registers are unequal an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction. Note that positive and negative zero are treated as equal.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | 94 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | 94 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra <> Rb)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## FBUN –Branch if Unordered

Description:

If the comparison is unordered an eleven bit sign extended value is shifted left twice and added to the program counter. The branch is relative to the address of the instruction directly following the branch. The displacement value may not be extended with a prefix instruction.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 22 | 21 | 19 16 | 15 11 | 10 6 | 5 1 | 0 |
| Displacement10 | P2 | Fh4 | Rb5 | Ra5 | 18h5 | D1 |

A branch to a value computed in a register may be performed using the instruction format shown below. Rc contains the target address which is an absolute address.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 27 | 26 | 24 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| ~5 | P2 | Fh4 | Rc5 | Rb5 | Ra5 | 03h6 |

Operation:

if (Ra ? Rb)

pc = pc + displacement

The P2 field is reserved for branch prediction hints.

|  |  |
| --- | --- |
| P2 | Prediction Type |
| 0 | no static prediction (use branch history) |
| 1 | reserved |
| 2 | always predict as not-taken |
| 3 | always predict as taken |

If a branch prediction is supplied, then the branch instruction doesn’t occupy room in the history tables.

## FCMP - Float Compare

**Description:**

The register compare instruction compares two registers as floating point values and sets the flags in the target register as a result.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 066 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

**Clock Cycles:** 2

**Execution Units:** FPU

**Operation:**

if Ra < Rb

Rt[1]= true

else

Rt[1] = false

if mag Ra < mag Rb

Rt[2] = true

else

Rt[2] = false

if Ra = Rb

Rt[0] = true

else

Rt[0] = false

if Ra <= Rb

Rt[3] = true

else

Rt[3] = false

if unordered

Rt[4] = true

else

Rt[4] = false

## FDIV – Floating point divide

**Description:**

Divide two floating point numbers in registers Ra and Rb and place the result into target register Rt.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 086 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

**Clock Cycles: 115**

**Execution Units:** Floating Point

## FCX – Clear Floating Point Exceptions

**Description:**

This instruction clears floating point exceptions. The Exceptions to clear are identified as the bits set in the union of register Ra and an immediate field in the instruction. Either the immediate or Ra should be zero.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 2322 | 21 16 | 15 11 | 10 6 | 5 0 |
| 21h6 | Prec2 | ~2 | Imm6 | 05 | Ra5 | 0Bh6 |

**Execution Units:** All Floating Point

**Operation:**

**Exceptions:**

|  |  |
| --- | --- |
| Bit | Exception Enabled |
| 0 | global invalid operation clears the following:   * division of infinities * zero divided by zero * subtraction of infinities * infinity times zero * NaN comparison * division by zero |
| 1 | overflow |
| 2 | underflow |
| 3 | divide by zero |
| 4 | inexact operation |
| 5 | summary exception |

## FDX – Floating Disable Exceptions

**Description:**

This instruction disables floating point exceptions. The Exceptions disabled are identified as the bits set in the union of register Ra and an immediate field in the instruction. Either the immediate or Ra should be zero. Exceptions won’t be disabled until the instruction commits and the state of the machine is updated. This instruction should be followed by a synchronization instruction (FSYNC) to ensure that following floating point operations recognize the disabled exceptions.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 2322 | 21 16 | 15 11 | 10 6 | 5 0 |
| 23h6 | Prec2 | ~2 | Imm6 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FEX – Floating Enable Exceptions

**Description:**

This instruction enables floating point exceptions. The Exceptions enabled are identified as the bits set in the union of register Ra and an immediate field in the instruction. Either the immediate or Ra should be zero. Exceptions won’t be enabled until the instruction commits and the state of the machine is updated. This instruction should be followed by a synchronization instruction (FSYNC) to ensure that following floating point operations recognize the enabled exceptions.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 2322 | 21 16 | 15 11 | 10 6 | 5 0 |
| 22h6 | Prec2 | ~2 | Imm6 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FMUL – Floating point multiplication

**Description:**

Multiply two floating point numbers in registers Ra and Rb and place the result into target register Rt.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 086 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

**Clock Cycles: 12**

**Execution Units:** Floating Point

## FNABS – Floating Negative Absolute Value

**Description:**

Take the negative absolute value of the floating point number in registers Ra and place the result into target register Rt. The sign bit (bit 63) of the register is set to one. No rounding of the number occurs.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 18h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FNEG – Floating Negative Value

**Description:**

Negate the value of the floating point number in register Ra and place the result into target register Rt. The sign bit (bit 63) of the register is inverted. No rounding of the number occurs.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 14h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FSIGN – Floating Sign

**Description:**

FSIGN returns a value indicating the sign of the floating point number. If the value is zero, the target register is set to zero. If the value is negative the target register is set to the floating point value -1.0. Otherwise the target register is set to the floating point value +1.0. No rounding of the result occurs.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 16h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 2**

**Execution Units:** Floating Point

## FSUB – Floating point subtraction

**Description:**

Subtract two floating point numbers in registers Ra and Rb and place the result into target register Rt.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 056 | Prec2 | Rm3 | Rt5 | Rb5 | Ra5 | 0Bh6 |

**Clock Cycles: 10**

**Execution Units:** Floating Point

## FSYNC -Synchronize

Description:

All floating point instructions before the FSYNC are completed and committed to the architectural state before floating point instructions after the FSYNC are issued. This instruction is used to ensure that the machine state is valid before subsequent instructions are executed.

Instruction Format:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 36h6 | ~2 | ~3 | ~5 | ~5 | ~5 | 0Bh6 |

Clock Cycles: varies depending on queue contents

## FTOI – Floating Convert to Integer

**Description:**

Convert the floating point value in Ra into an integer and place the result into target register Rt. If the result overflows the value placed in Rt is a maximum integer value.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 12h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 3**

**Execution Units:** Floating Point

## FTX – Trigger Floating Point Exceptions

**Description:**

This instruction triggers floating point exceptions. The Exceptions to trigger are identified as the bits set in the union of register Ra and an immediate field in the instruction. Either the immediate or Ra should be zero.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 2322 | 21 16 | 15 11 | 10 6 | 5 0 |
| 20h6 | Prec2 | ~2 | Imm6 | 05 | Ra5 | 0Bh6 |

**Execution Units:** All Floating Point

**Operation:**

**Exceptions:**

|  |  |
| --- | --- |
| Bit | Exception Enabled |
| 0 | global invalid operation |
| 1 | overflow |
| 2 | underflow |
| 3 | divide by zero |
| 4 | inexact operation |
| 5 | reserved |

## ITOF – Convert Integer to Float

**Description:**

Convert the integer value in Ra into a floating point value and place the result into target register Rt. Some precision of the integer converted may be lost if the integer is larger than 52 bits. Double precision floating point values only have a precision of 53 bits.

**Instruction Format:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 31 26 | 25 24 | 23 21 | 20 16 | 15 11 | 10 6 | 5 0 |
| 15h6 | Prec2 | Rm3 | Rt5 | 05 | Ra5 | 0Bh6 |

**Clock Cycles: 3**

**Execution Units:** Floating Point

# Opcode Tables

## Major Opcode (inst. bits 0 to 5)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | x0 | x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | xA | xB | xC | xD | xE | xF |
| 0x | BRK |  | {RR} | BccR | ADDI | SUBI | CMPI | CMPUI | ANDI | ORI | XORI | {FLOAT} | TGT | REX | CSR | EXEC |
| 1x | LH | LHU | LW | LB | SH | SB | SW | SWC | JAL | CALL | IMM | IMM | NOP | LWR | CACHE |  |
| 2x | LC | LCU |  | LBU | SC | CAS | BBc | | JMP | RET | LINK | CALL | MODUI | MODSUI | MODI |  |
| 3x | Bcc | | BEQ# | |  |  |  |  | MULUI | MULSUI | MULI |  | DIVUI | DIVSUI | DIVI |  |

## Major Funct (inst. bits 26 to 31)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | x0 | x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | xA | xB | xC | xD | xE | xF |
| 0x | {BCD} | {R1} | {Bitfield} | {shift} | ADD | SUB | CMP | CMPU | AND | OR | XOR |  | NAND | NOR | XNOR |  |
| 1x | LHX | LHUX | LWX | LBX | SHX | SBX | SWX | SWCX |  | PUSH | POP | UNLINK |  | LWRX | CACHEX | {shiftb} |
| 2x | LCX | LCUX |  | LBUX | SCX | CASX |  |  | CMOVEQ | CMOVNE | MUX | DEMUX | MIN | MAX | XCHG | {shiftc} |
| 3x | SEI / CLI | WAIT | RTI |  | MEMDB | MEMSB | SYNC |  | MULU | MULSU | MUL | CHK | DIVMODU | DIVMODSU | DIVMOD | {shifth} |

## Float Funct (inst. bits 26 to 31)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | x0 | x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | xA | xB | xC | xD | xE | xF |
| 0x |  |  |  |  | FADD | FSUB | FCMP |  | FMUL | FDIV |  |  |  |  |  |  |
| 1x | FMOV |  | FTOI | ITOF | FNEG | FABS | FSIGN | FMAN | FNABS |  |  |  | FSTAT |  |  |  |
| 2x | FTX | FCX | FEX | FDX | FRM |  |  |  |  |  |  |  |  |  |  |  |
| 3x |  |  |  |  |  |  | FSYNC |  |  |  |  |  |  |  |  |  |

## R1 (inst. bits 21 to 25)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | x0 | x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | xA | xB | xC | xD | xE | xF |
| 0x | CNTLZ | CNTLO | CNTPOP |  | ABS |  |  |  |  |  |  |  |  |  |  |  |
| 1x |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

# Appendix

## Reducing the size of the core.

Register renaming adds considerably to the size of the core. It uses approximately 30,000 LUTs to implement register renaming. The core (FT64a) may be built without register renaming by setting the RENAME parameter to zero.

Architectural Register vs Physical Registers

Architectural registers are the registers visible to the programmer as part of the programming model. Physical registers are the registers physically present in the machine’s hardware. There are substantially more physical registers than there are architectural ones. For FT64 there are 32 registers visible to be programmed which are supported by 64 physical registers.

Register Renaming

The core maintains an eight entry deep history file for register rename mappings and register in use flags. The depth of the history file corresponds to the number of entries in the re-order buffer. At most a new map will be needed for each re-order buffer entry. Typically the history file is cycled through at half or less the rate of the instruction queue as approximately 50% of instructions don’t have target registers.

The core can allocate up to two registers as target registers for every pair of instructions queued. If there are no target registers available the core stalls until previous instructions have made more target registers available.

Instruction Cache Miss

During a cache miss the core streams NOP operations to the instruction fetch unit while the core is waiting for the instruction cache to load. The program counters are not incremented however, and they remain at the value when the cache miss occurred.

Branches

Branches store the target address in iqentry\_a0 the immediate constant field of the queue. The target address has to be stored somewhere in the instruction queue so that it may be used to update the branch target buffer later. It can’t be stored in the result field, and it can’t be stored in one of the other argument fields. Arg0 is the only place it can be stored safely.

Branches are evaluated after the following instruction enqueues so that false branch mispredictions don’t occur. Mispredict logic looks at the address of the instruction following the branch to ensure that the branch address was predicted correctly.

## Instructions Supported Only on ALU #0

The following less frequently used instructions are only supported on ALU #0 in order to reduce the size of the core.

* + division and remainder instructions (DIV,DIVSU,DIVU,MOD,MODSU, MODU)
  + bit-field instructions (BFCLR, BFSET, BFCHG, BFINS, BFINSI, BFEXT, BFEXTU)
    - these are rarely used instructions
  + shift instructions (ASR, SHL, SHR)
    - The shift instructions use barrel shifters to shift by any amount in a single clock cycle and so are relatively resource expensive compared to how often they are used.
  + indexed memory loads / stores (LBX, LHX, LHUX, LWX, SBX, SHX, SWX)
    - since indexed memory instructions are infrequently used they are supported only on alu #0.
  + CSR instruction
    - CSR instructions are rarely used. They often also have synchronization issues as there is no bypassing for the CSR registers. Since they typically require synchronization operations there is no benefit to having multiple CSR instructions executing at the same time.

# WISHBONE Compatibility Datasheet

The FT64 core may be directly interfaced to a WISHBONE compatible bus.

|  |  |  |
| --- | --- | --- |
| WISHBONE Datasheet  WISHBONE SoC Architecture Specification, Revision B.3 | | |
|  |  | |
| Description: | Specifications: | |
| General Description: | Central processing unit (CPU core) | |
| Supported Cycles: | MASTER, READ / WRITE  MASTER, READ-MODIFY-WRITE  MASTER, BLOCK READ / WRITE, BURST READ (FIXED ADDRESS) | |
| Data port, size:  Data port, granularity:  Data port, maximum operand size:  Data transfer ordering:  Data transfer sequencing | 64 bit  8 bit  64 bit  Little Endian  any (undefined) | |
| Clock frequency constraints: |  | |
| Supported signal list and cross reference to equivalent WISHBONE signals | Signal Name:  ack\_i  adr\_o(31:0)  clk\_i  dat\_i(63:0)  dat\_o(63:0)  cyc\_o  stb\_o  wr\_o  sel\_o(7:0)  cti\_o(2:0)  bte\_o(1:0) | WISHBONE Equiv.  ACK\_I  ADR\_O()  CLK\_I  DAT\_I()  DAT\_O()  CYC\_O  STB\_O  WE\_O  SEL\_O  CTI\_O  BTE\_O |
| Special Requirements: |  | |