

# MicroBlaze Processor Reference Guide

**2017.1**

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# Revision History

The following table shows the revision history for this document.

| Date       | Version | Revision                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 03/20/2013 | 2013.1  | Initial Xilinx release. This User Guide is derived from UG081.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 06/19/2013 | 2013.2  | Updated for Vivado 2013.2 release.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 10/02/2013 | 2013.3  | Updated for Vivado 2013.3 release.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 12/18/2013 | 2013.4  | Updated for Vivado 2013.4 release.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 04/02/2014 | 2014.1  | Updated for Vivado 2014.1 release: <ul style="list-style-type: none"> <li>Added v9.3 to MicroBlaze release version code in PVR.</li> <li>Clarified availability and behavior of stack protection registers.</li> <li>Corrected description of LMB instruction and data bus exception.</li> <li>Included description of extended debug features, new in version 9.3: performance monitoring, program trace and non-intrusive profiling.</li> <li>Included definition of Reset Mode signals, new in version 9.3.</li> <li>Clarified how the AXI4-Stream TLAST signal is handled.</li> <li>Added UltraScale and updated performance and resource utilization for 2014.1.</li> </ul>                                                                                                                                                                               |
| 10/01/2014 | 2014.3  | Updated for Vivado 2014.3 release: <ul style="list-style-type: none"> <li>Corrected semantic description for PCMPEQ and PCMPNE in Table 2.1.</li> <li>Added version 9.4 to MicroBlaze release version code in PVR.</li> <li>Included description of external program trace, new in version 9.4</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 04/15/2015 | 2015.1  | Updated for Vivado 2015.1 release: <ul style="list-style-type: none"> <li>Included description of 16 word cache line length, new in version 9.5.</li> <li>Added version 9.5 to MicroBlaze release version code in PVR.</li> <li>Corrected description of supported endianness and parameter C_ENDIANNES.</li> <li>Corrected description of outstanding reads for instruction and data cache.</li> <li>Updated FPGA configuration memory protection document reference <a href="#">[Ref 10]</a>.</li> <li>Corrected Bus Index Range definitions for Lockstep Comparison in <a href="#">Table 3-14</a>.</li> <li>Clarified registers altered for IDIV instruction.</li> <li>Corrected PVR assembler mnemonics for MFS instruction.</li> <li>Updated performance and resource utilization for 2015.1.</li> <li>Added references to training resources.</li> </ul> |
| 04/06/2016 | 2016.1  | Updated for Vivado 2016.1 release: <ul style="list-style-type: none"> <li>Included description of address extension, new in version 9.6.</li> <li>Included description of pipeline pause functionality, new in version 9.6</li> <li>Included description of non-secure AXI access support, new in version 9.6.</li> <li>Included description of hibernate and suspend instructions, new in version 9.6.</li> <li>Added version 9.6 to MicroBlaze release version code in PVR.</li> <li>Corrected references to <a href="#">Table 2-45</a> and <a href="#">Table 2-46</a>.</li> <li>Replaced references to the deprecated Xilinx Microprocessor Debugger (XMD) with Xilinx System Debugger (XSDB).</li> <li>Removed C code function attributes svc_handler and svc_table_handler.</li> </ul>                                                                    |

| Date       | Version | Revision                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10/05/2016 | 2016.3  | Updated for Vivado 2016.3 release: <ul style="list-style-type: none"> <li>• Added description of frequency optimized 8-stage pipeline, new in version 10.0.</li> <li>• Describe bit field instructions, new in version 10.0.</li> <li>• Include information on parallel debug interface, new in version 10.0.</li> <li>• Added version 10.0 to MicroBlaze release version code in PVR.</li> <li>• Included Spartan-7 target architecture in PVR.</li> <li>• Updated description of MSR reset value.</li> <li>• Updated Xilinx automotive applications disclaimer.</li> </ul>                                                                                                     |
| 04/05/2017 | 2017.1  | Updated for Vivado 2017.1 release: <ul style="list-style-type: none"> <li>• Added description of MMU Physical Address Extension (PAE), new in version 10.0.</li> <li>• Extended privileged instruction list, and updated instruction descriptions.</li> <li>• Updated information on debug program trace.</li> <li>• Added reference to the Triple Modular Redundancy (TMR) subsystem.</li> <li>• Corrected description of BSIFI instruction.</li> <li>• Updated MFSE instruction description with PAE information.</li> <li>• Added MTSE instruction used with PAE, new in version 10.0.</li> <li>• Updated WDC instruction for external cache invalidate and flush.</li> </ul> |

# Table of Contents

## Chapter 1: Introduction

|                      |   |
|----------------------|---|
| Guide Contents ..... | 6 |
|----------------------|---|

## Chapter 2: MicroBlaze Architecture

|                                                |     |
|------------------------------------------------|-----|
| Overview .....                                 | 7   |
| Data Types and Endianness .....                | 11  |
| Instructions .....                             | 12  |
| Registers .....                                | 23  |
| Pipeline Architecture .....                    | 47  |
| Memory Architecture .....                      | 50  |
| Privileged Instructions .....                  | 52  |
| Virtual-Memory Management .....                | 54  |
| Reset, Interrupts, Exceptions, and Break ..... | 67  |
| Instruction Cache .....                        | 76  |
| Data Cache .....                               | 80  |
| Floating Point Unit (FPU) .....                | 84  |
| Stream Link Interfaces .....                   | 89  |
| Debug and Trace .....                          | 90  |
| Fault Tolerance .....                          | 110 |
| Lockstep Operation .....                       | 117 |
| Coherency .....                                | 120 |
| Data and Instruction Address Extension .....   | 123 |

## Chapter 3: MicroBlaze Signal Interface Description

|                                                    |     |
|----------------------------------------------------|-----|
| Overview .....                                     | 125 |
| MicroBlaze I/O Overview .....                      | 126 |
| AXI4 and ACE Interface Description .....           | 138 |
| Local Memory Bus (LMB) Interface Description ..... | 144 |
| Lockstep Interface Description .....               | 153 |
| Debug Interface Description .....                  | 158 |
| Trace Interface Description .....                  | 160 |
| MicroBlaze Core Configurability .....              | 163 |



## Chapter 4: MicroBlaze Application Binary Interface

|                                               |     |
|-----------------------------------------------|-----|
| Data Types .....                              | 174 |
| Register Usage Conventions .....              | 175 |
| Stack Convention .....                        | 177 |
| Memory Model .....                            | 179 |
| Interrupt, Break and Exception Handling ..... | 180 |

## Chapter 5: MicroBlaze Instruction Set Architecture

|                    |     |
|--------------------|-----|
| Notation .....     | 182 |
| Formats .....      | 184 |
| Instructions ..... | 184 |

## Appendix A: Performance and Resource Utilization

|                                                              |     |
|--------------------------------------------------------------|-----|
| Performance .....                                            | 291 |
| Resource Utilization .....                                   | 292 |
| IP Characterization and fMAX Margin System Methodology ..... | 297 |

## Appendix B: Additional Resources and Legal Notices

|                                            |     |
|--------------------------------------------|-----|
| Xilinx Resources .....                     | 298 |
| Solution Centers .....                     | 298 |
| References .....                           | 298 |
| Training Resources .....                   | 299 |
| Please Read: Important Legal Notices ..... | 300 |

# Introduction

The MicroBlaze™ Processor Reference Guide provides information about the 32-bit soft processor, MicroBlaze, which is included in the Vivado® release. The document is intended as a guide to the MicroBlaze hardware architecture.

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## Guide Contents

This guide contains the following chapters:

- [Chapter 2, MicroBlaze Architecture](#), contains an overview of MicroBlaze features as well as information on Big-Endian and Little-Endian bit-reversed format, 32-bit general purpose registers, cache software support, and AXI4-Stream interfaces.
- [Chapter 3, MicroBlaze Signal Interface Description](#), describes the types of signal interfaces that can be used to connect MicroBlaze.
- [Chapter 4, MicroBlaze Application Binary Interface](#), describes the Application Binary Interface important for developing software in assembly language for the processor.
- [Chapter 5, MicroBlaze Instruction Set Architecture](#), provides notation, formats, and instructions for the Instruction Set Architecture (ISA) of MicroBlaze.
- [Appendix A, Performance and Resource Utilization](#), contains maximum frequencies and resource utilization numbers for different configurations and devices.
- [Appendix B, Additional Resources and Legal Notices](#), provides links to documentation and additional resources.

## MicroBlaze Architecture

This chapter contains an overview of MicroBlaze™ features and detailed information on MicroBlaze architecture including Big-Endian or Little-Endian bit-reversed format, 32-bit general purpose registers, virtual-memory management, cache software support, and AXI4-Stream interfaces.

### Overview

The MicroBlaze embedded processor soft core is a reduced instruction set computer (RISC) optimized for implementation in Xilinx® Field Programmable Gate Arrays (FPGAs).

Figure 2-1 shows a functional block diagram of the MicroBlaze core.

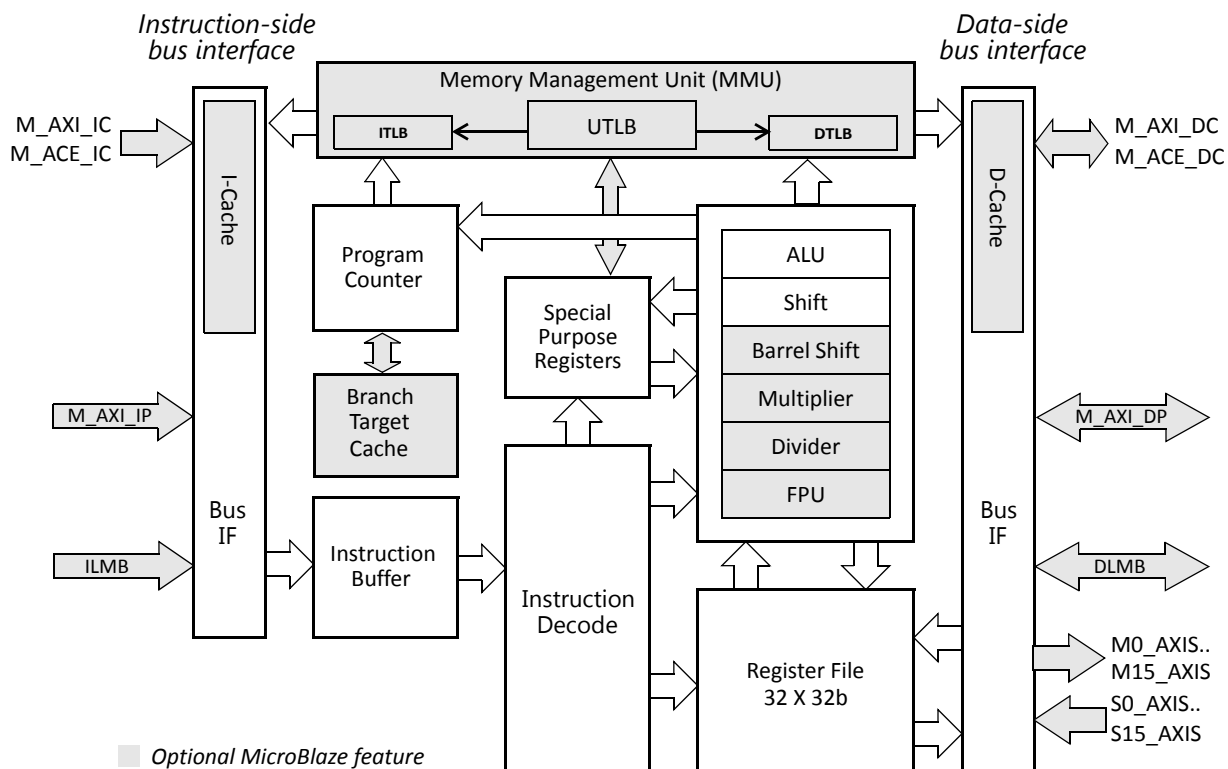


Figure 2-1: MicroBlaze Core Block Diagram

## Features

The MicroBlaze soft core processor is highly configurable, allowing you to select a specific set of features required by your design.

The fixed feature set of the processor includes:

- Thirty-two 32-bit general purpose registers
- 32-bit instruction word with three operands and two addressing modes
- Default 32-bit address bus, extensible to 64 bits
- Single issue pipeline

In addition to these fixed features, the MicroBlaze processor is parameterized to allow selective enabling of additional functionality. Older (deprecated) versions of MicroBlaze support a subset of the optional features described in this manual. Only the latest (preferred) version of MicroBlaze (v10.0) supports all options.

Xilinx recommends that all new designs use the latest **preferred** version of the MicroBlaze processor.

[Table 2-1, page 8](#) provides an overview of the configurable features by MicroBlaze versions.

**Table 2-1: Configurable Feature Overview by MicroBlaze Version**

| Feature                                           | MicroBlaze versions |            |            |            |            |           |
|---------------------------------------------------|---------------------|------------|------------|------------|------------|-----------|
|                                                   | v9.2                | v9.3       | v9.4       | v9.5       | v9.6       | v10.0     |
| Version Status                                    | deprecated          | deprecated | deprecated | deprecated | deprecated | preferred |
| Processor pipeline depth                          | 3/5                 | 3/5        | 3/5        | 3/5        | 3/5        | 3/5/8     |
| Local Memory Bus (LMB) data side interface        | option              | option     | option     | option     | option     | option    |
| Local Memory Bus (LMB) instruction side interface | option              | option     | option     | option     | option     | option    |
| Hardware barrel shifter                           | option              | option     | option     | option     | option     | option    |
| Hardware divider                                  | option              | option     | option     | option     | option     | option    |
| Hardware debug logic                              | option              | option     | option     | option     | option     | option    |
| Stream link interfaces                            | 0-16 AXI            | 0-16 AXI   | 0-16 AXI   | 0-16 AXI   | 0-16 AXI   | 0-16 AXI  |
| Machine status set and clear instructions         | option              | option     | option     | option     | option     | option    |
| Cache line word length                            | 4, 8                | 4, 8       | 4, 8       | 4, 8, 16   | 4, 8, 16   | 4, 8, 16  |
| Hardware exception support                        | option              | option     | option     | option     | option     | option    |
| Pattern compare instructions                      | option              | option     | option     | option     | option     | option    |
| Floating point unit (FPU)                         | option              | option     | option     | option     | option     | option    |
| Disable hardware multiplier <sup>1</sup>          | option              | option     | option     | option     | option     | option    |

**Table 2-1: Configurable Feature Overview by MicroBlaze Version**

| Feature                                                | MicroBlaze versions |        |        |        |        |        |
|--------------------------------------------------------|---------------------|--------|--------|--------|--------|--------|
|                                                        | v9.2                | v9.3   | v9.4   | v9.5   | v9.6   | v10.0  |
| Hardware debug readable ESR and EAR                    | Yes                 | Yes    | Yes    | Yes    | Yes    | Yes    |
| Processor Version Register (PVR)                       | option              | option | option | option | option | option |
| Area or speed optimized                                | option              | option | option | option | option | option |
| Hardware multiplier 64-bit result                      | option              | option | option | option | option | option |
| LUT cache memory                                       | option              | option | option | option | option | option |
| Floating point conversion and square root instructions | option              | option | option | option | option | option |
| Memory Management Unit (MMU)                           | option              | option | option | option | option | option |
| Extended stream instructions                           | option              | option | option | option | option | option |
| Use Cache Interface for All I-Cache Memory Accesses    | option              | option | option | option | option | option |
| Use Cache Interface for All D-Cache Memory Accesses    | option              | option | option | option | option | option |
| Use Write-back Caching Policy for D-Cache              | option              | option | option | option | option | option |
| Branch Target Cache (BTC)                              | option              | option | option | option | option | option |
| Streams for I-Cache                                    | option              | option | option | option | option | option |
| Victim handling for I-Cache                            | option              | option | option | option | option | option |
| Victim handling for D-Cache                            | option              | option | option | option | option | option |
| AXI4 (M_AXI_DP) data side interface                    | option              | option | option | option | option | option |
| AXI4 (M_AXI_IP) instruction side interface             | option              | option | option | option | option | option |
| AXI4 (M_AXI_DC) protocol for D-Cache                   | option              | option | option | option | option | option |
| AXI4 (M_AXI_IC) protocol for I-Cache                   | option              | option | option | option | option | option |
| AXI4 protocol for stream accesses                      | option              | option | option | option | option | option |
| Fault tolerant features                                | option              | option | option | option | option | option |
| Force distributed RAM for cache tags                   | option              | option | option | option | option | option |
| Configurable cache data widths                         | option              | option | option | option | option | option |
| Count Leading Zeros instruction                        | option              | option | option | option | option | option |
| Memory Barrier instruction                             | Yes                 | Yes    | Yes    | Yes    | Yes    | Yes    |
| Stack overflow and underflow detection                 | option              | option | option | option | option | option |
| Allow stream instructions in user mode                 | option              | option | option | option | option | option |
| Lockstep support                                       | option              | option | option | option | option | option |
| Configurable use of FPGA primitives                    | option              | option | option | option | option | option |

**Table 2-1: Configurable Feature Overview by MicroBlaze Version**

| Feature                                                                        | MicroBlaze versions |        |        |        |        |        |
|--------------------------------------------------------------------------------|---------------------|--------|--------|--------|--------|--------|
|                                                                                | v9.2                | v9.3   | v9.4   | v9.5   | v9.6   | v10.0  |
| Low-latency interrupt mode                                                     | option              | option | option | option | option | option |
| Swap instructions                                                              | option              | option | option | option | option | option |
| Sleep mode and sleep instruction                                               | Yes                 | Yes    | Yes    | Yes    | Yes    | Yes    |
| Relocatable base vectors                                                       | option              | option | option | option | option | option |
| ACE (M_ACE_DC) protocol for D-Cache                                            | option              | option | option | option | option | option |
| ACE (M_ACE_IC) protocol for I-Cache                                            | option              | option | option | option | option | option |
| Extended debug: performance monitoring, program trace, non-intrusive profiling |                     | option | option | option | option | option |
| Reset mode: enter sleep or debug halt at reset                                 |                     | option | option | option | option | option |
| Extended debug: external program trace                                         |                     |        | option | option | option | option |
| Extended data addressing                                                       |                     |        |        |        | option | option |
| Pipeline pause functionality                                                   |                     |        |        |        | Yes    | Yes    |
| Hibernate and suspend instructions                                             |                     |        |        |        | Yes    | Yes    |
| Non-secure mode                                                                |                     |        |        |        | Yes    | Yes    |
| Bit field instructions <sup>2</sup>                                            |                     |        |        |        |        | option |
| Parallel debug interface                                                       |                     |        |        |        |        | option |
| MMU Physical Address Extension                                                 |                     |        |        |        |        | option |

1. Used for saving DSP48E primitives.

2. Bit field instructions are available when C\_USE\_BARREL = 1.

## Data Types and Endianness

MicroBlaze uses Big-Endian or Little-Endian format to represent data, depending on the selected endianness. The parameter `C_ENDIANNESS` is by default set to 1 (little-endian).

The hardware supported data types for MicroBlaze are word, half word, and byte. When using the reversed load and store instructions LHUR, LWR, SHR and SWR, the bytes in the data are reversed, as indicated by the byte-reversed order.

The bit and byte organization for each type is shown in the following tables.

**Table 2-2: Word Data Type**

|                                   |        |     |     |        |
|-----------------------------------|--------|-----|-----|--------|
| Big-Endian Byte Address           | n      | n+1 | n+2 | n+3    |
| Big-Endian Byte Significance      | MSByte |     |     | LSByte |
| Big-Endian Byte Order             | n      | n+1 | n+2 | n+3    |
| Big-Endian Byte-Reversed Order    | n+3    | n+2 | n+1 | n      |
| Little-Endian Byte Address        | n+3    | n+2 | n+1 | n      |
| Little-Endian Byte Significance   | MSByte |     |     | LSByte |
| Little-Endian Byte Order          | n+3    | n+2 | n+1 | n      |
| Little-Endian Byte-Reversed Order | n      | n+1 | n+2 | n+3    |
| Bit Label                         | 0      |     |     | 31     |
| Bit Significance                  | MSBit  |     |     | LSBit  |

**Table 2-3: Half Word Data Type**

|                                   |        |        |
|-----------------------------------|--------|--------|
| Big-Endian Byte Address           | n      | n+1    |
| Big-Endian Byte Significance      | MSByte | LSByte |
| Big-Endian Byte Order             | n      | n+1    |
| Big-Endian Byte-Reversed Order    | n+1    | n      |
| Little-Endian Byte Address        | n+1    | n      |
| Little-Endian Byte Significance   | MSByte | LSByte |
| Little-Endian Byte Order          | n+1    | n      |
| Little-Endian Byte-Reversed Order | n      | n+1    |
| Bit Label                         | 0      | 15     |
| Bit Significance                  | MSBit  | LSBit  |

**Table 2-4: Byte Data Type**

|                  |             |
|------------------|-------------|
| Byte Address     | n           |
| Bit Label        | 0 7         |
| Bit Significance | MSBit LSBit |

# Instructions

## Instruction Summary

All MicroBlaze instructions are 32 bits and are defined as either Type A or Type B. Type A instructions have up to two source register operands and one destination register operand. Type B instructions have one source register and a 16-bit immediate operand (which can be extended to 32 bits by preceding the Type B instruction with an imm instruction). Type B instructions have a single destination register operand. Instructions are provided in the following functional categories: arithmetic, logical, branch, load/store, and special.

[Table 2-6](#) lists the MicroBlaze instruction set. Refer to [Chapter 5, MicroBlaze Instruction Set Architecture](#) for more information on these instructions. [Table 2-5](#) describes the instruction set nomenclature used in the semantics of each instruction.

**Table 2-5: Instruction Set Nomenclature**

| Symbol        | Description                                                                               |
|---------------|-------------------------------------------------------------------------------------------|
| Ra            | R0 - R31, General Purpose Register, source operand a                                      |
| Rb            | R0 - R31, General Purpose Register, source operand b                                      |
| Rd            | R0 - R31, General Purpose Register, destination operand                                   |
| SPR[x]        | Special Purpose Register number <i>x</i>                                                  |
| MSR           | Machine Status Register = SPR[1]                                                          |
| ESR           | Exception Status Register = SPR[5]                                                        |
| EAR           | Exception Address Register = SPR[3]                                                       |
| FSR           | Floating Point Unit Status Register = SPR[7]                                              |
| PVRx          | Processor Version Register, where <i>x</i> is the register number = SPR[8192 + <i>x</i> ] |
| BTR           | Branch Target Register = SPR[11]                                                          |
| PC            | Execute stage Program Counter = SPR[0]                                                    |
| x[y]          | Bit <i>y</i> of register <i>x</i>                                                         |
| x[y:z]        | Bit range <i>y</i> to <i>z</i> of register <i>x</i>                                       |
| $\bar{x}$     | Bit inverted value of register <i>x</i>                                                   |
| Imm           | 16 bit immediate value                                                                    |
| Immx          | <i>x</i> bit immediate value                                                              |
| FSLx          | 4 bit AXI4-Stream port designator, where <i>x</i> is the port number                      |
| C             | Carry flag, MSR[29]                                                                       |
| Sa            | Special Purpose Register, source operand                                                  |
| Sd            | Special Purpose Register, destination operand                                             |
| s( <i>x</i> ) | Sign extend argument <i>x</i> to 32-bit value                                             |
| *Addr         | Memory contents at location Addr (data-size aligned)                                      |



Table 2-5: Instruction Set Nomenclature (Cont'd)

| Symbol               | Description                                                                                                                                  |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| :=                   | Assignment operator                                                                                                                          |
| =                    | Equality comparison                                                                                                                          |
| !=                   | Inequality comparison                                                                                                                        |
| >                    | Greater than comparison                                                                                                                      |
| >=                   | Greater than or equal comparison                                                                                                             |
| <                    | Less than comparison                                                                                                                         |
| <=                   | Less than or equal comparison                                                                                                                |
| +                    | Arithmetic add                                                                                                                               |
| *                    | Arithmetic multiply                                                                                                                          |
| /                    | Arithmetic divide                                                                                                                            |
| >> x                 | Bit shift right x bits                                                                                                                       |
| << x                 | Bit shift left x bits                                                                                                                        |
| and                  | Logic AND                                                                                                                                    |
| or                   | Logic OR                                                                                                                                     |
| xor                  | Logic exclusive OR                                                                                                                           |
| op1 if cond else op2 | Perform <i>op1</i> if condition <i>cond</i> is true, else perform <i>op2</i>                                                                 |
| &                    | Concatenate. For example "0000100 & Imm7" is the concatenation of the fixed field "0000100" and a 7 bit immediate value.                     |
| signed               | Operation performed on signed integer data type. All arithmetic operations are performed on signed word operands, unless otherwise specified |
| unsigned             | Operation performed on unsigned integer data type                                                                                            |
| float                | Operation performed on floating point data type                                                                                              |
| clz(r)               | Count leading zeros                                                                                                                          |

Table 2-6: MicroBlaze Instruction Set Summary

| Type A         | 0-5    | 6-10 | 11-15 | 16-20 | 21-31        | Semantics                                                                             |
|----------------|--------|------|-------|-------|--------------|---------------------------------------------------------------------------------------|
| Type B         | 0-5    | 6-10 | 11-15 | 16-31 |              |                                                                                       |
| ADD Rd,Ra,Rb   | 000000 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + Ra$                                                                       |
| RSUB Rd,Ra,Rb  | 000001 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + \overline{Ra} + 1$                                                        |
| ADDC Rd,Ra,Rb  | 000010 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + Ra + C$                                                                   |
| RSUBC Rd,Ra,Rb | 000011 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + \overline{Ra} + C$                                                        |
| ADDK Rd,Ra,Rb  | 000100 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + Ra$                                                                       |
| RSUBK Rd,Ra,Rb | 000101 | Rd   | Ra    | Rb    | 000000000000 | $Rd := Rb + \overline{Ra} + 1$                                                        |
| CMP Rd,Ra,Rb   | 000101 | Rd   | Ra    | Rb    | 000000000001 | $Rd := Rb + \overline{Ra} + 1$<br>$Rd[0] := 0$ if $(Rb \geq Ra)$ else<br>$Rd[0] := 1$ |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A            | 0-5    | 6-10  | 11-15 | 16-20 | 21-31           | Semantics                                                                                                         |
|-------------------|--------|-------|-------|-------|-----------------|-------------------------------------------------------------------------------------------------------------------|
| Type B            | 0-5    | 6-10  | 11-15 | 16-31 |                 |                                                                                                                   |
| CMPU Rd,Ra,Rb     | 000101 | Rd    | Ra    | Rb    | 00000000011     | Rd := Rb + $\overline{Ra}$ + 1 (unsigned)<br>Rd[0] := 0 if (Rb >= Ra, unsigned) else<br>Rd[0] := 1                |
| ADDKC Rd,Ra,Rb    | 000110 | Rd    | Ra    | Rb    | 00000000000     | Rd := Rb + Ra + C                                                                                                 |
| RSUBKC Rd,Ra,Rb   | 000111 | Rd    | Ra    | Rb    | 00000000000     | Rd := Rb + $\overline{Ra}$ + C                                                                                    |
| ADDI Rd,Ra,Imm    | 001000 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + Ra                                                                                                 |
| RSUBI Rd,Ra,Imm   | 001001 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + $\overline{Ra}$ + 1                                                                                |
| ADDIC Rd,Ra,Imm   | 001010 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + Ra + C                                                                                             |
| RSUBIC Rd,Ra,Imm  | 001011 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + $\overline{Ra}$ + C                                                                                |
| ADDIK Rd,Ra,Imm   | 001100 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + Ra                                                                                                 |
| RSUBIK Rd,Ra,Imm  | 001101 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + $\overline{Ra}$ + 1                                                                                |
| ADDIKC Rd,Ra,Imm  | 001110 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + Ra + C                                                                                             |
| RSUBIKC Rd,Ra,Imm | 001111 | Rd    | Ra    | Imm   |                 | Rd := s(Imm) + $\overline{Ra}$ + C                                                                                |
| MUL Rd,Ra,Rb      | 010000 | Rd    | Ra    | Rb    | 00000000000     | Rd := Ra * Rb                                                                                                     |
| MULH Rd,Ra,Rb     | 010000 | Rd    | Ra    | Rb    | 00000000001     | Rd := (Ra * Rb) >> 32 (signed)                                                                                    |
| MULHU Rd,Ra,Rb    | 010000 | Rd    | Ra    | Rb    | 00000000011     | Rd := (Ra * Rb) >> 32 (unsigned)                                                                                  |
| MULHSU Rd,Ra,Rb   | 010000 | Rd    | Ra    | Rb    | 00000000010     | Rd := (Ra, signed * Rb, unsigned) >> 32 (signed)                                                                  |
| BSRL Rd,Ra,Rb     | 010001 | Rd    | Ra    | Rb    | 00000000000     | Rd := 0 & (Ra >> Rb)                                                                                              |
| BSRA Rd,Ra,Rb     | 010001 | Rd    | Ra    | Rb    | 01000000000     | Rd := s(Ra >> Rb)                                                                                                 |
| BSLL Rd,Ra,Rb     | 010001 | Rd    | Ra    | Rb    | 10000000000     | Rd := (Ra << Rb) & 0                                                                                              |
| IDIV Rd,Ra,Rb     | 010010 | Rd    | Ra    | Rb    | 00000000000     | Rd := Rb/Ra                                                                                                       |
| IDIVU Rd,Ra,Rb    | 010010 | Rd    | Ra    | Rb    | 00000000010     | Rd := Rb/Ra, unsigned                                                                                             |
| TNEAGETD Rd,Rb    | 010011 | Rd    | 00000 | Rb    | 0N0TAE<br>00000 | Rd := FSL Rb[28:31] (data read)<br>MSR[FSL] := 1 if (FSL_S_Control = 1)<br>MSR[C] := not FSL_S_Exists if N = 1    |
| TNAPUTD Ra,Rb     | 010011 | 00000 | Ra    | Rb    | 0N0TA0<br>00000 | FSL Rb[28:31] := Ra (data write)<br>MSR[C] := FSL_M_Full if N = 1                                                 |
| TNECAGETD Rd,Rb   | 010011 | Rd    | 00000 | Rb    | 0N1TAE<br>00000 | Rd := FSL Rb[28:31] (control read)<br>MSR[FSL] := 1 if (FSL_S_Control = 0)<br>MSR[C] := not FSL_S_Exists if N = 1 |
| TNCAPUTD Ra,Rb    | 010011 | 00000 | Ra    | Rb    | 0N1TA0<br>00000 | FSL Rb[28:31] := Ra (control write)<br>MSR[C] := FSL_M_Full if N = 1                                              |
| FADD Rd,Ra,Rb     | 010110 | Rd    | Ra    | Rb    | 00000000000     | Rd := Rb+Ra, float <sup>1</sup>                                                                                   |
| FRSUB Rd,Ra,Rb    | 010110 | Rd    | Ra    | Rb    | 00010000000     | Rd := Rb-Ra, float <sup>1</sup>                                                                                   |
| FMUL Rd,Ra,Rb     | 010110 | Rd    | Ra    | Rb    | 00100000000     | Rd := Rb*Ra, float <sup>1</sup>                                                                                   |
| FDIV Rd,Ra,Rb     | 010110 | Rd    | Ra    | Rb    | 00110000000     | Rd := Rb/Ra, float <sup>1</sup>                                                                                   |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A                                             | 0-5    | 6-10  | 11-15 | 16-20                                              | 21-31       | Semantics                                                                                                                                                                                             |
|----------------------------------------------------|--------|-------|-------|----------------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Type B                                             | 0-5    | 6-10  | 11-15 | 16-31                                              |             |                                                                                                                                                                                                       |
| FCMP.UN Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01000000000 | Rd := 1 if (Rb = NaN or Ra = NaN, float <sup>1</sup> )<br>else<br>Rd := 0                                                                                                                             |
| FCMP.LT Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01000010000 | Rd := 1 if (Rb < Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                             |
| FCMP.EQ Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01000100000 | Rd := 1 if (Rb = Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                             |
| FCMP.LE Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01000110000 | Rd := 1 if (Rb <= Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                            |
| FCMP.GT Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01001000000 | Rd := 1 if (Rb > Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                             |
| FCMP.NE Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01001010000 | Rd := 1 if (Rb != Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                            |
| FCMP.GE Rd,Ra,Rb                                   | 010110 | Rd    | Ra    | Rb                                                 | 01001100000 | Rd := 1 if (Rb >= Ra, float <sup>1</sup> ) else<br>Rd := 0                                                                                                                                            |
| FLT Rd,Ra                                          | 010110 | Rd    | Ra    | 0                                                  | 01010000000 | Rd := float (Ra) <sup>1</sup>                                                                                                                                                                         |
| FINT Rd,Ra                                         | 010110 | Rd    | Ra    | 0                                                  | 01100000000 | Rd := int (Ra) <sup>1</sup>                                                                                                                                                                           |
| FSQRT Rd,Ra                                        | 010110 | Rd    | Ra    | 0                                                  | 01110000000 | Rd := sqrt (Ra) <sup>1</sup>                                                                                                                                                                          |
| MULI Rd,Ra,Imm                                     | 011000 | Rd    | Ra    | Imm                                                |             | Rd := Ra * s(Imm)                                                                                                                                                                                     |
| BSRLI Rd,Ra,Imm                                    | 011001 | Rd    | Ra    | 00000000000 & Imm5                                 |             | Rd := 0 & (Ra >> Imm5)                                                                                                                                                                                |
| BSRAI Rd,Ra,Imm                                    | 011001 | Rd    | Ra    | 00000010000 & Imm5                                 |             | Rd := s(Ra >> Imm5)                                                                                                                                                                                   |
| BSLLI Rd,Ra,Imm                                    | 011001 | Rd    | Ra    | 00000100000 & Imm5                                 |             | Rd := (Ra << Imm5) & 0                                                                                                                                                                                |
| BSEFI Rd,Ra,<br>Imm <sub>W</sub> ,Imm <sub>S</sub> | 011001 | Rd    | Ra    | 01000 &<br>Imm <sub>W</sub> & 0 & Imm <sub>S</sub> |             | Rd[0:31-Imm <sub>W</sub> ] := 0<br>Rd[32-Imm <sub>W</sub> :31] := (Ra >> Imm <sub>S</sub> )                                                                                                           |
| BSIFI Rd,Ra,<br>Width,Imm <sub>S</sub>             | 011001 | Rd    | Ra    | 10000 &<br>Imm <sub>W</sub> & 0 & Imm <sub>S</sub> |             | M := (0xffffffff << (Imm <sub>W</sub> + 1)) xor<br>(0xffffffff << Imm <sub>S</sub> )<br>Rd := ((Ra << Imm <sub>S</sub> ) and M) xor<br>(Rd and M)<br>Imm <sub>W</sub> := Imm <sub>S</sub> + Width - 1 |
| TNEAGET Rd,FSLx                                    | 011011 | Rd    | 00000 | 0N0TAE000000 & FSLx                                |             | Rd := FSLx (data read, blocking if N = 0)<br>MSR[FSL] := 1 if (FSLx_S_Control = 1)<br>MSR[C] := not FSLx_S_Exists if N = 1                                                                            |
| TNAPUT Ra,FSLx                                     | 011011 | 00000 | Ra    | 1N0TA0000000 & FSLx                                |             | FSLx := Ra (data write, block if N = 0)<br>MSR[C] := FSLx_M_Full if N = 1                                                                                                                             |
| TNECAGET Rd,FSLx                                   | 011011 | Rd    | 00000 | 0N1TAE000000 & FSLx                                |             | Rd := FSLx (control read, block if N = 0)<br>MSR[FSL] := 1 if (FSLx_S_Control = 0)<br>MSR[C] := not FSLx_S_Exists if N = 1                                                                            |
| TNCAPUT Ra,FSLx                                    | 011011 | 00000 | Ra    | 1N1TA0000000 & FSLx                                |             | FSLx := Ra (control write, block if N = 0)<br>MSR[C] := FSLx_M_Full if N = 1                                                                                                                          |
| OR Rd,Ra,Rb                                        | 100000 | Rd    | Ra    | Rb                                                 | 00000000000 | Rd := Ra or Rb                                                                                                                                                                                        |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A          | 0-5    | 6-10  | 11-15 | 16-20              | 21-31        | Semantics                                                                                                                                                                                                                                    |
|-----------------|--------|-------|-------|--------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Type B          | 0-5    | 6-10  | 11-15 | 16-31              |              |                                                                                                                                                                                                                                              |
| PCMPBF Rd,Ra,Rb | 100000 | Rd    | Ra    | Rb                 | 100000000000 | Rd := 1 if (Rb[0:7] = Ra[0:7]) else<br>Rd := 2 if (Rb[8:15] = Ra[8:15]) else<br>Rd := 3 if (Rb[16:23] = Ra[16:23]) else<br>Rd := 4 if (Rb[24:31] = Ra[24:31]) else<br>Rd := 0                                                                |
| AND Rd,Ra,Rb    | 100001 | Rd    | Ra    | Rb                 | 000000000000 | Rd := Ra and Rb                                                                                                                                                                                                                              |
| XOR Rd,Ra,Rb    | 100010 | Rd    | Ra    | Rb                 | 000000000000 | Rd := Ra xor Rb                                                                                                                                                                                                                              |
| PCMPEQ Rd,Ra,Rb | 100010 | Rd    | Ra    | Rb                 | 100000000000 | Rd := 1 if (Rb = Ra) else<br>Rd := 0                                                                                                                                                                                                         |
| ANDN Rd,Ra,Rb   | 100011 | Rd    | Ra    | Rb                 | 000000000000 | Rd := Ra and $\overline{\text{Rb}}$                                                                                                                                                                                                          |
| PCMPNE Rd,Ra,Rb | 100011 | Rd    | Ra    | Rb                 | 100000000000 | Rd := 1 if (Rb != Ra) else<br>Rd := 0                                                                                                                                                                                                        |
| SRA Rd,Ra       | 100100 | Rd    | Ra    | 000000000000000001 |              | Rd := s(Ra >> 1)<br>C := Ra[31]                                                                                                                                                                                                              |
| SRC Rd,Ra       | 100100 | Rd    | Ra    | 0000000000100001   |              | Rd := C & (Ra >> 1)<br>C := Ra[31]                                                                                                                                                                                                           |
| SRL Rd,Ra       | 100100 | Rd    | Ra    | 0000000001000001   |              | Rd := 0 & (Ra >> 1)<br>C := Ra[31]                                                                                                                                                                                                           |
| SEXT8 Rd,Ra     | 100100 | Rd    | Ra    | 0000000001100000   |              | Rd := s(Ra[24:31])                                                                                                                                                                                                                           |
| SEXT16 Rd,Ra    | 100100 | Rd    | Ra    | 0000000001100001   |              | Rd := s(Ra[16:31])                                                                                                                                                                                                                           |
| CLZ Rd, Ra      | 100100 | Rd    | Ra    | 0000000011100000   |              | Rd = clz(Ra)                                                                                                                                                                                                                                 |
| SWAPB Rd, Ra    | 100100 | Rd    | Ra    | 0000000111100000   |              | Rd = (Ra)[24:31, 16:23, 8:15, 0:7]                                                                                                                                                                                                           |
| SWAPH Rd, Ra    | 100100 | Rd    | Ra    | 0000000111100010   |              | Rd = (Ra)[16:31, 0:15]                                                                                                                                                                                                                       |
| WIC Ra,Rb       | 100100 | 00000 | Ra    | Rb                 | 00001101000  | ICache_Line[Ra >> 4].Tag := 0 if<br>(C_ICACHE_LINE_LEN = 4)<br>ICache_Line[Ra >> 5].Tag := 0 if<br>(C_ICACHE_LINE_LEN = 8)<br>ICache_Line[Ra >> 6].Tag := 0 if<br>(C_ICACHE_LINE_LEN = 16)                                                   |
| WDC Ra,Rb       | 100100 | 00000 | Ra    | Rb                 | 00001100100  | Cache line is cleared, discarding stored data.<br>DCache_Line[Ra >> 4].Tag := 0 if<br>(C_DCACHE_LINE_LEN = 4)<br>DCache_Line[Ra >> 5].Tag := 0 if<br>(C_DCACHE_LINE_LEN = 8)<br>DCache_Line[Ra >> 6].Tag := 0 if<br>(C_DCACHE_LINE_LEN = 16) |
| WDC.FLUSH Ra,Rb | 100100 | 00000 | Ra    | Rb                 | 00001110100  | Cache line is flushed, writing stored data to memory, and then cleared. Used when C_DCACHE_USE_WRITEBACK = 1.                                                                                                                                |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A             | 0-5    | 6-10  | 11-15 | 16-20      | 21-31       | Semantics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------|--------|-------|-------|------------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Type B             | 0-5    | 6-10  | 11-15 | 16-31      |             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| WDC.CLEAR Ra,Rb    | 100100 | 00000 | Ra    | Rb         | 00001100110 | Cache line with matching address is cleared, discarding stored data. Used when C_DCACHE_USE_WRITEBACK = 1.                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| WDC.CLEAR.EA Ra,Rb | 100100 | 00000 | Ra    | Rb         | 00011100110 | Cache line with matching extended address Ra & Rb is cleared. Used when C_DCACHE_USE_WRITEBACK = 1.                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| MTS Sd,Ra          | 100101 | 00000 | Ra    | 11 & Sd    |             | SPR[Sd] := Ra, where: <ul style="list-style-type: none"><li>· SPR[0x0001] is MSR</li><li>· SPR[0x0007] is FSR</li><li>· SPR[0x0800] is SLR</li><li>· SPR[0x0802] is SHR</li><li>· SPR[0x1000] is PID</li><li>· SPR[0x1001] is ZPR</li><li>· SPR[0x1002] is TLBX</li><li>· SPR[0x1003] is TLBLO[LSH]</li><li>· SPR[0x1004] is TLBHI</li><li>· SPR[0x1005] is TLBSX</li></ul>                                                                                                                                                                    |
| MTSE Sd,Ra         | 100101 | 01000 | Ra    | 11 & Sd    |             | SPR[Sd] := Ra, where: <ul style="list-style-type: none"><li>· SPR[0x1003] is TLBLO[MSH]</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| MFS Rd,Sa          | 100101 | Rd    | 00000 | 10 & Sa    |             | Rd := SPR[Sa], where: <ul style="list-style-type: none"><li>· SPR[0x0000] is PC</li><li>· SPR[0x0001] is MSR</li><li>· SPR[0x0003] is EAR[LSH]</li><li>· SPR[0x0005] is ESR</li><li>· SPR[0x0007] is FSR</li><li>· SPR[0x000B] is BTR</li><li>· SPR[0x000D] is EDR</li><li>· SPR[0x0800] is SLR</li><li>· SPR[0x0802] is SHR</li><li>· SPR[0x1000] is PID</li><li>· SPR[0x1001] is ZPR</li><li>· SPR[0x1002] is TLBX</li><li>· SPR[0x1003] is TLBLO[LSH]</li><li>· SPR[0x1004] is TLBHI</li><li>· SPR[0x2000-200B] is PVR[0-12][LSH]</li></ul> |
| MFSE Rd,Sa         | 100101 | Rd    | 01000 | 10 & Sa    |             | Rd := SPR[Sa][MSH], where: <ul style="list-style-type: none"><li>· SPR[0x0003] is EAR[MSH]</li><li>· SPR[0x1003] is TLBLO[MSH]</li><li>· SPR[0x2006-2009] is PVR[6-9][MSH]</li></ul>                                                                                                                                                                                                                                                                                                                                                           |
| MSRCLR Rd,Imm      | 100101 | Rd    | 00001 | 00 & Imm14 |             | Rd := MSR<br>MSR := MSR and $\overline{\text{Imm14}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A          | 0-5    | 6-10  | 11-15 | 16-20      | 21-31       | Semantics                             |
|-----------------|--------|-------|-------|------------|-------------|---------------------------------------|
| Type B          | 0-5    | 6-10  | 11-15 | 16-31      |             |                                       |
| MSRSET Rd,Imm   | 100101 | Rd    | 00000 | 00 & Imm14 |             | Rd := MSR<br>MSR := MSR or Imm14      |
| BR Rb           | 100110 | 00000 | 00000 | Rb         | 00000000000 | PC := PC + Rb                         |
| BRD Rb          | 100110 | 00000 | 10000 | Rb         | 00000000000 | PC := PC + Rb                         |
| BRLD Rd,Rb      | 100110 | Rd    | 10100 | Rb         | 00000000000 | PC := PC + Rb<br>Rd := PC             |
| BRA Rb          | 100110 | 00000 | 01000 | Rb         | 00000000000 | PC := Rb                              |
| BRAD Rb         | 100110 | 00000 | 11000 | Rb         | 00000000000 | PC := Rb                              |
| BRALD Rd,Rb     | 100110 | Rd    | 11100 | Rb         | 00000000000 | PC := Rb<br>Rd := PC                  |
| BRK Rd,Rb       | 100110 | Rd    | 01100 | Rb         | 00000000000 | PC := Rb<br>Rd := PC<br>MSR[BIP] := 1 |
| BEQ Ra,Rb       | 100111 | 00000 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra = 0               |
| BNE Ra,Rb       | 100111 | 00001 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra != 0              |
| BLT Ra,Rb       | 100111 | 00010 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra < 0               |
| BLE Ra,Rb       | 100111 | 00011 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra <= 0              |
| BGT Ra,Rb       | 100111 | 00100 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra > 0               |
| BGE Ra,Rb       | 100111 | 00101 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra >= 0              |
| BEQD Ra,Rb      | 100111 | 10000 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra = 0               |
| BNED Ra,Rb      | 100111 | 10001 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra != 0              |
| BLTD Ra,Rb      | 100111 | 10010 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra < 0               |
| BLED Ra,Rb      | 100111 | 10011 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra <= 0              |
| BGTD Ra,Rb      | 100111 | 10100 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra > 0               |
| BGED Ra,Rb      | 100111 | 10101 | Ra    | Rb         | 00000000000 | PC := PC + Rb if Ra >= 0              |
| ORI Rd,Ra,Imm   | 101000 | Rd    | Ra    | Imm        |             | Rd := Ra or s(Imm)                    |
| ANDI Rd,Ra,Imm  | 101001 | Rd    | Ra    | Imm        |             | Rd := Ra and s(Imm)                   |
| XORI Rd,Ra,Imm  | 101010 | Rd    | Ra    | Imm        |             | Rd := Ra xor s(Imm)                   |
| ANDNI Rd,Ra,Imm | 101011 | Rd    | Ra    | Imm        |             | Rd := Ra and $\overline{s(Imm)}$      |
| IMM Imm         | 101100 | 00000 | 00000 | Imm        |             | Imm[0:15] := Imm                      |
| RTSD Ra,Imm     | 101101 | 10000 | Ra    | Imm        |             | PC := Ra + s(Imm)                     |
| RTID Ra,Imm     | 101101 | 10001 | Ra    | Imm        |             | PC := Ra + s(Imm)<br>MSR[IE] := 1     |
| RTBD Ra,Imm     | 101101 | 10010 | Ra    | Imm        |             | PC := Ra + s(Imm)<br>MSR[BIP] := 0    |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A                        | 0-5    | 6-10  | 11-15 | 16-20            | 21-31                        | Semantics                                                    |
|-------------------------------|--------|-------|-------|------------------|------------------------------|--------------------------------------------------------------|
| Type B                        | 0-5    | 6-10  | 11-15 | 16-31            |                              |                                                              |
| RTED Ra,Imm                   | 101101 | 10100 | Ra    | Imm              |                              | PC := Ra + s(Imm)<br>MSR[EE] := 1, MSR[EIP] := 0<br>ESR := 0 |
| BRI Imm                       | 101110 | 00000 | 00000 | Imm              |                              | PC := PC + s(Imm)                                            |
| MBAR Imm                      | 101110 | Imm   | 00010 | 0000000000000100 |                              | PC := PC + 4; Wait for memory accesses.                      |
| BRID Imm                      | 101110 | 00000 | 10000 | Imm              |                              | PC := PC + s(Imm)                                            |
| BRLID Rd,Imm                  | 101110 | Rd    | 10100 | Imm              |                              | PC := PC + s(Imm)<br>Rd := PC                                |
| BRAI Imm                      | 101110 | 00000 | 01000 | Imm              |                              | PC := s(Imm)                                                 |
| BRAID Imm                     | 101110 | 00000 | 11000 | Imm              |                              | PC := s(Imm)                                                 |
| BRALID Rd,Imm                 | 101110 | Rd    | 11100 | Imm              |                              | PC := s(Imm)<br>Rd := PC                                     |
| BRKI Rd,Imm                   | 101110 | Rd    | 01100 | Imm              |                              | PC := s(Imm)<br>Rd := PC<br>MSR[BIP] := 1                    |
| BEQI Ra,Imm                   | 101111 | 00000 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra = 0                                  |
| BNEI Ra,Imm                   | 101111 | 00001 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra != 0                                 |
| BLTI Ra,Imm                   | 101111 | 00010 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra < 0                                  |
| BLEI Ra,Imm                   | 101111 | 00011 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra <= 0                                 |
| BGTI Ra,Imm                   | 101111 | 00100 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra > 0                                  |
| BGEI Ra,Imm                   | 101111 | 00101 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra >= 0                                 |
| BEQID Ra,Imm                  | 101111 | 10000 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra = 0                                  |
| BNEID Ra,Imm                  | 101111 | 10001 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra != 0                                 |
| BLTID Ra,Imm                  | 101111 | 10010 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra < 0                                  |
| BLEID Ra,Imm                  | 101111 | 10011 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra <= 0                                 |
| BGTID Ra,Imm                  | 101111 | 10100 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra > 0                                  |
| BGEID Ra,Imm                  | 101111 | 10101 | Ra    | Imm              |                              | PC := PC + s(Imm) if Ra >= 0                                 |
| LBU Rd,Ra,Rb<br>LBUR Rd,Ra,Rb | 110000 | Rd    | Ra    | Rb               | 000000000000<br>010000000000 | Addr := Ra + Rb<br>Rd[0:23] := 0<br>Rd[24:31] := *Addr[0:7]  |
| LBUEA Rd,Ra,Rb                | 110000 | Rd    | Ra    | Rb               | 000100000000                 | Addr := Ra & Rb<br>Rd[0:23] := 0<br>Rd[24:31] := *Addr[0:7]  |
| LHU Rd,Ra,Rb<br>LHUR Rd,Ra,Rb | 110001 | Rd    | Ra    | Rb               | 000000000000<br>010000000000 | Addr := Ra + Rb<br>Rd[0:15] := 0<br>Rd[16:31] := *Addr[0:15] |

Table 2-6: MicroBlaze Instruction Set Summary (Cont'd)

| Type A                      | 0-5    | 6-10 | 11-15 | 16-20 | 21-31                      | Semantics                                                             |
|-----------------------------|--------|------|-------|-------|----------------------------|-----------------------------------------------------------------------|
| Type B                      | 0-5    | 6-10 | 11-15 | 16-31 |                            |                                                                       |
| LHUEA Rd,Ra,Rb              | 110001 | Rd   | Ra    | Rb    | 00010000000                | Addr := Ra & Rb<br>Rd[0:15] := 0<br>Rd[16:31] := *Addr[0:15]          |
| LW Rd,Ra,Rb<br>LWR Rd,Ra,Rb | 110010 | Rd   | Ra    | Rb    | 00000000000<br>01000000000 | Addr := Ra + Rb<br>Rd := *Addr                                        |
| LWX Rd,Ra,Rb                | 110010 | Rd   | Ra    | Rb    | 10000000000                | Addr := Ra + Rb<br>Rd := *Addr<br>Reservation := 1                    |
| LWEA Rd,Ra,Rb               | 110010 | Rd   | Ra    | Rb    | 00010000000                | Addr := Ra & Rb<br>Rd := *Addr                                        |
| SB Rd,Ra,Rb<br>SBR Rd,Ra,Rb | 110100 | Rd   | Ra    | Rb    | 00000000000<br>01000000000 | Addr := Ra + Rb<br>*Addr[0:8] := Rd[24:31]                            |
| SBEA Rd,Ra,Rb               | 110100 | Rd   | Ra    | Rb    | 00010000000                | Addr := Ra & Rb<br>*Addr[0:8] := Rd[24:31]                            |
| SH Rd,Ra,Rb<br>SHR Rd,Ra,Rb | 110101 | Rd   | Ra    | Rb    | 00000000000<br>01000000000 | Addr := Ra + Rb<br>*Addr[0:16] := Rd[16:31]                           |
| SHEA Rd,Ra,Rb               | 110101 | Rd   | Ra    | Rb    | 00010000000                | Addr := Ra & Rb<br>*Addr[0:16] := Rd[16:31]                           |
| SW Rd,Ra,Rb<br>SWR Rd,Ra,Rb | 110110 | Rd   | Ra    | Rb    | 00000000000<br>01000000000 | Addr := Ra + Rb<br>*Addr := Rd                                        |
| SWX Rd,Ra,Rb                | 110110 | Rd   | Ra    | Rb    | 10000000000                | Addr := Ra + Rb<br>*Addr := Rd if Reservation = 1<br>Reservation := 0 |
| SWEA Rd,Ra,Rb               | 110110 | Rd   | Ra    | Rb    | 00010000000                | Addr := Ra & Rb<br>*Addr := Rd                                        |
| LBUI Rd,Ra,Imm              | 111000 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>Rd[0:23] := 0<br>Rd[24:31] := *Addr[0:7]       |
| LHUI Rd,Ra,Imm              | 111001 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>Rd[0:15] := 0<br>Rd[16:31] := *Addr[0:15]      |
| LWI Rd,Ra,Imm               | 111010 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>Rd := *Addr                                    |
| SBI Rd,Ra,Imm               | 111100 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>*Addr[0:7] := Rd[24:31]                        |
| SHI Rd,Ra,Imm               | 111101 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>*Addr[0:15] := Rd[16:31]                       |
| SWI Rd,Ra,Imm               | 111110 | Rd   | Ra    | Imm   |                            | Addr := Ra + s(Imm)<br>*Addr := Rd                                    |

1. Due to the many different corner cases involved in floating point arithmetic, only the normal behavior is described. A full description of the behavior can be found in [Chapter 5, "MicroBlaze Instruction Set Architecture."](#)



## Semaphore Synchronization

The LWX and SWX instructions are used to implement common semaphore operations, including test and set, compare and swap, exchange memory, and fetch and add. They are also used to implement spinlocks.

These instructions are typically used by system programs and are called by application programs as needed. Generally, a program uses LWX to load a semaphore from memory, causing the reservation to be set (the processor maintains the reservation internally). The program can compute a result based on the semaphore value and conditionally store the result back to the same memory location using the SWX instruction. The conditional store is performed based on the existence of the reservation established by the preceding LWX instruction. If the reservation exists when the store is executed, the store is performed and MSR[C] is cleared to 0. If the reservation does not exist when the store is executed, the target memory location is not modified and MSR[C] is set to 1.

If the store is successful, the sequence of instructions from the semaphore load to the semaphore store appear to be executed atomically—no other device modified the semaphore location between the read and the update. Other devices can read from the semaphore location during the operation. For a semaphore operation to work properly, the LWX instruction must be paired with an SWX instruction, and both must specify identical addresses. The reservation granularity in MicroBlaze is a word. For both instructions, the address must be word aligned. No unaligned exceptions are generated for these instructions.

The conditional store is always attempted when a reservation exists, even if the store address does not match the load address that set the reservation.

Only one reservation can be maintained at a time. The address associated with the reservation can be changed by executing a subsequent LWX instruction. The conditional store is performed based upon the reservation established by the last LWX instruction executed. Executing an SWX instruction always clears a reservation held by the processor, whether the address matches that established by the LWX or not.

Reset, interrupts, exceptions, and breaks (including the BRK and BRKI instructions) all clear the reservation.

The following provides general guidelines for using the LWX and SWX instructions:

- The LWX and SWX instructions should be paired and use the same address.
- An unpaired SWX instruction to an arbitrary address can be used to clear any reservation held by the processor.
- A conditional sequence begins with an LWX instruction. It can be followed by memory accesses and/or computations on the loaded value. The sequence ends with an SWX instruction. In most cases, failure of the SWX instruction should cause a branch back to the LWX for a repeated attempt.

- An LWX instruction can be left unpaired when executing certain synchronization primitives if the value loaded by the LWX is not zero. An implementation of Test and Set exemplifies this:

```
loop: lw      r5,r3,r0    ; load and reserve
      bnei    r5,next     ; branch if not equal to zero
      addik   r5,r5,1     ; increment value
      swx     r5,r3,r0    ; try to store non-zero value
      addic   r5,r0,0     ; check reservation
      bnei    r5,loop     ; loop if reservation lost
next:
```

- Performance can be improved by minimizing looping on an LWX instruction that fails to return a desired value. Performance can also be improved by using an ordinary load instruction to do the initial value check. An implementation of a spinlock exemplifies this:

```
loop: lw      r5,r3,r0    ; load the word
      bnei    r5,loop     ; loop back if word not equal to 0
      lwx     r5,r3,r0    ; try reserving again
      bnei    r5,loop     ; likely that no branch is needed
      addik   r5,r5,1     ; increment value
      swx     r5,r3,r0    ; try to store non-zero value
      addic   r5,r0,0     ; check reservation
      bnei    r5,loop     ; loop if reservation lost
```

- Minimizing the looping on an LWX/SWX instruction pair increases the likelihood that forward progress is made. The old value should be tested before attempting the store. If the order is reversed (store before load), more SWX instructions are executed and reservations are more likely to be lost between the LWX and SWX instructions.

## Self-modifying Code

When using self-modifying code software must ensure that the modified instructions have been written to memory prior to fetching them for execution. There are several aspects to consider:

- The instructions to be modified may already have been fetched prior to modification:
  - .. into the instruction prefetch buffer,
  - .. into the instruction cache, if it is enabled,
  - .. into a stream buffer, if instruction cache stream buffers are used,
  - .. into the instruction cache, and then saved in a victim buffer, if victim buffers are used.

To ensure that the modified code is always executed instead of the old unmodified code, software must handle all these cases.

- If one or more of the instructions to be modified is a branch, and the branch target cache is used, the branch target address may have been cached.

To avoid using the cached branch target address, software must ensure that the branch target cache is cleared prior to executing the modified code.

- The modified instructions may not have been written to memory prior to execution:
  - .. they may be en route to memory, in temporary storage in the interconnect or the memory controller,
  - .. they may be stored in the data cache, if write-back cache is used,
  - .. they may be saved in a victim buffer, if write-back cache and victim buffers are used.

Software must ensure that the modified instructions have been written to memory before being fetched by the processor.

The annotated code below shows how each of the above issues can be addressed. This code assumes that both instruction cache and write-back data cache is used. If not, the corresponding instructions can be omitted.

The following code exemplifies storing a modified instruction:

```
swi      r5,r6,0 ; r5 = new instruction
                        ; r6 = physical instruction address
wdc.flush r6,r0   ; flush write-back data cache line
mbar     1        ; ensure new instruction is written to memory
wic      r7,r0    ; invalidate line, empty stream & victim buffers
                        ; r7 = virtual instruction address
mbar     2        ; empty prefetch buffer, clear branch target cache
```

The physical and virtual addresses above are identical, unless MMU virtual mode is used. If the MMU is enabled, the code sequences must be executed in real mode, since WIC and WDC are privileged instructions. The first instruction after the code sequences above must not be modified, since it may have been prefetched.

---

## Registers

MicroBlaze has an orthogonal instruction set architecture. It has thirty-two 32-bit general purpose registers and up to eighteen 32-bit special purpose registers, depending on configured options.

### General Purpose Registers

The thirty-two 32-bit General Purpose Registers are numbered R0 through R31. The register file is reset on bit stream download (reset value is 0x00000000). [Figure 2-2](#) is a representation of a General Purpose Register and [Table 2-7](#) provides a description of each register and the register reset value (if existing).

**Note:** The register file is **not** reset by the external reset inputs: Reset and Debug\_Rst.

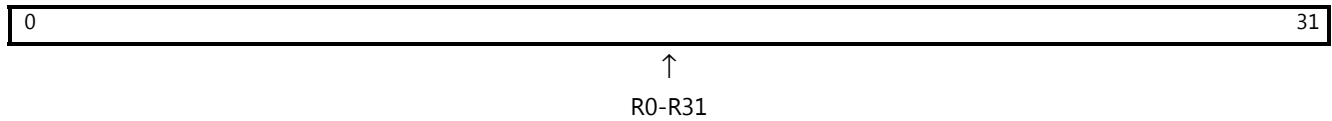


Figure 2-2: R0-R31

Table 2-7: General Purpose Registers (R0-R31)

| Bits | Name            | Description                                                                                                                                                                                                                                                                                                           | Reset Value |
|------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:31 | R0              | Always has a value of zero. Anything written to R0 is discarded                                                                                                                                                                                                                                                       | 0x00000000  |
| 0:31 | R1 through R13  | 32-bit general purpose registers                                                                                                                                                                                                                                                                                      | -           |
| 0:31 | R14             | 32-bit register used to store return addresses for interrupts.                                                                                                                                                                                                                                                        | -           |
| 0:31 | R15             | 32-bit general purpose register. Recommended for storing return addresses for user vectors.                                                                                                                                                                                                                           | -           |
| 0:31 | R16             | 32-bit register used to store return addresses for breaks.                                                                                                                                                                                                                                                            | -           |
| 0:31 | R17             | If MicroBlaze is configured to support hardware exceptions, this register is loaded with the address of the instruction following the instruction causing the HW exception, except for exceptions in delay slots that use BTR instead (see "Branch Target Register (BTR)"); if not, it is a general purpose register. | -           |
| 0:31 | R18 through R31 | R18 through R31 are 32-bit general purpose registers.                                                                                                                                                                                                                                                                 | -           |

Refer to [Table 4-2](#) for software conventions on general purpose register usage.

## Special Purpose Registers

### Program Counter (PC)

The Program Counter (PC) is the 32-bit address of the execution instruction. It can be read with an MFS instruction, but it cannot be written with an MTS instruction. When used with the MFS instruction the PC register is specified by setting Sa = 0x0000. [Figure 2-3](#) illustrates the PC and [Table 2-8](#) provides a description and reset value.

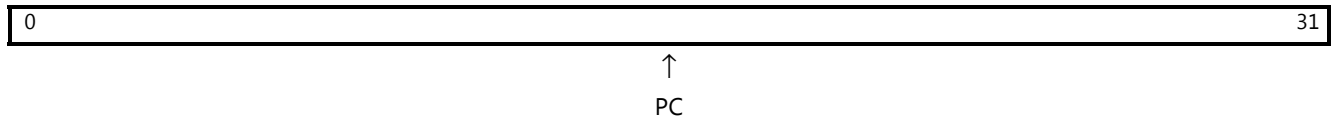


Figure 2-3: PC

Table 2-8: Program Counter (PC)

| Bits | Name | Description                                                                                                                      | Reset Value |
|------|------|----------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:31 | PC   | Program Counter<br>Address of executing instruction, that is, "mfs r2 0" stores the address of the mfs instruction itself in R2. | 0x00000000  |

## Machine Status Register (MSR)

The Machine Status Register contains control and status bits for the processor. It can be read with an MFS instruction. When reading the MSR, bit 29 is replicated in bit 0 as the carry copy. MSR can be written using either an MTS instruction or the dedicated MSRSET and MSRCLR instructions.

When writing to the MSR using MSRSET or MSRCLR, the Carry bit takes effect immediately and the remaining bits take effect one clock cycle later. When writing using MTS, all bits take effect one clock cycle later. Any value written to bit 0 is discarded.

When used with an MTS or MFS instruction, the MSR is specified by setting  $S_x = 0x0001$ . Figure 2-4 illustrates the MSR register and Table 2-9 provides the bit description and reset values.



Figure 2-4: MSR

Table 2-9: Machine Status Register (MSR)

| Bits | Name     | Description                                                                                     | Reset Value |
|------|----------|-------------------------------------------------------------------------------------------------|-------------|
| 0    | CC       | Arithmetic Carry Copy<br>Copy of the Arithmetic Carry (bit 29). CC is always the same as bit C. | 0           |
| 1:16 | Reserved |                                                                                                 |             |

Table 2-9: Machine Status Register (MSR) (Cont'd)

| Bits | Name | Description                                                                                                                                                                                                                                                                                                                                                                                                                                            | Reset Value              |
|------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| 17   | VMS  | Virtual Protected Mode Save<br>Only available when configured with an MMU<br>(if C_USE_MMU > 1 and C_AREA_OPTIMIZED = 0 or 2)<br>Read/Write                                                                                                                                                                                                                                                                                                            | 0                        |
| 18   | VM   | Virtual Protected Mode<br>0 = MMU address translation and access protection disabled, with C_USE_MMU = 3 (Virtual). Access protection disabled with C_USE_MMU = 2 (Protection)<br>1 = MMU address translation and access protection enabled, with C_USE_MMU = 3 (Virtual). Access protection enabled, with C_USE_MMU = 2 (Protection).<br>Only available when configured with an MMU<br>(if C_USE_MMU > 1 and C_AREA_OPTIMIZED = 0 or 2)<br>Read/Write | 0                        |
| 19   | UMS  | User Mode Save<br>Only available when configured with an MMU<br>(if C_USE_MMU > 0 and C_AREA_OPTIMIZED = 0 or 2)<br>Read/Write                                                                                                                                                                                                                                                                                                                         | 0                        |
| 20   | UM   | User Mode<br>0 = Privileged Mode, all instructions are allowed<br>1 = User Mode, certain instructions are not allowed<br>Only available when configured with an MMU<br>(if C_USE_MMU > 0 and C_AREA_OPTIMIZED = 0 or 2)<br>Read/Write                                                                                                                                                                                                                  | 0                        |
| 21   | PVR  | Processor Version Register exists<br>0 = No Processor Version Register<br>1 = Processor Version Register exists<br>Read only                                                                                                                                                                                                                                                                                                                           | Based on parameter C_PVR |
| 22   | EIP  | Exception In Progress<br>0 = No hardware exception in progress<br>1 = Hardware exception in progress<br>Only available if configured with exception support<br>(C*_EXCEPTION or C_USE_MMU > 0)<br>Read/Write                                                                                                                                                                                                                                           | 0                        |
| 23   | EE   | Exception Enable<br>0 = Hardware exceptions disabled <sup>1</sup><br>1 = Hardware exceptions enabled<br><br>Only available if configured with exception support<br>(C*_EXCEPTION or C_USE_MMU > 0)<br><br>Read/Write                                                                                                                                                                                                                                   | 0                        |

Table 2-9: Machine Status Register (MSR) (Cont'd)

| Bits | Name | Description                                                                                                                                                                                                                                                                                                                                                | Reset Value |
|------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 24   | DCE  | Data Cache Enable<br>0 = Data Cache disabled<br>1 = Data Cache enabled<br><br>Only available if configured to use data cache<br>(C_USE_DCACHE = 1)<br><br>Read/Write                                                                                                                                                                                       | 0           |
| 25   | DZO  | Division by Zero or Division Overflow <sup>2</sup><br>0 = No division by zero or division overflow has occurred<br>1 = Division by zero or division overflow has occurred<br><br>Only available if configured to use hardware divider<br>(C_USE_DIV = 1)<br><br>Read/Write                                                                                 | 0           |
| 26   | ICE  | Instruction Cache Enable<br>0 = Instruction Cache disabled<br>1 = Instruction Cache enabled<br><br>Only available if configured to use instruction cache<br>(C_USE_ICACHE = 1)<br><br>Read/Write                                                                                                                                                           | 0           |
| 27   | FSL  | AXI4-Stream Error<br>0 = get or getd had no error<br>1 = get or getd control type mismatch<br>This bit is sticky, that is it is set by a get or getd instruction when a control bit mismatch occurs. To clear it an MTS or MSRCLR instruction must be used.<br><br>Only available if configured to use stream links<br>(C_FSL_LINKS > 0)<br><br>Read/Write | 0           |
| 28   | BIP  | Break in Progress<br>0 = No Break in Progress<br>1 = Break in Progress<br>Break Sources can be software break instruction or hardware break from Ext_Brk or Ext_NM_Brk pin.<br>Read/Write                                                                                                                                                                  | 0           |
| 29   | C    | Arithmetic Carry<br>0 = No Carry (Borrow)<br>1 = Carry (No Borrow)<br>Read/Write                                                                                                                                                                                                                                                                           | 0           |

Table 2-9: Machine Status Register (MSR) (Cont'd)

| Bits | Name | Description                                                                         | Reset Value |
|------|------|-------------------------------------------------------------------------------------|-------------|
| 30   | IE   | Interrupt Enable<br>0 = Interrupts disabled<br>1 = Interrupts enabled<br>Read/Write | 0           |
| 31   | -    | Reserved                                                                            | 0           |

1. The MMU exceptions (Data Storage Exception, Instruction Storage Exception, Data TLB Miss Exception, Instruction TLB Miss Exception) cannot be disabled, and are not affected by this bit.
2. This bit is only used for integer divide-by-zero or divide overflow signaling. There is a floating point equivalent in the FSR. The DZO-bit flags divide by zero or divide overflow conditions regardless if the processor is configured with exception handling or not.

## Exception Address Register (EAR)

The Exception Address Register stores the full load/store address that caused the exception for the following:

- An unaligned access exception that specifies the unaligned access data address
- An M\_AXI\_DP exception that specifies the failing AXI4 data access address
- A data storage exception that specifies the (virtual) effective address accessed
- An instruction storage exception that specifies the (virtual) effective address read
- A data TLB miss exception that specifies the (virtual) effective address accessed
- An instruction TLB miss exception that specifies the (virtual) effective address read

The contents of this register is undefined for all other exceptions. When read with the MFS or MFSE instruction, the EAR is specified by setting Sa = 0x0003. The EAR register is illustrated in Figure 2-5 and Table 2-10 provides bit descriptions and reset values.

With extended data addressing is enabled (parameter C\_ADDR\_SIZE > 32), the 32 least significant bits of the register are read with the MFS instruction, and the most significant bits with the MFSE instruction.

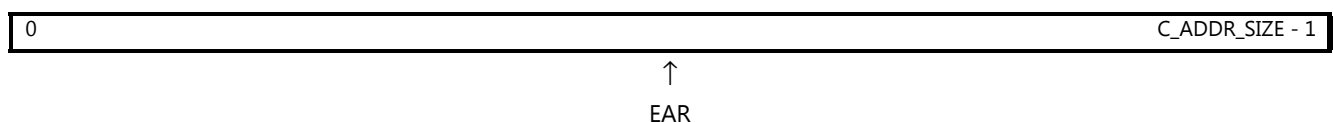


Figure 2-5: EAR

Table 2-10: Exception Address Register (EAR)

| Bits            | Name | Description                | Reset Value |
|-----------------|------|----------------------------|-------------|
| 0:C_ADDR_SIZE-1 | EAR  | Exception Address Register | 0           |



## Exception Status Register (ESR)

The Exception Status Register contains status bits for the processor. When read with the MFS instruction, the ESR is specified by setting Sa = 0x0005. The ESR register is illustrated in [Figure 2-6](#), [Table 2-11](#) provides bit descriptions and reset values, and [Table 2-12](#) provides the Exception Specific Status (ESS).

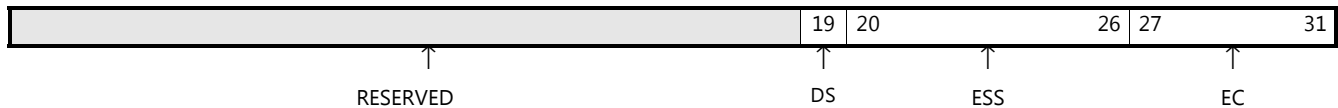


Figure 2-6: ESR

Table 2-11: Exception Status Register (ESR)

| Bits  | Name     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Reset Value                    |
|-------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| 0:18  | Reserved |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                |
| 19    | DS       | Delay Slot Exception.<br>0 = not caused by delay slot instruction<br>1 = caused by delay slot instruction<br>Read-only                                                                                                                                                                                                                                                                                                                                                                                                                           | 0                              |
| 20:26 | ESS      | Exception Specific Status<br>For details refer to <a href="#">Table 2-12</a> .<br>Read-only                                                                                                                                                                                                                                                                                                                                                                                                                                                      | See <a href="#">Table 2-12</a> |
| 27:31 | EC       | Exception Cause<br>00000 = Stream exception<br>00001 = Unaligned data access exception<br>00010 = Illegal op-code exception<br>00011 = Instruction bus error exception<br>00100 = Data bus error exception<br>00101 = Divide exception<br>00110 = Floating point unit exception<br>00111 = Privileged instruction exception<br>00111 = Stack protection violation exception<br>10000 = Data storage exception<br>10001 = Instruction storage exception<br>10010 = Data TLB miss exception<br>10011 = Instruction TLB miss exception<br>Read-only | 0                              |

**Table 2-12: Exception Specific Status (ESS)**

| Exception Cause            | Bits  | Name     | Description                                                                                                              | Reset Value |
|----------------------------|-------|----------|--------------------------------------------------------------------------------------------------------------------------|-------------|
| Unaligned Data Access      | 20    | W        | Word Access Exception<br>0 = unaligned halfword access<br>1 = unaligned word access                                      | 0           |
|                            | 21    | S        | Store Access Exception<br>0 = unaligned load access<br>1 = unaligned store access                                        | 0           |
|                            | 22:26 | Rx       | Source/Destination Register<br>General purpose register used as source (Store) or destination (Load) in unaligned access | 0           |
| Illegal Instruction        | 20:26 | Reserved |                                                                                                                          | 0           |
| Instruction bus error      | 20    | ECC      | Exception caused by ILMB correctable or uncorrectable error                                                              | 0           |
|                            | 21:26 | Reserved |                                                                                                                          | 0           |
| Data bus error             | 20    | ECC      | Exception caused by DLMB correctable or uncorrectable error                                                              | 0           |
|                            | 21:26 | Reserved |                                                                                                                          | 0           |
| Divide                     | 20    | DEC      | Divide - Division exception cause<br>0 = Divide-By-Zero<br>1 = Division Overflow                                         | 0           |
|                            | 21:26 | Reserved |                                                                                                                          | 0           |
| Floating point unit        | 20:26 | Reserved |                                                                                                                          | 0           |
| Privileged instruction     | 20:26 | Reserved |                                                                                                                          | 0           |
| Stack protection violation | 20:26 | Reserved |                                                                                                                          | 0           |
| Stream                     | 20:22 | Reserved |                                                                                                                          | 0           |
|                            | 23:26 | FSL      | AXI4-Stream index that caused the exception                                                                              | 0           |
| Data storage               | 20    | DIZ      | Data storage - Zone protection<br>0 = Did not occur<br>1 = Occurred                                                      | 0           |
|                            | 21    | S        | Data storage - Store instruction<br>0 = Did not occur<br>1 = Occurred                                                    | 0           |
|                            | 22:26 | Reserved |                                                                                                                          | 0           |
| Instruction storage        | 20    | DIZ      | Instruction storage - Zone protection<br>0 = Did not occur<br>1 = Occurred                                               | 0           |
|                            | 21:26 | Reserved |                                                                                                                          | 0           |

Table 2-12: Exception Specific Status (ESS) (Cont'd)

| Exception Cause      | Bits  | Name     | Description                                                            | Reset Value |
|----------------------|-------|----------|------------------------------------------------------------------------|-------------|
| Data TLB miss        | 20    | Reserved |                                                                        | 0           |
|                      | 21    | S        | Data TLB miss - Store instruction<br>0 = Did not occur<br>1 = Occurred | 0           |
|                      | 22:26 | Reserved |                                                                        | 0           |
| Instruction TLB miss | 20:26 | Reserved |                                                                        | 0           |

## Branch Target Register (BTR)

The Branch Target Register only exists if the MicroBlaze processor is configured to use exceptions. The register stores the branch target address for all delay slot branch instructions executed while MSR[EIP] = 0. If an exception is caused by an instruction in a delay slot (that is, ESR[DS]=1), the exception handler should return execution to the address stored in BTR instead of the normal exception return address stored in R17. When read with the MFS instruction, the BTR is specified by setting Sa = 0x000B. The BTR register is illustrated in Figure 2-7 and Table 2-13 provides bit descriptions and reset values.

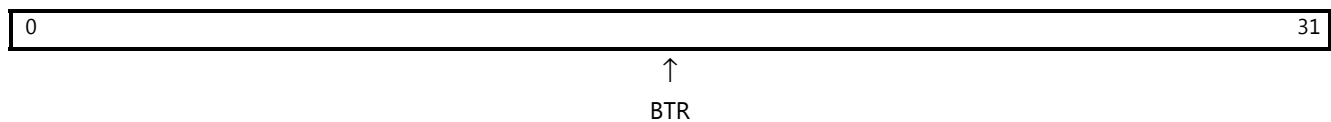


Figure 2-7: BTR

Table 2-13: Branch Target Register (BTR)

| Bits | Name | Description                                                                                                                   | Reset Value |
|------|------|-------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:31 | BTR  | Branch target address used by handler when returning from an exception caused by an instruction in a delay slot.<br>Read-only | 0x00000000  |

## Floating Point Status Register (FSR)

The Floating Point Status Register contains status bits for the floating point unit. It can be read with an MFS, and written with an MTS instruction. When read or written, the register is specified by setting Sa = 0x0007. The bits in this register are sticky – floating point instructions can only set bits in the register, and the only way to clear the register is by

using the MTS instruction. Figure 2-8 illustrates the FSR register and Table 2-14 provides bit descriptions and reset values.

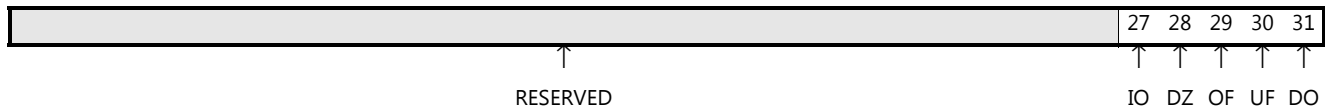


Figure 2-8: FSR

Table 2-14: Floating Point Status Register (FSR)

| Bits | Name     | Description                | Reset Value |
|------|----------|----------------------------|-------------|
| 0:26 | Reserved |                            | undefined   |
| 27   | IO       | Invalid operation          | 0           |
| 28   | DZ       | Divide-by-zero             | 0           |
| 29   | OF       | Overflow                   | 0           |
| 30   | UF       | Underflow                  | 0           |
| 31   | DO       | Denormalized operand error | 0           |

## Exception Data Register (EDR)

The Exception Data Register stores data read on an AXI4-Stream link that caused a stream exception.

The contents of this register is undefined for all other exceptions. When read with the MFS instruction, the EDR is specified by setting Sa = 0x000D. Figure 2-9 illustrates the EDR register and Table 2-15 provides bit descriptions and reset values.

**Note:** The register is only implemented if C\_FSL\_LINKS is greater than 0 and C\_FSL\_EXCEPTION is set to 1.

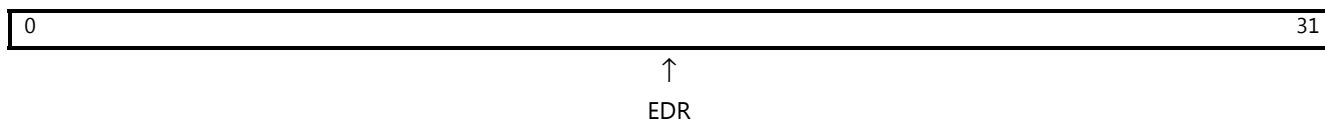


Figure 2-9: EDR

Table 2-15: Exception Data Register (EDR)

| Bits | Name | Description             | Reset Value |
|------|------|-------------------------|-------------|
| 0:31 | EDR  | Exception Data Register | 0x00000000  |

## Stack Low Register (SLR)

The Stack Low Register stores the stack low limit use to detect stack overflow. When the address of a load or store instruction using the stack pointer (register R1) as rA is less than

the Stack Low Register, a stack overflow occurs, causing a Stack Protection Violation exception if exceptions are enabled in MSR.

When read with the MFS instruction, the SLR is specified by setting Sa = 0x0800.

Figure 2-10 illustrates the SLR register and Table 2-16 provides bit descriptions and reset values.

**Note:** The register is only implemented if stack protection is enabled by setting the parameter C\_USE\_STACK\_PROTECTION to 1. If stack protection is not implemented, writing to the register has no effect.

**Note:** Stack protection is not available when the MMU is enabled (C\_USE\_MMU > 0). With the MMU page-based memory protection is provided through the UTLB instead.

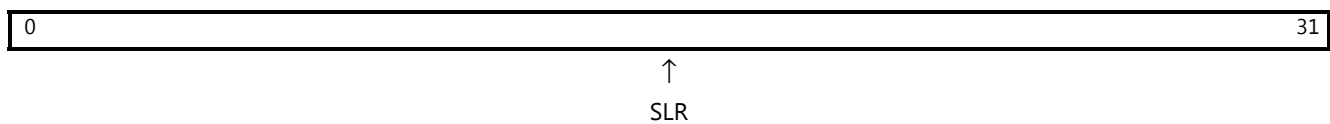


Figure 2-10: SLR

Table 2-16: Stack Low Register (SLR)

| Bits | Name | Description        | Reset Value |
|------|------|--------------------|-------------|
| 0:31 | SLR  | Stack Low Register | 0x00000000  |

## Stack High Register (SHR)

The Stack High Register stores the stack high limit use to detect stack underflow. When the address of a load or store instruction using the stack pointer (register R1) as rA is greater than the Stack High Register, a stack underflow occurs, causing a Stack Protection Violation exception if exceptions are enabled in MSR.

When read with the MFS instruction, the SHR is specified by setting Sa = 0x0802.

Figure 2-11 illustrates the SHR register and Table 2-17 provides bit descriptions and reset values.

**Note:** The register is only implemented if stack protection is enabled by setting the parameter C\_USE\_STACK\_PROTECTION to 1. If stack protection is not implemented, writing to the register has no effect.

**Note:** Stack protection is not available when the MMU is enabled (C\_USE\_MMU > 0). With the MMU page-based memory protection is provided through the UTLB instead.

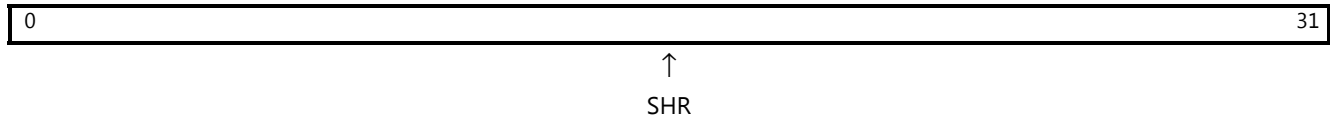


Figure 2-11: SHR

Table 2-17: Stack High Register (SHR)

| Bits | Name | Description         | Reset Value |
|------|------|---------------------|-------------|
| 0:31 | SHR  | Stack High Register | 0xFFFFFFFF  |

## Process Identifier Register (PID)

The Process Identifier Register is used to uniquely identify a software process during MMU address translation. It is controlled by the `C_USE_MMU` configuration option on MicroBlaze. The register is only implemented if `C_USE_MMU` is greater than 1 (User Mode) and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency). When accessed with the MFS and MTS instructions, the PID is specified by setting `Sa = 0x1000`. The register is accessible according to the memory management special registers parameter `C_MMU_TLB_ACCESS`.

PID is also used when accessing a TLB entry:

- When writing Translation Look-Aside Buffer High (TLBHI) the value of PID is stored in the TID field of the TLB entry
- When reading TLBHI and `MSR[UM]` is not set, the value in the TID field is stored in PID

Figure 2-12 illustrates the PID register and Table 2-18 provides bit descriptions and reset values.

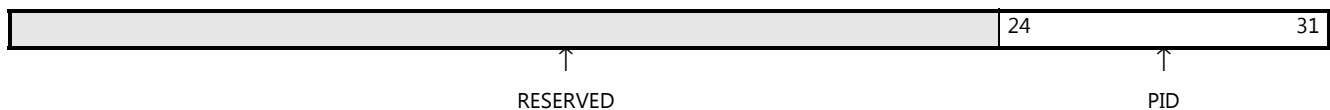


Figure 2-12: PID

Table 2-18: Process Identifier Register (PID)

| Bits  | Name     | Description                                                                                | Reset Value |
|-------|----------|--------------------------------------------------------------------------------------------|-------------|
| 0:23  | Reserved |                                                                                            |             |
| 24:31 | PID      | Used to uniquely identify a software process during MMU address translation.<br>Read/Write | 0x00        |

## Zone Protection Register (ZPR)

The Zone Protection Register is used to override MMU memory protection defined in TLB entries. It is controlled by the `C_USE_MMU` configuration option on MicroBlaze. The register is only implemented if `C_USE_MMU` is greater than 1 (User Mode), `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency), and if the number of specified memory protection zones is greater than zero (`C_MMU_ZONES > 0`). The implemented register bits depend on the number of specified memory protection zones (`C_MMU_ZONES`). When accessed with the MFS and MTS instructions, the ZPR is specified by setting `Sa = 0x1001`. The register is accessible according to the memory management special registers parameter `C_MMU_TLB_ACCESS`.

Figure 2-13 illustrates the ZPR register and Table 2-19 provides bit descriptions and reset values.

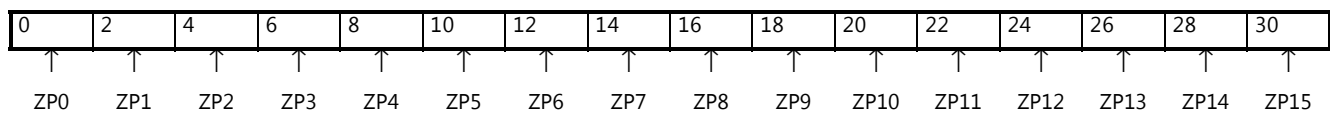


Figure 2-13: ZPR

Table 2-19: Zone Protection Register (ZPR)

| Bits  | Name | Description                                                                      | Reset Value |
|-------|------|----------------------------------------------------------------------------------|-------------|
| 0:1   | ZP0  | Zone Protect                                                                     | 0x00000000  |
| 2:3   | ZP1  | <u>User mode (MSR[UM] = 1):</u>                                                  |             |
| ...   | ...  | 00 = Override V in TLB entry. No access to the page is allowed                   |             |
| 30:31 | ZP15 | 01 = No override. Use V, WR and EX from TLB entry                                |             |
|       |      | 10 = No override. Use V, WR and EX from TLB entry                                |             |
|       |      | 11 = Override WR and EX in TLB entry. Access the page as writable and executable |             |
|       |      | <u>Privileged mode (MSR[UM] = 0):</u>                                            |             |
|       |      | 00 = No override. Use V, WR and EX from TLB entry                                |             |
|       |      | 01 = No override. Use V, WR and EX from TLB entry                                |             |
|       |      | 10 = Override WR and EX in TLB entry. Access the page as writable and executable |             |
|       |      | 11 = Override WR and EX in TLB entry. Access the page as writable and executable |             |
|       |      | Read/Write                                                                       |             |

## Translation Look-Aside Buffer Low Register (TLBLO)

The Translation Look-Aside Buffer Low Register is used to access MMU Unified Translation Look-Aside Buffer (UTLB) entries. It is controlled by the `C_USE_MMU` configuration option on MicroBlaze. The register is only implemented if `C_USE_MMU` is greater than 1 (User Mode), and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency). When accessed with the MFS and MTS instructions, the TLBLO is specified by setting `Sa = 0x1003`. When reading or writing TLBLO, the UTLB entry indexed by the TLBX register is accessed. The register is

readable according to the memory management special registers parameter

C\_MMU\_TLB\_ACCESS.

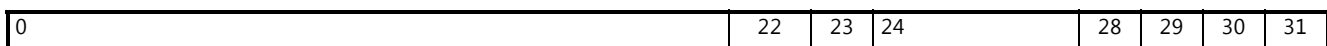
When the MMU Physical Address Extension (PAE) is enabled (parameters C\_USE\_MMU = 3 and C\_ADDR\_SIZE > 32), the 32 least significant bits of TLBLO are accessed with the MFS and MTS instructions, and the most significant bits with the MFSE and MTSE instruction. When writing the register with PAE enabled, the most significant bits must be written first.

The UTLB is reset on bit stream download (reset value is 0x00000000 for all TLBLO entries).

**Note:** The UTLB is **not** reset by the external reset inputs: Reset and Debug\_Rst. This means that the entire UTLB must be initialized after reset, to avoid any stale data.

Figure 2-14 illustrates the TLBLO register and Table 2-20 provides bit descriptions and reset values. When PAE is enabled the RPN field of the register is extended according to the C\_ADDR\_SIZE parameter up to 54 bits to be able to hold up to a 64-bit physical address.

C\_ADDR\_SIZE = 32 or C\_USE\_MMU ≠ 3:



PAE: C\_ADDR\_SIZE > 32 and C\_USE\_MMU = 3 (n = C\_ADDR\_SIZE):

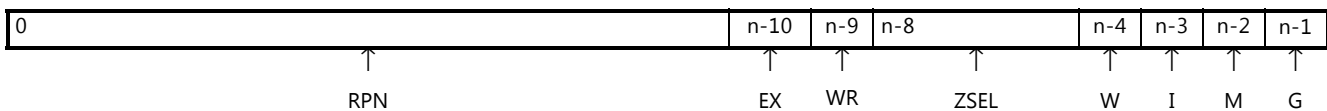


Figure 2-14: TLBLO

Table 2-20: Translation Look-Aside Buffer Low Register (TLBLO)

| Bits <sup>1</sup> | Name | Description                                                                                                                                                                                                                                                                                                                                                              | Reset Value |
|-------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:21<br>0:n-11    | RPN  | Real Page Number or Physical Page Number<br>When a TLB hit occurs, this field is read from the TLB entry and is used to form the physical address. Depending on the value of the SIZE field, some of the RPN bits are not used in the physical address. Software must clear unused bits in this field to zero.<br>Only defined when C_USE_MMU=3 (Virtual).<br>Read/Write | 0x000000    |
| 22<br>n-10        | EX   | Executable<br>When bit is set to 1, the page contains executable code, and instructions can be fetched from the page. When bit is cleared to 0, instructions cannot be fetched from the page. Attempts to fetch instructions from a page with a clear EX bit cause an instruction-storage exception.<br>Read/Write                                                       | 0           |



**Table 2-20: Translation Look-Aside Buffer Low Register (TLBLO) (Cont'd)**

| Bits <sup>1</sup> | Name | Description                                                                                                                                                                                                                                                                                                                                                                                       | Reset Value |
|-------------------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 23<br>n-9         | WR   | <p>Writable</p> <p>When bit is set to 1, the page is writable and store instructions can be used to store data at addresses within the page.</p> <p>When bit is cleared to 0, the page is read-only (not writable). Attempts to store data into a page with a clear WR bit cause a data storage exception.</p> <p>Read/Write</p>                                                                  | 0           |
| 24:27<br>n-8:n-5  | ZSEL | <p>Zone Select</p> <p>This field selects one of 16 zone fields (Z0-Z15) from the zone-protection register (ZPR).</p> <p>For example, if ZSEL 0x5, zone field Z5 is selected. The selected ZPR field is used to modify the access protection specified by the TLB entry EX and WR fields. It is also used to prevent access to a page by overriding the TLB V (valid) field.</p> <p>Read/Write</p> | 0x0         |
| 28<br>n-4         | W    | <p>Write Through</p> <p>When the parameter C_DCACHE_USE_WRITEBACK is set to 1, this bit controls caching policy. A write-through policy is selected when set to 1, and a write-back policy is selected otherwise.</p> <p>This bit is fixed to 1, and write-through is always used, when C_DCACHE_USE_WRITEBACK is cleared to 0.</p> <p>Read/Write</p>                                             | 0/1         |
| 29<br>n-3         | I    | <p>Inhibit Caching</p> <p>When bit is set to 1, accesses to the page are not cached (caching is inhibited).</p> <p>When cleared to 0, accesses to the page are cacheable.</p> <p>Read/Write</p>                                                                                                                                                                                                   | 0           |
| 30<br>n-2         | M    | <p>Memory Coherent</p> <p>This bit is fixed to 0, because memory coherence is not implemented on MicroBlaze.</p> <p>Read Only</p>                                                                                                                                                                                                                                                                 | 0           |
| 31<br>n-1         | G    | <p>Guarded</p> <p>When bit is set to 1, speculative page accesses are not allowed (memory is guarded).</p> <p>When cleared to 0, speculative page accesses are allowed.</p> <p>The G attribute can be used to protect memory-mapped I/O devices from inappropriate instruction accesses.</p> <p>Read/Write</p>                                                                                    | 0           |

1. The bit index n = C\_ADDR\_SIZE applies when PAE is enabled.

## Translation Look-Aside Buffer High Register (TLBHI)

The Translation Look-Aside Buffer High Register is used to access MMU Unified Translation Look-Aside Buffer (UTLB) entries. It is controlled by the C\_USE\_MMU configuration option on MicroBlaze. The register is only implemented if C\_USE\_MMU is greater than 1 (User Mode),

and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency). When accessed with the MFS and MTS instructions, the TLBHI is specified by setting `Sa = 0x1004`. When reading or writing TLBHI, the UTLB entry indexed by the TLBX register is accessed. The register is readable according to the memory management special registers parameter `C_MMU_TLB_ACCESS`.

PID is also used when accessing a TLB entry:

- When writing TLBHI the value of PID is stored in the TID field of the TLB entry
- When reading TLBHI and `MSR[UM]` is not set, the value in the TID field is stored in PID

The UTLB is reset on bit stream download (reset value is 0x00000000 for all TLBHI entries).

**Note:** The UTLB is **not** reset by the external reset inputs: `Reset` and `Debug_Rst`.

Figure 2-15 illustrates the TLBHI register and Table 2-21 provides bit descriptions and reset values.

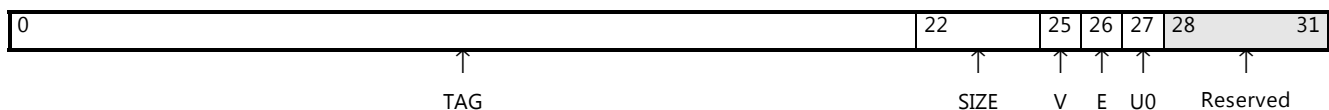


Figure 2-15: TLBHI

Table 2-21: Translation Look-Aside Buffer High Register (TLBHI)

| Bits  | Name | Description                                                                                                                                                                                                                                     | Reset Value |
|-------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:21  | TAG  | TLB-entry tag<br>Is compared with the page number portion of the virtual memory address under the control of the SIZE field.<br>Read/Write                                                                                                      | 0x000000    |
| 22:24 | SIZE | Size<br>Specifies the page size. The SIZE field controls the bit range used in comparing the TAG field with the page number portion of the virtual memory address. The page sizes defined by this field are listed in Table 2-37.<br>Read/Write | 000         |
| 25    | V    | Valid<br>When this bit is set to 1, the TLB entry is valid and contains a page-translation entry.<br>When cleared to 0, the TLB entry is invalid.<br>Read/Write                                                                                 | 0           |

Table 2-21: Translation Look-Aside Buffer High Register (TLBHI) (Cont'd) (Cont'd)

| Bits  | Name     | Description                                                                                                                                                                                                                                                                                                                                                                                               | Reset Value |
|-------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 26    | E        | <p>Endian</p> <p>When this bit is set to 1, the page is accessed as a big endian page. When cleared to 0, the page is accessed as a little endian page.</p> <p>The E bit only affects data read or data write accesses. Instruction accesses are not affected.</p> <p>The E bit is only implemented when the parameter C_USE_REORDER_INSTR is set to 1, otherwise it is fixed to 0.</p> <p>Read/Write</p> | 0           |
| 27    | U0       | <p>User Defined</p> <p>This bit is fixed to 0, since there are no user defined storage attributes on MicroBlaze.</p> <p>Read Only</p>                                                                                                                                                                                                                                                                     | 0           |
| 28:31 | Reserved |                                                                                                                                                                                                                                                                                                                                                                                                           |             |

## Translation Look-Aside Buffer Index Register (TLBX)

The Translation Look-Aside Buffer Index Register is used as an index to the Unified Translation Look-Aside Buffer (UTLB) when accessing the TLBLO and TLBHI registers. It is controlled by the C\_USE\_MMU configuration option on MicroBlaze. The register is only implemented if C\_USE\_MMU is greater than 1 (User Mode), and C\_AREA\_OPTIMIZED is set to 0 (Performance) or 2 (Frequency). When accessed with the MFS and MTS instructions, the TLBX is specified by setting Sa = 0x1002. Figure 2-16 illustrates the TLBX register and Table 2-22 provides bit descriptions and reset values.



Figure 2-16: TLBX

Table 2-22: Translation Look-Aside Buffer Index Register (TLBX)

| Bits | Name | Description                                                                                                                                                                                                                                                                                                                                                                                                   | Reset Value |
|------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0    | MISS | <p>TLB Miss</p> <p>This bit is cleared to 0 when the TLBSX register is written with a virtual address, and the virtual address is found in a TLB entry. The bit is set to 1 if the virtual address is not found. It is also cleared when the TLBX register itself is written.</p> <p>Read Only</p> <p>Can be read if the memory management special registers parameter C_MMU_TLB_ACCESS &gt; 0 (MINIMAL).</p> | 0           |

Table 2-22: Translation Look-Aside Buffer Index Register (TLBX) (Cont'd)

| Bits  | Name     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Reset Value |
|-------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 1:25  | Reserved |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |             |
| 26:31 | INDEX    | <p>TLB Index</p> <p>This field is used to index the Translation Look-Aside Buffer entry accessed by the TLBLO and TLBHI registers. The field is updated with a TLB index when the TLBSX register is written with a virtual address, and the virtual address is found in the corresponding TLB entry.</p> <p>Read/Write</p> <p>Can be read and written if the memory management special registers parameter <code>C_MMU_TLB_ACCESS &gt; 0</code> (MINIMAL).</p> | 000000      |

## Translation Look-Aside Buffer Search Index Register (TLBSX)

The Translation Look-Aside Buffer Search Index Register is used to search for a virtual page number in the Unified Translation Look-Aside Buffer (UTLB). It is controlled by the `C_USE_MMU` configuration option on MicroBlaze. The register is only implemented if `C_USE_MMU` is greater than 1 (User Mode), and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency). When written with the MTS instruction, the TLBSX is specified by setting `Sa = 0x1005`. Figure 2-17 illustrates the TLBSX register and Table 2-23 provides bit descriptions and reset values.

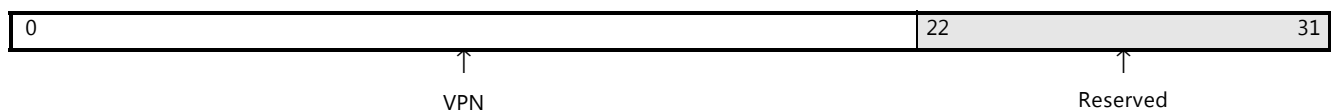


Figure 2-17: TLBSX

Table 2-23: Translation Look-Aside Buffer Index Search Register (TLBSX)

| Bits  | Name     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Reset Value |
|-------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 0:21  | VPN      | <p>Virtual Page Number</p> <p>This field represents the page number portion of the virtual memory address. It is compared with the page number portion of the virtual memory address under the control of the SIZE field, in each of the Translation Look-Aside Buffer entries that have the V bit set to 1.</p> <p>If the virtual page number is found, the TLBX register is written with the index of the TLB entry and the MISS bit in TLBX is cleared to 0. If the virtual page number is not found in any of the TLB entries, the MISS bit in the TLBX register is set to 1.</p> <p>Write Only</p> |             |
| 22:31 | Reserved |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |

## Processor Version Register (PVR)

The Processor Version Register is controlled by the C\_PVR configuration option on MicroBlaze.

- When C\_PVR is set to 0 (None) the processor does not implement any PVR and MSR[PVR]=0.
- When C\_PVR is set to 1 (Basic), MicroBlaze implements only the first register: PVR0, and if set to 2 (Full), all 13 PVR registers (PVR0 to PVR12) are implemented.

When read with the MFS or MFSE instruction the PVR is specified by setting Sa = 0x200x, with x being the register number between 0x0 and 0xB.

With extended data addressing is enabled (parameter C\_ADDR\_SIZE > 32), the 32 least significant bits of PVR8 and PVR9 are read with the MFS instruction, and the most significant bits with the MFSE instruction. When Physical Address Extension (PAE) is enabled (parameters C\_USE\_MMU = 3 and C\_ADDR\_SIZE > 32), the 32 least significant bits of PVR6 and PVR7 are read with the MFS instruction, and the most significant bits with the MFSE instruction.

Table 2-24 through Table 2-35 provide bit descriptions and values.

Table 2-24: Processor Version Register 0 (PVR0)

| Bits  | Name     | Description                                      | Value                                                      |
|-------|----------|--------------------------------------------------|------------------------------------------------------------|
| 0     | CFG      | PVR implementation:<br>0 = Basic, 1 = Full       | Based on C_PVR                                             |
| 1     | BS       | Use barrel shifter                               | C_USE_BARREL                                               |
| 2     | DIV      | Use divider                                      | C_USE_DIV                                                  |
| 3     | MUL      | Use hardware multiplier                          | C_USE_HW_MUL > 0 (None)                                    |
| 4     | FPU      | Use FPU                                          | C_USE_FPU > 0 (None)                                       |
| 5     | EXC      | Use any type of exceptions                       | Based on C_*_EXCEPTION<br>Also set if C_USE_MMU > 0 (None) |
| 6     | ICU      | Use instruction cache                            | C_USE_ICACHE                                               |
| 7     | DCU      | Use data cache                                   | C_USE_DCACHE                                               |
| 8     | MMU      | Use MMU                                          | C_USE_MMU > 0 (None)                                       |
| 9     | BTC      | Use branch target cache                          | C_USE_BRANCH_TARGET_CACHE                                  |
| 10    | ENDI     | Selected endianness:<br>Always 1 = Little endian | C_ENDIANNES                                                |
| 11    | FT       | Implement fault tolerant features                | C_FAULT_TOLERANT                                           |
| 12    | SPROT    | Use stack protection                             | C_USE_STACK_PROTECTION                                     |
| 13    | REORD    | Implement reorder instructions                   | C_USE_REORDER_INSTR                                        |
| 14:15 | Reserved |                                                  | 0                                                          |

Table 2-24: Processor Version Register 0 (PVR0) (Cont'd)

| Bits  | Name | Description                                                                                                                                                                                    | Value            |
|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 16:23 | MBV  | MicroBlaze release version code<br>0x19 = v8.40.b      0x21 = v9.4<br>0x1B = v9.0          0x22 = v9.5<br>0x1D = v9.1          0x23 = v9.6<br>0x1F = v9.2          0x24 = v10.0<br>0x20 = v9.3 | Release Specific |
| 24:31 | USR1 | User configured value 1                                                                                                                                                                        | C_PVR_USER1      |

Table 2-25: Processor Version Register 1 (PVR1)

| Bits | Name | Description             | Value       |
|------|------|-------------------------|-------------|
| 0:31 | USR2 | User configured value 2 | C_PVR_USER2 |

Table 2-26: Processor Version Register 2 (PVR2)

| Bits | Name     | Description                                                                         | Value                          |
|------|----------|-------------------------------------------------------------------------------------|--------------------------------|
| 0    | DAXI     | Data side AXI4 or ACE in use                                                        | C_D_AXI                        |
| 1    | DLMB     | Data side LMB in use                                                                | C_D_LMB                        |
| 2    | IAXI     | Instruction side AXI4 or ACE in use                                                 | C_I_AXI                        |
| 3    | ILMB     | Instruction side LMB in use                                                         | C_I_LMB                        |
| 4    | IRQEDGE  | Interrupt is edge triggered                                                         | C_INTERRUPT_IS_EDGE            |
| 5    | IRQPOS   | Interrupt edge is positive                                                          | C_EDGE_IS_POSITIVE             |
| 6    | CEEXC    | Generate bus exceptions for ECC correctable errors in LMB memory                    | C_ECC_USE_CE_EXCEPTION         |
| 7    | FREQ     | Select implementation to optimize processor frequency                               | C_AREA_OPTIMIZED=2 (Frequency) |
| 8    | Reserved |                                                                                     | 0                              |
| 9    | Reserved |                                                                                     | 1                              |
| 10   | ACE      | Use ACE interconnect                                                                | C_INTERCONNECT = 3 (ACE)       |
| 11   | AXI4DP   | Data Peripheral AXI interface uses AXI4 protocol, with support for exclusive access | C_M_AXI_DP_EXCLUSIVE_ACCESS    |
| 12   | FSL      | Use extended AXI4-Stream instructions                                               | C_USE_EXTENDED_FSL_INSTR       |
| 13   | FSLEXC   | Generate exception for AXI4-Stream control bit mismatch                             | C_FSL_EXCEPTION                |
| 14   | MSR      | Use mrsrset and mrsclr instructions                                                 | C_USE_MSR_INSTR                |
| 15   | PCMP     | Use pattern compare and CLZ instructions                                            | C_USE_PCMP_INSTR               |
| 16   | AREA     | Select implementation to optimize area with lower instruction throughput            | C_AREA_OPTIMIZED = 1 (Area)    |
| 17   | BS       | Use barrel shifter                                                                  | C_USE_BARREL                   |

Table 2-26: Processor Version Register 2 (PVR2) (Cont'd)

| Bits | Name     | Description                                                  | Value                    |
|------|----------|--------------------------------------------------------------|--------------------------|
| 18   | DIV      | Use divider                                                  | C_USE_DIV                |
| 19   | MUL      | Use hardware multiplier                                      | C_USE_HW_MUL > 0 (None)  |
| 20   | FPU      | Use FPU                                                      | C_USE_FPU > 0 (None)     |
| 21   | MUL64    | Use 64-bit hardware multiplier                               | C_USE_HW_MUL = 2 (Mul64) |
| 22   | FPU2     | Use floating point conversion and square root instructions   | C_USE_FPU = 2 (Extended) |
| 23   | IMPEXC   | Allow imprecise exceptions for ECC errors in LMB memory      | C_IMPRECISE_EXCEPTIONS   |
| 24   | Reserved |                                                              | 0                        |
| 25   | OP0EXC   | Generate exception for 0x0 illegal opcode                    | C_OPCODE_0x0_ILLEGAL     |
| 26   | UNEXC    | Generate exception for unaligned data access                 | C_UNALIGNED_EXCEPTIONS   |
| 27   | OPEXC    | Generate exception for any illegal opcode                    | C_ILL_OPCODE_EXCEPTION   |
| 28   | AXIDEXC  | Generate exception for M_AXI_D error                         | C_M_AXI_D_BUS_EXCEPTION  |
| 29   | AXIEXC   | Generate exception for M_AXI_I error                         | C_M_AXI_I_BUS_EXCEPTION  |
| 30   | DIVEXC   | Generate exception for division by zero or division overflow | C_DIV_ZERO_EXCEPTION     |
| 31   | FPUEXC   | Generate exceptions from FPU                                 | C_FPU_EXCEPTION          |

Table 2-27: Processor Version Register 3 (PVR3)

| Bits  | Name      | Description                         | Value                          |
|-------|-----------|-------------------------------------|--------------------------------|
| 0     | DEBUG     | Use debug logic                     | C_DEBUG_ENABLED > 0            |
| 1     | EXT_DEBUG | Use extended debug logic            | C_DEBUG_ENABLED = 2 (Extended) |
| 2     | Reserved  |                                     |                                |
| 3:6   | PCBRK     | Number of PC breakpoints            | C_NUMBER_OF_PC_BRK             |
| 7:9   | Reserved  |                                     |                                |
| 10:12 | RDADDR    | Number of read address breakpoints  | C_NUMBER_OF_RD_ADDR_BRK        |
| 13:15 | Reserved  |                                     |                                |
| 16:18 | WRADDR    | Number of write address breakpoints | C_NUMBER_OF_WR_ADDR_BRK        |
| 19    | Reserved  |                                     | 0                              |
| 20:24 | FSL       | Number of AXI4-Stream links         | C_FSL_LINKS                    |
| 25:28 | Reserved  |                                     |                                |
| 29:31 | BTC_SIZE  | Branch Target Cache size            | C_BRANCH_TARGET_CACHE_SIZE     |

**Table 2-28: Processor Version Register 4 (PVR4)**

| Bits  | Name     | Description                                                                      | Value                           |
|-------|----------|----------------------------------------------------------------------------------|---------------------------------|
| 0     | ICU      | Use instruction cache                                                            | C_USE_ICACHE                    |
| 1:5   | ICTS     | Instruction cache tag size                                                       | C_ADDR_TAG_BITS                 |
| 6     | Reserved |                                                                                  | 1                               |
| 7     | ICW      | Allow instruction cache write                                                    | C_ALLOW_ICACHE_WR               |
| 8:10  | ICLL     | The base two logarithm of the instruction cache line length                      | $\log_2(C\_ICACHE\_LINE\_LEN)$  |
| 11:15 | ICBS     | The base two logarithm of the instruction cache byte size                        | $\log_2(C\_CACHE\_BYTE\_SIZE)$  |
| 16    | IAU      | The instruction cache is used for all memory accesses within the cacheable range | C_ICACHE_ALWAYS_USED            |
| 17:18 | Reserved |                                                                                  | 0                               |
| 19:21 | ICV      | Instruction cache victims                                                        | 0-3: C_ICACHE_VICTIMS = 0,2,4,8 |
| 22:23 | ICS      | Instruction cache streams                                                        | C_ICACHE_STREAMS                |
| 24    | IFTL     | Instruction cache tag uses distributed RAM                                       | C_ICACHE_FORCE_TAG_LUTRAM       |
| 25    | ICDW     | Instruction cache data width                                                     | C_ICACHE_DATA_WIDTH > 0         |
| 26:31 | Reserved |                                                                                  | 0                               |

**Table 2-29: Processor Version Register 5 (PVR5)**

| Bits  | Name     | Description                                                               | Value                           |
|-------|----------|---------------------------------------------------------------------------|---------------------------------|
| 0     | DCU      | Use data cache                                                            | C_USE_DCACHE                    |
| 1:5   | DCTS     | Data cache tag size                                                       | C_DCACHE_ADDR_TAG               |
| 6     | Reserved |                                                                           | 1                               |
| 7     | DCW      | Allow data cache write                                                    | C_ALLOW_DCACHE_WR               |
| 8:10  | DCLL     | The base two logarithm of the data cache line length                      | $\log_2(C\_DCACHE\_LINE\_LEN)$  |
| 11:15 | DCBS     | The base two logarithm of the data cache byte size                        | $\log_2(C\_DCACHE\_BYTE\_SIZE)$ |
| 16    | DAU      | The data cache is used for all memory accesses within the cacheable range | C_DCACHE_ALWAYS_USED            |
| 17    | DWB      | Data cache policy is write-back                                           | C_DCACHE_USE_WRITEBACK          |
| 18    | Reserved |                                                                           | 0                               |
| 19:21 | DCV      | Data cache victims                                                        | 0-3: C_DCACHE_VICTIMS = 0,2,4,8 |
| 22:23 | Reserved |                                                                           | 0                               |
| 24    | DFTL     | Data cache tag uses distributed RAM                                       | C_DCACHE_FORCE_TAG_LUTRAM       |



Table 2-29: Processor Version Register 5 (PVR5) (Cont'd)

| Bits  | Name     | Description                                                                    | Value                       |
|-------|----------|--------------------------------------------------------------------------------|-----------------------------|
| 25    | DCDW     | Data cache data width                                                          | C_DCACHE_DATA_WIDTH > 0     |
| 26    | AXI4DC   | Data Cache AXI interface uses AXI4 protocol, with support for exclusive access | C_M_AXI_DC_EXCLUSIVE_ACCESS |
| 27:31 | Reserved |                                                                                | 0                           |

Table 2-30: Processor Version Register 6 (PVR6)

| Bits            | Name | Description                    | Value             |
|-----------------|------|--------------------------------|-------------------|
| 0:C_ADDR_SIZE-1 | ICBA | Instruction Cache Base Address | C_ICACHE_BASEADDR |

Table 2-31: Processor Version Register 7 (PVR7)

| Bits            | Name | Description                    | Value             |
|-----------------|------|--------------------------------|-------------------|
| 0:C_ADDR_SIZE-1 | ICHA | Instruction Cache High Address | C_ICACHE_HIGHADDR |

Table 2-32: Processor Version Register 8 (PVR8)

| Bits            | Name | Description             | Value             |
|-----------------|------|-------------------------|-------------------|
| 0:C_ADDR_SIZE-1 | DCBA | Data Cache Base Address | C_DCACHE_BASEADDR |

Table 2-33: Processor Version Register 9 (PVR9)

| Bits            | Name | Description             | Value             |
|-----------------|------|-------------------------|-------------------|
| 0:C_ADDR_SIZE-1 | DCHA | Data Cache High Address | C_DCACHE_HIGHADDR |

Table 2-34: Processor Version Register 10 (PVR10)

| Bits  | Name     | Description                                                                                                                                                                                                                                                                                                                                                                                                               | Value                         |
|-------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| 0:7   | ARCH     | Target architecture:<br>0xF = Virtex®-7, Defense Grade Virtex-7 Q<br>0x10 = Kintex®-7, Defense Grade Kintex-7 Q<br>0x11 = Artix®-7, Automotive Artix-7, Defense Grade Artix-7 Q<br>0x12 = Zynq®-7000, Automotive Zynq-7000, Defense Grade Zynq-7000 Q<br>0x13 = UltraScale™ Virtex<br>0x14 = UltraScale Kintex<br>0x15 = UltraScale+™ Zynq<br>0x16 = UltraScale+ Virtex<br>0x17 = UltraScale+ Kintex<br>0x18 = Spartan®-7 | Defined by parameter C_FAMILY |
| 8:13  | ASIZE    | Number of extended address bits                                                                                                                                                                                                                                                                                                                                                                                           | C_ADDR_SIZE - 32              |
| 14:31 | Reserved |                                                                                                                                                                                                                                                                                                                                                                                                                           | 0                             |

Table 2-35: Processor Version Register 11 (PVR11)

| Bits  | Name     | Description                                                                                              | Value                                                                                                                                                 |
|-------|----------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0:1   | MMU      | Use MMU:<br>0 = None                      2 = Protection<br>1 = User Mode                3 = Virtual     | C_USE_MMU                                                                                                                                             |
| 2:4   | ITLB     | Instruction Shadow TLB size                                                                              | $\log_2(C\_MMU\_ITLB\_SIZE)$                                                                                                                          |
| 5:7   | DTLB     | Data Shadow TLB size                                                                                     | $\log_2(C\_MMU\_DTLB\_SIZE)$                                                                                                                          |
| 8:9   | TLBACC   | TLB register access:<br>0 = Minimal                  2 = Write<br>1 = Read                      3 = Full | C_MMU_TLB_ACCESS                                                                                                                                      |
| 10:14 | ZONES    | Number of memory protection zones                                                                        | C_MMU_ZONES                                                                                                                                           |
| 15    | PRIVINS  | Privileged instructions:<br>0 = Full protection<br>1 = Allow stream instructions                         | C_MMU_PRIVILEGED_INSTR                                                                                                                                |
| 16:16 | Reserved | Reserved for future use                                                                                  | 0                                                                                                                                                     |
| 17:31 | RSTMSR   | Reset value for MSR                                                                                      | C_RESET_MSR_IE << 2  <br>C_RESET_MSR_BIP << 4  <br>C_RESET_MSR_ICE << 6  <br>C_RESET_MSR_DCE << 8  <br>C_RESET_MSR_EE << 9  <br>C_RESET_MSR_EIP << 10 |

Table 2-36: Processor Version Register 12 (PVR12)

| Bits | Name    | Description                    | Value          |
|------|---------|--------------------------------|----------------|
| 0:31 | VECTORS | Location of MicroBlaze vectors | C_BASE_VECTORS |

## Pipeline Architecture

MicroBlaze instruction execution is pipelined. For most instructions, each stage takes one clock cycle to complete. Consequently, the number of clock cycles necessary for a specific instruction to complete is equal to the number of pipeline stages, and one instruction is completed on every cycle. A few instructions require multiple clock cycles in the execute stage to complete. This is achieved by stalling the pipeline.

When executing from slower memory, instruction fetches may take multiple cycles. This additional latency directly affects the efficiency of the pipeline. MicroBlaze implements an instruction prefetch buffer that reduces the impact of such multi-cycle instruction memory latency. While the pipeline is stalled by a multi-cycle instruction in the execution stage, the prefetch buffer continues to load sequential instructions. When the pipeline resumes execution, the fetch stage can load new instructions directly from the prefetch buffer instead of waiting for the instruction memory access to complete. If instructions are modified during execution (for example with self-modifying code), the prefetch buffer should be emptied before executing the modified instructions, to ensure that it does not contain the old unmodified instructions. The recommended way to do this is using an MBAR instruction, although it is also possible to use a synchronizing branch instruction, for example BRI 4.

### Three Stage Pipeline

With `C_AREA_OPTIMIZED` set to 1 (Area), the pipeline is divided into three stages to minimize hardware cost: Fetch, Decode, and Execute.

|               | cycle1 | cycle2 | cycle3  | cycle4  | cycle5  | cycle6  | cycle7  |
|---------------|--------|--------|---------|---------|---------|---------|---------|
| instruction 1 | Fetch  | Decode | Execute |         |         |         |         |
| instruction 2 |        | Fetch  | Decode  | Execute | Execute | Execute |         |
| instruction 3 |        |        | Fetch   | Decode  | Stall   | Stall   | Execute |

### Five Stage Pipeline

With `C_AREA_OPTIMIZED` set to 0 (Performance), the pipeline is divided into five stages to maximize performance: Fetch (IF), Decode (OF), Execute (EX), Access Memory (MEM), and Writeback (WB).

|               | cycle1 | cycle2 | cycle3 | cycle4 | cycle5 | cycle6 | cycle7 | cycle8 | cycle9 |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| instruction 1 | IF     | OF     | EX     | MEM    | WB     |        |        |        |        |
| instruction 2 |        | IF     | OF     | EX     | MEM    | MEM    | MEM    | WB     |        |
| instruction 3 |        |        | IF     | OF     | EX     | Stall  | Stall  | MEM    | WB     |

## Eight Stage Pipeline

With `C_AREA_OPTIMIZED` set to 2 (Frequency), the pipeline is divided into eight stages to maximize possible frequency: Fetch (IF), Decode (OF), Execute (EX), Access Memory 0 (M0), Access Memory 1 (M1), Access Memory 2 (M2), Access Memory 3 (M3) and Writeback (WB).

|               | cycle1 | cycle2 | cycle3 | cycle4 | cycle5 | cycle6 | cycle7 | cycle8 | cycle9 | cycle10 | cycle11 |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|
| instruction 1 | IF     | OF     | EX     | M0     | M1     | M2     | M3     | WB     |        |         |         |
| instruction 2 |        | IF     | OF     | EX     | M0     | M0     | M1     | M2     | M3     | WB      |         |
| instruction 3 |        |        | IF     | OF     | EX     | Stall  | M0     | M1     | M2     | M3      | WB      |

## Branches

Normally the instructions in the fetch and decode stages (as well as prefetch buffer) are flushed when executing a taken branch. The fetch pipeline stage is then reloaded with a new instruction from the calculated branch address. A taken branch in MicroBlaze takes three clock cycles to execute, two of which are required for refilling the pipeline. To reduce this latency overhead, MicroBlaze supports branches with delay slots.

### Delay Slots

When executing a taken branch with delay slot, only the fetch pipeline stage in MicroBlaze is flushed. The instruction in the decode stage (branch delay slot) is allowed to complete. This technique effectively reduces the branch penalty from two clock cycles to one. Branch instructions with delay slots have a D appended to the instruction mnemonic. For example, the BNE instruction does not execute the subsequent instruction (does not have a delay slot), whereas BNED executes the next instruction before control is transferred to the branch location.

A delay slot must not contain the following instructions: IMM, branch, or break. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

Instructions that could cause recoverable exceptions (for example unaligned word or halfword load and store) are allowed in the delay slot. If an exception is caused in a delay slot the ESR[DS] bit is set, and the exception handler is responsible for returning the execution to the branch target (stored in the special purpose register BTR). If the ESR[DS] bit is set, register R17 is not valid (otherwise it contains the address following the instruction causing the exception).

### Branch Target Cache

To improve branch performance, MicroBlaze provides a Branch Target Cache (BTC) coupled with a branch prediction scheme. With the BTC enabled, a correctly predicted immediate branch or return instruction incurs no overhead.

The BTC operates by saving the target address of each immediate branch and return instruction the first time the instruction is encountered. The next time it is encountered, it is usually found in the Branch Target Cache, and the Instruction Fetch Program Counter is then simply changed to the saved target address, in case the branch should be taken. Unconditional branches and return instructions are always taken, whereas conditional branches use branch prediction, to avoid taking a branch that should not have been taken and vice versa.

The BTC is cleared when a memory barrier (MBAR 0) or synchronizing branch (BRI 4) is executed. This also occurs when the memory barrier or synchronizing branch follows immediately after a branch instruction, even if that branch is taken. To avoid inadvertently clearing the BTC, the memory barrier or synchronizing branch should not be placed immediately after a branch instruction.

There are three cases where the branch prediction can cause a mispredict, namely:

- A conditional branch that should not have been taken, is actually taken,
- A conditional branch that should actually have been taken, is not taken,
- The target address of a return instruction is incorrect, which may occur when returning from a function called from different places in the code.

All of these cases are detected and corrected when the branch or return instruction reaches the execute stage, and the branch prediction bits or target address are updated in the BTC, to reflect the actual instruction behavior. This correction incurs a penalty of 2 clock cycles for the 5-stage pipeline and 7-9 clock cycles for the 8-stage pipeline.

The size of the BTC can be selected with `C_BRANCH_TARGET_CACHE_SIZE`. The default recommended setting uses one block RAM, and provides 512 entries. When selecting 64 entries or below, distributed RAM is used to implement the BTC, otherwise block RAM is used.

When the BTC uses block RAM, and `C_FAULT_TOLERANT` is set to 1, block RAMs are protected by parity. In case of a parity error, the branch is not predicted. To avoid accumulating errors in this case, the BTC should be cleared periodically by a synchronizing branch.

The Branch Target Cache is available when `C_USE_BRANCH_TARGET_CACHE` is set to 1 and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency).

## Memory Architecture

MicroBlaze is implemented with a Harvard memory architecture; instruction and data accesses are done in separate address spaces.

The instruction address space has a 32-bit virtual address range (that is, handles up to 4GB of instructions), and can be extended up to a 64-bit physical address range when using the MMU in virtual mode.

The data address space has a default 32-bit range, and can be extended up to a 64-bit range (that is, handles from 4GB to 16EB of data). The instruction and data memory ranges can be made to overlap by mapping them both to the same physical memory. The latter is necessary for software debugging.

Both instruction and data interfaces of MicroBlaze are default 32 bits wide and use big endian or little endian, bit-reversed format, depending on the selected endianness. MicroBlaze supports word, halfword, and byte accesses to data memory.

Big endian format is only supported when using the MMU in virtual or protected mode (`C_USE_MMU > 1`) or when reorder instructions are enabled (`C_USE_REORDER_INSTR = 1`).

Data accesses must be aligned (word accesses must be on word boundaries, halfword on halfword boundaries), unless the processor is configured to support unaligned exceptions. All instruction accesses must be word aligned.

MicroBlaze prefetches instructions to improve performance, using the instruction prefetch buffer and (if enabled) instruction cache streams. To avoid attempts to prefetch instructions beyond the end of physical memory, which may cause an instruction bus error or a processor stall, instructions must not be located too close to the end of physical memory. The instruction prefetch buffer requires 16 bytes margin, and using instruction cache streams adds two additional cache lines (32, 64 or 128 bytes).

MicroBlaze does not separate data accesses to I/O and memory (it uses memory mapped I/O). The processor has up to three interfaces for memory accesses:

- Local Memory Bus (LMB)
- Advanced eXtensible Interface (AXI4) for peripheral access
- Advanced eXtensible Interface (AXI4) or AXI Coherency Extension (ACE) for cache access

The LMB memory address range must not overlap with AXI4 ranges.

The `C_ENDIANNES` parameter is always set to little endian.

MicroBlaze has a single cycle latency for accesses to local memory (LMB) and for cache read hits, except with `C_AREA_OPTIMIZED` set to 1 (Area), when data side accesses and data cache

read hits require two clock cycles, and with `C_FAULT_TOLERANT` set to 1, when byte writes and halfword writes to LMB normally require two clock cycles.

The data cache write latency depends on `C_DCACHE_USE_WRITEBACK`. When `C_DCACHE_USE_WRITEBACK` is set to 1, the write latency normally is one cycle (more if the cache needs to do memory accesses). When `C_DCACHE_USE_WRITEBACK` is cleared to 0, the write latency normally is two cycles (more if the posted-write buffer in the memory controller is full).

The MicroBlaze instruction and data caches can be configured to use 4, 8 or 16 word cache lines. When using a longer cache line, more bytes are prefetched, which generally improves performance for software with sequential access patterns. However, for software with a more random access pattern the performance can instead decrease for a given cache size. This is caused by a reduced cache hit rate due to fewer available cache lines.

For details on the different memory interfaces refer to [Chapter 3, MicroBlaze Signal Interface Description](#).

## Privileged Instructions

The following MicroBlaze instructions are privileged:

- GET, GETD, PUT, PUTD (except when explicitly allowed)
- WIC, WDC
- MTS, MTSE
- MSRCLR, MSRSET (except when only the C bit is affected)
- BRK
- RTID, RTBD, RTED
- BRKI (except when jumping to physical address `C_BASE_VECTORS + 0x8` or `C_BASE_VECTORS + 0x18`)
- SLEEP, HIBERNATE, SUSPEND
- LBUEA, LHUEA, LWEA, SBEA, SHEA, SWEA (except when explicitly allowed)

Attempted use of these instructions when running in user mode causes a privileged instruction exception.

When setting the parameter `C_MMU_PRIVILEGED_INSTR` to 1 or 3, the instructions GET, GETD, PUT, and PUTD are not considered privileged, and can be executed when running in user mode. It is strongly discouraged to do this, unless absolutely necessary for performance reasons, since it allows application processes to interfere with each other.

When setting the parameter `C_MMU_PRIVILEGED_INSTR` to 2 or 3, the extended address instructions LBUEA, LHUEA, LWEA, SBEA, SHEA, and SWEA are not considered privileged, and will bypass the MMU translation, treating the extended address as a physical address. This is useful to run software in virtual mode while still having direct access to the full physical address space, but is discouraged in all cases where protection between application processes is necessary.

There are six ways to leave user mode and virtual mode:

1. Hardware generated reset (including debug reset)
2. Hardware exception
3. Non-maskable break or hardware break
4. Interrupt
5. Executing "BRALID Re, C\_BASE\_VECTORS + 0x8" to perform a user vector exception
6. Executing the software break instructions "BRKI" jumping to physical address `C_BASE_VECTORS + 0x8` or `C_BASE_VECTORS + 0x18`



In all of these cases, except hardware generated reset, the user mode and virtual mode status is saved in the MSR UMS and VMS bits.

Application (user-mode) programs transfer control to system-service routines (privileged mode programs) using the `BRALID` or `BRKI` instruction, jumping to physical address `C_BASE_VECTORS + 0x8`. Executing this instruction causes a system-call exception to occur. The exception handler determines which system-service routine to call and whether the calling application has permission to call that service. If permission is granted, the exception handler performs the actual procedure call to the system-service routine on behalf of the application program.

The execution environment expected by the system-service routine requires the execution of prologue instructions to set up that environment. Those instructions usually create the block of storage that holds procedural information (the activation record), update and initialize pointers, and save volatile registers (registers the system-service routine uses). Prologue code can be inserted by the linker when creating an executable module, or it can be included as stub code in either the system-call interrupt handler or the system-library routines.

Returns from the system-service routine reverse the process described above. Epilogue code is executed to unwind and deallocate the activation record, restore pointers, and restore volatile registers. The interrupt handler executes a return from exception instruction (RTED) to return to the application.

## Virtual-Memory Management

Programs running on MicroBlaze use effective addresses to access a flat 4 GB address space. The processor can interpret this address space in one of two ways, depending on the translation mode:

- In real mode, effective addresses are used to directly access physical memory
- In virtual mode, effective addresses are translated into physical addresses by the virtual-memory management hardware in the processor

Virtual mode provides system software with the ability to relocate programs and data anywhere in the physical address space. System software can move inactive programs and data out of physical memory when space is required by active programs and data.

Relocation can make it appear to a program that more memory exists than is actually implemented by the system. This frees the programmer from working within the limits imposed by the amount of physical memory present in a system. Programmers do not need to know which physical-memory addresses are assigned to other software processes and hardware devices. The addresses visible to programs are translated into the appropriate physical addresses by the processor.

Virtual mode provides greater control over memory protection. Blocks of memory as small as 1 KB can be individually protected from unauthorized access. Protection and relocation enable system software to support multitasking. This capability gives the appearance of simultaneous or near-simultaneous execution of multiple programs.

In MicroBlaze, virtual mode is implemented by the memory-management unit (MMU), available when `C_USE_MMU` is set to 3 (Virtual) and `C_AREA_OPTIMIZED` is set to 0 (Performance) or 2 (Frequency). The MMU controls effective-address to physical-address mapping and supports memory protection. Using these capabilities, system software can implement demand-paged virtual memory and other memory management schemes.

The MicroBlaze MMU implementation is based upon PowerPC™ 405. For details, see the *PowerPC Processor Reference Guide* ([UG011](#)) document.

The MMU features are summarized as follows:

- Translates effective addresses into physical addresses
- Controls page-level access during address translation
- Provides additional virtual-mode protection control through the use of zones
- Provides independent control over instruction-address and data-address translation and protection
- Supports eight page sizes: 1 kB, 4 kB, 16 kB, 64 kB, 256 kB, 1 MB, 4 MB, and 16 MB. Any combination of page sizes can be used by system software
- Software controls the page-replacement strategy

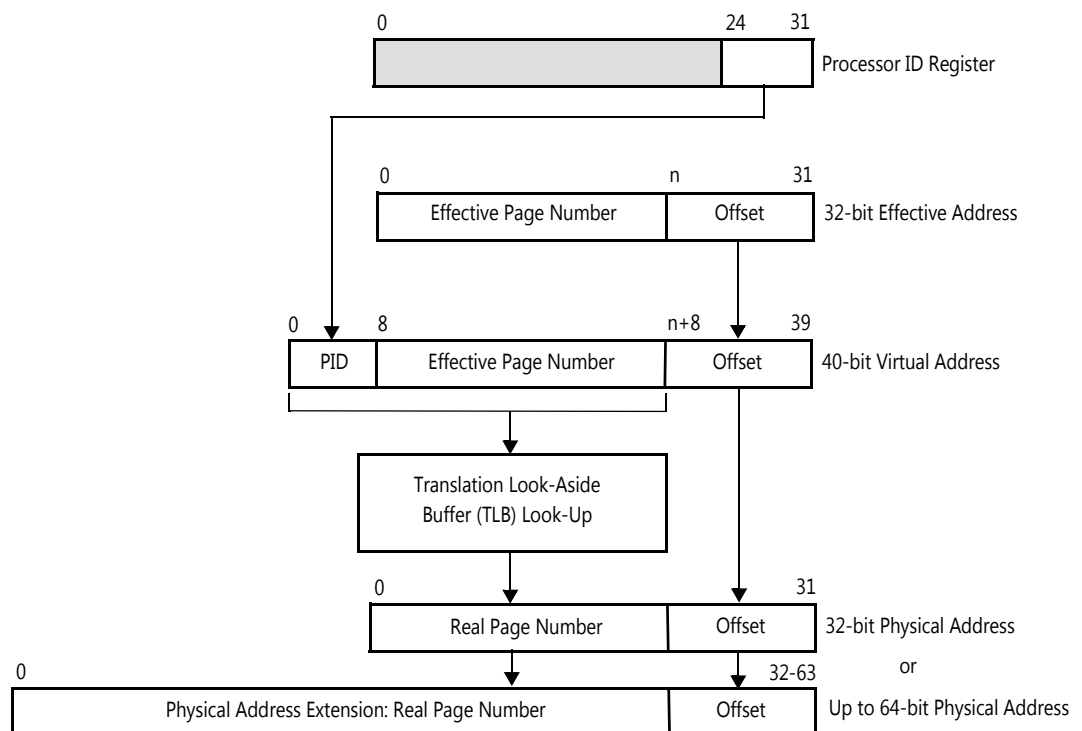
## Real Mode

The processor references memory when it fetches an instruction and when it accesses data with a load or store instruction. Programs reference memory locations using a 32-bit effective address calculated by the processor. When real mode is enabled, the physical address is identical to the effective address and the processor uses it to access physical memory. After a processor reset, the processor operates in real mode. Real mode can also be enabled by clearing the VM bit in the MSR.

Physical-memory data accesses (loads and stores) are performed in real mode using the effective address. Real mode does not provide system software with virtual address translation, but the full memory access-protection is available, implemented when `C_USE_MMU > 1` (User Mode) and `C_AREA_OPTIMIZED = 0` (Performance) or 2 (Frequency). Implementation of a real-mode memory manager is more straightforward than a virtual-mode memory manager. Real mode is often an appropriate solution for memory management in simple embedded environments, when access-protection is necessary, but virtual address translation is not required.

## Virtual Mode

In virtual mode, the processor translates an effective address into a physical address using the process shown in [Figure 2-18](#). With the Physical Address Extension (PAE) the physical address can be extended up to 64 bits. Virtual mode can be enabled by setting the VM bit in the MSR.



**Figure 2-18: Virtual-Mode Address Translation**

Each address shown in [Figure 2-18](#) contains a page-number field and an offset field. The page number represents the portion of the address translated by the MMU. The offset represents the byte offset into a page and is not translated by the MMU. The virtual address consists of an additional field, called the process ID (PID), which is taken from the PID register (see Process-ID Register, page 34). The combination of PID and effective page number (EPN) is referred to as the virtual page number (VPN). The value  $n$  is determined by the page size, as shown in [Table 2-37](#).

System software maintains a page-translation table that contains entries used to translate each virtual page into a physical page. The page size defined by a page translation entry determines the size of the page number and offset fields. For example, when a 4 kB page size is used, the page-number field is 20 bits and the offset field is 12 bits. The VPN in this case is 28 bits.

Then the most frequently used page translations are stored in the translation look-aside buffer (TLB). When translating a virtual address, the MMU examines the page-translation entries for a matching VPN (PID and EPN). Rather than examining all entries in the table, only entries contained in the processor TLB are examined. When a page-translation entry is found with a matching VPN, the corresponding physical-page number is read from the entry and combined with the offset to form the physical address. This physical address is used by the processor to reference memory.

System software can use the PID to uniquely identify software processes (tasks, subroutines, threads) running on the processor. Independently compiled processes can operate in effective-address regions that overlap each other. This overlap must be resolved by system software if multitasking is supported. Assigning a PID to each process enables system software to resolve the overlap by relocating each process into a unique region of virtual-address space. The virtual-address space mappings enable independent translation of each process into the physical-address space.

## ***Page-Translation Table***

The page-translation table is a software-defined and software-managed data structure containing page translations. The requirement for software-managed page translation represents an architectural trade-off targeted at embedded-system applications. Embedded systems tend to have a tightly controlled operating environment and a well-defined set of application software. That environment enables virtual-memory management to be optimized for each embedded system in the following ways:

- The page-translation table can be organized to maximize page-table search performance (also called table walking) so that a given page-translation entry is located quickly. Most general-purpose processors implement either an indexed page table (simple search method, large page-table size) or a hashed page table (complex search method, small page-table size). With software table walking, any hybrid organization can be employed that suits the particular embedded system. Both the page-table size and access time can be optimized.

- Independent page sizes can be used for application modules, device drivers, system service routines, and data. Independent page-size selection enables system software to more efficiently use memory by reducing fragmentation (unused memory). For example, a large data structure can be allocated to a 16 MB page and a small I/O device-driver can be allocated to a 1 KB page.
- Page replacement can be tuned to minimize the occurrence of missing page translations. As described in the following section, the most-frequently used page translations are stored in the translation look-aside buffer (TLB). Software is responsible for deciding which translations are stored in the TLB and which translations are replaced when a new translation is required. The replacement strategy can be tuned to avoid thrashing, whereby page-translation entries are constantly being moved in and out of the TLB. The replacement strategy can also be tuned to prevent replacement of critical-page translations, a process sometimes referred to as page locking.

The unified 64-entry TLB, managed by software, caches a subset of instruction and data page-translation entries accessible by the MMU. Software is responsible for reading entries from the page-translation table in system memory and storing them in the TLB. The following section describes the unified TLB in more detail. Internally, the MMU also contains shadow TLBs for instructions and data, with sizes configurable by `C_MMU_ITLB_SIZE` and `C_MMU_DTLB_SIZE` respectively.

These shadow TLBs are managed entirely by the processor (transparent to software) and are used to minimize access conflicts with the unified TLB.

## Translation Look-Aside Buffer

The translation look-aside buffer (TLB) is used by the MicroBlaze MMU for address translation when the processor is running in virtual mode, memory protection, and storage control. Each entry within the TLB contains the information necessary to identify a virtual page (PID and effective page number), specify its translation into a physical page, determine the protection characteristics of the page, and specify the storage attributes associated with the page.

The MicroBlaze TLB is physically implemented as three separate TLBs:

- Unified TLB—The UTLB contains 64 entries and is pseudo-associative. Instruction-page and data-page translation can be stored in any UTLB entry. The initialization and management of the UTLB is controlled completely by software.
- Instruction Shadow TLB—The ITLB contains instruction page-translation entries and is fully associative. The page-translation entries stored in the ITLB represent the most-recently accessed instruction-page translations from the UTLB. The ITLB is used to minimize contention between instruction translation and UTLB-update operations. The initialization and management of the ITLB is controlled completely by hardware and is transparent to software.

- **Data Shadow TLB**—The DTLB contains data page-translation entries and is fully associative. The page-translation entries stored in the DTLB represent the most-recently accessed data-page translations from the UTLB. The DTLB is used to minimize contention between data translation and UTLB-update operations. The initialization and management of the DTLB is controlled completely by hardware and is transparent to software.

Figure 2-19 provides the translation flow for TLB.

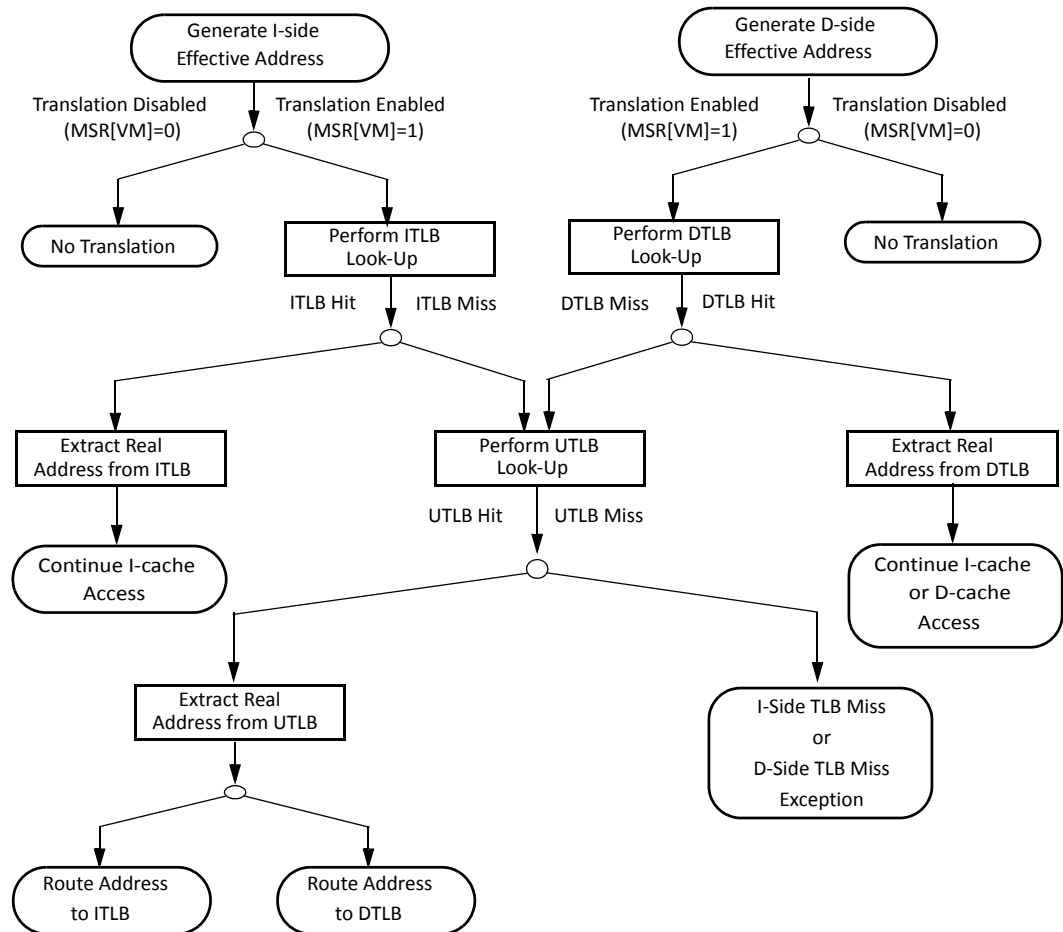


Figure 2-19: TLB Address Translation Flow

### TLB Entry Format

Figure 2-20 shows the format of a TLB entry. Each TLB entry ranges from 68 bits up to 100 bits and is composed of two portions: TLBLO (also referred to as the data entry), and TLBHI (also referred to as the tag entry). When the Physical Address Extension (PAE) is enabled the TLB entry is extended with up to 32 additional bits in the TLBLO RPN field to support up to a 64 bit physical address.



**Figure 2-20: TLB Entry Format (PAE disabled)**

Table 2-37: Page-Translation Bit Ranges by Page Size

| Page Size | SIZE TLBHI Field | Tag Comparison Bit Range  | Page Offset    | PAE Disabled         |                     | PAE Enabled <sup>1</sup> |                     |
|-----------|------------------|---------------------------|----------------|----------------------|---------------------|--------------------------|---------------------|
|           |                  |                           |                | Physical Page Number | RPN Bits Clear to 0 | Physical Page Number     | RPN Bits Clear to 0 |
| 1 KB      | 000              | TAG[0:21] - Address[0:21] | Address[22:31] | RPN[0:21]            | -                   | RPN[0:n-11]              | -                   |
| 4 KB      | 001              | TAG[0:19] - Address[0:19] | Address[20:31] | RPN[0:19]            | 20:21               | RPN[0:n-13]              | n-12:n-11           |
| 16 KB     | 010              | TAG[0:17] - Address[0:17] | Address[18:31] | RPN[0:17]            | 18:21               | RPN[0:n-15]              | n-14:n-11           |
| 64 KB     | 011              | TAG[0:15] - Address[0:15] | Address[16:31] | RPN[0:15]            | 16:21               | RPN[0:n-17]              | n-16:n-11           |
| 256 KB    | 100              | TAG[0:13] - Address[0:13] | Address[14:31] | RPN[0:13]            | 14:21               | RPN[0:n-19]              | n-18:n-11           |
| 1 MB      | 101              | TAG[0:11] - Address[0:11] | Address[12:31] | RPN[0:11]            | 12:21               | RPN[0:n-21]              | n-20:n-11           |
| 4 MB      | 110              | TAG[0:9] - Address[0:9]   | Address[10:31] | RPN[0:9]             | 10:21               | RPN[0:n-23]              | n-22:n-11           |
| 16 MB     | 111              | TAG[0:7] - Address[0:7]   | Address[8:31]  | RPN[0:7]             | 8:21                | RPN[0:n-25]              | n-24:n-11           |

1. The bit index n = C\_ADDR\_SIZE.

## TLB Access

When the MMU translates a virtual address (the combination of PID and effective address) into a physical address, it first examines the appropriate shadow TLB for the page translation entry. If an entry is found, it is used to access physical memory. If an entry is not found, the MMU examines the UTLB for the entry. A delay occurs each time the UTLB must be accessed due to a shadow TLB miss. The miss latency ranges from 2-32 cycles. The DTLB has priority over the ITLB if both simultaneously access the UTLB.

Figure 2-21, page 62 shows the logical process the MMU follows when examining a page-translation entry in one of the shadow TLBs or the UTLB. All valid entries in the TLB are checked.

A TLB hit occurs when all of the following conditions are met by a TLB entry:

- The entry is valid
- The TAG field in the entry matches the effective address EPN under the control of the SIZE field in the entry
- The TID field in the entry matches the PID

If any of the above conditions are not met, a TLB miss occurs. A TLB miss causes an exception, described as follows:

A TID value of 0x00 causes the MMU to ignore the comparison between the TID and PID. Only the TAG and EA[EPN] are compared. A TLB entry with TID=0x00 represents a process-independent translation. Pages that are accessed globally by all processes should be assigned a TID value of 0x00. A PID value of 0x00 does not identify a process that can access any page. When PID=0x00, a page-translation hit only occurs when TID=0x00. It is possible for software to load the TLB with multiple entries that match an EA[EPN] and PID



combination. However, this is considered a programming error and results in undefined behavior.

When a hit occurs, the MMU reads the RPN field from the corresponding TLB entry. Some or all of the bits in this field are used, depending on the value of the `SIZE` field (see [Table 2-37](#)).

For example, with PAE disabled, if the `SIZE` field specifies a 256 kB page size, `RPN[0:13]` represents the physical page number and is used to form the physical address. `RPN[14:21]` is not used, and software must clear those bits to 0 when initializing the TLB entry. The remainder of the physical address is taken from the page-offset portion of the EA. If the page size is 256 kB, the 32-bit physical address is formed by concatenating `RPN[0:13]` with bits 14:31 of the effective address.

Instead, with PAE enabled and assuming a physical address size of 40 bits (`C_ADDR_SIZE` set to 40), `RPN[0:21]` represents the physical page number and `RPN[22:29]` is not used. The 40-bit physical address is formed by concatenating `RPN[0:21]` with bits 14:31 of the effective address.

Prior to accessing physical memory, the MMU examines the TLB-entry access-control fields. These fields indicate whether the currently executing program is allowed to perform the requested memory access.

If access is allowed, the MMU checks the storage-attribute fields to determine how to access the page. The storage-attribute fields specify the caching policy for memory accesses.

### ***TLB Access Failures***

A TLB-access failure causes an exception to occur. This interrupts execution of the instruction that caused the failure and transfers control to an interrupt handler to resolve the failure. A TLB access can fail for two reasons:

- A matching TLB entry was not found, resulting in a TLB miss
- A matching TLB entry was found, but access to the page was prevented by either the storage attributes or zone protection

When an interrupt occurs, the processor enters real mode by clearing `MSR[VM]` to 0. In real mode, all address translation and memory-protection checks performed by the MMU are disabled. After system software initializes the UTLB with page-translation entries, management of the MicroBlaze UTLB is usually performed using interrupt handlers running in real mode.

Figure 2-21 diagrams the general process for examining a TLB entry.

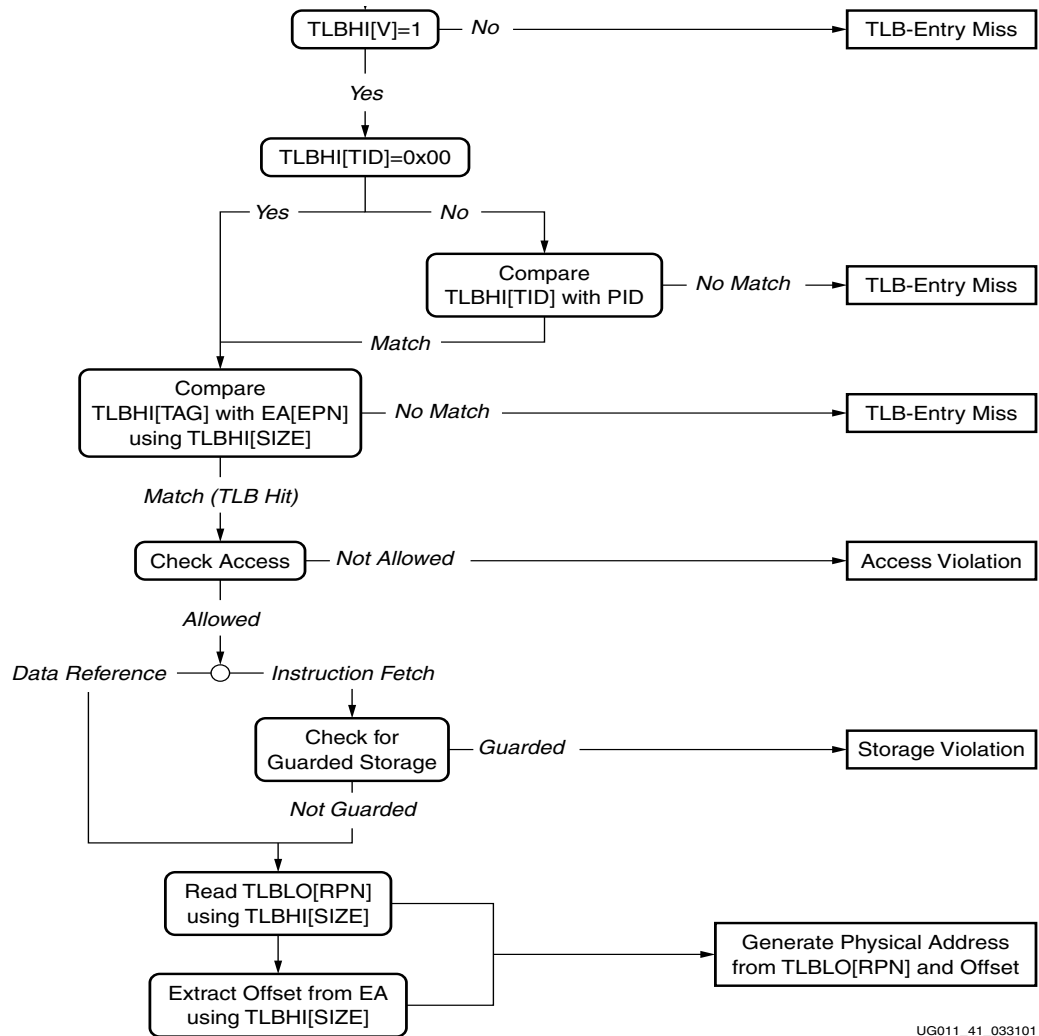


Figure 2-21: General Process for Examining a TLB Entry

The following sections describe the conditions under which exceptions occur due to TLB access failures.

### Data-Storage Exception

When virtual mode is enabled, (MSR[VM]=1), a data-storage exception occurs when access to a page is not permitted for any of the following reasons:

- From user mode:
  - .. The TLB entry specifies a zone field that prevents access to the page (ZPR[Zn]=00). This applies to load and store instructions.
  - .. The TLB entry specifies a read-only page (TLBLO[WR]=0) that is not otherwise overridden by the zone field (ZPR[Zn], 11). This applies to store instructions.

- From privileged mode:
  - .. The TLB entry specifies a read-only page (TLBLO[WR]=0) that is not otherwise overridden by the zone field (ZPR[Zn], 10 and ZPR[Zn], 11). This applies to store instructions.

### **Instruction-Storage Exception**

When virtual mode is enabled, (MSR[VM]=1), an instruction-storage exception occurs when access to a page is not permitted for any of the following reasons:

- From user mode:
  - .. The TLB entry specifies a zone field that prevents access to the page (ZPR[Zn]=00).
  - .. The TLB entry specifies a non-executable page (TLBLO[EX]=0) that is not otherwise overridden by the zone field (ZPR[Zn], 11).
  - .. The TLB entry specifies a guarded-storage page (TLBLO[G]=1).
- From privileged mode:
  - .. The TLB entry specifies a non-executable page (TLBLO[EX]=0) that is not otherwise overridden by the zone field (ZPR[Zn], 10 and ZPR[Zn], 11).
  - .. The TLB entry specifies a guarded-storage page (TLBLO[G]=1).

### **Data TLB-Miss Exception**

When virtual mode is enabled (MSR[VM]=1) a data TLB-miss exception occurs if a valid, matching TLB entry was not found in the TLB (shadow and UTLB). Any load or store instruction can cause a data TLB-miss exception.

### **Instruction TLB-Miss Exception**

When virtual mode is enabled (MSR[VM]=1) an instruction TLB-miss exception occurs if a valid, matching TLB entry was not found in the TLB (shadow and UTLB). Any instruction fetch can cause an instruction TLB-miss exception.

## **Access Protection**

System software uses access protection to protect sensitive memory locations from improper access. System software can restrict memory accesses for both user-mode and privileged-mode software. Restrictions can be placed on reads, writes, and instruction fetches. Access protection is available when virtual protected mode is enabled.

Access control applies to instruction fetches, data loads, and data stores. The TLB entry for a virtual page specifies the type of access allowed to the page. The TLB entry also specifies a zone-protection field in the zone-protection register that is used to override the access controls specified by the TLB entry.

## ***TLB Access-Protection Controls***

Each TLB entry controls three types of access:

- **Process**—Processes are protected from unauthorized access by assigning a unique process ID (PID) to each process. When system software starts a user-mode application, it loads the PID for that application into the PID register. As the application executes, memory addresses are translated using only TLB entries with a TID field in Translation Look-Aside Buffer High (TLBHI) that matches the PID. This enables system software to restrict accesses for an application to a specific area in virtual memory. A TLB entry with TID=0x00 represents a process-independent translation. Pages that are accessed globally by all processes should be assigned a TID value of 0x00.
- **Execution**—The processor executes instructions only if they are fetched from a virtual page marked as executable (TLBLO[EX]=1). Clearing TLBLO[EX] to 0 prevents execution of instructions fetched from a page, instead causing an instruction-storage interrupt (ISI) to occur. The ISI does not occur when the instruction is fetched, but instead occurs when the instruction is executed. This prevents speculatively fetched instructions that are later discarded (rather than executed) from causing an ISI.

The zone-protection register can override execution protection.

- **Read/Write**—Data is written only to virtual pages marked as writable (TLBLO[WR]=1). Clearing TLBLO[WR] to 0 marks a page as read-only. An attempt to write to a read-only page causes a data-storage interrupt (DSI) to occur.

The zone-protection register can override write protection.

TLB entries cannot be used to prevent programs from reading pages. In virtual mode, zone protection is used to read-protect pages. This is done by defining a no-access-allowed zone (ZPR[Zn] = 00) and using it to override the TLB-entry access protection. Only programs running in user mode can be prevented from reading a page. Privileged programs always have read access to a page.

## ***Zone Protection***

Zone protection is used to override the access protection specified in a TLB entry. Zones are an arbitrary grouping of virtual pages with common access protection. Zones can contain any number of pages specifying any combination of page sizes. There is no requirement for a zone to contain adjacent pages.

The zone-protection register (ZPR) is a 32-bit register used to specify the type of protection override applied to each of 16 possible zones. The protection override for a zone is encoded in the ZPR as a 2-bit field. The 4-bit zone-select field in a TLB entry (TLBLO[ZSEL]) selects one of the 16 zone fields from the ZPR (Z0–Z15). For example, zone Z5 is selected when ZSEL = 0101.

Changing a zone field in the ZPR applies a protection override across all pages in that zone. Without the ZPR, protection changes require individual alterations to each page translation entry within the zone.

Unimplemented zones (when `C_MMU_ZONES < 16`) are treated as if they contained 11.

## UTLB Management

The UTLB serves as the interface between the processor MMU and memory-management software. System software manages the UTLB to tell the MMU how to translate virtual addresses into physical addresses. When a problem occurs due to a missing translation or an access violation, the MMU communicates the problem to system software using the exception mechanism. System software is responsible for providing interrupt handlers to correct these problems so that the MMU can proceed with memory translation.

Software reads and writes UTLB entries using the MFS and MTS instructions, respectively. With PAE enabled, the MFSE and MTSE instructions are used to access the most significant part of the real page number. These instructions use the TLBX register index (numbered 0 to 63) corresponding to one of the 64 entries in the UTLB. The tag and data portions are read and written separately, so software must execute two MFS or MTS instructions, and also an additional MFSE or MTSE instruction when PAE is enabled, to completely access an entry.

The UTLB is searched for a specific translation using the TLBSX register. TLBSX locates a translation using an effective address and loads the corresponding UTLB index into the TLBX register.

Individual UTLB entries are invalidated using the MTS instruction to clear the valid bit in the tag portion of a TLB entry (TLBHI[V]).

When `C_FAULT_TOLERANT` is set to 1, the UTLB block RAM is protected by parity. In case of a parity error, a TLB miss exception occurs. To avoid accumulating errors in this case, each entry in the UTLB should be periodically invalidated.

## Recording Page Access and Page Modification

Software management of virtual-memory poses several challenges:

- In a virtual-memory environment, software and data often consume more memory than is physically available. Some of the software and data pages must be stored outside physical memory, such as on a hard drive, when they are not used. Ideally, the most-frequently used pages stay in physical memory and infrequently used pages are stored elsewhere.
- When pages in physical-memory are replaced to make room for new pages, it is important to know whether the replaced (old) pages were modified. If they were modified, they must be saved prior to loading the replacement (new) pages. If the old pages were not modified, the new pages can be loaded without saving the old pages.

- A limited number of page translations are kept in the UTLB. The remaining translations must be stored in the page-translation table. When a translation is not found in the UTLB (due to a miss), system software must decide which UTLB entry to discard so that the missing translation can be loaded. It is desirable for system software to replace infrequently used translations rather than frequently used translations.

Solving the above problems in an efficient manner requires keeping track of page accesses and page modifications. MicroBlaze does not track page access and page modification in hardware. Instead, system software can use the TLB-miss exceptions and the data-storage exception to collect this information. As the information is collected, it can be stored in a data structure associated with the page-translation table.

Page-access information is used to determine which pages should be kept in physical memory and which are replaced when physical-memory space is required. System software can use the valid bit in the TLB entry (TLBHI[V]) to monitor page accesses. This requires page translations be initialized as not valid (TLBHI[V]=0) to indicate they have not been accessed. The first attempt to access a page causes a TLB-miss exception, either because the UTLB entry is marked not valid or because the page translation is not present in the UTLB. The TLB-miss handler updates the UTLB with a valid translation (TLBHI[V]=1). The set valid bit serves as a record that the page and its translation have been accessed. The TLB-miss handler can also record the information in a separate data structure associated with the page-translation entry.

Page-modification information is used to indicate whether an old page can be overwritten with a new page or the old page must first be stored to a hard disk. System software can use the write-protection bit in the TLB entry (TLBLO[WR]) to monitor page modification. This requires page translations be initialized as read-only (TLBLO[WR]=0) to indicate they have not been modified. The first attempt to write data into a page causes a data-storage exception, assuming the page has already been accessed and marked valid as described above. If software has permission to write into the page, the data-storage handler marks the page as writable (TLBLO[WR]=1) and returns. The set write-protection bit serves as a record that a page has been modified. The data-storage handler can also record this information in a separate data structure associated with the page-translation entry.

Tracking page modification is useful when virtual mode is first entered and when a new process is started.

## Reset, Interrupts, Exceptions, and Break

MicroBlaze supports reset, interrupt, user exception, break, and hardware exceptions. The following section describes the execution flow associated with each of these events.

The relative priority starting with the highest is:

1. Reset
2. Hardware Exception
3. Non-maskable Break
4. Break
5. Interrupt
6. User Vector (Exception)

[Table 2-38](#) defines the memory address locations of the associated vectors and the hardware enforced register file locations for return addresses. Each vector allocates two addresses to allow full address range branching (requires an `IMM` followed by a `BRAI` instruction). Normally the vectors start at address `0x00000000`, but the parameter `C_BASE_VECTORS` can be used to locate them anywhere in memory.

The address range `0x28` to `0x4F` is reserved for future software support by Xilinx. Allocating these addresses for user applications is likely to conflict with future releases of SDK support software.

**Table 2-38: Vectors and Return Address Register File Location**

| Event                             | Vector Address                                                                         | Register File Return Address |
|-----------------------------------|----------------------------------------------------------------------------------------|------------------------------|
| Reset                             | <code>C_BASE_VECTORS + 0x00000000</code> -<br><code>C_BASE_VECTORS + 0x00000004</code> | -                            |
| User Vector (Exception)           | <code>C_BASE_VECTORS + 0x00000008</code> -<br><code>C_BASE_VECTORS + 0x0000000C</code> | Rx                           |
| Interrupt <sup>1</sup>            | <code>C_BASE_VECTORS + 0x00000010</code> -<br><code>C_BASE_VECTORS + 0x00000014</code> | R14                          |
| Break: Non-maskable hardware      | <code>C_BASE_VECTORS + 0x00000018</code> -<br><code>C_BASE_VECTORS + 0x0000001C</code> | R16                          |
| Break: Hardware                   |                                                                                        |                              |
| Break: Software                   |                                                                                        |                              |
| Hardware Exception                | <code>C_BASE_VECTORS + 0x00000020</code> -<br><code>C_BASE_VECTORS + 0x00000024</code> | R17 or BTR                   |
| Reserved by Xilinx for future use | <code>C_BASE_VECTORS + 0x00000028</code> -<br><code>C_BASE_VECTORS + 0x0000004F</code> | -                            |

1. With low-latency interrupt mode, the vector address is supplied by the Interrupt Controller.

All of these events will clear the reservation bit, used together with the `LWX` and `SWX` instructions to implement mutual exclusion, such as semaphores and spinlocks.

## Reset

When a `Reset` or `Debug_Rst`<sup>(1)</sup> occurs, MicroBlaze flushes the pipeline and starts fetching instructions from the reset vector (address 0x0). Both external reset signals are active high and should be asserted for a minimum of 16 cycles. See “[MicroBlaze Core Configurability](#)” in [Chapter 3](#) for more information on the MSR reset value parameters.

### Equivalent Pseudocode

```
PC ← C_BASE_VECTORS + 0x00000000
MSR ← C_RESET_MSR_IE << 2 | C_RESET_MSR_BIP << 4 | C_RESET_MSR_ICE << 6 |
      C_RESET_MSR_DCE << 8 | C_RESET_MSR_EE << 9 | C_RESET_MSR_EIP << 10
EAR ← 0; ESR ← 0; FSR ← 0
PID ← 0; ZPR ← 0; TLBX ← 0
Reservation ← 0
```

## Hardware Exceptions

MicroBlaze can be configured to trap the following internal error conditions: illegal instruction, instruction and data bus error, and unaligned access. The divide exception can only be enabled if the processor is configured with a hardware divider (`C_USE_DIV=1`). When configured with a hardware floating point unit (`C_USE_FPU>0`), it can also trap the following floating point specific exceptions: underflow, overflow, float division-by-zero, invalid operation, and denormalized operand error.

When configured with a hardware Memory Management Unit, it can also trap the following memory management specific exceptions: Illegal Instruction Exception, Data Storage Exception, Instruction Storage Exception, Data TLB Miss Exception, and Instruction TLB Miss Exception.

A hardware exception causes MicroBlaze to flush the pipeline and branch to the hardware exception vector (address `C_BASE_VECTORS + 0x20`). The execution stage instruction in the exception cycle is not executed.

The exception also updates the general purpose register R17 in the following manner:

- For the MMU exceptions (Data Storage Exception, Instruction Storage Exception, Data TLB Miss Exception, Instruction TLB Miss Exception) the register R17 is loaded with the appropriate program counter value to re-execute the instruction causing the exception upon return. The value is adjusted to return to a preceding `IMM` instruction, if any. If the exception is caused by an instruction in a branch delay slot, the value is adjusted to return to the branch instruction, including adjustment for a preceding `IMM` instruction, if any.

---

1. Reset input controlled by the debugger via MDM.



- For all other exceptions the register R17 is loaded with the program counter value of the subsequent instruction, unless the exception is caused by an instruction in a branch delay slot. If the exception is caused by an instruction in a branch delay slot, the ESR[DS] bit is set. In this case the exception handler should resume execution from the branch target address stored in BTR.

The EE and EIP bits in MSR are automatically reverted when executing the `RTED` instruction.

The VM and UM bits in MSR are automatically reverted from VMS and UMS when executing the `RTED`, `RTBD`, and `RTID` instructions.

### ***Exception Priority***

When two or more exceptions occur simultaneously, they are handled in the following order, from the highest priority to the lowest:

- Instruction Bus Exception
- Instruction TLB Miss Exception
- Instruction Storage Exception
- Illegal Opcode Exception
- Privileged Instruction Exception or Stack Protection Violation Exception
- Data TLB Miss Exception
- Data Storage Exception
- Unaligned Exception
- Data Bus Exception
- Divide Exception
- FPU Exception
- Stream Exception

### ***Exception Causes***

- Stream Exception

The AXI4-Stream exception is caused by executing a `get` or `getd` instruction with the 'e' bit set to '1' when there is a control bit mismatch.

- Instruction Bus Exception

The instruction bus exception is caused by errors when reading data from memory.

- The instruction peripheral AXI4 interface (M\_AXI\_IP) exception is caused by an error response on `M_AXI_IP_RRESP`.

- .. The instruction cache AXI4 interface (M\_AXI\_IC) is caused by an error response on M\_AXI\_IC\_RRESP. The exception can only occur when C\_ICACHE\_ALWAYS\_USED is set to 1 and the cache is turned off, or if the MMU Inhibit Caching bit is set for the address. In all other cases the response is ignored.
- .. The instructions side local memory (ILMB) can only cause instruction bus exception when either an uncorrectable error occurs in the LMB memory, as indicated by the IUE signal, or C\_ECC\_USE\_CE\_EXCEPTION is set to 1 and a correctable error occurs in the LMB memory, as indicated by the ICE signal.

- **Illegal Opcode Exception**

The illegal opcode exception is caused by an instruction with an invalid major opcode (bits 0 through 5 of instruction). Bits 6 through 31 of the instruction are not checked. Optional processor instructions are detected as illegal if not enabled. If the optional feature C\_OPCODE\_0x0\_ILLEGAL is enabled, an illegal opcode exception is also caused if the instruction is equal to 0x00000000.

- **Data Bus Exception**

The data bus exception is caused by errors when reading data from memory or writing data to memory.

- .. The data peripheral AXI4 interface (M\_AXI\_DP) exception is caused by an error response on M\_AXI\_DP\_RRESP or M\_AXI\_DP\_BRESP.
- .. The data cache AXI4 interface (M\_AXI\_DC) exception is caused by:
  - An error response on M\_AXI\_DC\_RRESP or M\_AXI\_DC\_BRESP,
  - OKAY response on M\_AXI\_DC\_RRESP in case of an exclusive access using LWX.

The exception can only occur when C\_DCACHE\_ALWAYS\_USED is set to 1 and the cache is turned off, when an exclusive access using LWX or SWX is performed, or if the MMU Inhibit Caching bit is set for the address. In all other cases the response is ignored.

- .. The data side local memory (DLMB) can only cause instruction bus exception when either an uncorrectable error occurs in the LMB memory, as indicated by the DUE signal, or C\_ECC\_USE\_CE\_EXCEPTION is set to 1 and a correctable error occurs in the LMB memory, as indicated by the DCE signal. An error can occur for all read accesses, and for byte and halfword write accesses.

- **Unaligned Exception**

The unaligned exception is caused by a word access where the address to the data bus has bits 30 or 31 set, or a half-word access with bit 31 set.

- **Divide Exception**

The divide exception is caused by an integer division (idiv or idivu) where the divisor is zero, or by a signed integer division (idiv) where overflow occurs (-2147483648 / -1).

- **FPU Exception**

An FPU exception is caused by an underflow, overflow, divide-by-zero, illegal operation, or denormalized operand occurring with a floating point instruction.

- .. Underflow occurs when the result is denormalized.
- .. Overflow occurs when the result is not-a-number (NaN).
- .. The divide-by-zero FPU exception is caused by the rA operand to fdiv being zero when rB is not infinite.
- .. Illegal operation is caused by a signaling NaN operand or by illegal infinite or zero operand combinations.

- **Privileged Instruction Exception**

The Privileged Instruction exception is caused by an attempt to execute a privileged instruction in User Mode.

- **Stack Protection Violation Exception**

A Stack Protection Violation exception is caused by executing a load or store instruction using the stack pointer (register R1) as rA with an address outside the stack boundaries defined by the special Stack Low and Stack High registers, causing a stack overflow or a stack underflow.

- **Data Storage Exception**

The Data Storage exception is caused by an attempt to access data in memory that results in a memory-protection violation.

- **Instruction Storage Exception**

The Instruction Storage exception is caused by an attempt to access instructions in memory that results in a memory-protection violation.

- **Data TLB Miss Exception**

The Data TLB Miss exception is caused by an attempt to access data in memory, when a valid Translation Look-Aside Buffer entry is not present, and virtual protected mode is enabled.

- **Instruction TLB Miss Exception**

The Instruction TLB Miss exception is caused by an attempt to access instructions in memory, when a valid Translation Look-Aside Buffer entry is not present, and virtual protected mode is enabled.

Should an Instruction Bus Exception, Illegal Opcode Exception or Data Bus Exception occur when `C_FAULT_TOLERANT` is set to 1, and an exception is in progress (that is `MSR[EIP]` set and `MSR[EE]` cleared), the pipeline is halted, and the external signal `MB_Error` is set.

### ***Imprecise Exceptions***

Normally all exceptions in MicroBlaze are precise, meaning that any instructions in the pipeline after the instruction causing an exception are invalidated, and have no effect.

When `C_IMPRECISE_EXCEPTIONS` is set to 1 (ECC) an Instruction Bus Exception or Data Bus Exception caused by ECC errors in LMB memory is not precise, meaning that a subsequent memory access instruction in the pipeline may be executed. If this behavior is acceptable, the maximum frequency can be improved by setting this parameter to 1.

### ***Equivalent Pseudocode***

```

ESR[DS] ← exception in delay slot
if ESR[DS] then
    BTR ← branch target PC
    if MMU exception then
        if branch preceded by IMM then
            r17 ← PC - 8
        else
            r17 ← PC - 4
    else
        r17 ← invalid value
else if MMU exception then
    if instruction preceded by IMM then
        r17 ← PC - 4
    else
        r17 ← PC
else
    r17 ← PC + 4
PC ← C_BASE_VECTORS + 0x00000020
MSR[EE] ← 0, MSR[EIP] ← 1
MSR[UMS] ← MSR[UM], MSR[UM] ← 0, MSR[VMS] ← MSR[VM], MSR[VM] ← 0
ESR[EC] ← exception specific value
ESR[ESS] ← exception specific value
EAR ← exception specific value
FSR ← exception specific value
Reservation ← 0

```

## **Breaks**

There are two kinds of breaks:

- Hardware (external) breaks
- Software (internal) breaks

## Hardware Breaks

Hardware breaks are performed by asserting the external break signal (that is, the `Ext_BRK` and `Ext_NM_BRK` input ports). On a break, the instruction in the execution stage completes while the instruction in the decode stage is replaced by a branch to the break vector (address `C_BASE_VECTORS + 0x18`). The break return address (the PC associated with the instruction in the decode stage at the time of the break) is automatically loaded into general purpose register R16. MicroBlaze also sets the Break In Progress (`BIP`) flag in the Machine Status Register (MSR).

A normal hardware break (that is, the `Ext_BRK` input port) is only handled when `MSR[BIP]` and `MSR[EIP]` are set to 0 (that is, there is no break or exception in progress). The Break In Progress flag disables interrupts. A non-maskable break (that is, the `Ext_NM_BRK` input port) is always handled immediately.

The `BIP` bit in the MSR is automatically cleared when executing the `RTBD` instruction.

The `Ext_BRK` signal must be kept asserted until the break has occurred, and deasserted before the `RTBD` instruction is executed. The `Ext_NM_BRK` signal must only be asserted one clock cycle.

## Software Breaks

To perform a software break, use the `brk` and `brki` instructions. Refer to [Chapter 5, MicroBlaze Instruction Set Architecture](#) for detailed information on software breaks.

As a special case, when `C_DEBUG_ENABLED` is greater than zero, and “`brki rD, 0x18`” is executed, a software breakpoint is signaled to the debugger, for example the Xilinx System Debugger (XSDb) tool, irrespective of the value of `C_BASE_VECTORS`.

## Latency

The time it takes MicroBlaze to enter a break service routine from the time the break occurs depends on the instruction currently in the execution stage and the latency to the memory storing the break vector.

## Equivalent Pseudocode

```

r16 ← PC
PC ← C_BASE_VECTORS + 0x00000018
MSR[BIP] ← 1
MSR[UMS] ← MSR[UM], MSR[UM] ← 0, MSR[VMS] ← MSR[VM], MSR[VM] ← 0
Reservation ← 0

```

## Interrupt

MicroBlaze supports one external interrupt source (connected to the `Interrupt` input port). The processor only reacts to interrupts if the Interrupt Enable (IE) bit in the Machine Status

Register (MSR) is set to 1. On an interrupt, the instruction in the execution stage completes while the instruction in the decode stage is replaced by a branch to the interrupt vector. This is either address `C_BASE_VECTORS + 0x10`, or with low-latency interrupt mode, the address supplied by the Interrupt Controller.

The interrupt return address (the PC associated with the instruction in the decode stage at the time of the interrupt) is automatically loaded into general purpose register R14. In addition, the processor also disables future interrupts by clearing the IE bit in the MSR. The IE bit is automatically set again when executing the RTID instruction.

Interrupts are ignored by the processor if either of the break in progress (BIP) or exception in progress (EIP) bits in the MSR are set to 1.

By using the parameter `C_INTERRUPT_IS_EDGE`, the external interrupt can either be set to level-sensitive or edge-triggered:

- When using level-sensitive interrupts, the `Interrupt` input must remain set until MicroBlaze has taken the interrupt, and jumped to the interrupt vector. Software must acknowledge the interrupt at the source to clear it before returning from the interrupt handler. If not, the interrupt is taken again, as soon as interrupts are enabled when returning from the interrupt handler.
- When using edge-triggered interrupts, MicroBlaze detects and latches the `Interrupt` input edge, which means that the input only needs to be asserted one clock cycle. The interrupt input can remain asserted, but must be deasserted at least one clock cycle before a new interrupt can be detected. The latching of an edge sensitive interrupt is independent of the IE bit in MSR. Should an interrupt occur while the IE bit is 0, it will immediately be serviced when the IE bit is set to 1.

With periodic interrupt sources, such as the FIT Timer IP core, that do not have a method to clear the interrupt from software, it is recommended to use edge-triggered interrupts.

### ***Low-latency Interrupt Mode***

A low-latency interrupt mode is available, which allows the Interrupt Controller to directly supply the interrupt vector for each individual interrupt (via the `Interrupt_Address` input port). The address of each fast interrupt handler must be passed to the Interrupt Controller when initializing the interrupt system. When a particular interrupt occurs, this address is supplied by the Interrupt Controller, which allows MicroBlaze to directly jump to the handler code.

With this mode, MicroBlaze also directly sends the appropriate interrupt acknowledge to the Interrupt Controller (via the `Interrupt_Ack` output port), although it is still the responsibility of the Interrupt Service Routine to acknowledge level sensitive interrupts at the source.

This information allows the Interrupt Controller to acknowledge interrupts appropriately, both for level-sensitive and edge-triggered interrupt.

To inform the Interrupt Controller of the interrupt handling events, `Interrupt_Ack` is set to:

- 01 - when MicroBlaze jumps to the interrupt handler code,
- 10 - when the RTID instruction is executed to return from interrupt,
- 11 - when MSR[IE] is changed from 0 to 1, which enables interrupts again.

The `Interrupt_Ack` output port is active during one clock cycle, and is then reset to 00.

### **Latency**

The time it takes MicroBlaze to enter an Interrupt Service Routine (ISR) from the time an interrupt occurs, depends on the configuration of the processor and the latency of the memory controller storing the interrupt vectors. If MicroBlaze is configured to have a hardware divider, the largest latency happens when an interrupt occurs during the execution of a division instruction.

With low-latency interrupt mode, the time to enter the ISR is significantly reduced, since the interrupt vector for each individual interrupt is directly supplied by the Interrupt Controller. With compiler support for fast interrupts, there is no need for a common ISR at all. Instead, the ISR for each individual interrupt will be directly called, and the compiler takes care of saving and restoring registers used by the ISR.

### **Equivalent Pseudocode**

```

r14 ← PC
if C_USE_INTERRUPT = 2
    PC ← Interrupt_Address
    Interrupt_Ack ← 01
else
    PC ← C_BASE_VECTORS + 0x00000010
    MSR[IE] ← 0
    MSR[UMS] ← MSR[UM], MSR[UM] ← 0, MSR[VMS] ← MSR[VM], MSR[VM] ← 0
    Reservation ← 0

```

### **User Vector (Exception)**

The user exception vector is located at address 0x8. A user exception is caused by inserting a 'BRALID Rx,0x8' instruction in the software flow. Although Rx could be any general purpose register, Xilinx recommends using R15 for storing the user exception return address, and to use the RTSD instruction to return from the user exception handler.

### **Pseudocode**

```

rx ← PC
PC ← C_BASE_VECTORS + 0x00000008
MSR[UMS] ← MSR[UM], MSR[UM] ← 0, MSR[VMS] ← MSR[VM], MSR[VM] ← 0
Reservation ← 0

```

# Instruction Cache

## Overview

MicroBlaze can be used with an optional instruction cache for improved performance when executing code that resides outside the LMB address range.

The instruction cache has the following features:

- Direct mapped (1-way associative)
- User selectable cacheable memory address range
- Configurable cache and tag size
- Caching over AXI4 interface (M\_AXI\_IC)
- Option to use 4, 8 or 16 word cache-line
- Cache on and off controlled using a bit in the MSR
- Optional WIC instruction to invalidate instruction cache lines
- Optional stream buffers to improve performance by speculatively prefetching instructions
- Optional victim cache to improve performance by saving evicted cache lines
- Optional parity protection that invalidates cache lines if a Block RAM bit error is detected
- Optional data width selection to either use 32 bits, an entire cache line, or 512 bits

## General Instruction Cache Functionality

When the instruction cache is used, the memory address space is split into two segments: a cacheable segment and a non-cacheable segment. The cacheable segment is determined by two parameters: `C_ICACHE_BASEADDR` and `C_ICACHE_HIGHADDR`. All addresses within this range correspond to the cacheable address segment. All other addresses are non-cacheable.

The cacheable segment size must be  $2^N$ , where  $N$  is a positive integer. The range specified by `C_ICACHE_BASEADDR` and `C_ICACHE_HIGHADDR` must comprise a complete power-of-two range, such that  $\text{range} = 2^N$  and the  $N$  least significant bits of `C_ICACHE_BASEADDR` must be zero.

The cacheable instruction address consists of two parts: the cache address, and the tag address. The MicroBlaze instruction cache can be configured from 64 bytes to 64 kB. This corresponds to a cache address of between 6 and 16 bits. The tag address together with the cache address should match the full address of cacheable memory. When selecting cache



sizes below 2 kB, distributed RAM is used to implement the Tag RAM and Instruction RAM. Distributed RAM is always used to implement the Tag RAM, when setting the parameter `C_ICACHE_FORCE_TAG_LUTRAM` to 1. This parameter is only available with cache size 8 kB and less for 4 word cache-lines, with 16 kB and less for 8 word cache-lines, and with 32 kB and less for 16 word cache-lines.

For example: in a MicroBlaze configured with `C_ICACHE_BASEADDR= 0x00300000`, `C_ICACHE_HIGHADDR=0x0030ffff`, `C_CACHE_BYTE_SIZE=4096`, `C_ICACHE_LINE_LEN=8`, and `C_ICACHE_FORCE_TAG_LUTRAM=0`; the cacheable memory of 64 kB uses 16 bits of byte address, and the 4 kB cache uses 12 bits of byte address, thus the required address tag width is:  $16-12=4$  bits. The total number of block RAM primitives required in this configuration is: 2 RAMB16 for storing the 1024 instruction words, and 1 RAMB16 for 128 cache line entries, each consisting of: 4 bits of tag, 8 word-valid bits, 1 line-valid bit. In total 3 RAMB16 primitives.

Figure 2-22, page 77 shows the organization of Instruction Cache.

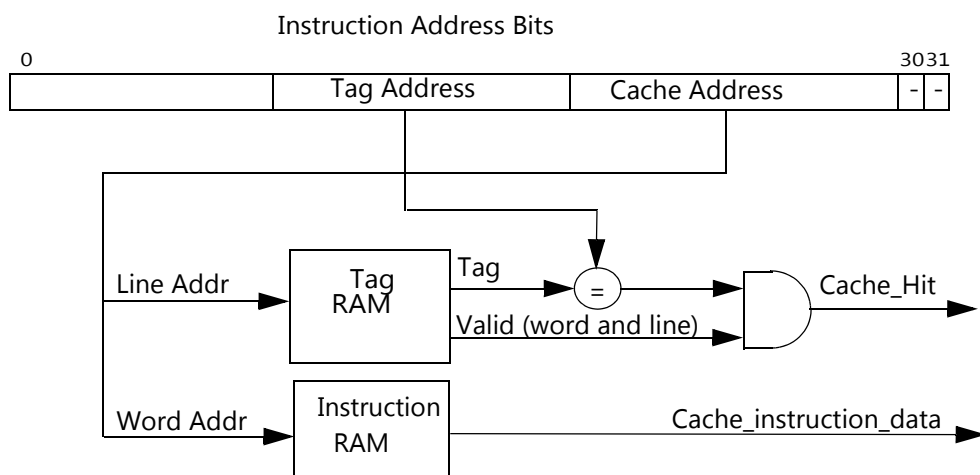


Figure 2-22: **Instruction Cache Organization**

## Instruction Cache Operation

For every instruction fetched, the instruction cache detects if the instruction address belongs to the cacheable segment. If the address is non-cacheable, the cache controller ignores the instruction and lets the M\_AXI\_IP or LMB complete the request. If the address is cacheable, a lookup is performed on the tag memory to check if the requested address is currently cached. The lookup is successful if: the word and line valid bits are set, and the tag address matches the instruction address tag segment. On a cache miss, the cache controller requests the new instruction over the instruction AXI4 interface (M\_AXI\_IC), and waits for the memory controller to return the associated cache line.

`C_ICACHE_DATA_WIDTH` determines the bus data width, either 32 bits, an entire cache line (128, 256 or 512 bits), or 512 bits.

When `C_FAULT_TOLERANT` is set to 1, a cache miss also occurs if a parity error is detected in a tag or instruction Block RAM.

The instruction cache issues burst accesses for the AXI4 interface when 32-bit data width is used, otherwise single accesses are used.

### ***Stream Buffers***

When stream buffers are enabled, by setting the parameter `C_ICACHE_STREAMS` to 1, the cache will speculatively fetch cache lines in advance in sequence following the last requested address, until the stream buffer is full. The stream buffer can hold up to two cache lines. Should the processor subsequently request instructions from a cache line prefetched by the stream buffer, which occurs in linear code, they are immediately available.

The stream buffer often improves performance, since the processor generally has to spend less time waiting for instructions to be fetched from memory.

`C_ICACHE_DATA_WIDTH` determines the amount of data transferred from the stream buffer each clock cycle, either 32 bits or an entire cache line.

To be able to use instruction cache stream buffers, area optimization must not be enabled.

### ***Victim Cache***

The victim cache is enabled by setting the parameter `C_ICACHE_VICTIMS` to 2, 4 or 8. This defines the number of cache lines that can be stored in the victim cache. Whenever a cache line is evicted from the cache, it is saved in the victim cache. By saving the most recent lines they can be fetched much faster, should the processor request them, thereby improving performance. If the victim cache is not used, all evicted cache lines must be read from memory again when they are needed.

`C_ICACHE_DATA_WIDTH` determines the amount of data transferred from/to the victim cache each clock cycle, either 32 bits or an entire cache line.

Note that to be able to use the victim cache, area optimization must not be enabled.

## **Instruction Cache Software Support**

### ***MSR Bit***

The ICE bit in the MSR provides software control to enable and disable caches.

The contents of the cache are preserved by default when the cache is disabled. You can invalidate cache lines using the WIC instruction or using the hardware debug logic of MicroBlaze.

### ***WIC Instruction***

The optional WIC instruction (`C_ALLOW_ICACHE_WR=1`) is used to invalidate cache lines in the instruction cache from an application. For a detailed description, refer to [Chapter 5, MicroBlaze Instruction Set Architecture](#).

The WIC instruction can also be used together with parity protection to periodically invalidate entries the cache, to avoid accumulating errors.

# Data Cache

## Overview

MicroBlaze can be used with an optional data cache for improved performance. The cached memory range must not include addresses in the LMB address range. The data cache has the following features:

- Direct mapped (1-way associative)
- Write-through or Write-back
- User selectable cacheable memory address range
- Configurable cache size and tag size
- Caching over AXI4 interface (M\_AXI\_DC)
- Option to use 4, 8 or 16 word cache-lines
- Cache on and off controlled using a bit in the MSR
- Optional WDC instruction to invalidate or flush data cache lines
- Optional victim cache with write-back to improve performance by saving evicted cache lines
- Optional parity protection for write-through cache that invalidates cache lines if a Block RAM bit error is detected
- Optional data width selection to either use 32 bits, an entire cache line, or 512 bits

## General Data Cache Functionality

When the data cache is used, the memory address space is split into two segments: a cacheable segment and a non-cacheable segment. The cacheable area is determined by two parameters: `C_DCACHE_BASEADDR` and `C_DCACHE_HIGHADDR`. All addresses within this range correspond to the cacheable address space. All other addresses are non-cacheable.

The cacheable segment size must be  $2^N$ , where  $N$  is a positive integer. The range specified by `C_DCACHE_BASEADDR` and `C_DCACHE_HIGHADDR` must comprise a complete power-of-two range, such that  $\text{range} = 2^N$  and the  $N$  least significant bits of `C_DCACHE_BASEADDR` must be zero.

Figure 2-23 shows the Data Cache Organization.

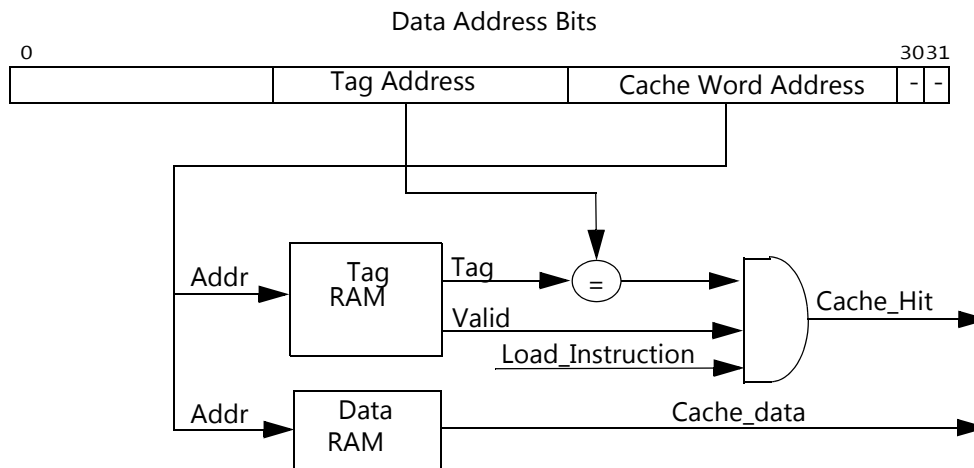


Figure 2-23: Data Cache Organization

The cacheable data address consists of two parts: the cache address, and the tag address. The MicroBlaze data cache can be configured from 64 bytes to 64 kB. This corresponds to a cache address of between 6 and 16 bits. The tag address together with the cache address should match the full address of cacheable memory. When selecting cache sizes below 2 kB, distributed RAM is used to implement the Tag RAM and Data RAM, except that block RAM is always used for the Data RAM when `C_AREA_OPTIMIZED` is set to 1 (Area) and `C_DCACHE_USE_WRITEBACK` is not set. Distributed RAM is always used to implement the Tag RAM, when setting the parameter `C_DCACHE_FORCE_TAG_LUTRAM` to 1. This parameter is only available with cache size 8 kB and less for 4 word cache-lines, with 16 kB and less for 8 word cache-lines, and with 32 kB and less for 16 word cache-lines.

For example, in a MicroBlaze configured with `C_DCACHE_BASEADDR=0x00400000`, `C_DCACHE_HIGHADDR=0x00403fff`, `C_DCACHE_BYTE_SIZE=2048`, `C_DCACHE_LINE_LEN=4`, and `C_DCACHE_FORCE_TAG_LUTRAM=0`; the cacheable memory of 16 kB uses 14 bits of byte address, and the 2 kB cache uses 11 bits of byte address, thus the required address tag width is  $14-11=3$  bits. The total number of block RAM primitives required in this configuration is 1 RAMB16 for storing the 512 data words, and 1 RAMB16 for 128 cache line entries, each consisting of 3 bits of tag, 4 word-valid bits, 1 line-valid bit. In total, 2 RAMB16 primitives.

## Data Cache Operation

The caching policy used by the MicroBlaze data cache, write-back or write-through, is determined by the parameter `C_DCACHE_USE_WRITEBACK`. When this parameter is set, a write-back protocol is implemented, otherwise write-through is implemented. However, when configured with an MMU (`C_USE_MMU > 1`, `C_AREA_OPTIMIZED = 0` (Performance) or 2 (Frequency), `C_DCACHE_USE_WRITEBACK = 1`), the caching policy in virtual mode is determined by the W storage attribute in the TLB entry, whereas write-back is used in real mode.

With the write-back protocol, a store to an address within the cacheable range always updates the cached data. If the target address word is not in the cache (that is, the access is a cache miss), and the location in the cache contains data that has not yet been written to memory (the cache location is dirty), the old data is written over the data AXI4 interface (M\_AXI\_DC) to external memory before updating the cache with the new data. If only a single word needs to be written, a single word write is used, otherwise a burst write is used. For byte or halfword stores, in case of a cache miss, the address is first requested over the data AXI4 interface, while a word store only updates the cache.

With the write-through protocol, a store to an address within the cacheable range generates an equivalent byte, halfword, or word write over the data AXI4 interface to external memory. The write also updates the cached data if the target address word is in the cache (that is, the write is a cache hit). A write cache-miss does not load the associated cache line into the cache.

Provided that the cache is enabled a load from an address within the cacheable range triggers a check to determine if the requested data is currently cached. If it is (that is, on a cache hit) the requested data is retrieved from the cache. If not (that is, on a cache miss) the address is requested over the data AXI4 interface using a burst read, and the processor pipeline stalls until the cache line associated to the requested address is returned from the external memory controller.

The parameter `C_DCACHE_DATA_WIDTH` determines the bus data width, either 32 bits, an entire cache line (128, 256 or 512 bits), or 512 bits.

When `C_FAULT_TOLERANT` is set to 1 and write-through protocol is used, a cache miss also occurs if a parity error is detected in the tag or data Block RAM.

All types of accesses issued by the data cache AXI4 interface are summarized in [Table 2-39](#).

**Table 2-39: Data Cache Interface Accesses**

| Policy        | State          | Direction | Access Type                                                                                                     |
|---------------|----------------|-----------|-----------------------------------------------------------------------------------------------------------------|
| Write-through | Cache Enabled  | Read      | Burst for 32-bit interface non-exclusive access and exclusive access with ACE enabled, single access otherwise  |
|               |                | Write     | Single access                                                                                                   |
|               | Cache Disabled | Read      | Burst for 32-bit interface exclusive access with ACE enabled, single access otherwise                           |
|               |                | Write     | Single access                                                                                                   |
| Write-back    | Cache Enabled  | Read      | Burst for 32-bit interface, single access otherwise                                                             |
|               |                | Write     | Burst for 32-bit interface cache lines with more than one valid word, a single access otherwise                 |
|               | Cache Disabled | Read      | Burst for 32-bit interface non-exclusive access, discarding all but the desired data, a single access otherwise |
|               |                | Write     | Single access                                                                                                   |

### ***Victim Cache***

The victim cache is enabled by setting the parameter `C_DCACHE_VICTIMS` to 2, 4 or 8. This defines the number of cache lines that can be stored in the victim cache. Whenever a complete cache line is evicted from the cache, it is saved in the victim cache. By saving the most recent lines they can be fetched much faster, should the processor request them, thereby improving performance. If the victim cache is not used, all evicted cache lines must be read from memory again when they are needed.

With the AXI4 interface, `C_DCACHE_DATA_WIDTH` determines the amount of data transferred from/to the victim cache each clock cycle, either 32 bits or an entire cache line.

Note that to be able to use the victim cache, write-back must be enabled and area optimization must not be enabled.

## **Data Cache Software Support**

### ***MSR Bit***

The DCE bit in the MSR controls whether or not the cache is enabled. When disabling caches the user must ensure that all the prior writes within the cacheable range have been completed in external memory before reading back over `M_AXI_DP`. This can be done by writing to a semaphore immediately before turning off caches, and then in a loop poll until it has been written.

The contents of the cache are preserved when the cache is disabled.

### ***WDC Instruction***

The optional WDC instruction (`C_ALLOW_DCACHE_WR=1`) is used to invalidate or flush cache lines in the data cache from an application. For a detailed description, please refer to [Chapter 5, MicroBlaze Instruction Set Architecture](#).

The WDC instruction can also be used together with parity protection to periodically invalidate entries the cache, to avoid accumulating errors.

With an external L2 cache, such as the System Cache, connected to MicroBlaze via the ACE interface, external cache invalidate or flush can be performed with WDC. See *LogiCore IP System Cache* ([PG118](#)) for more information on the System Cache.

# Floating Point Unit (FPU)

## Overview

The MicroBlaze floating point unit is based on the [IEEE 754-1985 standard](#):

- Uses IEEE 754 single precision floating point format, including definitions for infinity, not-a-number (NaN), and zero
- Supports addition, subtraction, multiplication, division, comparison, conversion and square root instructions
- Implements round-to-nearest mode
- Generates sticky status bits for: underflow, overflow, divide-by-zero and invalid operation

For improved performance, the following non-standard simplifications are made:

- Denormalized<sup>(1)</sup> operands are not supported. A hardware floating point operation on a denormalized number returns a quiet NaN and sets the sticky denormalized operand error bit in FSR; see "Floating Point Status Register (FSR)" on page 31
- A denormalized result is stored as a signed 0 with the underflow bit set in FSR. This method is commonly referred to as Flush-to-Zero (FTZ)
- An operation on a quiet NaN returns the fixed NaN: 0xFFC00000, rather than one of the NaN operands
- Overflow as a result of a floating point operation always returns signed  $\infty$

## Format

An IEEE 754 single precision floating point number is composed of the following three fields:

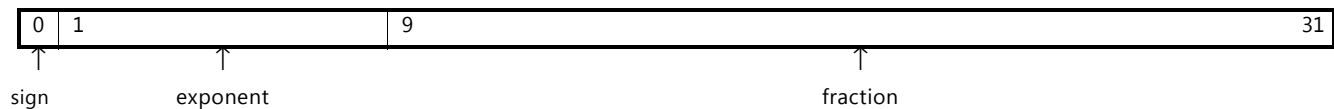
1. 1-bit *sign*
2. 8-bit biased *exponent*
3. 23-bit *fraction* (a.k.a. mantissa or significand)

---

1. Numbers that are so close to 0, that they cannot be represented with full precision, that is, any number  $n$  that falls in the following ranges: (  $1.17549 \times 10^{-38} > n > 0$  ), or (  $0 > n > -1.17549 \times 10^{-38}$  )



The fields are stored in a 32 bit word as defined in [Figure 2-24](#):



**Figure 2-24: IEEE 754 Single Precision Format**

The value of a floating point number  $v$  in MicroBlaze has the following interpretation:

1. If  $exponent = 255$  and  $fraction \neq 0$ , then  $v = NaN$ , regardless of the  $sign$  bit
2. If  $exponent = 255$  and  $fraction = 0$ , then  $v = (-1)^{sign} * \infty$
3. If  $0 < exponent < 255$ , then  $v = (-1)^{sign} * 2^{(exponent-127)} * (1.fraction)$
4. If  $exponent = 0$  and  $fraction \neq 0$ , then  $v = (-1)^{sign} * 2^{-126} * (0.fraction)$
5. If  $exponent = 0$  and  $fraction = 0$ , then  $v = (-1)^{sign} * 0$

For practical purposes only 3 and 5 are useful, while the others all represent either an error or numbers that can no longer be represented with full precision in a 32 bit format.

## Rounding

The MicroBlaze FPU only implements the default rounding mode, "Round-to-nearest", specified in IEEE 754. By definition, the result of any floating point operation should return the nearest single precision value to the infinitely precise result. If the two nearest representable values are equally near, then the one with its least significant bit zero is returned.

## Operations

All MicroBlaze FPU operations use the processors general purpose registers rather than a dedicated floating point register file, see ["General Purpose Registers"](#).

### Arithmetic

The FPU implements the following floating point operations:

- addition, fadd
- subtraction, fsub
- multiplication, fmul
- division, fdiv
- square root, fsqrt (available if `C_USE_FPU = 2, EXTENDED`)

## **Comparison**

The FPU implements the following floating point comparisons:

- compare less-than, `fcmp.lt`
- compare equal, `fcmp.eq`
- compare less-or-equal, `fcmp.le`
- compare greater-than, `fcmp.gt`
- compare not-equal, `fcmp.ne`
- compare greater-or-equal, `fcmp.ge`
- compare unordered, `fcmp.un` (used for NaN)

## **Conversion**

The FPU implements the following conversions (available if `C_USE_FPU = 2, EXTENDED`):

- convert from signed integer to floating point, `flt`
- convert from floating point to signed integer, `fint`

## **Exceptions**

The floating point unit uses the regular hardware exception mechanism in MicroBlaze. When enabled, exceptions are thrown for all the IEEE standard conditions: underflow, overflow, divide-by-zero, and illegal operation, as well as for the MicroBlaze specific exception: denormalized operand error.

A floating point exception inhibits the write to the destination register (Rd). This allows a floating point exception handler to operate on the uncorrupted register file.

## **Software Support**

The SDK compiler system, based on GCC, provides support for the Floating Point Unit compliant with the MicroBlaze API. Compiler flags are automatically added to the GCC command line based on the type of FPU present in the system, when using SDK.

All double-precision operations are emulated in software. Be aware that the `xil_printf()` function does not support floating-point output. The standard C library `printf()` and related functions do support floating-point output, but will increase the program code size.

## ***Libraries and Binary Compatibility***

The SDK compiler system only includes software floating point C runtime libraries. To take advantage of the hardware FPU, the libraries must be recompiled with the appropriate compiler switches.

For all cases where separate compilation is used, it is very important that you ensure the consistency of FPU compiler flags throughout the build.

## ***Operator Latencies***

The latencies of the various operations supported by the FPU are listed in [Chapter 5, “MicroBlaze Instruction Set Architecture.”](#) The FPU instructions are not pipelined, so only one operation can be ongoing at any time.

## ***C Language Programming***

To gain maximum benefit from the FPU without low-level assembly-language programming, it is important to consider how the C compiler will interpret your source code. Very often the same algorithm can be expressed in many different ways, and some are more efficient than others.

### **Immediate Constants**

Floating-point constants in C are double-precision by default. When using a single-precision FPU, careless coding may result in double-precision software emulation routines being used instead of the native single-precision instructions. To avoid this, explicitly specify (by cast or suffix) that immediate constants in your arithmetic expressions are single-precision values.

For example:

```
float x = 0.0;
...
x += (float)1.0; /* float addition */
x += 1.0F;      /* alternative to above */
x += 1.0;       /* warning - uses double addition! */
```

Note that the GNU C compiler can be instructed to treat all floating-point constants as single-precision (contrary to the ANSI C standard) by supplying the compiler flag `-fsingle-precision-constants`.

### **Avoid unnecessary casting**

While conversions between floating-point and integer formats are supported in hardware by the FPU, when `C_USE_FPU` is set to 2 (Extended), it is still best to avoid them when possible.

The following “bad” example calculates the sum of squares of the integers from 1 to 10 using floating-point representation:

```
float sum, t;
int i;
sum = 0.0f;
for (i = 1; i <= 10; i++) {
    t = (float)i;
    sum += t * t;
}
```

The above code requires a cast from an integer to a float on each loop iteration. This can be rewritten as:

```
float sum, t;
int i;
t = sum = 0.0f;
for(i = 1; i <= 10; i++) {
    t += 1.0f;
    sum += t * t;
}
```

Note that the compiler is not at liberty to perform this optimization in general, as the two code fragments above may give different results in some cases (for example, very large t).

### Square root runtime library function

The standard C runtime math library functions operate using double-precision arithmetic. When using a single-precision FPU, calls to the square root functions (`sqrt()`) result in inefficient emulation routines being used instead of FPU instructions:

```
#include <math.h>
...
float x=-1.0F;
...
x = sqrt(x); /* uses double precision */
```

Here the `math.h` header is included to avoid a warning message from the compiler.

When used with single-precision data types, the result is a cast to double, a runtime library call is made (which does not use the FPU) and then a truncation back to float is performed.

The solution is to use the non-ANSI function `sqrtof()` instead, which operates using single precision and can be carried out using the FPU. For example:

```
#include <math.h>
...
float x=-1.0F;
...
x = sqrtof(x); /* uses single precision */
```

Note that when compiling this code, the compiler flag `-fno-math-errno` (in addition to `-mhard-float` and `-mxl-float-sqrt`) must be used, to ensure that the compiler does not generate unnecessary code to handle error conditions by updating the `errno` variable.

## Stream Link Interfaces

MicroBlaze can be configured with up to 16 AXI4-Stream interfaces, each consisting of one input and one output port. The channels are dedicated uni-directional point-to-point data streaming interfaces.

For detailed information on the AXI4-Stream interface, please refer to the *AMBA 4 AXI4-Stream Protocol Specification, Version 1.0* ([ARM IHI 0051A](#)) document.

The interfaces on MicroBlaze are 32 bits wide. A separate bit indicates whether the sent/received word is of control or data type. The get instruction in the MicroBlaze ISA is used to transfer information from a port to a general purpose register. The put instruction is used to transfer data in the opposite direction. Both instructions come in 4 flavors: blocking data, non-blocking data, blocking control, and non-blocking control. For a detailed description of the get and put instructions, please refer to [Chapter 5, MicroBlaze Instruction Set Architecture](#).

## Hardware Acceleration

Each link provides a low latency dedicated interface to the processor pipeline. Thus they are ideal for extending the processors execution unit with custom hardware accelerators. A simple example is illustrated in [Figure 2-25](#). The code uses RFSLx to indicate the used link.

Example code:

```
// Configure  $f_x$ 
cput Rc, RFSLx

// Store operands
put Ra, RFSLx // op 1
put Rb, RFSLx // op 2

// Load result
```

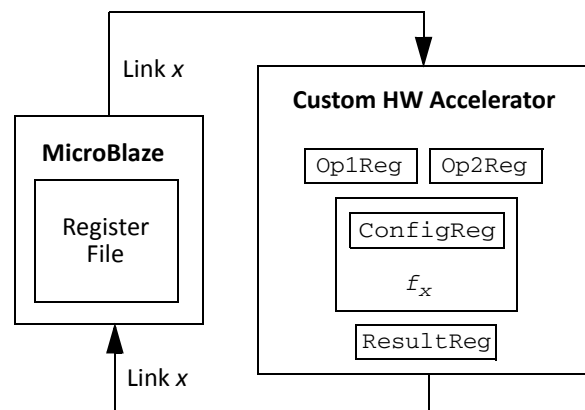


Figure 2-25: **Stream Link Used with HW Accelerated Function  $f_x$**

This method is similar to extending the ISA with custom instructions, but has the benefit of not making the overall speed of the processor pipeline dependent on the custom function. Also, there are no additional requirements on the software tool chain associated with this type of functional extension.

# Debug and Trace

## Debug Overview

MicroBlaze features a debug interface to support JTAG based software debugging tools (commonly known as BDM or Background Debug Mode debuggers) like the Xilinx System Debugger (XSDB) tool. The debug interface is designed to be connected to the Xilinx Microprocessor Debug Module (MDM) core, which interfaces with the JTAG port of Xilinx FPGAs. Multiple MicroBlaze instances can be interfaced with a single MDM to enable multiprocessor debugging.

To be able to download programs, set software breakpoints and disassemble code, the instruction and data memory ranges must overlap, and use the same physical memory.

Debug registers are accessed via the debug interface, and are not directly visible to software running on the processor, unless the MDM is configured to enable software access to user-accessible debug registers. The debug interface can either use JTAG serial access or AXI4-Lite parallel access, controlled by the parameter `C_DEBUG_INTERFACE`.

See the *MicroBlaze Debug Module (MDM) Product Guide* ([PG115](#)) for a detailed description of the MDM features.

The basic debugging features enabled by setting `C_DEBUG_ENABLED` to 1 (Basic) include:

- Configurable number of hardware breakpoints and watchpoints and unlimited software breakpoints
- External processor control enables debug tools to stop, reset, and single step MicroBlaze
- Read from and write to: memory, general purpose registers, and special purpose register, except EAR, EDR, ESR, BTR and PVR0 - PVR12, which can only be read
- Support for multiple processors

The extended debugging features enabled by setting `C_DEBUG_ENABLED` to 2 (Extended) include:

- Configurable number of performance monitoring event and latency counters
- Program Trace:
  - Embedded program trace with configurable trace buffer size
  - External program trace for multiple processors, provided by the MDM
- Non-intrusive profiling support with configurable profiling buffer size
- Cross trigger support between multiple processors, and external cross trigger inputs and outputs, provided by the MDM

## Performance Monitoring

With extended debugging, MicroBlaze provides performance monitoring counters to count various events and to measure latency during program execution. The number of event counters and latency counters can be configured with `C_DEBUG_EVENT_COUNTERS` and `C_DEBUG_LATENCY_COUNTERS` respectively, and the counter width can be set to 32, 48 or 64 bits with `C_DEBUG_COUNTER_WIDTH`. With the default configuration, the counter width is set to 32 bits and there are five event counters and one latency counter.

An event counter simply counts the number of times a certain event has occurred, whereas a latency counter provides the following information:

- Number of times the event has occurred ( $N$ )
- The sum of each event latency measured by counting clock cycles from the event starts until it finishes ( $\Sigma L$ ), used to calculate the mean latency
- The sum of each event latency squared ( $\Sigma L^2$ ), used to calculate the latency standard deviation
- The minimum, shortest, measured latency for all events ( $L_{min}$ )
- The maximum, longest, measured latency for all events ( $L_{max}$ )

The mean latency ( $\mu$ ) is calculated by the formula:

$$\mu = \frac{\Sigma L}{N}$$

The standard deviation ( $\sigma$ ) of the latency is calculated by the formula:

$$\sigma = \frac{\sqrt{N \Sigma L^2 - (\Sigma L)^2}}{N}$$

Counting can be started or stopped via the Performance Counter Command Register or by cross trigger events (see [Table 2-61](#)).

When configuring, reading or writing counters, they are accessed sequentially through the performance counter registers. After every access the selected counter item is incremented.

All counters are sampled simultaneously for reading via the Performance Counter Command Register. This can be done while counting, or after counting has been stopped.

When an event counter reaches its maximum value, the overflow status bit is set, and the external interrupt signal `Dbg_Intr` is set to one. The interrupt signal is reset to zero by clearing the counters via the Performance Counter Command Register.

By using one of the event counters to count number of clock cycles, and initializing this counter to overflow after a predetermined sampling interval, the external interrupt can be used to periodically sample the performance counters.

The available events are described in [Table 2-40](#), listed in numerical order.

A typical procedure to follow when initializing and using the performance monitoring counters is delineated in the steps below.

- Initialize the events to be monitored:
  - Use the Performance Command Register (Table 2-43) to reset the selected counter to the first counter, by setting the Reset bit.
  - Write the desired event numbers for all counters in order, using the Performance Control Register (Table 2-42). With the default configuration this means writing the register five times for the event counters and then once for the latency counter.
- Clear all counters and start monitoring using the Performance Command Register, by setting the Clear and Start bits.
- Run the program or function to be monitored.
- Sample counters and stop monitoring using the Performance Command Register, by setting the Sample and Stop bits.
- Read the results from all counters:
  - Use the Performance Command Register to reset the selected counter to the first counter, by setting the Reset bit.
  - Read the status for all counters in order, using the Performance Counter Status Register (Table 2-44). With the default configuration this means reading the register five times for the event counters and then once for the latency counter. Ensure that the result is valid by checking that the overflow and full bits are not set.
  - Use the Performance Command Register to reset the selected counter to the first counter, by setting the Reset bit.
  - Read the counter items for all counters in order, using the Performance Counter Data Read Register (Table 2-45). With the default configuration this means reading the register five times for the event counters and then four times for the latency counter as described in Table 2-46.
- Calculate the final results, depending on the measured events, for example:
  - Use the formulas above to determine the mean latency and standard deviation for any measured latency.
  - The clock cycles per instruction (CPI) can be calculated by  $E_{30} / E_0$ .
  - The instruction and data cache hit rates can be calculated by  $E_{11} / E_{10}$  and  $E_{47} / E_{46}$ .
  - The instruction cache miss latency is determined by  $(E_{60}(\Sigma L) - E_{60}(N)) / (E_{10} - E_{11})$ , and equivalent formulas can be used to determine the data cache read and write miss latencies.
  - The ratio of floating point instructions in a program is  $E_{29}/E_0$ .



Table 2-40: MicroBlaze Performance Monitoring Events

| Event                            | Description                                                                                  | Event | Description                                                                                           |
|----------------------------------|----------------------------------------------------------------------------------------------|-------|-------------------------------------------------------------------------------------------------------|
| Event Counter events             |                                                                                              |       |                                                                                                       |
| 0                                | Any valid instruction executed                                                               | 29    | Floating point ( <i>fadd</i> , ..., <i>fsqrt</i> )                                                    |
| 1                                | Load word ( <i>lw</i> , <i>lwi</i> , <i>lwx</i> ) executed                                   | 30    | Number of clock cycles                                                                                |
| 2                                | Load halfword ( <i>lhu</i> , <i>lhui</i> ) executed                                          | 31    | Immediate ( <i>imm</i> ) executed                                                                     |
| 3                                | Load byte ( <i>lbu</i> , <i>lbui</i> ) executed                                              | 32    | Pattern compare ( <i>pcmpbf</i> , <i>pcmpeq</i> , <i>pcmpne</i> )                                     |
| 4                                | Store word ( <i>sw</i> , <i>swi</i> , <i>swx</i> ) executed                                  | 33    | Sign extend instructions ( <i>sxt8</i> , <i>sxt16</i> ) executed                                      |
| 5                                | Store halfword ( <i>sh</i> , <i>shi</i> ) executed                                           | 34    | Instruction cache invalidate ( <i>wic</i> ) executed                                                  |
| 6                                | Store byte ( <i>sb</i> , <i>sbi</i> ) executed                                               | 35    | Data cache invalidate or flush ( <i>wdc</i> ) executed                                                |
| 7                                | Unconditional branch ( <i>br</i> , <i>bri</i> , <i>brk</i> , <i>brki</i> ) executed          | 36    | Machine status instructions ( <i>msrset</i> , <i>msrclr</i> )                                         |
| 8                                | Taken conditional branch ( <i>beq</i> , ..., <i>bnei</i> ) executed                          | 37    | Unconditional branch with delay slot executed                                                         |
| 9                                | Not taken conditional branch ( <i>beq</i> , ..., <i>bnei</i> ) executed                      | 38    | Taken conditional branch with delay slot executed                                                     |
| 10                               | Data request from instruction cache                                                          | 39    | Not taken conditional branch with delay slot                                                          |
| 11                               | Hit in instruction cache                                                                     | 40    | Delay slot with no operation instruction executed                                                     |
| 12                               | Read data requested from data cache                                                          | 41    | Load instruction ( <i>lbu</i> , ..., <i>lwx</i> ) executed                                            |
| 13                               | Read data hit in data cache                                                                  | 42    | Store instruction ( <i>sb</i> , ..., <i>swx</i> ) executed                                            |
| 14                               | Write data request to data cache                                                             | 43    | MMU data access request                                                                               |
| 15                               | Write data hit in data cache                                                                 | 44    | Conditional branch ( <i>beq</i> , ..., <i>bnei</i> ) executed                                         |
| 16                               | Load ( <i>lbu</i> , ..., <i>lwx</i> ) with r1 as operand executed                            | 45    | Branch ( <i>br</i> , <i>bri</i> , <i>brk</i> , <i>brki</i> , <i>beq</i> , ..., <i>bnei</i> ) executed |
| 17                               | Store ( <i>sb</i> , ..., <i>swx</i> ) with r1 as operand executed                            | 46    | Read or write data request from/to data cache                                                         |
| 18                               | Logical operation ( <i>and</i> , <i>andn</i> , <i>or</i> , <i>xor</i> ) executed             | 47    | Read or write data cache hit                                                                          |
| 19                               | Arithmetic operation ( <i>add</i> , <i>idiv</i> , <i>mul</i> , <i>rsub</i> ) executed        | 48    | MMU exception taken                                                                                   |
| 20                               | Multiply operation ( <i>mul</i> , <i>mulh</i> , <i>mulhu</i> , <i>mulhsu</i> , <i>muli</i> ) | 49    | MMU instruction side exception taken                                                                  |
| 21                               | Barrel shifter operation ( <i>bsrl</i> , <i>bsra</i> , <i>bsll</i> ) executed                | 50    | MMU data side exception taken                                                                         |
| 22                               | Shift operation ( <i>sra</i> , <i>src</i> , <i>srl</i> ) executed                            | 51    | Pipeline stalled                                                                                      |
| 23                               | Exception taken                                                                              | 52    | Branch target cache hit for a branch or return                                                        |
| 24                               | Interrupt occurred                                                                           | 53    | MMU instruction side access request                                                                   |
| 25                               | Pipeline stalled due to operand fetch stage (OF)                                             | 54    | MMU instruction TLB (ITLB) hit                                                                        |
| 26                               | Pipeline stalled due to execute stage (EX)                                                   | 55    | MMU data TLB (DTLB) hit                                                                               |
| 27                               | Pipeline stalled due to memory stage (MEM)                                                   | 56    | MMU unified TLB (UTLB) hit                                                                            |
| 28                               | Integer divide ( <i>idiv</i> , <i>idivu</i> ) executed                                       |       |                                                                                                       |
| Latency and Event Counter events |                                                                                              |       |                                                                                                       |
| 57                               | Interrupt latency from input to interrupt vector                                             | 61    | MMU address lookup latency                                                                            |
| 58                               | Data cache latency for memory read                                                           | 62    | Peripheral AXI interface data read latency                                                            |
| 59                               | Data cache latency for memory write                                                          | 63    | Peripheral AXI interface data write latency                                                           |
| 60                               | Instruction cache latency for memory read                                                    |       |                                                                                                       |

The debug registers used to configure and control performance monitoring, and to read or write the event and latency counters, are listed in [Table 2-41](#). All of these registers except the Performance Counter Command register are accessed repeatedly to read or write information, first for all of the event counters followed by all of the latency counters.

The DBG\_CTRL Value indicates the value to use in the MDM Debug Register Access Control Register to access the register, used with MDM software access to debug registers.

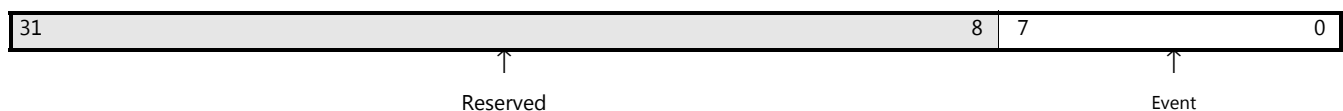
**Table 2-41: MicroBlaze Performance Monitoring Debug Registers**

| Register Name                  | Size (bits) | MDM Command | DBG_CTRL Value | R/W | Description                                                                       |
|--------------------------------|-------------|-------------|----------------|-----|-----------------------------------------------------------------------------------|
| Performance Counter Control    | 8           | 0101 0001   | 4A207          | W   | Select event for each configured counter, according to <a href="#">Table 2-40</a> |
| Performance Counter Command    | 5           | 0101 0010   | 4A404          | W   | Command to clear counters, start or stop counting, or sample counters             |
| Performance Counter Status     | 2           | 0101 0011   | 4A601          | R   | Read the sampled status for each configured performance counter                   |
| Performance Counter Data Read  | 32          | 0101 0110   | 4AC1F          | R   | Read the sampled values for each configured performance counter                   |
| Performance Counter Data Write | 32          | 0101 0111   | 4AE1F          | W   | Write initial values for each configured performance counter                      |

### Performance Counter Control Register

The Performance Counter Control Register (PCCTRLR) is used to define the events that are counted by the configured performance counters. To define the events for all configured counters, the register should be written repeatedly for each of the counters. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

Every time the register is written, the selected counter is incremented. By using the Performance Counter Command Register, the selected counter can be reset to the first counter again.



**Figure 2-26: Performance Counter Control Register**

**Table 2-42: Performance Counter Control Register (PCCTRLR)**

| Bits | Name  | Description                                                          | Reset Value |
|------|-------|----------------------------------------------------------------------|-------------|
| 7:0  | Event | Performance counter event, according to <a href="#">Table 2-40</a> . | 0           |

## Performance Counter Command Register

The Performance Counter Command Register (PCCMDR) is used to issue commands to clear, start, stop, or sample all counters. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

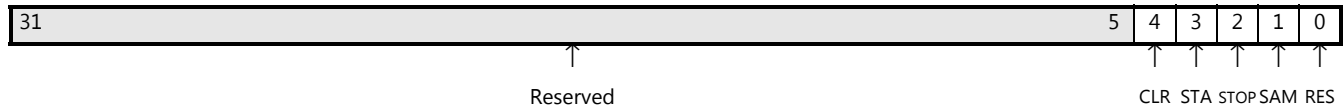


Figure 2-27: Performance Counter Command Register

Table 2-43: Performance Counter Command Register (PCCMDR)

| Bits | Name   | Description                                                                                                                          | Reset Value |
|------|--------|--------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 4    | Clear  | Clear all counters to zero                                                                                                           | 0           |
| 3    | Start  | Start counting configured events for all counters simultaneously                                                                     | 0           |
| 2    | Stop   | Stop counting all counters simultaneously                                                                                            | 0           |
| 1    | Sample | Sample status and values in all counters simultaneously for reading                                                                  | 0           |
| 0    | Reset  | Reset accessed counter to the first event counter for access using the Performance Counter Control, Status, Read Data and Write Data | 0           |

## Performance Counter Status Register

The Performance Counter Status Register (PCSR) reads the sampled status of the counters. To read the status for all configured counters, the register should be read repeatedly for each of the counters. This register is a read-only register. Issuing a write request to the register does nothing.

Every time the register is read, the selected counter is incremented. By using the Performance Counter Command Register, the selected counter can be reset to the first counter again.

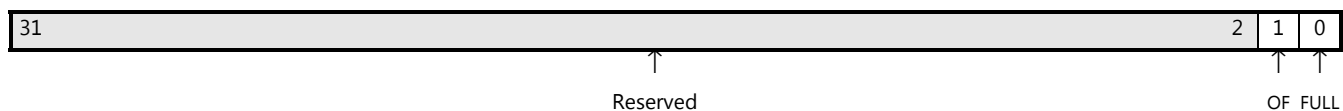


Figure 2-28: Performance Counter Status Register

Table 2-44: Performance Counter Status Register (PCSR)

| Bits | Name     | Description                                                                                                                                                             | Reset Value |
|------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 1    | Overflow | This bit is set when the counter has counted past its maximum value                                                                                                     | 0           |
| 0    | Full     | This bit is set when a new latency counter event is started before the previous event has finished. This indicates that the accuracy of the measured values is reduced. | 0           |

### Performance Counter Data Read Register

The Performance Counter Data Read Register (PCDRR) reads the sampled values of the counters. To read the values of all configured counters, the register should be read repeatedly. This register is a read-only register. Issuing a write request to the register does nothing.

Since a counter can have more than 32 bits, depending on the configuration, the register may need to be read repeatedly to retrieve all information for a particular counter. This is detailed in [Table 2-46](#).

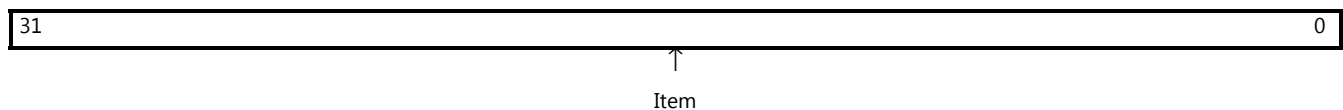


Figure 2-29: Performance Counter Data Read Register

Table 2-45: Performance Counter Data Read Register (PCDRR)

| Bits | Name | Description                | Reset Value |
|------|------|----------------------------|-------------|
| 31:0 | Item | Sampled counter value item | 0           |

Table 2-46: Performance Counter Data Items

| Counter Type               | Item | Description                                                                           |
|----------------------------|------|---------------------------------------------------------------------------------------|
| C_DEBUG_COUNTER_WIDTH = 32 |      |                                                                                       |
| Event Counter              | 1    | The number of times the event occurred                                                |
| Latency Counter            | 1    | The number of times the event occurred                                                |
|                            | 2    | The sum of each event latency                                                         |
|                            | 3    | The sum of each event latency squared                                                 |
|                            | 4    | 31:16 Minimum measured latency, 16 bits<br>15:0 Maximum measured latency, 16 bits     |
| C_DEBUG_COUNTER_WIDTH = 48 |      |                                                                                       |
| Event Counter              | 1    | 31:16 0x0000<br>15:0 The number of times the event occurred, 16 most significant bits |
|                            | 2    | The number of times the event occurred, 32 least significant bits                     |

Table 2-46: Performance Counter Data Items (Cont'd)

| Counter Type               | Item | Description                                                       |                                                                           |
|----------------------------|------|-------------------------------------------------------------------|---------------------------------------------------------------------------|
| Latency Counter            | 1    | The number of times the event occurred                            |                                                                           |
|                            | 2    | 31:16<br>15:0                                                     | 0x0000<br>The sum of each event latency, 16 most significant bits         |
|                            | 3    | The sum of each event latency, 32 least significant bits          |                                                                           |
|                            | 4    | 31:16<br>15:0                                                     | 0x0000<br>The sum of each event latency squared, 16 most significant bits |
|                            | 5    | The sum of each event latency squared, 32 least significant bits  |                                                                           |
|                            | 6    | Minimum measured latency, 32 bits                                 |                                                                           |
|                            | 7    | Maximum measured latency, 32 bits                                 |                                                                           |
| C_DEBUG_COUNTER_WIDTH = 64 |      |                                                                   |                                                                           |
| Event Counter              | 1    | The number of times the event occurred, 32 most significant bits  |                                                                           |
|                            | 2    | The number of times the event occurred, 32 least significant bits |                                                                           |
| Latency Counter            | 1    | The number of times the event occurred, 32 bits                   |                                                                           |
|                            | 2    | The sum of each event latency, 32 most significant bits           |                                                                           |
|                            | 3    | The sum of each event latency, 32 least significant bits          |                                                                           |
|                            | 4    | The sum of each event latency squared, 32 most significant bits   |                                                                           |
|                            | 5    | The sum of each event latency squared, 32 least significant bits  |                                                                           |
|                            | 6    | Minimum measured latency, 32 bits                                 |                                                                           |
|                            | 7    | Maximum measured latency, 32 bits                                 |                                                                           |

### Performance Counter Data Write Register

The Performance Counter Data Write Register (PCDWR) writes initial values to the counters. To write all configured counters, the register should be written repeatedly. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

Since a counter can have more than 32 bits, depending on the configuration, the register may need to be written repeatedly to update all information for a particular counter, as described in [Table 2-46](#).

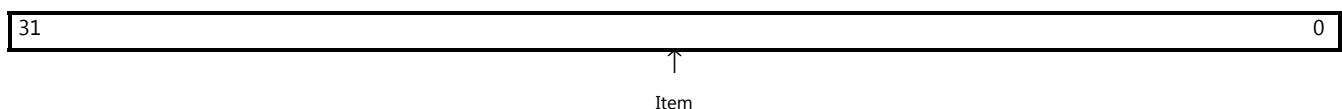


Figure 2-30: Performance Counter Data Write Register

Table 2-47: Performance Counter Data Write Register (PCDWR)

| Bits | Name | Description                                | Reset Value |
|------|------|--------------------------------------------|-------------|
| 31:0 | Item | Counter value item to write into a counter | 0           |

## Program Trace

With extended debugging, MicroBlaze provides program trace, either storing information in the Embedded Trace Buffer or transmitting it to the MDM, to enable program execution tracing. The MDM is used when the parameter `C_DEBUG_EXTERNAL_TRACE` is set, allowing output of program trace from multiple processors via external interfaces.

The size of the Embedded Trace Buffer can be configured from 8KB to 128KB using the parameter `C_DEBUG_TRACE_SIZE`. The default buffer size with external trace is 8KB, but it can also be configured from 32B to 256B to use distributed RAM. It is recommended to always keep the default 8KB size, unless Block-RAM resources are very scarce. By setting `C_DEBUG_TRACE_SIZE` to 0 (None), program trace is disabled.

Program trace uses compression to reduce the amount of trace data, while still allowing reconstruction of the program execution flow or the entire processor software state. There are three main compression levels:

- Complete trace

Stores complete trace information including cycle count for each executed instruction using 144 bits, ranging from 512 to 8192 items depending on the configured Embedded Trace Buffer size. Complete trace is not available when `C_DEBUG_EXTERNAL_TRACE` is set.

- Program flow

Stores program flow changes, that is the sequence of branches taken or not taken, and the new program counter for indirect branches, interrupts, exceptions and hardware breaks.

The program counter may also optionally be stored for return instructions to simplify program flow reconstruction, or for all taken branches to handle self-modifying code.

Data read from memory or fetched from AXI4-Stream interfaces may optionally be stored to allow reconstructing the entire processor software state, enabling reverse single step functionality. When the data access instruction is in a delay slot of a dynamic branch or return, the data is stored first followed by the branch target program counter. For data access instructions in delay slots of static branches, the program flow change is first saved followed by the data.

- Program flow and cycle count

Stores the cycle count between instructions along with the same information as program flow alone, to also allow reconstruction of the program execution time.

Tracing can be started via the Trace Command Register, by hitting a program breakpoint or watchpoint configured as a tracepoint in the Trace Control Register, or by a cross trigger event (see [Table 2-61](#)).

Tracing is automatically stopped when the trace buffer becomes full, and can be stopped via the Trace Command Register or by a cross trigger event (see [Table 2-61](#)).

The cycle count can measure up to 32768 clock cycles when using complete trace, and up to 8192 cycles between instructions when using program flow and cycle count. If the cycle count exceeds this value, the Trace Status Register overflow bit is set to one.

It is possible to configure trace to halt the processor when the trace buffer becomes full or when the cycle count overflows. This allows continuous trace of the entire program flow, albeit not in real time due to the time required to read the trace buffer.

The debug registers used to configure and control tracing, and to read the Embedded Trace Buffer, are listed in [Table 2-48](#).

The DBG\_CTRL Value indicates the value to use in the MDM Debug Register Access Control Register to access the register, used with MDM software access to debug registers.

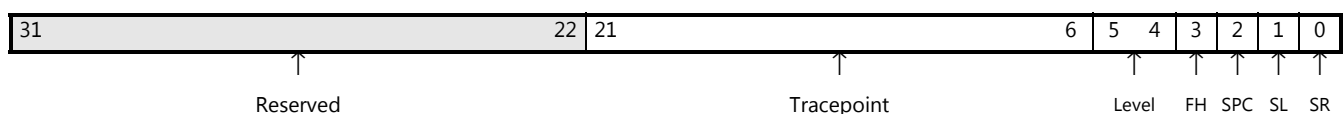
**Table 2-48: MicroBlaze Program Trace Debug Registers**

| Register Name                | Size (bits) | MDM Command | DBG_CTRL Value | R/W | Description                                                                                   |
|------------------------------|-------------|-------------|----------------|-----|-----------------------------------------------------------------------------------------------|
| Trace Control                | 22          | 0110 0001   | 4C215          | W   | Set tracepoints, trace compression level and optionally stored trace information              |
| Trace Command                | 4           | 0110 0010   | 4C403          | W   | Command to clear trace buffer, start or stop trace, and sample number of current buffer items |
| Trace Status                 | 18          | 0110 0011   | 4C611          | R   | Read the sampled trace buffer status                                                          |
| Trace Data Read <sup>1</sup> | 18          | 0110 0110   | 4CC11          | R   | Read the oldest item from the Embedded Trace Buffer                                           |

1. This register is not available when C\_DEBUG\_EXTERNAL\_TRACE is set

### Trace Control Register

The Trace Control Register (TCTRLR) is used to define the trace behavior. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.



**Figure 2-31: Trace Control Register**

Table 2-49: Trace Control Register (TCTRLR)

| Bits | Name        | Description                                                                                                                                                                  | Reset Value |
|------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 21:6 | Tracepoint  | Change corresponding breakpoint or watchpoint to a tracepoint                                                                                                                | 0           |
| 5:4  | Level       | Trace compression level:<br>00 = Complete trace, not available with C_DEBUG_EXTERNAL_TRACE<br>01 = Program flow<br>10 = <i>Reserved</i><br>11 = Program flow and cycle count | 00          |
| 3    | Full Halt   | Debug Halt on full trace buffer or cycle count overflow                                                                                                                      | 0           |
| 2    | Save PC     | Save new program counter for all taken branches                                                                                                                              | 0           |
| 1    | Save Load   | Save load and get instruction new data value                                                                                                                                 | 0           |
| 0    | Save Return | Save new program counter for return instructions                                                                                                                             | 0           |

### Trace Command Register

The Trace Command Register (TCMDR) is used to issue commands to clear, start, or stop trace, as well as sample the number of trace items. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

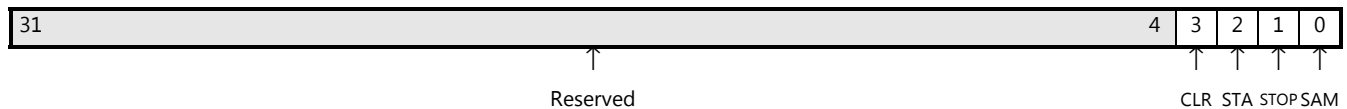


Figure 2-32: Trace Command Register

Table 2-50: Trace Command Register (TCMDR)

| Bits | Name   | Description                                            | Reset Value |
|------|--------|--------------------------------------------------------|-------------|
| 3    | Clear  | Clear trace status and empty the trace buffer          | 0           |
| 2    | Start  | Start trace immediately                                | 0           |
| 1    | Stop   | Stop trace immediately                                 | 0           |
| 0    | Sample | Sample the number of current items in the trace buffer | 0           |

### Trace Status Register

The Trace Status Register (TSR) can be used to determine if trace has been started or not, to check for cycle count overflow and to read the sampled number of items in the Embedded



Trace Buffer. This register is a read-only register. Issuing a write request to the register does nothing.

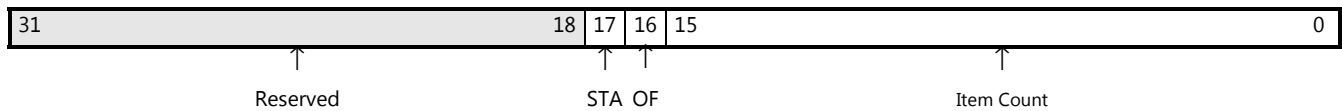


Figure 2-33: Trace Status Register

Table 2-51: Trace Status Register (TSR)

| Bits | Name       | Description                                                                                               | Reset Value |
|------|------------|-----------------------------------------------------------------------------------------------------------|-------------|
| 17   | Started    | Trace started, set to one when trace is started and cleared to zero when it is stopped                    | 0           |
| 16   | Overflow   | Cycle count overflow, set to one when the cycle count overflows, and cleared to zero by the Clear command | 0           |
| 15:0 | Item Count | Sampled trace buffer item count                                                                           | 0x0000      |

## Trace Data Read Register

The Trace Data Read Register (TDRR) contains the oldest item read from the Embedded Trace Buffer. When the register has been read, the next item is read from the trace buffer. It is an error to read more items than are available in the trace buffer, as indicated by the item count in the Trace Status Register. This register is a read-only register. Issuing a write request to the register does nothing.

Since a trace data entity can consist of more than 18 bits, depending on the compression level and stored data, the register may need to be read repeatedly to retrieve all information for a particular data entity. This is detailed in [Table 2-53](#).

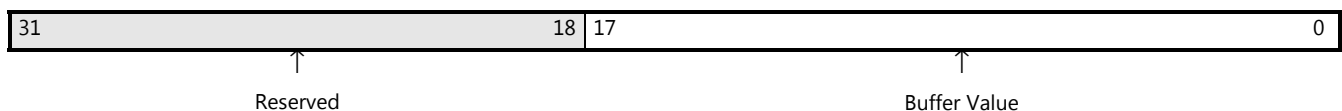


Figure 2-34: Trace Data Read Register

Table 2-52: Trace Data Read Register (TDRR)

| Bits | Name         | Description                | Reset Value |
|------|--------------|----------------------------|-------------|
| 17:0 | Buffer Value | Embedded Trace Buffer item | 0x00000     |

Table 2-53: Trace Counter Data Entities

| Entity                        | Item | Bits                                  | Description                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------|------|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Complete Trace                | 1    | 17:3<br>2:0                           | Cycle count for the executed instruction<br><a href="#">Machine Status Register</a> [17:19]                                                                                                                                                                                                                                                                                 |
|                               | 2    | 17:6<br>5:1<br>0                      | <a href="#">Machine Status Register</a> [20:31]<br>Destination register address (r0 - r31), valid if written<br>Destination register written if set to one                                                                                                                                                                                                                  |
|                               | 3    | 17:13<br>12<br>11<br>10<br>9:6<br>5:0 | <a href="#">Exception Kind</a> , valid if exception taken<br>Exception taken if set to one<br>Load instruction reading data if set to one<br>Store instruction writing data if set to one<br>Byte enable, valid for store instruction<br>Write data [0:5] for store instructions, or Destination register data [0:5] for other instructions                                 |
|                               | 4    | 17:0                                  | Write data [6:23] or Destination register data [6:23]                                                                                                                                                                                                                                                                                                                       |
|                               | 5    | 17:10<br>9:0                          | Write data [24:31] or Destination register data [24:31]<br>Data address [0:9] for load and store instructions, or Executed instruction [0:9] for other instruction                                                                                                                                                                                                          |
|                               | 6    | 17:0                                  | Data address [10:27] or Executed instruction [10:27]                                                                                                                                                                                                                                                                                                                        |
|                               | 7    | 17:14<br>13:0                         | Data address [28:31] or Executed instruction [28:31]<br><a href="#">Program Counter</a> [0:13]                                                                                                                                                                                                                                                                              |
|                               | 8    | 17:0                                  | <a href="#">Program Counter</a> [14:31]                                                                                                                                                                                                                                                                                                                                     |
| Program Flow: Branches        | 1    | 17:16<br>15:12<br>11:0                | 00 - The item contains program flow branches<br>Number of branches (N) counted in the item (0 - 12)<br>The N leftmost bits represent branches in the program flow. If the bit is set to one the branch is taken, otherwise it is not taken.<br><br>An item with 0 branches can be ignored, and may occur when flushing external trace, in order to complete a trace packet. |
| Program Flow: Program Counter | 1    | 17:16<br>15:0                         | 01 - The item contains a Program Counter value<br><a href="#">Program Counter</a> [0:15]                                                                                                                                                                                                                                                                                    |
|                               | 2    | 17:16<br>15:0                         | 01 - The item contains a Program Counter value<br><a href="#">Program Counter</a> [16:31]                                                                                                                                                                                                                                                                                   |
| Program Flow: Read Data       | 1    | 17:16<br>15:0                         | 10 - The item contains read data<br>Data read by load and get instructions [0:15]                                                                                                                                                                                                                                                                                           |
|                               | 2    | 17:16<br>15:0                         | 10 - The item contains read data<br>Data read by load and get instructions [15:31]                                                                                                                                                                                                                                                                                          |

**Table 2-53: Trace Counter Data Entities (Cont'd)**

| Entity                                                           | Item | Bits                                    | Description                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------|------|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Program Flow with Cycle Count:<br>Branches and short cycle count | 1    | 17:16<br>15:14<br>13:8<br>7<br>6:1<br>0 | 00 - The item contains program flow branches<br>01, 10 - Number of branches (N) counted (1 - 2)<br>Cycle count for previously executed instructions<br>Branch is taken if set to one, otherwise it is not taken<br>Cycle count for previously executed instructions<br>Branch is taken if set to one, otherwise it is not taken |
| Program Flow with Cycle Count:<br>Branch and long cycle count    | 1    | 17:16<br>15:14<br>13:1<br>0             | 00 - The item contains program flow branches<br>11 - The item contains branch and long cycle count<br>Cycle count for previously executed instructions<br>Branch is taken if set to one, otherwise it is not taken                                                                                                              |

## Non-Intrusive Profiling

With extended debugging, non-intrusive profiling is provided, which uses a Profiling Buffer to store program execution statistics. The size of the profiling buffer can be configured from 4KB to 128KB using the parameter `C_DEBUG_PROFILE_SIZE`. By setting `C_DEBUG_PROFILE_SIZE` to 0 (None), non-intrusive profiling is disabled.

The Profiling Buffer is divided into a number of bins, each counting the number of executed instructions or clock cycles within a certain address range. Each bin counts up to  $2^{36} - 1 = 68719476735$  instructions or cycles.

The address range of each bin is determined by the buffer size and the profiled address range defined via the Profiling Low Address Register and Profiling High Address Register.

Profiling can be started or stopped via the Profiling Control Register or by cross trigger events (see [Table 2-61](#)).

The debug registers used to configure and control profiling, and to read or write the Profiling Buffer, are listed in [Table 2-54](#).

The `DBG_CTRL` Value indicates the value to use in the MDM Debug Register Access Control Register to access the register, used with MDM software access to debug registers.

**Table 2-54: MicroBlaze Profiling Debug Registers**

| Register Name            | Size (bits) | MDM Command | DBG_CTRL Value                            | R/W | Description                                                          |
|--------------------------|-------------|-------------|-------------------------------------------|-----|----------------------------------------------------------------------|
| Profiling Control        | 8           | 0111 0001   | 4E207                                     | W   | Enable or disable profiling, configure counting method and bin usage |
| Profiling Low Address    | 30          | 0111 0010   | 4E41D                                     | W   | Defines the low address of the profiled address range                |
| Profiling High Address   | 30          | 0111 0011   | 4E61D                                     | W   | Defines the high address of the profiled address range               |
| Profiling Buffer Address | 9 - 14      | 0111 0100   | 9: 4E808<br>10: 4E809<br>...<br>14: 4E80D | W   | Sets the address (bin) in the Profiling Buffer to read or write      |
| Profiling Data Read      | 36          | 0111 0110   | 4EC23                                     | R   | Read data from the Profiling Buffer                                  |
| Profiling Data Write     | 32          | 0111 0111   | 4EE1F                                     | W   | Write data to the Profiling Buffer                                   |

## Profiling Control Register

The Profiling Control Register (PCTRLR) is used to enable (start) profiling and disable (stop) profiling. It is also used to configure whether to count the number of executed instructions or the number of executed clock cycles, as well as define the Profiling Buffer bin usage. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

The Bin Control value (B) can be calculated by the formula

$$B = \left\lceil \log_2 \frac{H - L + S \cdot 4}{S \cdot 4} \right\rceil$$

where  $L$  is the Profiling Low Register,  $H$  is the Profiling High Register, and  $S$  is the parameter `C_DEBUG_PROFILE_SIZE`.

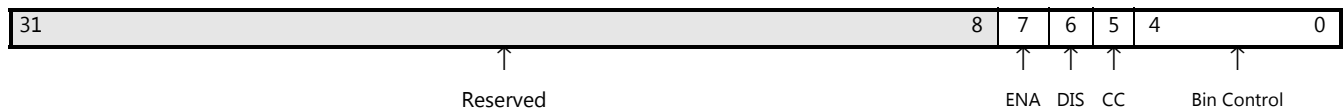


Figure 2-35: Profiling Control Register

Table 2-55: Profiling Control Register (PCTRLR)

| Bits | Name               | Description                                                                                                                                                                             | Reset Value |
|------|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 7    | Enable             | Enable and start profiling                                                                                                                                                              | 0           |
| 6    | Disable            | Disable and stop profiling                                                                                                                                                              | 0           |
| 5    | Enable Cycle Count | Enable cycle count to count clock cycles of executed instruction<br>0 = Disabled, number of executed instructions counted<br>1 = Enabled, clock cycles of executed instructions counted | 0           |
| 4:0  | Bin Control        | The number of addresses counted by each bin in the Profiling Buffer                                                                                                                     | 00000       |

## Profiling Low Address Register

The Profiling Low Address Register (PLAR) is used to define the low word address of the profiled area. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

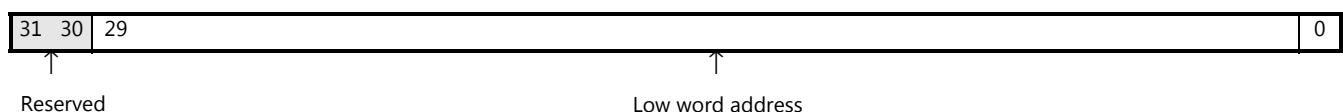


Figure 2-36: Profiling Low Address Register

Table 2-56: Profiling Low Address Register (PLAR)

| Bits | Name     | Description                           | Reset Value |
|------|----------|---------------------------------------|-------------|
| 29:0 | Low word | Low word address of the profiled area | 0           |

### Profiling High Address Register

The Profiling High Address Register (PHAR) is used to define the high word address of the profiled area. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

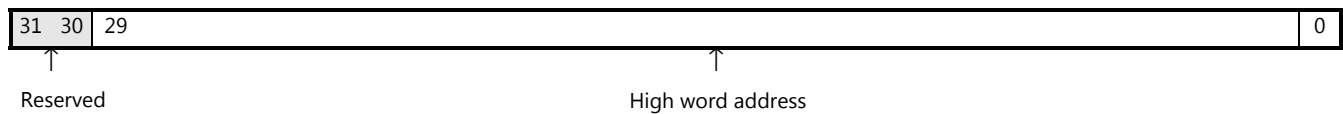


Figure 2-37: Profiling High Address Register

Table 2-57: Profiling High Address Register (PHAR)

| Bits | Name      | Description                            | Reset Value |
|------|-----------|----------------------------------------|-------------|
| 29:0 | High word | High word address of the profiled area | 0           |

### Profiling Buffer Address Register

The Profiling Buffer Address Register (PBAR) is used to define the bin in the Profiling Buffer to be read or written. This register has variable number of bits, depending on the parameter C\_DEBUG\_PROFILE\_SIZE. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

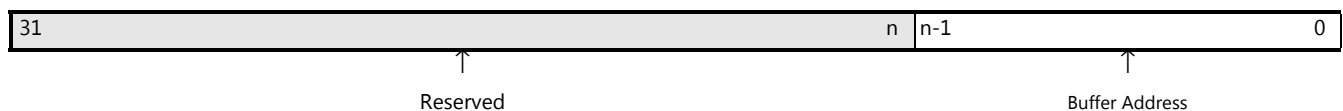


Figure 2-38: Profiling Buffer Address Register

Table 2-58: Profiling Buffer Address Register (PBAR)

| Bits  | Name           | Description                                                                                                                                   | Reset Value |
|-------|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| n-1:0 | Buffer Address | Bin in the Profiling Buffer to read or write. The number of bits (n) is 10 for a 4KB buffer, 11 for a 8KB buffer, ..., 15 for a 128KB buffer. | 0           |

## Profiling Data Read Register

The Profiling Data Read Register (PDRR) reads the bin value indicated by the Profiling Buffer Address Register and increments the Profiling Buffer Address Register. This register is a read-only register. Issuing a write request to the register does nothing.

When reading this register with MDM software access to debug registers, data is read with two consecutive accesses.

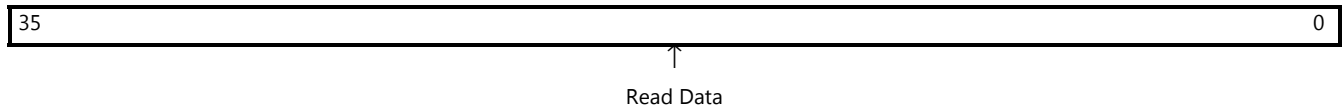


Figure 2-39: Profiling Data Read Register

Table 2-59: Profiling Data Read Register (PDRR)

| Bits | Name      | Description                                                         | Reset Value |
|------|-----------|---------------------------------------------------------------------|-------------|
| 35:0 | Read Data | Number of executed instructions or executed clock cycles in the bin | 0           |

## Profiling Data Write Register

The Profiling Data Write Register (PDWR) writes a new value to the bin indicated by the Profiling Buffer Address Register and increments the Profiling Buffer Address Register. This register is a write-only register. Issuing a read request has no effect, and undefined data is read.

This register can be used to clear the Profiling Buffer before enabling profiling.

The 4 most significant bits in the Profiling Buffer bin are set to zero when writing the new value.



Figure 2-40: Profiling Data Write Register

Table 2-60: Profiling Data Write Register (PDWR)

| Bits | Name       | Description            | Reset Value |
|------|------------|------------------------|-------------|
| 31:0 | Write Data | Data to write to a bin | 0           |

## Cross Trigger Support

With basic debugging, cross trigger support is provided by two signals, `DBG_STOP` and `MB_Halted`.

- When the `DBG_STOP` input is set to 1, MicroBlaze will halt after a few instructions. XSDB will detect that MicroBlaze has halted, and indicate where the halt occurred. The signal can be used to halt MicroBlaze at any external event, for example when a Vivado® integrated logic analyzer is triggered.
- Whenever MicroBlaze is halted the `MB_Halted` output signal is set to 1, for example after a breakpoint or watchpoint is hit, after a stop XSDB command, or when the `DBG_STOP` input is set. The output is cleared when MicroBlaze execution is resumed by an XSDB command.

The `MB_Halted` signal may be used to trigger a Vivado integrated logic analyzer, or halt other MicroBlaze cores in a multiprocessor system by connecting the signal to their `DBG_STOP` inputs.

With extended debugging, cross trigger support is available in conjunction with the MDM. The MDM provides programmable cross triggering between all connected processors, as well as external trigger inputs and outputs. For details, see the *MicroBlaze Debug Module (MDM) Product Guide* (PG115).

MicroBlaze can handle up to eight cross trigger actions. Cross trigger actions are generated by the corresponding MDM cross trigger outputs, connected via the Debug bus. The effect of each of the cross trigger actions is listed in [Table 2-61](#).

MicroBlaze can generate up to eight cross trigger events. Cross trigger events affect the corresponding MDM cross trigger inputs, connected via the Debug bus. The cross trigger events are described in [Table 2-62](#).

**Table 2-61: MicroBlaze Cross Trigger Actions**

| Number | Action                       | Description                                                                                                                                                       |
|--------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0      | Debug stop                   | Stop MicroBlaze if the processor is executing, and set the <code>MB_Halted</code> output. The same effect is achieved by setting the <code>Dbg_Stop</code> input. |
| 1      | Continue execution           | Continue execution if the processor is stopped, and clear the <code>MB_Halted</code> output.                                                                      |
| 2      | Stop program trace           | Stop program trace if tracing is in progress.                                                                                                                     |
| 3      | Start program trace          | Start program trace if trace is stopped.                                                                                                                          |
| 4      | Stop performance monitoring  | Stop performance monitoring if it is in progress.                                                                                                                 |
| 5      | Start performance monitoring | Start performance monitoring if it is stopped.                                                                                                                    |
| 6      | Disable profiling            | Disable profiling if it is in progress.                                                                                                                           |
| 7      | Enable profiling             | Enable profiling if it is disabled.                                                                                                                               |



**Table 2-62: MicroBlaze Cross Trigger Events**

| Number | Event                          | Description                                                                                                                                                              |
|--------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0      | MicroBlaze halted              | Generate an event when MicroBlaze is halted. The same event is signalled when the <code>MB_Halted</code> output is set.                                                  |
| 1      | Execution resumed              | Generate an event when the processor resumes execution from debug halt. The same event is signalled when the <code>MB_Halted</code> output is cleared.                   |
| 2      | Program trace stopped          | Generate an event when program trace is stopped by writing a command to the Program Trace Command Register, when the trace buffer is full, or by a cross trigger action. |
| 3      | Program trace started          | Generate an event when program trace is started by writing a command to the Program Trace Command Register, by hitting a tracepoint, or by a cross trigger action.       |
| 4      | Performance monitoring stopped | Generate an event when performance monitoring is stopped by writing a command to the Performance Counter Command Register or by a cross trigger action.                  |
| 5      | Performance monitoring started | Generate an event when performance monitoring is started by writing a command to the Performance Counter Command Register, or by a cross trigger action.                 |
| 6      | Profiling disabled             | Generate an event when profiling is enabled by writing a command to the Profiling Control Register or by a cross trigger action.                                         |
| 7      | Profiling enabled              | Generate an event when profiling is disabled by writing a command to the Profiling Control Register or by a cross trigger action.                                        |

## Trace Interface Overview

The MicroBlaze trace interface exports a number of internal state signals for performance monitoring and analysis. Xilinx recommends that users only use the trace interface through Xilinx developed analysis cores. This interface is not guaranteed to be backward compatible in future releases of MicroBlaze.

See [Table 3-16](#) for a list of exported signals.

## Fault Tolerance

The fault tolerance features included in MicroBlaze, enabled with `C_FAULT_TOLERANT`, provide Error Detection for internal block RAMs (in the Instruction Cache, Data Cache, Branch Target Cache, and MMU), and support for Error Detection and Correction (ECC) in LMB block RAMs. When fault tolerance is enabled, all soft errors in block RAMs are detected and corrected, which significantly reduces overall failure intensity.

In addition to protecting block RAM, the FPGA configuration memory also generally needs to be protected. A detailed explanation of this topic, and further references, can be found in the two documents *LogiCore IP Soft Error Mitigation Controller* ([PG036](#)) and *LogiCore IP UltraScale Architecture Soft Error Mitigation Controller* ([PG187](#)).

To further increase fault tolerance, a complete Triple Modular Redundancy (TMR) solution is provided for MicroBlaze, using additional cores to handle majority voting and fault detection. See *Triple Modular Redundancy (TMR) Subsystem* ([PG268](#)) for a complete description and implementation details.

## Configuration

### ***Using MicroBlaze Configuration***

Fault tolerance can be enabled in the MicroBlaze configuration dialog, on the General page.

After enabling fault tolerance in MicroBlaze, ECC is automatically enabled in the connected LMB BRAM Interface Controllers by the tools, when the system is generated. This means that nothing else needs to be configured to enable fault tolerance and minimal ECC support.

It is possible (albeit not recommended) to manually override ECC support, leaving the LMB BRAM unprotected, by disabling `C_ECC` in the configuration dialogs of all connected LMB BRAM Interface Controllers. In this case, the internal MicroBlaze block RAM protection is still enabled, since fault tolerance is enabled.

### ***Using LMB BRAM Interface Controller Configuration***

As an alternative to the method described above, it is also possible to enable ECC in the configuration dialogs of all connected LMB BRAM Interface Controllers. In this case, fault tolerance is automatically enabled in MicroBlaze by the tools, when the system is generated. This means that nothing else needs to be configured to enable ECC support and MicroBlaze fault tolerance.

ECC must either be enabled or disabled in all Controllers, which is enforced by a DRC.

It is possible to manually override fault tolerance support in MicroBlaze, by explicitly disabling `C_FAULT_TOLERANT` in the MicroBlaze configuration dialog. This is not recommended, unless no block RAM is used in MicroBlaze, and there is no need to handle bus exceptions from uncorrectable ECC errors.

## Features

An overview of all MicroBlaze fault tolerance features is given here. Further details on each feature can be found in the following sections:

- ["Instruction Cache Operation"](#)
- ["Data Cache Operation"](#)
- ["UTLB Management"](#)
- ["Branch Target Cache"](#)
- ["Instruction Bus Exception"](#)
- ["Data Bus Exception"](#)
- ["Exception Causes"](#)

The LMB BRAM Interface Controller v4.0 or later provides the LMB ECC implementation. For details, including performance and resource utilization, see the *LogiCORE IP LMB BRAM Interface Controller* ([PG112](#)) product guide, in the Xilinx IP Documentation.

### ***Instruction and Data Cache Protection***

To protect the block RAM in the Instruction and Data Cache, parity is used. When a parity error is detected, the corresponding cache line is invalidated. This forces the cache to reload the correct value from external memory. Parity is checked whenever a cache hit occurs.

Note that this scheme only works for write-through, and thus write-back data cache is not available when fault tolerance is enabled. This is enforced by a DRC.

When new values are written to a block RAM in the cache, parity is also calculated and written. One parity bit is used for the tag, one parity bit for the instruction cache data, and one parity bit for each word in a data cache line.

In many cases, enabling fault tolerance does not increase the required number of cache block RAMs, since spare bits can be used for the parity. Any increase in resource utilization, in particular number of block RAMs, can easily be seen in the MicroBlaze configuration dialog, when enabling fault tolerance.

### ***Memory Management Unit Protection***

To protect the block RAM in the MMU Unified Translation Look-Aside Buffer (UTLB), parity is used. When a parity error is detected during an address translation, a TLB miss exception occurs, forcing software to reload the entry.

When a new TLB entry is written using the TLBHI and TLBLO registers, parity is calculated. One parity bit is used for each entry.

Parity is also checked when a UTLB entry is read using the TLBHI and TLBLO registers. When a parity error is detected in this case, the entry is marked invalid by clearing the valid bit.

Enabling fault tolerance does not increase the MMU block RAM size, since a spare bit is available for the parity.

### ***Branch Target Cache Protection***

To protect block RAM in the Branch Target Cache, parity is used. When a parity error is detected when looking up a branch target address, the address is ignored, forcing a normal branch.

When a new branch address is written to the Branch Target Cache, parity is calculated. One parity bit is used for each address.

Enabling fault tolerance does not increase the Branch Target Cache block RAM size, since a spare bit is available for the parity.

### ***Exception Handling***

With fault tolerance enabled, if an error occurs in LMB block RAM, the LMB BRAM Interface Controller generates error signals on the LMB interface.

If exceptions are enabled in MicroBlaze, by setting the EE bit in the Machine Status Register, the uncorrectable error signal either generates an instruction bus exception or a data bus exception, depending on the affected interface.

Should a bus exception occur when an exception is in progress, MicroBlaze is halted, and the external error signal `MB_Error` is set. This behavior ensures that it is impossible to execute an instruction corrupted by an uncorrectable error.

## **Software Support**

### ***Scrubbing***

To ensure that bit errors are not accumulated in block RAMs, they must be periodically scrubbed.

The standalone BSP provides the function `microblaze_scrub()` to perform scrubbing of the entire LMB block RAM and all MicroBlaze internal block RAMs used in a particular configuration. This function is intended to be called periodically from a timer interrupt routine.

The following example code illustrates how this can be done.

```
#include "xparameters.h"
#include "xtmrctr.h"
#include "xintc.h"
#include "mb_interface.h"

#define SCRUB_PERIOD ...

XIntc InterruptController; /* The Interrupt Controller instance */
XTmrCtr TimerCounterInst; /* The Timer Counter instance */

void MicroBlazeScrubHandler(void *CallBackRef, u8 TmrCtrNumber)
{
    /* Perform other timer interrupt processing here */
    microblaze_scrub();
}

int main (void)
{
    int Status;

    /*
     * Initialize the timer counter so that it's ready to use,
     * specify the device ID that is generated in xparameters.h
     */
    Status = XTmrCtr_Initialize(&TimerCounterInst, TMRCTR_DEVICE_ID);
    if (Status != XST_SUCCESS) {
        return XST_FAILURE;
    }

    /*
     * Connect the timer counter to the interrupt subsystem such that
     * interrupts can occur.
     */
    Status = XIntc_Initialize(&InterruptController, INTC_DEVICE_ID);
    if (Status != XST_SUCCESS) {
        return XST_FAILURE;
    }

    /*
     * Connect a device driver handler that will be called when an
     * interrupt for the device occurs, the device driver handler performs
     * the specific interrupt processing for the device
     */
    Status = XIntc_Connect(&InterruptController, TMRCTR_DEVICE_ID,
        (XInterruptHandler)XTmrCtr_InterruptHandler,
        (void *) &TimerCounterInst);
    if (Status != XST_SUCCESS) {
        return XST_FAILURE;
    }
}
```

```

/*
 * Start the interrupt controller such that interrupts are enabled for
 * all devices that cause interrupts, specifying real mode so that the
 * timer counter can cause interrupts thru the interrupt controller.
 */
Status = XIntc_Start(&InterruptController, XIN_REAL_MODE);
if (Status != XST_SUCCESS) {
    return XST_FAILURE;
}

/*
 * Setup the handler for the timer counter that will be called from the
 * interrupt context when the timer expires, specify a pointer to the
 * timer counter driver instance as the callback reference so the
 * handler is able to access the instance data
 */
XTmrCtr_SetHandler(&TimerCounterInst, MicroBlazeScrubHandler,
                  &TimerCounterInst);

/*
 * Enable the interrupt of the timer counter so interrupts will occur
 * and use auto reload mode such that the timer counter will reload
 * itself automatically and continue repeatedly, without this option
 * it would expire once only
 */
XTmrCtr_SetOptions(&TimerCounterInst, TIMER_CNTR_0,
                  XTC_INT_MODE_OPTION | XTC_AUTO_RELOAD_OPTION);

/*
 * Set a reset value for the timer counter such that it will expire
 * earlier than letting it roll over from 0, the reset value is loaded
 * into the timer counter when it is started
 */
XTmrCtr_SetResetValue(TmrCtrInstancePtr, TmrCtrNumber, SCRUB_PERIOD);

/*
 * Start the timer counter such that it's incrementing by default,
 * then wait for it to timeout a number of times
 */
XTmrCtr_Start(&TimerCounterInst, TIMER_CNTR_0);

...
}

```

See the section “[Scrubbing](#)” below for further details on how scrubbing is implemented, including how to calculate the scrubbing rate.

## **BRAM Driver**

The standalone BSP BRAM driver is used to access the ECC registers in the LMB BRAM Interface Controller, and also provides a comprehensive self test.

By implementing the SDK Xilinx C Project "Peripheral Tests", a self-test example including the BRAM self test for each LMB BRAM Interface Controller in the system is generated. Depending on the ECC features enabled in the LMB BRAM Interface Controller, this code will perform all possible tests of the ECC function.

The self-test example can be found in the standalone BSP BRAM driver source code, typically in the subdirectory `microblaze_0/libsrc/bram_v3_03_a/src/xbram_selftest.c`.

## Scrubbing

### Scrubbing Methods

Scrubbing is performed using specific methods for the different block RAMs:

- Instruction and data caches: All lines in the caches are cyclically invalidated using the WIC and WDC instructions respectively. This forces the cache to reload the cache line from external memory.
- Memory Management Unit UTLB: All entries in the UTLB are cyclically invalidated by writing the TLBHI register with the valid bit cleared.
- Branch Target Cache: The entire BTC is invalidated by doing a synchronizing branch, BRI 4.
- LMB block RAM: All addresses in the memory are cyclically read and written, thus correcting any single bit errors on each address.

It is also possible to add interrupts for correctable errors from the LMB BRAM Interface Controllers, and immediately scrub this address in the interrupt handler, although in most cases it only improves reliability slightly.

The failing address can be determined by reading the Correctable Error First Failing Address Register in each of the LMB BRAM Interface Controllers. To be able to generate an interrupt `C_ECC_STATUS_REGISTERS` must be set to 1 in the connected LMB BRAM Interface Controllers, and to read the failing address `C_CE_FAILING_REGISTERS` must be set to 1.

### Calculating Scrubbing Rate

The scrubbing rate depends on failure intensity and desired reliability.

The approximate equation to determine the LMB memory scrubbing rate is in our case given by

$$P_W \approx 760 \left( \frac{BER^2}{SR^2} \right)$$

where  $P_W$  is the probability of an uncorrectable error in a memory word,  $BER$  is the soft error rate for a single memory bit, and  $SR$  is the Scrubbing Rate.

The soft error rates affecting block RAM for each product family can be found in the *Device Reliability Report* ([UG116](#)).

## Use Cases

Several common use cases are described here. These use cases are derived from the *LogiCore IP Processor LMB BRAM Interface Controller* ([PG112](#)) product guide.

### ***Minimal***

This system is obtained when enabling fault tolerance in MicroBlaze, without doing any other configuration.

The system is suitable when area constraints are high, and there is no need for testing of the ECC function, or analysis of error frequency and location. No ECC registers are implemented. Single bit errors are corrected by the ECC logic before being passed to MicroBlaze. Uncorrectable errors set an error signal, which generates an exception in MicroBlaze.

### ***Small***

This system should be used when it is necessary to monitor error frequency, but there is no need for testing of the ECC function. It is a minimal system with Correctable Error Counter Register added to monitor single bit error rates. If the error rate is too high, the scrubbing rate should be increased to minimize the risk of a single bit error becoming an uncorrectable double bit error. Parameters set are `C_ECC = 1` and `C_CE_COUNTER_WIDTH = 10`.

### ***Typical***

This system represents a typical use case, where it is required to monitor error frequency, as well as generating an interrupt to immediately correct a single bit error through software. It does not provide support for testing of the ECC function. It is a small system with Correctable Error First Failing registers and Status register added. A single bit error will latch the address for the access into the Correctable Error First Failing Address Register and set the `CE_STATUS` bit in the ECC Status Register. An interrupt will be generated triggering MicroBlaze to read the failing address and then perform a read followed by a write on the failing address. This will remove the single bit error from the BRAM, thus reducing the risk of the single bit error becoming a uncorrectable double bit error. Parameters set are `C_ECC = 1`, `C_CE_COUNTER_WIDTH = 10`, `C_ECC_STATUS_REGISTER = 1` and `C_CE_FAILING_REGISTERS = 1`.

### ***Full***

This system uses all of the features provided by the LMB BRAM Interface Controller, to enable full error injection capability, as well as error monitoring and interrupt generation. It is a typical system with Uncorrectable Error First Failing registers and Fault Injection registers added. All features are switched on for full control of ECC functionality for system debug or systems with high fault tolerance requirements. Parameters set are `C_ECC = 1`, `C_CE_COUNTER_WIDTH = 10`, `C_ECC_STATUS_REGISTER = 1` and `C_CE_FAILING_REGISTERS = 1`, `C_UE_FAILING_REGISTERS = 1` and `C_FAULT_INJECT = 1`.



## Lockstep Operation

MicroBlaze is able to operate in a lockstep configuration, where two or more identical MicroBlaze cores execute the same program. By comparing the outputs of the cores, any tampering attempts, transient faults or permanent hardware faults can be detected.

### System Configuration

The parameter `C_LOCKSTEP_SLAVE` is set to one on all slave MicroBlaze cores in the system, except the master (or primary) core. The master core drives all the output signals, and handles the debug functionality. The port `Lockstep_Master_Out` on the master is connected to the port `Lockstep_Slave_In` on the slaves, in order to handle debugging.

The slave cores should not drive any output signals, only receive input signals. This must be ensured by only connecting signals to the input ports of the slaves. For buses this means that each individual input port must be explicitly connected.

The port `Lockstep_Out` on the master and slave cores provide all output signals for comparison. Unless an error occurs, individual signals from each of the cores are identical every clock cycle.

To ensure that lockstep operation works properly, all input signals to the cores must be synchronous. Input signals that may require external synchronization are `Interrupt`, `Reset`, `Ext_Brk`, and `Ext_Nm_Brk`.

### Use Cases

Two common use cases are described here. In addition, lockstep operation provides the basis for implementing triple modular redundancy on MicroBlaze core level.

#### ***Tamper Protection***

This application represents a high assurance use case, where it is required that the system is tamper-proof. A typically example is a cryptographic application.

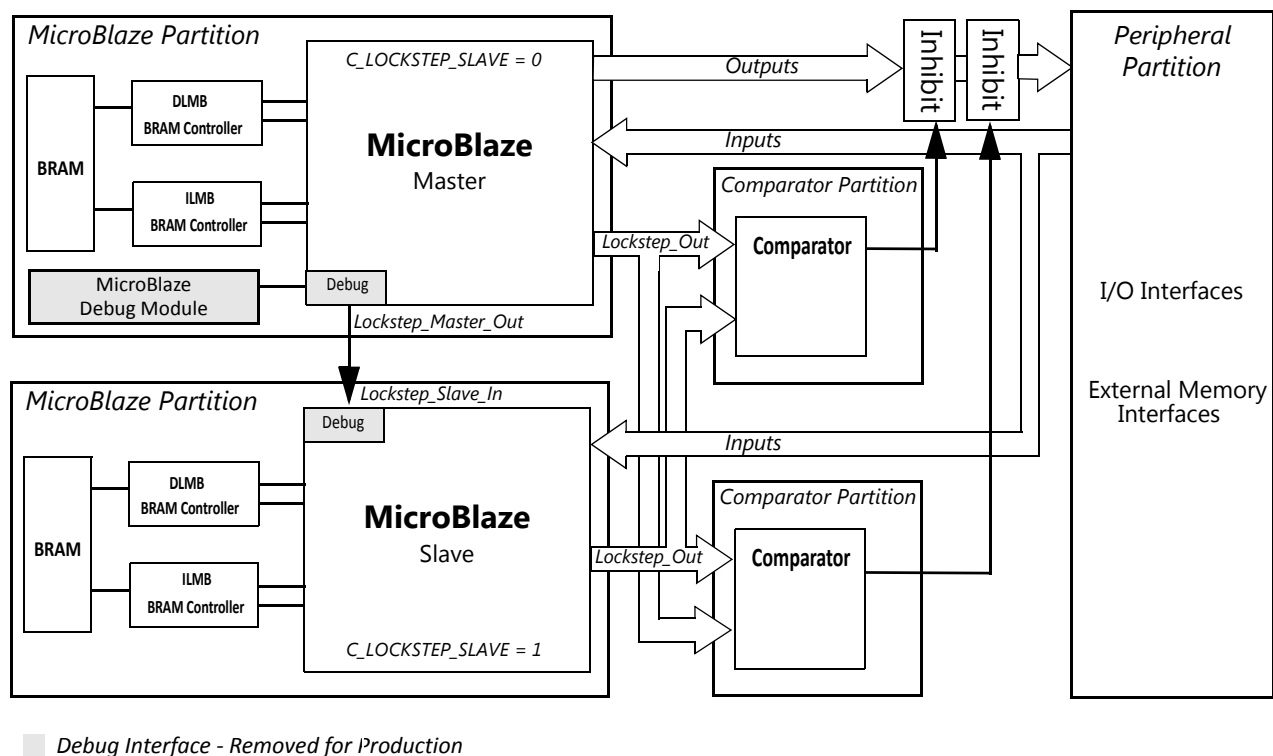
The approach involves having two redundant MicroBlaze processors with dedicated local memory and redundant comparators, each in a protected area. The outputs from each processor feed two comparators and each processor receive copies of every input signal.

The redundant MicroBlaze processors are functionally identical and completely independent of each other, without any connecting signals. The only exception is debug logic and associated signals, since it is assumed that debugging is disabled before any productization and certification of the system.

The outputs from the master MicroBlaze core drive the peripherals in the system. All data leaving the protected area pass through inhibitors. Each inhibitor is controlled from its associated comparator.

Each protected area of the design must be implemented in its own partition, using a hierarchical Single Chip Cryptography (SCC) flow. A detailed explanation of this flow, and further references, can be found in the document *Hierarchical Design Methodology Guide* ([UG748](#)).

A block diagram of the system is shown in [Figure 2-41](#).



**Figure 2-41: Lockstep Tamper Protection Application**

## Error Detection

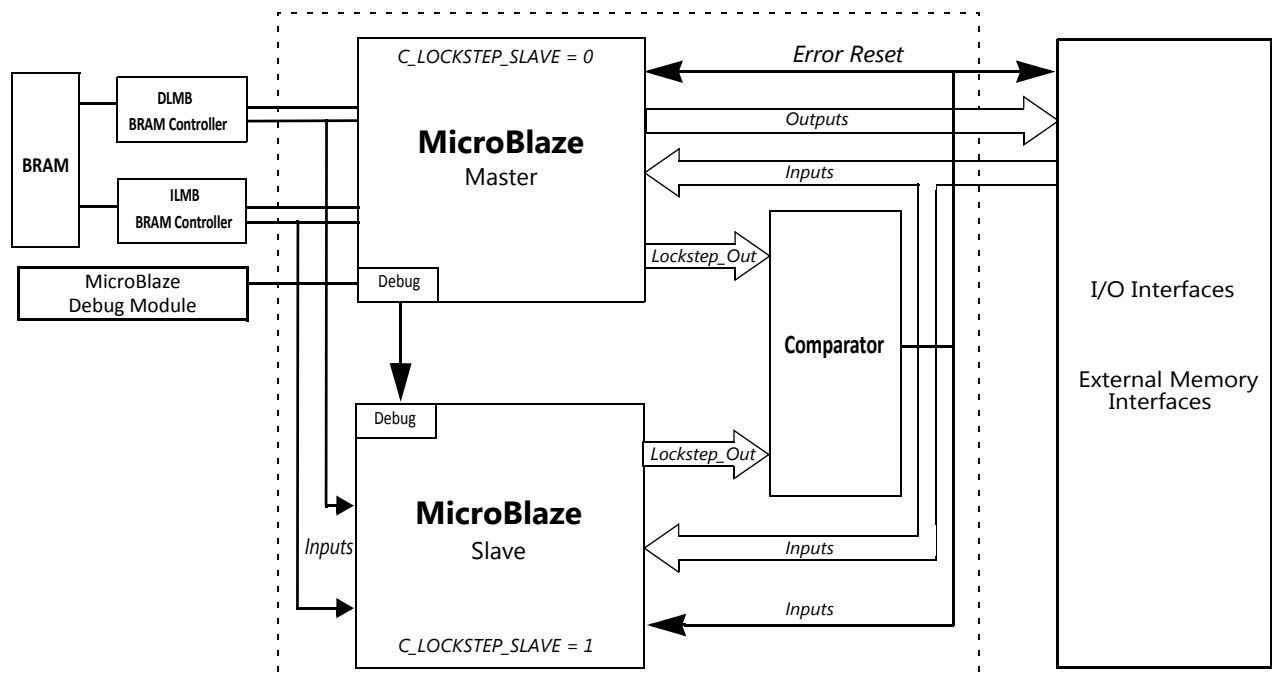
The error detection use case requires that all transient and permanent faults are detected. This is essential in fail safe and fault tolerant applications, where redundancy is utilized to improve system availability.

In this system two redundant MicroBlaze processors run in lockstep. A comparator is used to signal an error when a mis-match is detected on the outputs of the two processors. Any error immediately causes both processors to halt, preventing further error propagation.

The redundant MicroBlaze processors are functionally identical, except for debug logic and associated signals. The outputs from the master MicroBlaze core drive the peripherals in the system. The slave MicroBlaze core only has inputs connected; all outputs are left open.

The system contains the basic building block for designing a complete fault tolerant application, where one or more additional blocks must be added to provide redundancy.

This use case is illustrated in [Figure 2-42](#).



**Figure 2-42: Lockstep Error Detection Application**

## Coherency

MicroBlaze supports cache coherency, as well as invalidation of caches and translation look-aside buffers, using the AXI Coherency Extension (ACE) defined in *AMBA® AXI and ACE Protocol Specification (ARM IHI 0022E)*. The coherency support is enabled when the parameter `C_INTERCONNECT` is set to 3 (ACE).

Using ACE ensures coherency between the caches of all MicroBlaze processors in the coherency domain. The peripheral ports (AXI\_IP, AXI\_DP) and local memory (ILMB, DLMB) are outside the coherency domain.

Coherency is not supported with write-back data cache, wide cache interfaces (more than 32-bit data), instruction cache streams, instruction cache victims or when area optimization is enabled. In addition both `C_ICACHE_ALWAYS_USED` and `C_DCACHE_ALWAYS_USED` must be set to 1.

## Invalidation

The coherency hardware handles invalidation in the following cases:

- **Data Cache invalidation:**  
When a MicroBlaze core in the coherency domain invalidates a data cache line with an external cache invalidation instruction (WDC.EXT.CLEAR or WDC.EXT.FLUSH), hardware messages ensure that all other cores in the coherency domain will do the same. The physical address is always used.
- **Instruction Cache invalidation:**  
When a MicroBlaze core in the coherency domain invalidates an instruction cache line, hardware messages ensure that all other cores in the coherency domain will do the same. When the MMU is in virtual mode the virtual address is used, otherwise the physical address is used.
- **MMU TLB invalidation:**  
When a MicroBlaze core in the coherency domain invalidates an entry in the UTLB (that is writes TLBHI with a zero Valid flag), hardware messages ensure that all other cores in the coherency domain will invalidate all entries in their unified TLBs having a TAG matching the invalidated virtual address, as well as empty their shadow TLBs.

The TID is not taken into account when matching the entries, which can result in invalidation of entries belonging to other processes. Subsequent accesses to these entries will generate TLB miss exceptions, which must be handled by software.

Before invalidating an MMU page, it must first be loaded into the UTLB to ensure that the hardware invalidation is propagated within the coherency domain. It is not sufficient to simply invalidate the page in memory, since other processors in the coherency domain may have this particular entry stored in their TLBs.

After a MicroBlaze core has invalidated one or more entries, it must execute a memory barrier instruction (MBAR), to ensure that all peer processors have completed their TLB invalidation.

- **Branch Target Cache invalidation:**  
When a MicroBlaze core in the coherency domain invalidates the Branch Target Cache, either with a memory barrier instruction or with a synchronizing branch, hardware messages ensure that all other cores in the coherency domain will do the same.

In particular, this means that self-modifying code can be used transparently within the coherency domain in a multi-processor system, provided that the guidelines in “[Self-modifying Code](#)” are followed.

## Protocol Compliance

The MicroBlaze instruction cache interface issues the following subset of the possible ACE transactions:

- **ReadClean**  
Issued when a cache line is allocated.
- **ReadOnce**  
Issued when the cache is off, or if the MMU Inhibit Caching bit is set for the cache line.

The MicroBlaze data cache interface issues the following subset of the possible ACE transactions:

- **ReadClean**  
Issued when a cache line is allocated.
- **CleanUnique**  
Issued when an SWX instruction is executed as part of an exclusive access sequence.
- **ReadOnce**  
Issued when the cache is off, or if the MMU Inhibit Caching bit is set for the cache line.
- **WriteUnique**  
Issued whenever a store instruction performs a write.
- **CleanInvalid**  
Issued when a WDC.EXT.FLUSH instruction is executed.
- **MakeInvalid**  
Issued when a WDC.EXT.CLEAR instruction is executed.

Both interfaces issue the following subset of the possible Distributed Virtual Memory (DVM) transactions:

- DVM Operation
  - .. TLB Invalidate – Hypervisor TLB Invalidate by VA
  - .. Branch Predictor Invalidate – Branch Predictor Invalidate all
  - .. Physical Instruction Cache Invalidate – Non-secure Physical Instruction Cache Invalidate by PA without Virtual Index
  - .. Virtual Instruction Cache Invalidate – Hypervisor Invalidate by VA
- DVM Sync
  - .. Synchronization
- DVM Complete
  - .. In addition to the DVM transactions above, the interfaces only accept the CleanInvalid and MakeInvalid transactions. These transactions have no effect in the instruction cache, and invalidate the indicated data cache lines. If any other transactions are received, the behavior is undefined.
  - .. Only a subset of AXI4 transactions are utilized by the interfaces, as described in ["Cache Interfaces"](#).

## Data and Instruction Address Extension

MicroBlaze has the ability to address up to 16EB of data controlled by the parameter `C_ADDR_SIZE`, and also supports a physical instruction address up to 16EB when the MMU Physical Address Extension (PAE) is enabled by setting `C_USE_MMU = 3` (Virtual).

The parameter `C_ADDR_SIZE` can be set to the following values:

|         |                               |                                                         |
|---------|-------------------------------|---------------------------------------------------------|
| ◦ NONE  | 4 * 1024 <sup>3</sup> bytes   | 32-bit address, no extended address instructions or PAE |
| ◦ 64GB  | 64 * 1024 <sup>3</sup> bytes  | 36-bit address                                          |
| ◦ 1TB   | 1024 <sup>4</sup> bytes       | 40-bit address                                          |
| ◦ 16TB  | 16 * 1024 <sup>4</sup> bytes  | 44-bit address                                          |
| ◦ 256TB | 256 * 1024 <sup>4</sup> bytes | 48-bit address                                          |
| ◦ 16EB  | 16 * 1024 <sup>6</sup> bytes  | 64-bit address                                          |

There are a number of software limitations with extended addressing:

- The GNU tools only generate ELF files with 32-bit addresses, which means that program instruction and data memory must be located in the first 4GB of the address space. This is also the reason the instruction address space does not provide an extended address unless PAE is enabled.

With PAE enabled, the majority of the program instruction and data can be located at any physical address, but all software running in real mode must be located in the first 4GB of the address space. The MMU UTLB must also be initialized to set up the virtual to physical address translation by software running in real mode, before virtual mode is activated.

- Since all software drivers use address pointers that are 32-bit unsigned integers, it is not possible to access physical extended addresses above 4GB without modifying the driver code, and consequently all AXI peripherals should be located in the first 4GB of the address space.

With PAE enabled, AXI peripherals can be located at any physical address, provided that the virtual address remains in the first 4GB of the address space.

- The extended address is only treated as a physical address, and the MMU cannot be used to translate from an extended virtual address to a physical address.

This also means that without PAE support, Linux can only use the data address extension through a dedicated driver operating in real mode.

The extended address load and store instructions are privileged when the MMU is enabled, unless they are allowed by setting the parameter `C_MMU_PRIVILEGED_INSTR`

appropriately. If allowed, the instructions bypass the MMU translation treating the extended address as a physical address.

- The GNU compiler does not handle 64-bit address pointers, which means that unless PAE is enabled the only way to access an extended address is using the specific extended addressing instructions, available as macros.

The following C code exemplifies how an extended address can be used to access data:

```
#include "xil_types.h"
#include "mb_interface.h"

int main()
{
    u64 Addr = 0x000000FF00000000LL; /* Extended address */
    u32 Word;
    u8 Byte;

    Word = lwea(Addr); /* Load word from extended address */
    swea(Addr, Word); /* Store word to extended address */
    Byte = lbuea(Addr); /* Load byte from extended address */
    sbea(Addr, Byte); /* Store byte to extended address */
}
```



# MicroBlaze Signal Interface Description

This chapter describes the types of signal interfaces that can be used to connect MicroBlaze™.

---

## Overview

The MicroBlaze core is organized as a Harvard architecture with separate bus interface units for data and instruction accesses. The following two memory interfaces are supported: Local Memory Bus (LMB), and the AMBA® AXI4 interface (AXI4) and ACE interface (ACE).

The LMB provides single-cycle access to on-chip dual-port block RAM. The AXI4 interfaces provide a connection to both on-chip and off-chip peripherals and memory. The ACE interfaces provide cache coherent connections to memory.

MicroBlaze also supports up to 16 AXI4-Stream interface ports, each with one master and one slave interface.

## Features

MicroBlaze can be configured with the following bus interfaces:

- The AMBA AXI4 Interface for peripheral interfaces, and the AMBA AXI4 or AXI Coherency Extension (ACE) Interface for cache interfaces (see ARM® *AMBA® AXI and ACE Protocol Specification*, [ARM IHI 0022E](http://www.arm.com/Imb/IHI0022E)).
- LMB provides a simple synchronous protocol for efficient block RAM transfers
- AXI4-Stream provides a fast non-arbitrated streaming communication mechanism
- Debug interface for use with the Microprocessor Debug Module (MDM) core
- Trace interface for performance analysis

## MicroBlaze I/O Overview

The core interfaces shown in Figure 3-1 and the following Table 3-1 are defined as follows:

- M\_AXI\_DP:** Peripheral Data Interface, AXI4-Lite or AXI4 interface
- DLMB:** Data interface, Local Memory Bus (BRAM only)
- M\_AXI\_IP:** Peripheral Instruction interface, AXI4-Lite interface
- ILMB:** Instruction interface, Local Memory Bus (BRAM only)
- M0\_AXIS..M15\_AXIS:** AXI4-Stream interface master direct connection interfaces
- S0\_AXIS..S15\_AXIS:** AXI4-Stream interface slave direct connection interfaces
- M\_AXI\_DC:** Data side cache AXI4 interface
- M\_ACE\_DC:** Data side cache AXI Coherency Extension (ACE) interface
- M\_AXI\_IC:** Instruction side cache AXI4 interface
- M\_ACE\_IC:** Instruction side cache AXI Coherency Extension (ACE) interface
- Core:** Miscellaneous signals for: clock, reset, interrupt, debug, trace

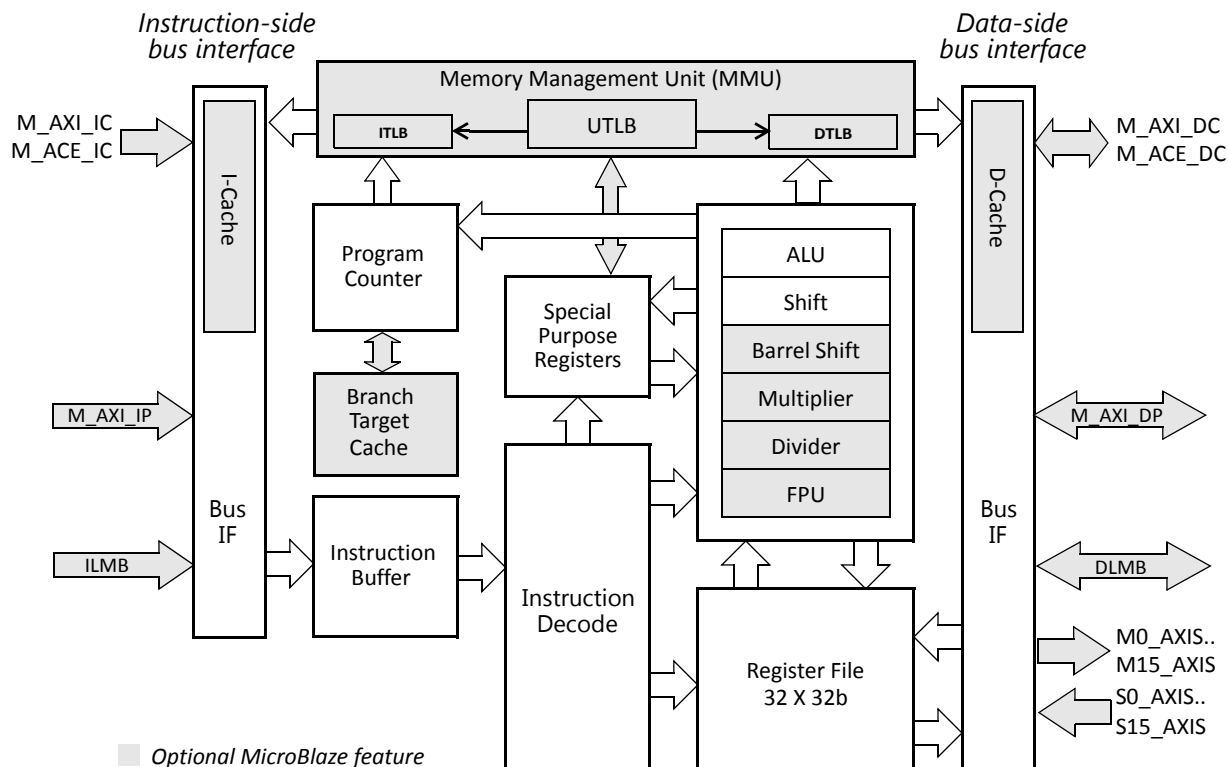


Figure 3-1: MicroBlaze Core Block Diagram

**Table 3-1: Summary of MicroBlaze Core I/O**

| Signal           | Interface | I/O | Description                |
|------------------|-----------|-----|----------------------------|
| M_AXI_DP_AWID    | M_AXI_DP  | O   | Master Write address ID    |
| M_AXI_DP_AWADDR  | M_AXI_DP  | O   | Master Write address       |
| M_AXI_DP_AWLEN   | M_AXI_DP  | O   | Master Burst length        |
| M_AXI_DP_AWSIZE  | M_AXI_DP  | O   | Master Burst size          |
| M_AXI_DP_AWBURST | M_AXI_DP  | O   | Master Burst type          |
| M_AXI_DP_AWLOCK  | M_AXI_DP  | O   | Master Lock type           |
| M_AXI_DP_AWCACHE | M_AXI_DP  | O   | Master Cache type          |
| M_AXI_DP_AWPROT  | M_AXI_DP  | O   | Master Protection type     |
| M_AXI_DP_AWQOS   | M_AXI_DP  | O   | Master Quality of Service  |
| M_AXI_DP_AWVALID | M_AXI_DP  | O   | Master Write address valid |
| M_AXI_DP_AWREADY | M_AXI_DP  | I   | Slave Write address ready  |
| M_AXI_DP_WDATA   | M_AXI_DP  | O   | Master Write data          |
| M_AXI_DP_WSTRB   | M_AXI_DP  | O   | Master Write strobes       |
| M_AXI_DP_WLAST   | M_AXI_DP  | O   | Master Write last          |
| M_AXI_DP_WVALID  | M_AXI_DP  | O   | Master Write valid         |
| M_AXI_DP_WREADY  | M_AXI_DP  | I   | Slave Write ready          |
| M_AXI_DP_BID     | M_AXI_DP  | I   | Slave Response ID          |
| M_AXI_DP_BRESP   | M_AXI_DP  | I   | Slave Write response       |
| M_AXI_DP_BVALID  | M_AXI_DP  | I   | Slave Write response valid |
| M_AXI_DP_BREADY  | M_AXI_DP  | O   | Master Response ready      |
| M_AXI_DP_ARID    | M_AXI_DP  | O   | Master Read address ID     |
| M_AXI_DP_ARADDR  | M_AXI_DP  | O   | Master Read address        |
| M_AXI_DP_ARLEN   | M_AXI_DP  | O   | Master Burst length        |
| M_AXI_DP_ARSIZE  | M_AXI_DP  | O   | Master Burst size          |
| M_AXI_DP_ARBURST | M_AXI_DP  | O   | Master Burst type          |
| M_AXI_DP_ARLOCK  | M_AXI_DP  | O   | Master Lock type           |
| M_AXI_DP_ARCACHE | M_AXI_DP  | O   | Master Cache type          |
| M_AXI_DP_ARPROT  | M_AXI_DP  | O   | Master Protection type     |
| M_AXI_DP_ARQOS   | M_AXI_DP  | O   | Master Quality of Service  |
| M_AXI_DP_ARVALID | M_AXI_DP  | O   | Master Read address valid  |
| M_AXI_DP_ARREADY | M_AXI_DP  | I   | Slave Read address ready   |

Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)

| Signal           | Interface | I/O | Description                |
|------------------|-----------|-----|----------------------------|
| M_AXI_DP_RID     | M_AXI_DP  | I   | Slave Read ID tag          |
| M_AXI_DP_RDATA   | M_AXI_DP  | I   | Slave Read data            |
| M_AXI_DP_RRESP   | M_AXI_DP  | I   | Slave Read response        |
| M_AXI_DP_RLAST   | M_AXI_DP  | I   | Slave Read last            |
| M_AXI_DP_RVALID  | M_AXI_DP  | I   | Slave Read valid           |
| M_AXI_DP_RREADY  | M_AXI_DP  | O   | Master Read ready          |
| M_AXI_IP_AWID    | M_AXI_IP  | O   | Master Write address ID    |
| M_AXI_IP_AWADDR  | M_AXI_IP  | O   | Master Write address       |
| M_AXI_IP_AWLEN   | M_AXI_IP  | O   | Master Burst length        |
| M_AXI_IP_AWSIZE  | M_AXI_IP  | O   | Master Burst size          |
| M_AXI_IP_AWBURST | M_AXI_IP  | O   | Master Burst type          |
| M_AXI_IP_AWLOCK  | M_AXI_IP  | O   | Master Lock type           |
| M_AXI_IP_AWCACHE | M_AXI_IP  | O   | Master Cache type          |
| M_AXI_IP_AWPROT  | M_AXI_IP  | O   | Master Protection type     |
| M_AXI_IP_AWQOS   | M_AXI_IP  | O   | Master Quality of Service  |
| M_AXI_IP_AWVALID | M_AXI_IP  | O   | Master Write address valid |
| M_AXI_IP_AWREADY | M_AXI_IP  | I   | Slave Write address ready  |
| M_AXI_IP_WDATA   | M_AXI_IP  | O   | Master Write data          |
| M_AXI_IP_WSTRB   | M_AXI_IP  | O   | Master Write strobes       |
| M_AXI_IP_WLAST   | M_AXI_IP  | O   | Master Write last          |
| M_AXI_IP_WVALID  | M_AXI_IP  | O   | Master Write valid         |
| M_AXI_IP_WREADY  | M_AXI_IP  | I   | Slave Write ready          |
| M_AXI_IP_BID     | M_AXI_IP  | I   | Slave Response ID          |
| M_AXI_IP_BRESP   | M_AXI_IP  | I   | Slave Write response       |
| M_AXI_IP_BVALID  | M_AXI_IP  | I   | Slave Write response valid |
| M_AXI_IP_BREADY  | M_AXI_IP  | O   | Master Response ready      |
| M_AXI_IP_ARID    | M_AXI_IP  | O   | Master Read address ID     |
| M_AXI_IP_ARADDR  | M_AXI_IP  | O   | Master Read address        |
| M_AXI_IP_ARLEN   | M_AXI_IP  | O   | Master Burst length        |
| M_AXI_IP_ARSIZE  | M_AXI_IP  | O   | Master Burst size          |
| M_AXI_IP_ARBURST | M_AXI_IP  | O   | Master Burst type          |
| M_AXI_IP_ARLOCK  | M_AXI_IP  | O   | Master Lock type           |

**Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)**

| Signal            | Interface | I/O | Description                       |
|-------------------|-----------|-----|-----------------------------------|
| M_AXI_IP_ARCACHE  | M_AXI_IP  | O   | Master Cache type                 |
| M_AXI_IP_ARPROT   | M_AXI_IP  | O   | Master Protection type            |
| M_AXI_IP_ARQOS    | M_AXI_IP  | O   | Master Quality of Service         |
| M_AXI_IP_ARVALID  | M_AXI_IP  | O   | Master Read address valid         |
| M_AXI_IP_ARREADY  | M_AXI_IP  | I   | Slave Read address ready          |
| M_AXI_IP_RID      | M_AXI_IP  | I   | Slave Read ID tag                 |
| M_AXI_IP_RDATA    | M_AXI_IP  | I   | Slave Read data                   |
| M_AXI_IP_RRESP    | M_AXI_IP  | I   | Slave Read response               |
| M_AXI_IP_RLAST    | M_AXI_IP  | I   | Slave Read last                   |
| M_AXI_IP_RVALID   | M_AXI_IP  | I   | Slave Read valid                  |
| M_AXI_IP_RREADY   | M_AXI_IP  | O   | Master Read ready                 |
| M_AXI_DC_AWADDR   | M_AXI_DC  | O   | Master Write address              |
| M_AXI_DC_AWLEN    | M_AXI_DC  | O   | Master Burst length               |
| M_AXI_DC_AWSIZE   | M_AXI_DC  | O   | Master Burst size                 |
| M_AXI_DC_AWBURST  | M_AXI_DC  | O   | Master Burst type                 |
| M_AXI_DC_AWLOCK   | M_AXI_DC  | O   | Master Lock type                  |
| M_AXI_DC_AWCACHE  | M_AXI_DC  | O   | Master Cache type                 |
| M_AXI_DC_AWPROT   | M_AXI_DC  | O   | Master Protection type            |
| M_AXI_DC_AWQOS    | M_AXI_DC  | O   | Master Quality of Service         |
| M_AXI_DC_AWVALID  | M_AXI_DC  | O   | Master Write address valid        |
| M_AXI_DC_AWREADY  | M_AXI_DC  | I   | Slave Write address ready         |
| M_AXI_DC_AWUSER   | M_AXI_DC  | O   | Master Write address user signals |
| M_AXI_DC_AWDOMAIN | M_ACE_DC  | O   | Master Write address domain       |
| M_AXI_DC_AWSNOOP  | M_ACE_DC  | O   | Master Write address snoop        |
| M_AXI_DC_AWBAR    | M_ACE_DC  | O   | Master Write address barrier      |
| M_AXI_DC_WDATA    | M_AXI_DC  | O   | Master Write data                 |
| M_AXI_DC_WSTRB    | M_AXI_DC  | O   | Master Write strobes              |
| M_AXI_DC_WLAST    | M_AXI_DC  | O   | Master Write last                 |
| M_AXI_DC_WVALID   | M_AXI_DC  | O   | Master Write valid                |
| M_AXI_DC_WREADY   | M_AXI_DC  | I   | Slave Write ready                 |
| M_AXI_DC_WUSER    | M_AXI_DC  | O   | Master Write user signals         |
| M_AXI_DC_BRESP    | M_AXI_DC  | I   | Slave Write response              |

**Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)**

| Signal            | Interface | I/O | Description                         |
|-------------------|-----------|-----|-------------------------------------|
| M_AXI_DC_BID      | M_AXI_DC  | I   | Slave Response ID                   |
| M_AXI_DC_BVALID   | M_AXI_DC  | I   | Slave Write response valid          |
| M_AXI_DC_BREADY   | M_AXI_DC  | O   | Master Response ready               |
| M_AXI_DC_BUSER    | M_AXI_DC  | I   | Slave Write response user signals   |
| M_AXI_DC_WACK     | M_ACE_DC  | O   | Slave Write acknowledge             |
| M_AXI_DC_ARID     | M_AXI_DC  | O   | Master Read address ID              |
| M_AXI_DC_ARADDR   | M_AXI_DC  | O   | Master Read address                 |
| M_AXI_DC_ARLEN    | M_AXI_DC  | O   | Master Burst length                 |
| M_AXI_DC_ARSIZE   | M_AXI_DC  | O   | Master Burst size                   |
| M_AXI_DC_ARBURST  | M_AXI_DC  | O   | Master Burst type                   |
| M_AXI_DC_ARLOCK   | M_AXI_DC  | O   | Master Lock type                    |
| M_AXI_DC_ARCACHE  | M_AXI_DC  | O   | Master Cache type                   |
| M_AXI_DC_ARPROT   | M_AXI_DC  | O   | Master Protection type              |
| M_AXI_DC_ARQOS    | M_AXI_DC  | O   | Master Quality of Service           |
| M_AXI_DC_ARVALID  | M_AXI_DC  | O   | Master Read address valid           |
| M_AXI_DC_ARREADY  | M_AXI_DC  | I   | Slave Read address ready            |
| M_AXI_DC_ARUSER   | M_AXI_DC  | O   | Master Read address user signals    |
| M_AXI_DC_ARDOMAIN | M_ACE_DC  | O   | Master Read address domain          |
| M_AXI_DC_ARSNOOP  | M_ACE_DC  | O   | Master Read address snoop           |
| M_AXI_DC_ARBAR    | M_ACE_DC  | O   | Master Read address barrier         |
| M_AXI_DC_RID      | M_AXI_DC  | I   | Slave Read ID tag                   |
| M_AXI_DC_RDATA    | M_AXI_DC  | I   | Slave Read data                     |
| M_AXI_DC_RRESP    | M_AXI_DC  | I   | Slave Read response                 |
| M_AXI_DC_RLAST    | M_AXI_DC  | I   | Slave Read last                     |
| M_AXI_DC_RVALID   | M_AXI_DC  | I   | Slave Read valid                    |
| M_AXI_DC_RREADY   | M_AXI_DC  | O   | Master Read ready                   |
| M_AXI_DC_RUSER    | M_AXI_DC  | I   | Slave Read user signals             |
| M_AXI_DC_RACK     | M_ACE_DC  | O   | Master Read acknowledge             |
| M_AXI_DC_ACVALID  | M_ACE_DC  | I   | Slave Snoop address valid           |
| M_AXI_DC_ACADDR   | M_ACE_DC  | I   | Slave Snoop address                 |
| M_AXI_DC_ACSNOOP  | M_ACE_DC  | I   | Slave Snoop address snoop           |
| M_AXI_DC_ACPROT   | M_ACE_DC  | I   | Slave Snoop address protection type |

**Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)**

| Signal            | Interface | I/O | Description                       |
|-------------------|-----------|-----|-----------------------------------|
| M_AXI_DC_ACREADY  | M_ACE_DC  | O   | Master Snoop ready                |
| M_AXI_DC_CRREADY  | M_ACE_DC  | I   | Slave Snoop response ready        |
| M_AXI_DC_CRVALID  | M_ACE_DC  | O   | Master Snoop response valid       |
| M_AXI_DC_CRRESP   | M_ACE_DC  | O   | Master Snoop response             |
| M_AXI_DC_CDVALID  | M_ACE_DC  | O   | Master Snoop data valid           |
| M_AXI_DC_CDREADY  | M_ACE_DC  | I   | Slave Snoop data ready            |
| M_AXI_DC_CDDATA   | M_ACE_DC  | O   | Master Snoop data                 |
| M_AXI_DC_CDLAST   | M_ACE_DC  | O   | Master Snoop data last            |
| M_AXI_IC_AWID     | M_AXI_IC  | O   | Master Write address ID           |
| M_AXI_IC_AWADDR   | M_AXI_IC  | O   | Master Write address              |
| M_AXI_IC_AWLEN    | M_AXI_IC  | O   | Master Burst length               |
| M_AXI_IC_AWSIZE   | M_AXI_IC  | O   | Master Burst size                 |
| M_AXI_IC_AWBURST  | M_AXI_IC  | O   | Master Burst type                 |
| M_AXI_IC_AWLOCK   | M_AXI_IC  | O   | Master Lock type                  |
| M_AXI_IC_AWCACHE  | M_AXI_IC  | O   | Master Cache type                 |
| M_AXI_IC_AWPROT   | M_AXI_IC  | O   | Master Protection type            |
| M_AXI_IC_AWQOS    | M_AXI_IC  | O   | Master Quality of Service         |
| M_AXI_IC_AWVALID  | M_AXI_IC  | O   | Master Write address valid        |
| M_AXI_IC_AWREADY  | M_AXI_IC  | I   | Slave Write address ready         |
| M_AXI_IC_AWUSER   | M_AXI_IC  | O   | Master Write address user signals |
| M_AXI_IC_AWDOMAIN | M_ACE_IC  | O   | Master Write address domain       |
| M_AXI_IC_AWSNOOP  | M_ACE_IC  | O   | Master Write address snoop        |
| M_AXI_IC_AWBAR    | M_ACE_IC  | O   | Master Write address barrier      |
| M_AXI_IC_WDATA    | M_AXI_IC  | O   | Master Write data                 |
| M_AXI_IC_WSTRB    | M_AXI_IC  | O   | Master Write strobes              |
| M_AXI_IC_WLAST    | M_AXI_IC  | O   | Master Write last                 |
| M_AXI_IC_WVALID   | M_AXI_IC  | O   | Master Write valid                |
| M_AXI_IC_WREADY   | M_AXI_IC  | I   | Slave Write ready                 |
| M_AXI_IC_WUSER    | M_AXI_IC  | O   | Master Write user signals         |
| M_AXI_IC_BID      | M_AXI_IC  | I   | Slave Response ID                 |
| M_AXI_IC_BRESP    | M_AXI_IC  | I   | Slave Write response              |
| M_AXI_IC_BVALID   | M_AXI_IC  | I   | Slave Write response valid        |

**Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)**

| Signal            | Interface | I/O | Description                         |
|-------------------|-----------|-----|-------------------------------------|
| M_AXI_IC_BREADY   | M_AXI_IC  | O   | Master Response ready               |
| M_AXI_IC_BUSER    | M_AXI_IC  | I   | Slave Write response user signals   |
| M_AXI_IC_WACK     | M_ACE_IC  | O   | Slave Write acknowledge             |
| M_AXI_IC_ARID     | M_AXI_IC  | O   | Master Read address ID              |
| M_AXI_IC_ARADDR   | M_AXI_IC  | O   | Master Read address                 |
| M_AXI_IC_ARLEN    | M_AXI_IC  | O   | Master Burst length                 |
| M_AXI_IC_ARSIZE   | M_AXI_IC  | O   | Master Burst size                   |
| M_AXI_IC_ARBURST  | M_AXI_IC  | O   | Master Burst type                   |
| M_AXI_IC_ARLOCK   | M_AXI_IC  | O   | Master Lock type                    |
| M_AXI_IC_ARCACHE  | M_AXI_IC  | O   | Master Cache type                   |
| M_AXI_IC_ARPROT   | M_AXI_IC  | O   | Master Protection type              |
| M_AXI_IC_ARQOS    | M_AXI_IC  | O   | Master Quality of Service           |
| M_AXI_IC_ARVALID  | M_AXI_IC  | O   | Master Read address valid           |
| M_AXI_IC_ARREADY  | M_AXI_IC  | I   | Slave Read address ready            |
| M_AXI_IC_ARUSER   | M_AXI_IC  | O   | Master Read address user signals    |
| M_AXI_IC_ARDOMAIN | M_ACE_IC  | O   | Master Read address domain          |
| M_AXI_IC_ARSNOOP  | M_ACE_IC  | O   | Master Read address snoop           |
| M_AXI_IC_ARBAR    | M_ACE_IC  | O   | Master Read address barrier         |
| M_AXI_IC_RID      | M_AXI_IC  | I   | Slave Read ID tag                   |
| M_AXI_IC_RDATA    | M_AXI_IC  | I   | Slave Read data                     |
| M_AXI_IC_RRESP    | M_AXI_IC  | I   | Slave Read response                 |
| M_AXI_IC_RLAST    | M_AXI_IC  | I   | Slave Read last                     |
| M_AXI_IC_RVALID   | M_AXI_IC  | I   | Slave Read valid                    |
| M_AXI_IC_RREADY   | M_AXI_IC  | O   | Master Read ready                   |
| M_AXI_IC_RUSER    | M_AXI_IC  | I   | Slave Read user signals             |
| M_AXI_IC_RACK     | M_ACE_IC  | O   | Master Read acknowledge             |
| M_AXI_IC_ACVALID  | M_ACE_IC  | I   | Slave Snoop address valid           |
| M_AXI_IC_ACADDR   | M_ACE_IC  | I   | Slave Snoop address                 |
| M_AXI_IC_ACSNOOP  | M_ACE_IC  | I   | Slave Snoop address snoop           |
| M_AXI_IC_ACPROT   | M_ACE_IC  | I   | Slave Snoop address protection type |
| M_AXI_IC_ACREADY  | M_ACE_IC  | O   | Master Snoop ready                  |
| M_AXI_IC_CRREADY  | M_ACE_IC  | I   | Slave Snoop response ready          |



**Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)**

| Signal           | Interface             | I/O | Description                                       |
|------------------|-----------------------|-----|---------------------------------------------------|
| M_AXI_IC_CRVALID | M_ACE_IC              | O   | Master Snoop response valid                       |
| M_AXI_IC_CRRESP  | M_ACE_IC              | O   | Master Snoop response                             |
| M_AXI_IC_CDVALID | M_ACE_IC              | O   | Master Snoop data valid                           |
| M_AXI_IC_CDREADY | M_ACE_IC              | I   | Slave Snoop data ready                            |
| M_AXI_IC_CDDATA  | M_ACE_IC              | O   | Master Snoop data                                 |
| M_AXI_IC_CDLAST  | M_ACE_IC              | O   | Master Snoop data last                            |
| Data_Addr[0:N-1] | DLMB                  | O   | Data interface LMB address bus, N = 32 - 64       |
| Byte_Enable[0:3] | DLMB                  | O   | Data interface LMB byte enables                   |
| Data_Write[0:31] | DLMB                  | O   | Data interface LMB write data bus                 |
| D_AS             | DLMB                  | O   | Data interface LMB address strobe                 |
| Read_Strobe      | DLMB                  | O   | Data interface LMB read strobe                    |
| Write_Strobe     | DLMB                  | O   | Data interface LMB write strobe                   |
| Data_Read[0:31]  | DLMB                  | I   | Data interface LMB read data bus                  |
| DReady           | DLMB                  | I   | Data interface LMB data ready                     |
| DWait            | DLMB                  | I   | Data interface LMB data wait                      |
| DCE              | DLMB                  | I   | Data interface LMB correctable error              |
| DUE              | DLMB                  | I   | Data interface LMB uncorrectable error            |
| Instr_Addr[0:31] | ILMB                  | O   | Instruction interface LMB address bus             |
| I_AS             | ILMB                  | O   | Instruction interface LMB address strobe          |
| IFetch           | ILMB                  | O   | Instruction interface LMB instruction fetch       |
| Instr[0:31]      | ILMB                  | I   | Instruction interface LMB read data bus           |
| IReady           | ILMB                  | I   | Instruction interface LMB data ready              |
| IWait            | ILMB                  | I   | Instruction interface LMB data wait               |
| ICE              | ILMB                  | I   | Instruction interface LMB correctable error       |
| IUE              | ILMB                  | I   | Instruction interface LMB uncorrectable error     |
| Mn_AXIS_TLAST    | M0_AXIS..<br>M15_AXIS | O   | Master interface output AXI4 channels write last  |
| Mn_AXIS_TDATA    | M0_AXIS..<br>M15_AXIS | O   | Master interface output AXI4 channels write data  |
| Mn_AXIS_TVALID   | M0_AXIS..<br>M15_AXIS | O   | Master interface output AXI4 channels write valid |
| Mn_AXIS_TREADY   | M0_AXIS..<br>M15_AXIS | I   | Master interface input AXI4 channels write ready  |

Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)

| Signal                         | Interface             | I/O | Description                                                                                                                                                                                                                                 |
|--------------------------------|-----------------------|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sn_AXIS_TLAST                  | S0_AXIS..<br>S15_AXIS | I   | Slave interface input AXI4 channels write last                                                                                                                                                                                              |
| Sn_AXIS_TDATA                  | S0_AXIS..<br>S15_AXIS | I   | Slave interface input AXI4 channels write data                                                                                                                                                                                              |
| Sn_AXIS_TVALID                 | S0_AXIS..<br>S15_AXIS | I   | Slave interface input AXI4 channels write valid                                                                                                                                                                                             |
| Sn_AXIS_TREADY                 | S0_AXIS..<br>S15_AXIS | O   | Slave interface output AXI4 channels write ready                                                                                                                                                                                            |
| Interrupt                      | Core                  | I   | Interrupt. The signal is synchronized to <code>Clk</code> if the parameter <code>C_ASYNC_INTERRUPT</code> is set.                                                                                                                           |
| Interrupt_Address <sup>1</sup> | Core                  | I   | Interrupt vector address                                                                                                                                                                                                                    |
| Interrupt_Ack <sup>1</sup>     | Core                  | O   | Interrupt acknowledge                                                                                                                                                                                                                       |
| Reset                          | Core                  | I   | Core reset, active high. Should be held for at least 1 <code>Clk</code> clock cycle.                                                                                                                                                        |
| Reset_Mode[0:1]                | Core                  | I   | Reset mode. Sampled when Reset is active. See Table 3-2 for details.                                                                                                                                                                        |
| Clk                            | Core                  | I   | Clock <sup>2</sup>                                                                                                                                                                                                                          |
| Ext_BRK                        | Core                  | I   | Break signal from MDM                                                                                                                                                                                                                       |
| Ext_NM_BRK                     | Core                  | I   | Non-maskable break signal from MDM                                                                                                                                                                                                          |
| MB_Halted                      | Core                  | O   | Pipeline is halted, either via the Debug Interface, by setting <code>Dbg_Stop</code> , or by setting <code>Reset_Mode[0:1]</code> to 10.                                                                                                    |
| Dbg_Stop                       | Core                  | I   | Unconditionally force pipeline to halt as soon as possible. Rising-edge detected pulse that should be held for at least 1 <code>Clk</code> clock cycle. The signal only has any effect when <code>C_DEBUG_ENABLED</code> is greater than 0. |
| Dbg_Intr                       | Core                  | O   | Debug interrupt output, set when a Performance Monitor counter overflows, available when <code>C_DEBUG_ENABLED</code> is set to 2 (Extended).                                                                                               |
| MB_Error                       | Core                  | O   | Pipeline is halted due to a missed exception, when <code>C_FAULT_TOLERANT</code> is set to 1.                                                                                                                                               |
| Sleep                          | Core                  | O   | MicroBlaze is in sleep mode after executing a SLEEP instruction or by setting <code>Reset_Mode[0:1]</code> to 10, all external accesses are completed, and the pipeline is halted.                                                          |
| Hibernate                      | Core                  | O   | MicroBlaze is in sleep mode after executing a HIBERNATE instruction, all external accesses are completed, and the pipeline is halted.                                                                                                       |

Table 3-1: Summary of MicroBlaze Core I/O (Cont'd)

| Signal          | Interface | I/O | Description                                                                                                                                                                                                                                  |
|-----------------|-----------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Suspend         | Core      | O   | MicroBlaze is in sleep mode after executing a SUSPEND instruction, all external accesses are completed, and the pipeline is halted.                                                                                                          |
| Wakeup[0:1]     | Core      | I   | Wake MicroBlaze from sleep mode when either or both bits are set to 1. Ignored if MicroBlaze is not in sleep mode. The signals are individually synchronized to Clk according to the parameter C_ASYNC_WAKEUP[0:1].                          |
| Dbg_Wakeup      | Core      | O   | Debug request that external logic should wake MicroBlaze from sleep mode with the Wakeup signal, to allow debug access. Synchronous to Dbg_Update.                                                                                           |
| Pause           | Core      | I   | When this signal is set MicroBlaze pipeline will be paused after completing all ongoing bus accesses, and the Pause_Ack signal will be set. When this signal is cleared again MicroBlaze will continue normal execution where it was paused. |
| Pause_Ack       | Core      | O   | MicroBlaze is in pause mode after the Pause input signal has been set.                                                                                                                                                                       |
| Dbg_Continue    | Core      | O   | Debug request that external logic should clear the Pause signal, to allow debug access.                                                                                                                                                      |
| Non_Secure[0:3] | Core      | I   | Determines whether AXI accesses are non-secure or secure. The default value is binary 0000, setting all interfaces to be secure.<br>Bit 0 = M_AXI_DP<br>Bit 1 = M_AXI_IP<br>Bit 2 = M_AXI_DC<br>Bit 3 = M_AXI_IC                             |
| Lockstep_...    | Core      | IO  | Lockstep signals for high integrity applications. See Table 3-13 for details.                                                                                                                                                                |
| Dbg_...         | Core      | IO  | Debug signals from MDM. See Table 3-15 for details.                                                                                                                                                                                          |
| Trace_...       | Core      | O   | Trace signals for real time HW analysis. See Table 3-16 for details.                                                                                                                                                                         |

1. Only used with C\_USE\_INTERRUPT = 2, for low-latency interrupt support.
2. MicroBlaze is a synchronous design clocked with the Clk signal, except for serial hardware debug logic, which is clocked with the Dbg\_Clk signal. If serial hardware debug logic is not used, there is no minimum frequency limit for Clk. However, if serial hardware debug logic is used, there are signals transferred between the two clock regions. In this case Clk must have a higher frequency than Dbg\_Clk.

Table 3-2: Effect of Reset Mode inputs

| Reset_Mode[0:1] | Description                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 00              | MicroBlaze starts executing at the reset vector, defined by C_BASE_VECTORS. This is the nominal default behavior.                                                                                                                                                                                                                                                                                                                 |
| 01              | MicroBlaze immediately enters sleep mode without performing any bus access, just as if a SLEEP instruction had been executed. The Sleep output is set to 1. When any of the Wakeup[0:1] signals is set, MicroBlaze starts executing at the reset vector, defined by C_BASE_VECTORS.<br><br>This functionality can be useful in a multiprocessor configuration, allowing secondary processors to be configured without LMB memory. |
| 10              | If C_DEBUG_ENABLED is 0, the behavior is the same as if Reset_Mode[0:1] = 00.<br><br>If C_DEBUG_ENABLED is greater than 0, MicroBlaze immediately enters debug halt without performing any bus access, and the MB_Halted output is set to 1. When execution is continued via the debug interface, MicroBlaze starts executing at the reset vector, defined by C_BASE_VECTORS.                                                     |
| 11              | Reserved                                                                                                                                                                                                                                                                                                                                                                                                                          |

In general MicroBlaze signals are synchronous to the Clk input signal. However, there are some exceptions controlled by parameters as described in [Table 3-3](#).

Table 3-3: Parameter Controlled Asynchronous Signals

| Signal      | Parameter                           | Default              | Description                                                              |
|-------------|-------------------------------------|----------------------|--------------------------------------------------------------------------|
| Interrupt   | C_ASYNC_INTERRUPT                   | Tool controlled      | Parameter set from connected signal                                      |
| Reset       | C_NUM_SYNC_FF_CLK                   | 2                    | Parameter can be manually set to 0 for synchronous reset                 |
| Wakeup[0:1] | C_ASYNC_WAKEUP<br>C_NUM_SYNC_FF_CLK | Tool controlled<br>2 | Set from connected signals<br>Can be manually set to 0 to override tool  |
| Dbg_Wakeup  | C_DEBUG_INTERFACE                   | 0 (serial)           | 0: Clocked by Dbg_Update<br>1: Clocked by DEBUG_ACLK, synchronous to Clk |

## Sleep and Pause Functionality

There are two distinct ways of halting MicroBlaze execution in a controlled manner:

- Software controlled by executing an MBAR instruction to enter sleep mode.
- Hardware controlled by setting the input signal Pause to pause the pipeline.

### Software Controlled

When an MBAR instruction is executed to enter sleep mode and MicroBlaze has completed all external accesses, the pipeline is halted and either the Sleep, Hibernate or Suspend output signal is set. This indicates to external hardware that it is safe to perform actions such as stopping the clock, resetting the processor or other IP cores. Different actions can be performed depending on which output signal is set.

To wake up MicroBlaze when in sleep mode, one (or both) of the `Wakeup` input signals must be set to one. In this case MicroBlaze continues execution after the MBAR instruction.

The `Dbg_Wakeup` output signal from MicroBlaze indicates that the debugger requests a wake up. External hardware should handle this signal and wake up the processor, after performing any other necessary hardware actions such as starting the clock.

If debug wake up is used, the software must be aware that this could be the reason for waking up, and go to sleep again if no other action is required.

In the simplest case, where no additional actions are needed before waking up the processor, one of the `Wakeup` inputs can be connected to the same signal as the MicroBlaze `Interrupt` input, and the other to the MicroBlaze `Dbg_Wakeup` output. This allows MicroBlaze to wake up when an interrupt occurs, or when the debugger requests it.

To implement a software reset functionality, for example the `Suspend` output signal can be connected to a suitable reset input, to either reset the processor or the entire system.

The MBAR sleep mode instructions are summarized in [Table 3-4](#).

**Table 3-4: MBAR Sleep Mode Instructions**

| Instruction | Assembler Pseudo Instruction | Output Signal |
|-------------|------------------------------|---------------|
| mbar 16     | sleep                        | Sleep         |
| mbar 8      | hibernate                    | Hibernate     |
| mbar 24     | suspend                      | Suspend       |

### **Hardware Controlled**

When the `Pause` input signal is set to one and MicroBlaze has completed all external accesses, the pipeline is halted and the `Pause_Ack` output signal is set. This indicates to external hardware that it is safe to perform actions such as stopping the clock, resetting the processor or other IP cores.

To continue from pause, the input signal `Pause` must be cleared to zero. In this case MicroBlaze continues instruction execution where it was previously paused.

The `Dbg_Continue` output signal from MicroBlaze indicates that the debugger requests the processor to continue from pause. External hardware should handle this signal and clear pause after performing any other necessary hardware actions such as starting the clock.

After external hardware has set or cleared `Pause`, it is recommended to wait until `Pause_Ack` is set or cleared before `Pause` is changed again, to avoid any issues due to incorrectly detected pause acknowledge.

All signals used for hardware control (`Pause`, `Pause_Ack`, and `Dbg_Continue`) are synchronous to the MicroBlaze clock.

# AXI4 and ACE Interface Description

## Memory Mapped Interfaces

### *Peripheral Interfaces*

The MicroBlaze AXI4 memory mapped peripheral interfaces are implemented as 32-bit masters. Each of these interfaces only have a single outstanding transaction at any time, and all transactions are completed in order.

- The instruction peripheral interface (M\_AXI\_IP) only performs single word read accesses, and is always set to use the AXI4-Lite subset.
- The data peripheral interface (M\_AXI\_DP) performs single word accesses, and is set to use the AXI4-Lite subset as default, but is set to use AXI4 when enabling exclusive access for LWX and SWX instructions. Halfword and byte writes are performed by setting the appropriate byte strobes.

The instruction peripheral interface (M\_AXI\_IP) address width can range from 32 - 64 bits when the MMU Physical Address Extension (PAE) is enabled, depending on the value of the parameter `C_ADDR_SIZE`.

The data peripheral interface (M\_AXI\_DP) address width can range from 32 - 64 bits, depending on the value of the parameter `C_ADDR_SIZE`.

### *Cache Interfaces*

The AXI4 memory mapped cache interfaces are implemented either as 32-bit, 128-bit, 256-bit, or 512-bit masters, depending on cache line length and data width parameters, whereas the AXI Coherency Extension (ACE) interfaces are implemented as 32-bit masters.

- With a 32-bit master, the instruction cache interface (M\_AXI\_IC or M\_ACE\_IC) performs 4 word, 8 word or 16 word burst read accesses, depending on cache line length. With 128-bit, 256-bit, or 512-bit masters, only single read accesses are performed.

With a 32-bit master, this interface can have multiple outstanding transactions, issuing up to 2 transactions or up to 5 transactions when stream cache is enabled. The stream cache can request two cache lines in advance, which means that in some cases 5 outstanding transactions can occur. In this case the number of outstanding reads is set to 8, since this must be a power of two. With 128-bit, 256-bit, or 512-bit masters, the interface only has a single outstanding transaction.

How memory locations are accessed depend on parameter `C_ICACHE_ALWAYS_USED`. If the parameter is 1, the cached memory range is always accessed via the AXI4 or ACE

cache interface. If the parameter is 0, the cached memory range is accessed over the AXI4 peripheral interface when the caches are software disabled (that is, MSR[ICE]=0).

- With a 32-bit master, the data cache interface (M\_AXI\_DC or M\_ACE\_DC) performs single word accesses, as well as 4 word, 8 word or 16 word burst accesses, depending on cache line length. Burst write accesses are only performed when using write-back cache with AXI4. With 128-bit, 256-bit, or 512-bit AXI4 masters, only single accesses are performed.

This interface can have multiple outstanding transactions, either issuing up to 2 transactions when reading, or up to 32 transactions when writing. MicroBlaze ensures that all outstanding writes are completed before a read is issued, since the processor must maintain an ordered memory model but AXI4 or ACE has separate read/write channels without any ordering. Using up to 32 outstanding write transactions improves performance, since it allows multiple writes to proceed without stalling the pipeline.

Word, halfword and byte writes are performed by setting the appropriate byte strobes.

Exclusive accesses can be enabled for LWX and SWX instructions.

How memory locations are accessed depend on the parameter C\_DCACHE\_ALWAYS\_USED. If the parameter is 1, the cached memory range is always accessed via the AXI4 or ACE cache interface. If the parameter is 0, the cached memory range is accessed over the AXI4 peripheral interface when the caches are software disabled (that is, MSR[DCE]=0).

## Interface Parameters and Signals

The relationship between MicroBlaze parameter settings and AXI4 interface behavior for tool-assigned parameters is summarized in [Table 3-5](#).

**Table 3-5: AXI Memory Mapped Interface Parameters**

| Interface            | Parameter             | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M_AXI_DP             | C_M_AXI_DP_PROTOCOL   | <b>AXI4-Lite:</b> Default.<br><b>AXI4:</b> Used to allow exclusive access when C_M_AXI_DP_EXCLUSIVE_ACCESS is 1.                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| M_AXI_IC<br>M_ACE_IC | C_M_AXI_IC_DATA_WIDTH | <b>32:</b> Default, single word accesses and burst accesses with C_ICACHE_LINE_LEN word busts used with AXI4 and ACE.<br><b>128:</b> Used when C_ICACHE_DATA_WIDTH is set to 1 and C_ICACHE_LINE_LEN is set to 4 with AXI4. Only single accesses can occur.<br><b>256:</b> Used when C_ICACHE_DATA_WIDTH is set to 1 and C_ICACHE_LINE_LEN is set to 8 with AXI4. Only single accesses can occur.<br><b>512:</b> Used when C_ICACHE_DATA_WIDTH is set to 2, or when it is set to 1 and C_ICACHE_LINE_LEN is set to 16 with AXI4. Only single accesses can occur. |

Table 3-5: AXI Memory Mapped Interface Parameters (Cont'd)

| Interface            | Parameter             | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M_AXI_DC<br>M_ACE_DC | C_M_AXI_DC_DATA_WIDTH | <p><b>32:</b> Default, single word accesses and burst accesses with C_DCACHE_LINE_LEN word bursts used with AXI4 and ACE.</p> <p>Write bursts are only used with AXI4 when C_DCACHE_USE_WRITEBACK is set to 1.</p> <p><b>128:</b> Used when C_DCACHE_DATA_WIDTH is set to 1 and C_DCACHE_LINE_LEN is set to 4 with AXI4. Only single accesses can occur.</p> <p><b>256:</b> Used when C_DCACHE_DATA_WIDTH is set to 1 and C_DCACHE_LINE_LEN is set to 8 with AXI4. Only single accesses can occur.</p> <p><b>512:</b> Used when C_DCACHE_DATA_WIDTH is set to 2, or when it is set to 1 and C_DCACHE_LINE_LEN is set to 16 with AXI4. Only single accesses can occur.</p> |
| M_AXI_IC<br>M_ACE_IC | NUM_READ_OUTSTANDING  | <p><b>1:</b> Default for 128-bit, 256-bit and 512-bit masters, a single outstanding read.</p> <p><b>2:</b> Default for 32-bit masters, 2 simultaneous outstanding reads.</p> <p><b>8:</b> Used for 32-bit masters when C_ICACHE_STREAMS is set to 1, allowing 8 simultaneous outstanding reads. Can be set to 1, 2, or 8.</p>                                                                                                                                                                                                                                                                                                                                             |
| M_AXI_DC<br>M_ACE_DC | NUM_READ_OUTSTANDING  | <p><b>1:</b> Default for 128-bit, 256-bit and 512-bit masters, a single outstanding read.</p> <p><b>2:</b> Default for 32-bit masters, 2 simultaneous outstanding reads. Can be set to 1 or 2.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| M_AXI_DC<br>M_ACE_DC | NUM_WRITE_OUTSTANDING | <p><b>32:</b> Default, 32 simultaneous outstanding writes. Can be set to 1, 2, 4, 8, 16, or 32.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |



Values for access permissions, memory types, quality of service and shareability domain are defined in Table 3-6.

Table 3-6: AXI Interface Signal Definitions

| Interface            | Signal                                     | Description                                                                                                                                                                                                                                                      |
|----------------------|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M_AXI_IP             | C_M_AXI_IP_ARPROT                          | Access Permission: <ul style="list-style-type: none"> <li>Unprivileged, secure instruction access (100) if input signal Non_Secure[1] = 0</li> <li>Unprivileged, non-secure instruction access (110) if input signal Non_Secure[1] = 1</li> </ul>                |
| M_AXI_DP             | C_M_AXI_DP_ARCACHE<br>C_M_AXI_DP_AWCACHE   | Memory Type, AXI4 protocol: <ul style="list-style-type: none"> <li>Normal Non-cacheable Bufferable (0011)</li> </ul>                                                                                                                                             |
|                      | C_M_AXI_DP_ARPROT<br>C_M_AXI_DP_AWPROT     | Access Permission, AXI4 and AXI4-Lite protocol: <ul style="list-style-type: none"> <li>Unprivileged, secure data access (000) if input signal Non_Secure[0] = 0</li> <li>Unprivileged, non-secure data access (010) if input signal Non_Secure[0] = 1</li> </ul> |
|                      | C_M_AXI_DP_ARQOS<br>C_M_AXI_DP_AWQOS       | Quality of Service, AXI4 protocol: <ul style="list-style-type: none"> <li>Priority 8 (1000)</li> </ul>                                                                                                                                                           |
| M_AXI_IC             | C_M_AXI_IC_ARCACHE                         | Memory Type: <ul style="list-style-type: none"> <li>Write-back Read and Write-allocate (1111)</li> </ul>                                                                                                                                                         |
| M_ACE_IC             | C_M_AXI_IC_ARCACHE                         | Memory Type, normal access: <ul style="list-style-type: none"> <li>Write-back Read and Write-allocate (1111)</li> </ul> Memory Type, DVM access: <ul style="list-style-type: none"> <li>Normal Non-cacheable Non-bufferable (0010)</li> </ul>                    |
|                      | C_M_AXI_IC_ARDOMAIN                        | Shareability Domain: <ul style="list-style-type: none"> <li>Inner shareable (01)</li> </ul>                                                                                                                                                                      |
| M_AXI_IC<br>M_ACE_IC | C_M_AXI_IC_ARPROT                          | Access Permission: <ul style="list-style-type: none"> <li>Unprivileged, secure instruction access (100) if input signal Non_Secure[3] = 0</li> <li>Unprivileged, non-secure instruction access (110) if input signal Non_Secure[3] = 1</li> </ul>                |
|                      | C_M_AXI_IC_ARQOS                           | Quality of Service: <ul style="list-style-type: none"> <li>Priority 7 (0111)</li> </ul>                                                                                                                                                                          |
| M_AXI_DC             | C_M_AXI_DC_ARCACHE                         | Memory Type, normal access: <ul style="list-style-type: none"> <li>Write-back Read and Write-allocate (1111)</li> </ul> Memory Type, exclusive access: <ul style="list-style-type: none"> <li>Normal Non-cacheable Non-bufferable (0010)</li> </ul>              |
| M_ACE_DC             | C_M_AXI_DC_ARCACHE                         | Memory Type, normal and exclusive access: <ul style="list-style-type: none"> <li>Write-back Read and Write-allocate (1111)</li> </ul> Memory Type, DVM access: <ul style="list-style-type: none"> <li>Normal Non-cacheable Non-bufferable (0010)</li> </ul>      |
|                      | C_M_AXI_DC_ARDOMAIN<br>C_M_AXI_DC_AWDOMAIN | Shareability Domain: <ul style="list-style-type: none"> <li>Inner shareable (01)</li> </ul>                                                                                                                                                                      |

**Table 3-6: AXI Interface Signal Definitions**

| Interface            | Signal                                 | Description                                                                                                                                                                                                                                               |
|----------------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M_AXI_DC<br>M_ACE_DC | C_M_AXI_DC_AWCACHE                     | Memory Type, normal access:<br><ul style="list-style-type: none"> <li>Write-back Read and Write-allocate (1111)</li> </ul> Memory Type, exclusive access:<br><ul style="list-style-type: none"> <li>Normal Non-cacheable Non-bufferable (0010)</li> </ul> |
|                      | C_M_AXI_DC_ARPROT<br>C_M_AXI_DC_AWPROT | Access Permission:<br><ul style="list-style-type: none"> <li>Unprivileged, secure data access (000) if input signal Non_Secure[2] = 0</li> <li>Unprivileged, non-secure data access (010) if input signal Non_Secure[2] = 1</li> </ul>                    |
|                      | C_M_AXI_DC_ARQOS                       | Quality of Service, read access:<br><ul style="list-style-type: none"> <li>Priority 12 ((1100)</li> </ul>                                                                                                                                                 |
|                      | C_M_AXI_DC_AWQOS                       | Quality of Service, write access:<br><ul style="list-style-type: none"> <li>Priority 8 (1000)</li> </ul>                                                                                                                                                  |

The instruction cache interface (M\_AXI\_IC) address width can range from 32 - 64 bits when the MMU Physical Address Extension (PAE) is enabled, depending on the value of the parameter C\_ADDR\_SIZE.

The data cache interface (M\_AXI\_DC or M\_ACE\_DC) address width can range from 32 - 64 bits, depending on the value of the parameter C\_ADDR\_SIZE.

Please refer to the *AMBA AXI and ACE Protocol Specification* ([ARM IHI 0022E](#)) document for details.

## Stream Interfaces

The MicroBlaze AXI4-Stream interfaces (M0\_AXIS..M15\_AXIS, S0\_AXIS..S15\_AXIS) are implemented as 32-bit masters and slaves. Please refer to the *AMBA 4 AXI4-Stream Protocol Specification, Version 1.0* ([ARM IHI 0051A](#)) document for further details.

### Write Operation

A write to the stream interface is performed by MicroBlaze using one of the put or putd instructions. A write operation transfers the register contents to an output AXI4 interface. The transfer is completed in a single clock cycle for blocking mode writes (put and cput instructions) as long as the interface is not busy. If the interface is busy, the processor stalls until it becomes available. The non-blocking instructions (with prefix n), always complete in a single clock cycle even if the interface is busy. If the interface was busy, the write is inhibited and the carry bit is set in the MSR.

The control instructions (with prefix c) set the AXI4-Stream TLAST output, to '1', which is used to indicate the boundary of a packet.

## ***Read Operation***

A read from the stream interface is performed by MicroBlaze using one of the `get` or `getd` instructions. A read operations transfers the contents of an input AXI4 interface to a general purpose register. The transfer is typically completed in 2 clock cycles for blocking mode reads as long as data is available. If data is not available, the processor stalls at this instruction until it becomes available. In the non-blocking mode (instructions with prefix `n`), the transfer is completed in one or two clock cycles irrespective of whether or not data was available. In case data was not available, the transfer of data does not take place and the carry bit is set in the MSR.

The data get instructions (without prefix `c`) expect the AXI4-Stream TLAST input to be cleared to '0', otherwise the instructions will set MSR[FSL] to '1'. Conversely, the control get instructions (with prefix `c`) expect the TLAST input to be set to '1', otherwise the instructions will set MSR[FSL] to '1'. This can be used to check for the boundary of a packet.

## Local Memory Bus (LMB) Interface Description

The LMB is a synchronous bus used primarily to access on-chip block RAM. It uses a minimum number of control signals and a simple protocol to ensure that local block RAM are accessed in a single clock cycle. LMB signals and definitions are shown in the following table. All LMB signals are active high.

### LMB Signal Interface

Table 3-7: LMB Bus Signals

| Signal                   | Data Interface                | Instruction Interface          | Type | Description                           |
|--------------------------|-------------------------------|--------------------------------|------|---------------------------------------|
| Addr[0:N-1] <sup>1</sup> | Data_Addr[0:N-1] <sup>1</sup> | Instr_Addr[0:N-1] <sup>2</sup> | O    | Address bus                           |
| Byte_Enable[0:3]         | Byte_Enable[0:3]              | <i>not used</i>                | O    | Byte enables                          |
| Data_Write[0:31]         | Data_Write[0:31]              | <i>not used</i>                | O    | Write data bus                        |
| AS                       | D_AS                          | I_AS                           | O    | Address strobe                        |
| Read_Strobe              | Read_Strobe                   | IFetch                         | O    | Read in progress                      |
| Write_Strobe             | Write_Strobe                  | <i>not used</i>                | O    | Write in progress                     |
| Data_Read[0:31]          | Data_Read[0:31]               | Instr[0:31]                    | I    | Read data bus                         |
| Ready                    | DReady                        | IReady                         | I    | Ready for next transfer               |
| Wait <sup>3</sup>        | DWait                         | IWait                          | I    | Wait until accepted transfer is ready |
| CE <sup>3</sup>          | DCE                           | ICE                            | I    | Correctable error                     |
| UE <sup>3</sup>          | DUE                           | IUE                            | I    | Uncorrectable error                   |
| Clk                      | Clk                           | Clk                            | I    | Bus clock                             |

1. N = 32 - 64, set according to parameter C\_ADDR\_SIZE, added in MicroBlaze v9.6.

2. N = 32 - 64, set according to parameter C\_ADDR\_SIZE when PAE is enabled, added in MicroBlaze v10.0.

3. Added in LMB for MicroBlaze v8.00

#### Addr[0:N-1]

The address bus is an output from the core and indicates the memory address that is being accessed by the current transfer. It is valid only when AS is high. In multicycle accesses (accesses requiring more than one clock cycle to complete), Addr[0:N-1] is valid only in the first clock cycle of the transfer.

#### Byte\_Enable[0:3]

The byte enable signals are outputs from the core and indicate which byte lanes of the data bus contain valid data. Byte\_Enable[0:3] is valid only when AS is high. In multicycle accesses (accesses requiring more than one clock cycle to complete), Byte\_Enable[0:3]

is valid only in the first clock cycle of the transfer. Valid values for `Byte_Enable[0:3]` are shown in the following table:

:

**Table 3-8: Valid Values for `Byte_Enable[0:3]`**

| <b>Byte_Enable[0:3]</b> | <b>Byte Lanes Used</b> |                   |                    |                    |
|-------------------------|------------------------|-------------------|--------------------|--------------------|
|                         | <b>Data[0:7]</b>       | <b>Data[8:15]</b> | <b>Data[16:23]</b> | <b>Data[24:31]</b> |
| 0001                    |                        |                   |                    | •                  |
| 0010                    |                        |                   | •                  |                    |
| 0100                    |                        | •                 |                    |                    |
| 1000                    | •                      |                   |                    |                    |
| 0011                    |                        |                   | •                  | •                  |
| 1100                    | •                      | •                 |                    |                    |
| 1111                    | •                      | •                 | •                  | •                  |

### ***Data\_Write[0:31]***

The write data bus is an output from the core and contains the data that is written to memory. It is valid only when `AS` is high. Only the byte lanes specified by `Byte_Enable[0:3]` contain valid data.

### ***AS***

The address strobe is an output from the core and indicates the start of a transfer and qualifies the address bus and the byte enables. It is high only in the first clock cycle of the transfer, after which it goes low and remains low until the start of the next transfer.

### ***Read\_Strobe***

The read strobe is an output from the core and indicates that a read transfer is in progress. This signal goes high in the first clock cycle of the transfer, and may remain high until the clock cycle after `Ready` is sampled high. If a new read transfer is directly started in the next clock cycle, then `Read_Strobe` remains high.

### ***Write\_Strobe***

The write strobe is an output from the core and indicates that a write transfer is in progress. This signal goes high in the first clock cycle of the transfer, and may remain high until the clock cycle after `Ready` is sampled high. If a new write transfer is directly started in the next clock cycle, then `Write_Strobe` remains high.

### ***Data\_Read[0:31]***

The read data bus is an input to the core and contains data read from memory. `Data_Read` is valid on the rising edge of the clock when `Ready` is high.

### ***Ready***

The `Ready` signal is an input to the core and indicates completion of the current transfer and that the next transfer can begin in the following clock cycle. It is sampled on the rising edge of the clock. For reads, this signal indicates the `Data_Read[0:31]` bus is valid, and for writes it indicates that the `Data_Write[0:31]` bus has been written to local memory.

### ***Wait***

The `Wait` signal is an input to the core and indicates that the current transfer has been accepted, but not yet completed. It is sampled on the rising edge of the clock.

### ***CE***

The `CE` signal is an input to the core and indicates that the current transfer had a correctable error. It is valid on the rising edge of the clock when `Ready` is high. For reads, this signal indicates that an error has been corrected on the `Data_Read[0:31]` bus, and for byte and halfword writes it indicates that the corresponding data word in local memory has been corrected before writing the new data.

### ***UE***

The `UE` signal is an input to the core and indicates that the current transfer had an uncorrectable error. It is valid on the rising edge of the clock when `Ready` is high. For reads, this signal indicates that the value of the `Data_Read[0:31]` bus is erroneous, and for byte and halfword writes it indicates that the corresponding data word in local memory was erroneous before writing the new data.

### ***Clk***

All operations on the LMB are synchronous to the MicroBlaze core clock.

## LMB Transactions

The following diagrams provide examples of LMB bus operations.

### Generic Write Operations

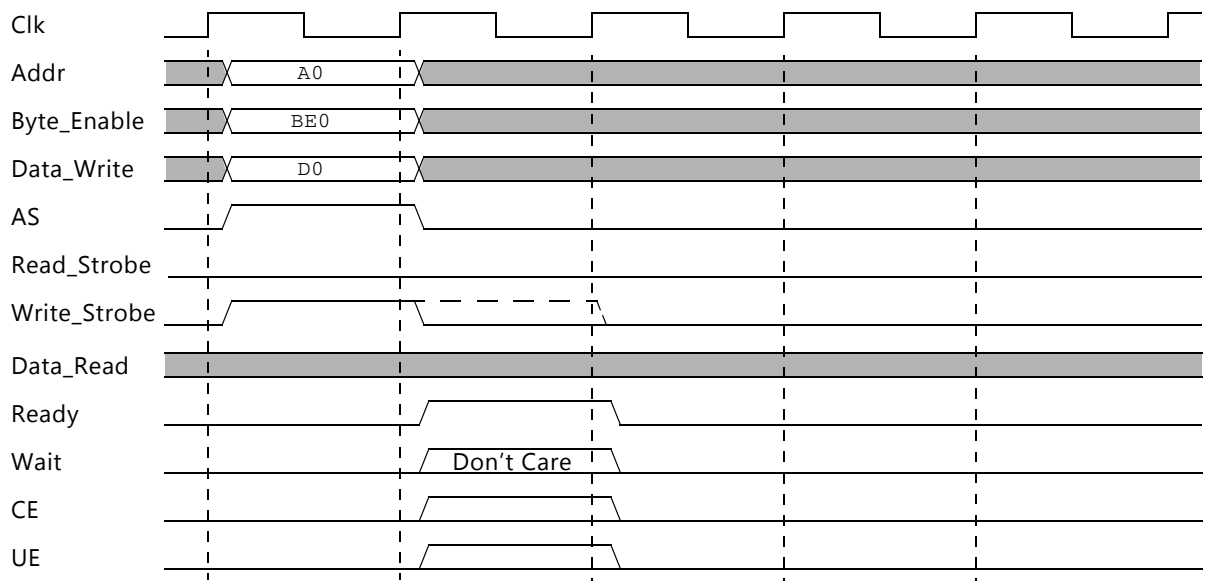


Figure 3-2: LMB Generic Write Operation, 0 Wait States

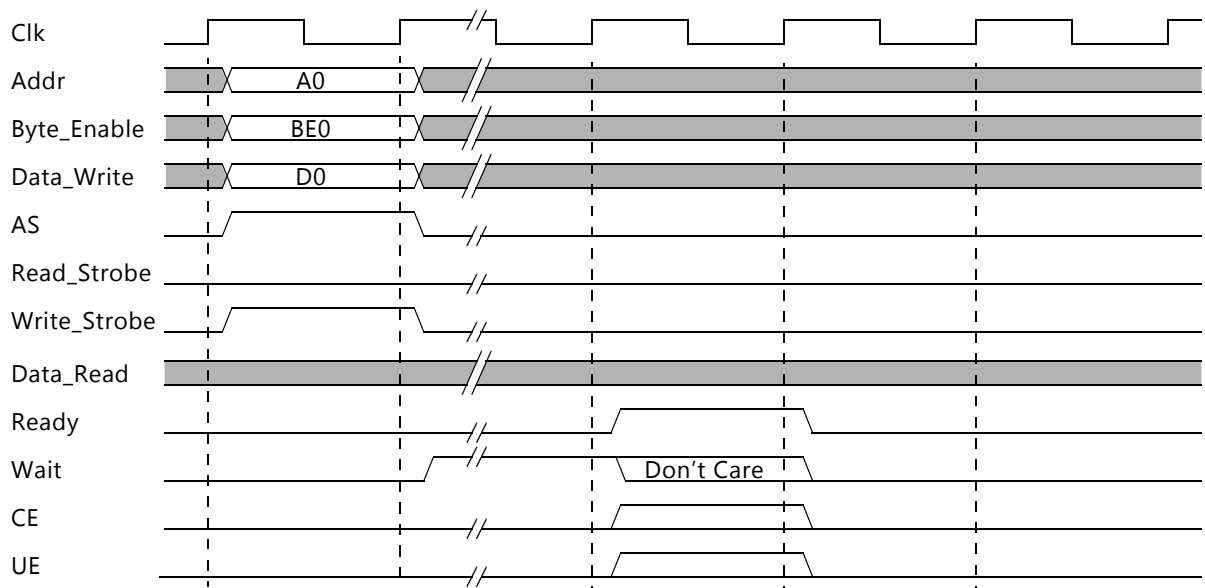


Figure 3-3: LMB Generic Write Operation, N Wait States

## Generic Read Operations

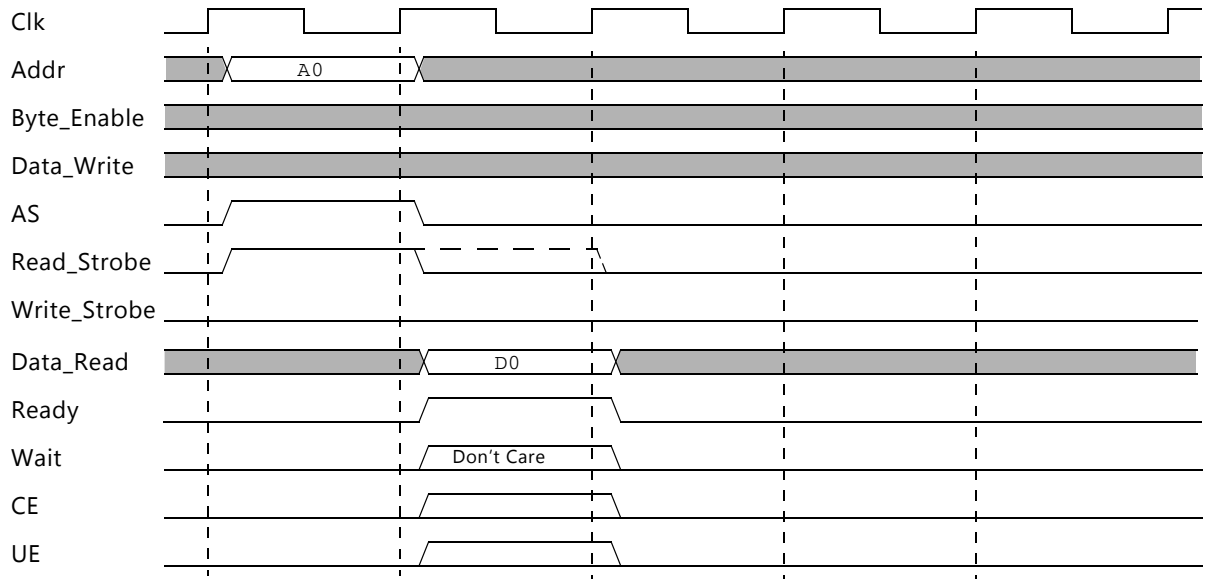


Figure 3-4: LMB Generic Read Operation, 0 Wait States

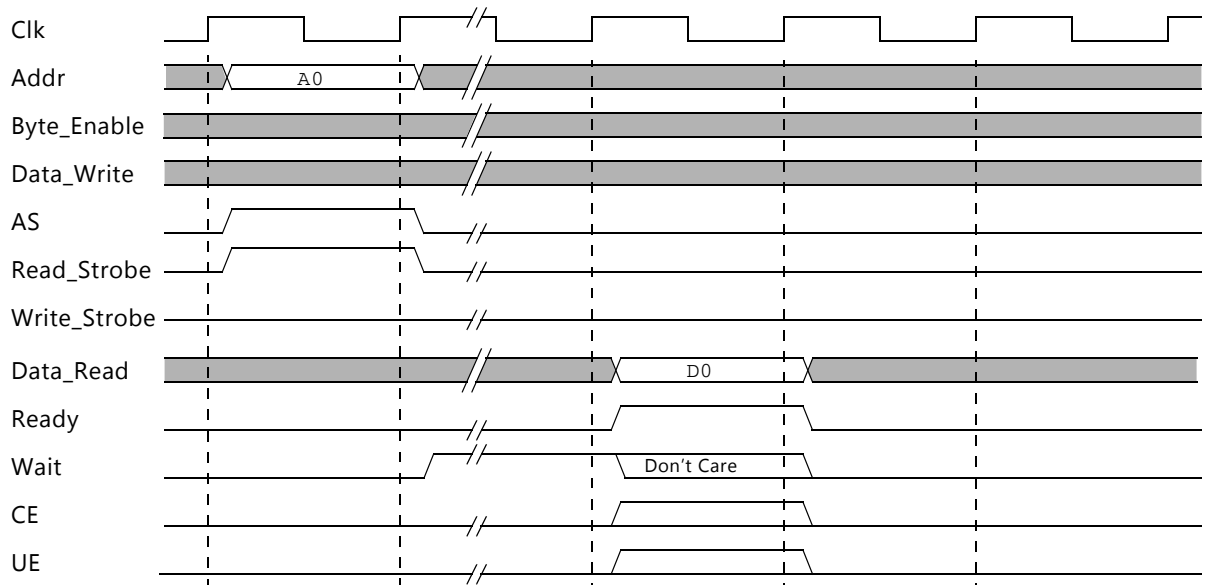


Figure 3-5: LMB Generic Read Operation, N Wait States



### Back-to-Back Write Operation

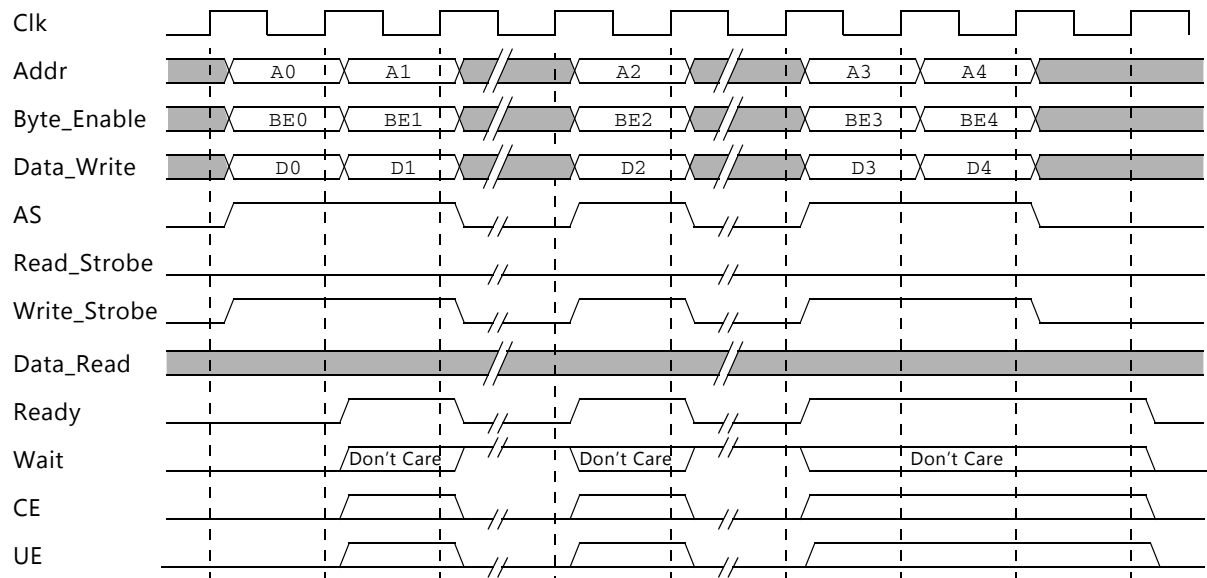


Figure 3-6: LMB Back-to-Back Write Operation

### Back-to-Back Read Operation

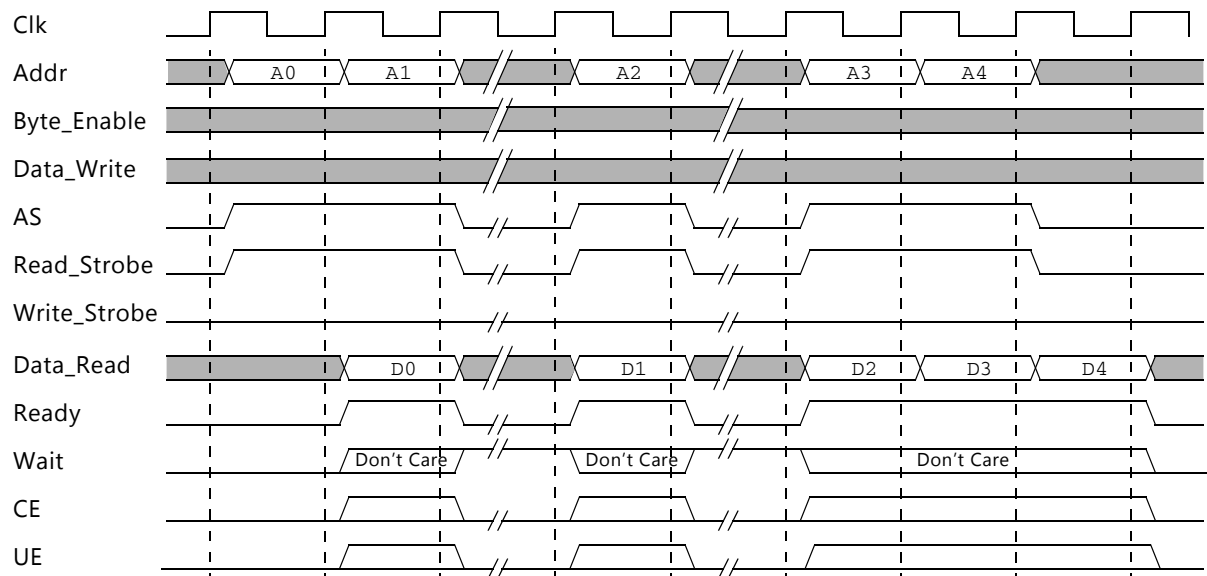


Figure 3-7: LMB Back-to-Back Read Operation

### Back-to-Back Mixed Write/Read Operation

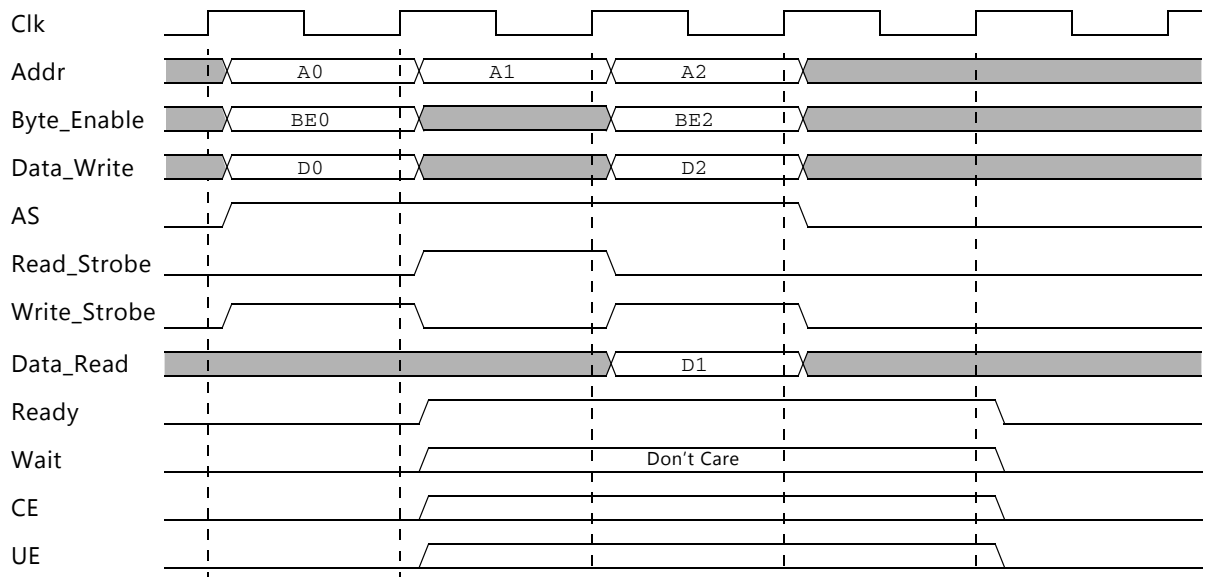


Figure 3-8: Back-to-Back Mixed Write/Read Operation, 0 Wait States

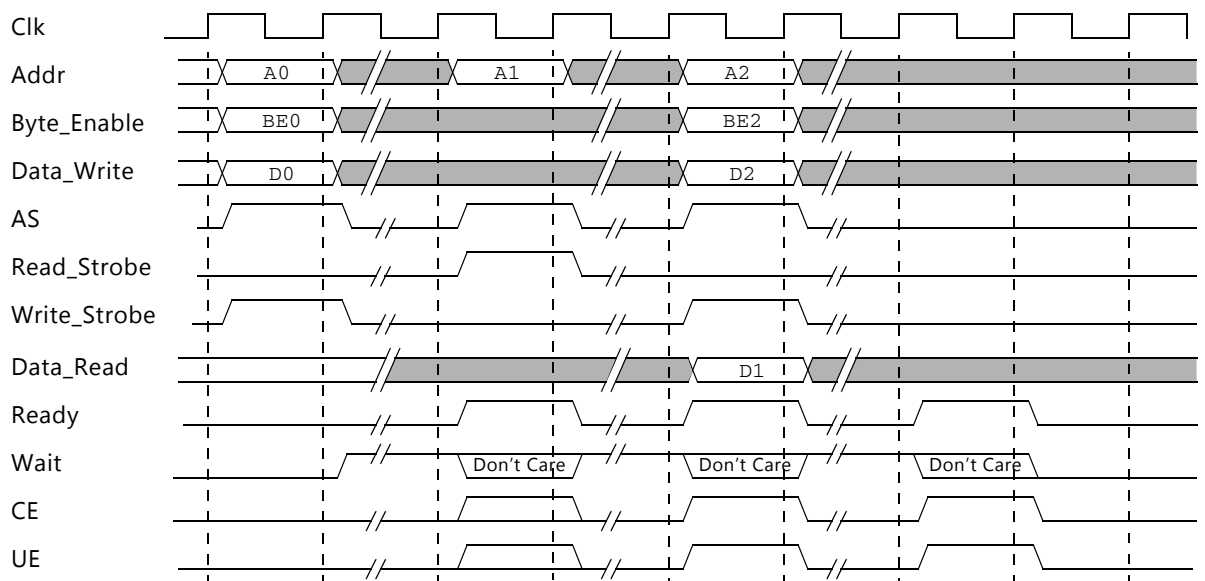


Figure 3-9: Back-to-Back Mixed Write/Read Operation, N Wait States

## Read and Write Data Steering

The MicroBlaze data-side bus interface performs the read steering and write steering required to support the following transfers:

- byte, halfword, and word transfers to word devices
- byte and halfword transfers to halfword devices
- byte transfers to byte devices

MicroBlaze does not support transfers that are larger than the addressed device. These types of transfers require dynamic bus sizing and conversion cycles that are not supported by the MicroBlaze bus interface. Data steering for read cycles are shown in [Table 3-9](#) and [Table 3-10](#), and data steering for write cycles are shown in [Table 3-11](#) and [Table 3-12](#).

Big endian format is only available when using the MMU in virtual or protected mode (`C_USE_MMU > 1`) or when reorder instructions are enabled (`C_USE_REORDER_INSTR = 1`).

**Table 3-9: Big Endian Read Data Steering (Load to Register rD)**

| Address<br>[LSB-1:LSB] | Byte_Enable<br>[0:3] | Transfer Size | Register rD Data |          |           |           |
|------------------------|----------------------|---------------|------------------|----------|-----------|-----------|
|                        |                      |               | rD[0:7]          | rD[8:15] | rD[16:23] | rD[24:31] |
| 11                     | 0001                 | byte          |                  |          |           | Byte3     |
| 10                     | 0010                 | byte          |                  |          |           | Byte2     |
| 01                     | 0100                 | byte          |                  |          |           | Byte1     |
| 00                     | 1000                 | byte          |                  |          |           | Byte0     |
| 10                     | 0011                 | halfword      |                  |          | Byte2     | Byte3     |
| 00                     | 1100                 | halfword      |                  |          | Byte0     | Byte1     |
| 00                     | 1111                 | word          | Byte0            | Byte1    | Byte2     | Byte3     |

**Table 3-10: Little Endian Read Data Steering (Load to Register rD)**

| Address<br>[LSB-1:LSB] | Byte_Enable<br>[0:3] | Transfer Size | Register rD Data |          |           |           |
|------------------------|----------------------|---------------|------------------|----------|-----------|-----------|
|                        |                      |               | rD[0:7]          | rD[8:15] | rD[16:23] | rD[24:31] |
| 11                     | 1000                 | byte          |                  |          |           | Byte0     |
| 10                     | 0100                 | byte          |                  |          |           | Byte1     |
| 01                     | 0010                 | byte          |                  |          |           | Byte2     |
| 00                     | 0001                 | byte          |                  |          |           | Byte3     |
| 10                     | 1100                 | halfword      |                  |          | Byte0     | Byte1     |
| 00                     | 0011                 | halfword      |                  |          | Byte2     | Byte3     |
| 00                     | 1111                 | word          | Byte0            | Byte1    | Byte2     | Byte3     |

Table 3-11: Big Endian Write Data Steering (Store from Register rD)

| Address<br>[LSB-1:LSB] | Byte_Enable<br>[0:3] | Transfer Size | Write Data Bus Bytes |           |           |           |
|------------------------|----------------------|---------------|----------------------|-----------|-----------|-----------|
|                        |                      |               | Byte0                | Byte1     | Byte2     | Byte3     |
| 11                     | 0001                 | byte          |                      |           |           | rD[24:31] |
| 10                     | 0010                 | byte          |                      |           | rD[24:31] |           |
| 01                     | 0100                 | byte          |                      | rD[24:31] |           |           |
| 00                     | 1000                 | byte          | rD[24:31]            |           |           |           |
| 10                     | 0011                 | halfword      |                      |           | rD[16:23] | rD[24:31] |
| 00                     | 1100                 | halfword      | rD[16:23]            | rD[24:31] |           |           |
| 00                     | 1111                 | word          | rD[0:7]              | rD[8:15]  | rD[16:23] | rD[24:31] |

Table 3-12: Little Endian Write Data Steering (Store from Register rD)

| Address<br>[LSB-1:LSB] | Byte_Enable<br>[0:3] | Transfer Size | Write Data Bus Bytes |           |           |           |
|------------------------|----------------------|---------------|----------------------|-----------|-----------|-----------|
|                        |                      |               | Byte3                | Byte2     | Byte1     | Byte0     |
| 11                     | 1000                 | byte          | rD[24:31]            |           |           |           |
| 10                     | 0100                 | byte          |                      | rD[24:31] |           |           |
| 01                     | 0010                 | byte          |                      |           | rD[24:31] |           |
| 00                     | 0001                 | byte          |                      |           |           | rD[24:31] |
| 10                     | 1100                 | halfword      | rD[16:23]            | rD[24:31] |           |           |
| 00                     | 0011                 | halfword      |                      |           | rD[16:23] | rD[24:31] |
| 00                     | 1111                 | word          | rD[0:7]              | rD[8:15]  | rD[16:23] | rD[24:31] |

**Note:** Other masters may have more restrictive requirements for byte lane placement than those allowed by MicroBlaze. Slave devices are typically attached "left-justified" with byte devices attached to the most-significant byte lane, and halfword devices attached to the most significant halfword lane. The MicroBlaze steering logic fully supports this attachment method.

## Lockstep Interface Description

The lockstep interface on MicroBlaze is designed to connect a master and one or more slave MicroBlaze instances. The lockstep signals on MicroBlaze are listed in [Table 3-13](#).

**Table 3-13: MicroBlaze Lockstep Signals**

| Signal Name         | Description                                                                         | VHDL Type | Direction |
|---------------------|-------------------------------------------------------------------------------------|-----------|-----------|
| Lockstep_Master_Out | Output with signals going from master to slave MicroBlaze. Not connected on slaves. | std_logic | output    |
| Lockstep_Slave_In   | Input with signals coming from master to slave MicroBlaze. Not connected on master. | std_logic | input     |
| Lockstep_Out        | Output with all comparison signals from both master and slaves.                     | std_logic | output    |

The comparison signals provided by Lockstep\_Out are listed in [Table 3-14](#).

**Table 3-14: MicroBlaze Lockstep Comparison Signals**

| Signal Name      | Bus Index Range | VHDL Type        |
|------------------|-----------------|------------------|
| MB_Halted        | 0               | std_logic        |
| MB_Error         | 1               | std_logic        |
| IFetch           | 2               | std_logic        |
| I_AS             | 3               | std_logic        |
| Instr_Addr       | 4 to 67         | std_logic_vector |
| Data_Addr        | 68 to 131       | std_logic_vector |
| Data_Write       | 132 to 163      | std_logic_vector |
| D_AS             | 196             | std_logic        |
| Read_Strobe      | 197             | std_logic        |
| Write_Strobe     | 198             | std_logic        |
| Byte_Enable      | 199 to 202      | std_logic_vector |
| M_AXI_IP_AWID    | 207             | std_logic        |
| M_AXI_IP_AWADDR  | 208 to 271      | std_logic_vector |
| M_AXI_IP_AWLEN   | 272 to 279      | std_logic_vector |
| M_AXI_IP_AWSIZE  | 280 to 282      | std_logic_vector |
| M_AXI_IP_AWBURST | 283 to 284      | std_logic_vector |
| M_AXI_IP_AWLOCK  | 285             | std_logic        |
| M_AXI_IP_AWCACHE | 286 to 289      | std_logic_vector |
| M_AXI_IP_AWPROT  | 290 to 292      | std_logic_vector |
| M_AXI_IP_AWQOS   | 293 to 296      | std_logic_vector |
| M_AXI_IP_AWVALID | 297             | std_logic        |
| M_AXI_IP_WDATA   | 298 to 329      | std_logic_vector |
| M_AXI_IP_WSTRB   | 362 to 365      | std_logic_vector |

Table 3-14: MicroBlaze Lockstep Comparison Signals (Cont'd)

| Signal Name      | Bus Index Range | VHDL Type        |
|------------------|-----------------|------------------|
| M_AXI_IP_WLAST   | 370             | std_logic        |
| M_AXI_IP_WVALID  | 371             | std_logic        |
| M_AXI_IP_BREADY  | 372             | std_logic        |
| M_AXI_IP_ARID    | 373             | std_logic        |
| M_AXI_IP_ARADDR  | 374 to 437      | std_logic_vector |
| M_AXI_IP_ARLEN   | 438 to 445      | std_logic_vector |
| M_AXI_IP_ARSIZE  | 446 to 448      | std_logic_vector |
| M_AXI_IP_ARBURST | 449 to 450      | std_logic_vector |
| M_AXI_IP_ARLOCK  | 451             | std_logic        |
| M_AXI_IP_ARCACHE | 452 to 455      | std_logic_vector |
| M_AXI_IP_ARPROT  | 456 to 458      | std_logic_vector |
| M_AXI_IP_ARQOS   | 459 to 462      | std_logic_vector |
| M_AXI_IP_ARVALID | 463             | std_logic        |
| M_AXI_IP_RREADY  | 464             | std_logic        |
| M_AXI_DP_AWID    | 465             | std_logic        |
| M_AXI_DP_AWADDR  | 466 to 529      | std_logic_vector |
| M_AXI_DP_AWLEN   | 530 to 537      | std_logic_vector |
| M_AXI_DP_AWSIZE  | 538 to 540      | std_logic_vector |
| M_AXI_DP_AWBURST | 541 to 542      | std_logic_vector |
| M_AXI_DP_AWLOCK  | 543             | std_logic        |
| M_AXI_DP_AWCACHE | 544 to 547      | std_logic_vector |
| M_AXI_DP_AWPROT  | 548 to 550      | std_logic_vector |
| M_AXI_DP_AWQOS   | 551 to 554      | std_logic_vector |
| M_AXI_DP_AWVALID | 555             | std_logic        |
| M_AXI_DP_WDATA   | 556 to 587      | std_logic_vector |
| M_AXI_DP_WSTRB   | 620 to 623      | std_logic_vector |
| M_AXI_DP_WLAST   | 628             | std_logic        |
| M_AXI_DP_WVALID  | 629             | std_logic        |
| M_AXI_DP_BREADY  | 630             | std_logic        |
| M_AXI_DP_ARID    | 631             | std_logic        |
| M_AXI_DP_ARADDR  | 632 to 695      | std_logic_vector |
| M_AXI_DP_ARLEN   | 696 to 703      | std_logic_vector |
| M_AXI_DP_ARSIZE  | 704 to 706      | std_logic_vector |
| M_AXI_DP_ARBURST | 707 to 708      | std_logic_vector |
| M_AXI_DP_ARLOCK  | 709             | std_logic        |
| M_AXI_DP_ARCACHE | 710 to 713      | std_logic_vector |
| M_AXI_DP_ARPROT  | 714 to 716      | std_logic_vector |
| M_AXI_DP_ARQOS   | 717 to 720      | std_logic_vector |
| M_AXI_DP_ARVALID | 721             | std_logic        |

Table 3-14: MicroBlaze Lockstep Comparison Signals (Cont'd)

| Signal Name                    | Bus Index Range                  | VHDL Type        |
|--------------------------------|----------------------------------|------------------|
| M_AXI_DP_RREADY                | 722                              | std_logic        |
| Mn_AXIS_TLAST                  | $723 + n * 35$                   | std_logic        |
| Mn_AXIS_TDATA                  | $758 + n * 35$ to $789 + n * 35$ | std_logic_vector |
| Mn_AXIS_TVALID                 | $790 + n * 35$                   | std_logic        |
| Sn_AXIS_TREADY                 | $791 + n * 35$                   | std_logic        |
| M_AXI_IC_AWID                  | 1283                             | std_logic        |
| M_AXI_IC_AWADDR                | 1284 to 1347                     | std_logic_vector |
| M_AXI_IC_AWLEN                 | 1348 to 1355                     | std_logic_vector |
| M_AXI_IC_AWSIZE                | 1356 to 1358                     | std_logic_vector |
| M_AXI_IC_AWBURST               | 1359 to 1360                     | std_logic_vector |
| M_AXI_IC_AWLOCK                | 1361                             | std_logic        |
| M_AXI_IC_AWCACHE               | 1362 to 1365                     | std_logic_vector |
| M_AXI_IC_AWPROT                | 1366 to 1368                     | std_logic_vector |
| M_AXI_IC_AWQOS                 | 1369 to 1372                     | std_logic_vector |
| M_AXI_IC_AWVALID               | 1373                             | std_logic        |
| M_AXI_IC_AWUSER                | 1374 to 1378                     | std_logic_vector |
| M_AXI_IC_AWDOMAIN <sup>1</sup> | 1379 to 1380                     | std_logic_vector |
| M_AXI_IC_AWSNOOP <sup>1</sup>  | 1381 to 1383                     | std_logic_vector |
| M_AXI_IC_AWBAR <sup>1</sup>    | 1384 to 1385                     | std_logic_vector |
| M_AXI_IC_WDATA                 | 1386 to 1897                     | std_logic_vector |
| M_AXI_IC_WSTRB                 | 1898 to 1961                     | std_logic_vector |
| M_AXI_IC_WLAST                 | 1962                             | std_logic        |
| M_AXI_IC_WVALID                | 1963                             | std_logic        |
| M_AXI_IC_WUSER                 | 1964                             | std_logic        |
| M_AXI_IC_BREADY                | 1965                             | std_logic        |
| M_AXI_IC_WACK                  | 1966                             | std_logic        |
| M_AXI_IC_ARID                  | 1967                             | std_logic_vector |
| M_AXI_IC_ARADDR                | 1968 to 2031                     | std_logic_vector |
| M_AXI_IC_ARLEN                 | 2032 to 2039                     | std_logic_vector |
| M_AXI_IC_ARSIZE                | 2040 to 2042                     | std_logic_vector |
| M_AXI_IC_ARBURST               | 2043 to 2044                     | std_logic_vector |
| M_AXI_IC_ARLOCK                | 2045                             | std_logic        |
| M_AXI_IC_ARCACHE               | 2046 to 2049                     | std_logic_vector |
| M_AXI_IC_ARPROT                | 2050 to 2052                     | std_logic_vector |
| M_AXI_IC_ARQOS                 | 2053 to 2056                     | std_logic_vector |
| M_AXI_IC_ARVALID               | 2057                             | std_logic        |
| M_AXI_IC_ARUSER                | 2058 to 2062                     | std_logic_vector |
| M_AXI_IC_ARDOMAIN <sup>1</sup> | 2063 to 2064                     | std_logic_vector |
| M_AXI_IC_ARSNOOP <sup>1</sup>  | 2065 to 2068                     | std_logic_vector |

Table 3-14: MicroBlaze Lockstep Comparison Signals (Cont'd)

| Signal Name                    | Bus Index Range | VHDL Type        |
|--------------------------------|-----------------|------------------|
| M_AXI_IC_ARBAR <sup>1</sup>    | 2069 to 2070    | std_logic_vector |
| M_AXI_IC_RREADY                | 2071            | std_logic        |
| M_AXI_IC_RACK <sup>1</sup>     | 2072            | std_logic        |
| M_AXI_IC_ACREADY <sup>1</sup>  | 2073            | std_logic        |
| M_AXI_IC_CRVALID <sup>1</sup>  | 2074            | std_logic        |
| M_AXI_IC_CRRESP <sup>1</sup>   | 2075 to 2079    | std_logic_vector |
| M_AXI_IC_CDVALID <sup>1</sup>  | 2080            | std_logic        |
| M_AXI_IC_CDLAST <sup>1</sup>   | 2081            | std_logic        |
| M_AXI_DC_AWID                  | 2082            | std_logic        |
| M_AXI_DC_AWADDR                | 2083 to 2146    | std_logic_vector |
| M_AXI_DC_AWLEN                 | 2147 to 2154    | std_logic_vector |
| M_AXI_DC_AWSIZE                | 2155 to 2157    | std_logic_vector |
| M_AXI_DC_AWBURST               | 2158 to 2159    | std_logic_vector |
| M_AXI_DC_AWLOCK                | 2160            | std_logic        |
| M_AXI_DC_AWCACHE               | 2161 to 2164    | std_logic_vector |
| M_AXI_DC_AWPROT                | 2165 to 2167    | std_logic_vector |
| M_AXI_DC_AWQOS                 | 2168 to 2171    | std_logic_vector |
| M_AXI_DC_AWVALID               | 2172            | std_logic        |
| M_AXI_DC_AWUSER                | 2172 to 2176    | std_logic_vector |
| M_AXI_DC_AWDOMAIN <sup>1</sup> | 2177 to 2178    | std_logic_vector |
| M_AXI_DC_AWSNOOP <sup>1</sup>  | 2179 to 2182    | std_logic_vector |
| M_AXI_DC_AWBAR <sup>1</sup>    | 2183 to 2184    | std_logic_vector |
| M_AXI_DC_WDATA                 | 2185 to 2696    | std_logic_vector |
| M_AXI_DC_WSTRB <sup>1</sup>    | 2697 to 2760    | std_logic_vector |
| M_AXI_DC_WLAST                 | 2761            | std_logic        |
| M_AXI_DC_WVALID                | 2762            | std_logic        |
| M_AXI_DC_WUSER                 | 2863            | std_logic        |
| M_AXI_DC_BREADY                | 2764            | std_logic        |
| M_AXI_DC_WACK <sup>1</sup>     | 2765            | std_logic        |
| M_AXI_DC_ARID                  | 2766            | std_logic        |
| M_AXI_DC_ARADDR                | 2767 to 2830    | std_logic_vector |
| M_AXI_DC_ARLEN                 | 2831 to 2838    | std_logic_vector |
| M_AXI_DC_ARSIZE                | 2839 to 2841    | std_logic_vector |
| M_AXI_DC_ARBURST               | 2842 to 2843    | std_logic_vector |
| M_AXI_DC_ARLOCK                | 2844            | std_logic        |
| M_AXI_DC_ARCACHE               | 2845 to 2848    | std_logic_vector |
| M_AXI_DC_ARPROT                | 2849 to 2851    | std_logic_vector |
| M_AXI_DC_ARQOS                 | 2852 to 2855    | std_logic_vector |
| M_AXI_DC_ARVALID               | 2856            | std_logic        |



Table 3-14: MicroBlaze Lockstep Comparison Signals (Cont'd)

| Signal Name                    | Bus Index Range | VHDL Type        |
|--------------------------------|-----------------|------------------|
| M_AXI_DC_ARUSER                | 2857 to 2861    | std_logic_vector |
| M_AXI_DC_ARDOMAIN <sup>1</sup> | 2862 to 2863    | std_logic_vector |
| M_AXI_DC_ARSNOOP <sup>1</sup>  | 2864 to 2867    | std_logic_vector |
| M_AXI_DC_ARBAR <sup>1</sup>    | 2868 to 2869    | std_logic_vector |
| M_AXI_DC_RREADY                | 2870            | std_logic        |
| M_AXI_DC_RACK <sup>1</sup>     | 2871            | std_logic        |
| M_AXI_DC_ACREADY <sup>1</sup>  | 2872            | std_logic        |
| M_AXI_DC_CRVALID <sup>1</sup>  | 2873            | std_logic        |
| M_AXI_DC_CRRESP <sup>1</sup>   | 2874 to 2878    | std_logic_vector |
| M_AXI_DC_CDVALID <sup>1</sup>  | 2879            | std_logic        |
| M_AXI_DC_CDLAST <sup>1</sup>   | 2880            | std_logic        |
| Trace_Instruction              | 2881 to 2912    | std_logic_vector |
| Trace_Valid_Instr              | 2913            | std_logic        |
| Trace_PC                       | 2914 to 2945    | std_logic_vector |
| Trace_Reg_Write                | 2978            | std_logic        |
| Trace_Reg_Addr                 | 2979 to 2983    | std_logic_vector |
| Trace_MSR_Reg                  | 2984 to 2998    | std_logic_vector |
| Trace_PID_Reg                  | 2999 to 3006    | std_logic_vector |
| Trace_New_Reg_Value            | 3007 to 3038    | std_logic_vector |
| Trace_Exception_Taken          | 3071            | std_logic        |
| Trace_Exception_Kind           | 3072 to 3076    | std_logic_vector |
| Trace_Jump_Taken               | 3077            | std_logic        |
| Trace_Delay_Slot               | 3078            | std_logic        |
| Trace_Data_Address             | 3079 to 3142    | std_logic_vector |
| Trace_Data_Write_Value         | 3143 to 3174    | std_logic_vector |
| Trace_Data_Byte_Enable         | 3207 to 3210    | std_logic_vector |
| Trace_Data_Access              | 3215            | std_logic        |
| Trace_Data_Read                | 3216            | std_logic        |
| Trace_Data_Write               | 3217            | std_logic        |
| Trace_DCache_Req               | 3218            | std_logic        |
| Trace_DCache_Hit               | 3219            | std_logic        |
| Trace_DCache_Rdy               | 3220            | std_logic        |
| Trace_DCache_Read              | 3221            | std_logic        |
| Trace_ICache_Req               | 3222            | std_logic        |
| Trace_ICache_Hit               | 3223            | std_logic        |
| Trace_ICache_Rdy               | 3224            | std_logic        |
| Trace_OF_PipeRun               | 3225            | std_logic        |
| Trace_EX_PipeRun               | 3226            | std_logic        |
| Trace_MEM_PipeRun              | 3227            | std_logic        |

Table 3-14: MicroBlaze Lockstep Comparison Signals (Cont'd)

| Signal Name             | Bus Index Range | VHDL Type |
|-------------------------|-----------------|-----------|
| Trace_MB_Halted         | 3228            | std_logic |
| Trace_Jump_Hit          | 3229            | std_logic |
| Reserved for future use | 3230 to 4095    |           |

1. This signal is only used when C\_INTERCONNECT = 3 (ACE).

## Debug Interface Description

The debug interface on MicroBlaze is designed to work with the Xilinx Microprocessor Debug Module (MDM) IP core. The MDM is controlled by the Xilinx System Debugger (XSDB) through the JTAG port of the FPGA. The MDM can control multiple MicroBlaze processors at the same time. The debug signals are grouped in the DEBUG bus.

The debug interface can be grouped in the DEBUG bus, using either JTAG serial signals (by setting C\_DEBUG\_INTERFACE = 0) or the AXI4-Lite compatible parallel signals (by setting C\_DEBUG\_INTERFACE = 1). The MDM configuration must also be set accordingly.

It is also possible to use only AXI4-Lite parallel signals (C\_DEBUG\_INTERFACE = 2) grouped in an AXI4 bus, in case the MDM is not used. However, this configuration is not supported by the tools.

The debug signals on MicroBlaze are listed in [Table 3-15](#).

Table 3-15: MicroBlaze Debug Signals

| Signal Name                   | Description                                                                        | VHDL Type        | Kind       |
|-------------------------------|------------------------------------------------------------------------------------|------------------|------------|
| Dbg_Clk                       | JTAG clock from MDM                                                                | std_logic        | serial in  |
| Dbg_TDI                       | JTAG TDI from MDM                                                                  | std_logic        | serial in  |
| Dbg_TDO                       | JTAG TDO to MDM                                                                    | std_logic        | serial out |
| Dbg_Reg_En                    | Debug register enable from MDM                                                     | std_logic_vector | serial in  |
| Dbg_Shift <sup>1</sup>        | JTAG BSCAN shift signal from MDM                                                   | std_logic        | serial in  |
| Dbg_Capture                   | JTAG BSCAN capture signal from MDM                                                 | std_logic        | serial in  |
| Dbg_Update                    | JTAG BSCAN update signal from MDM                                                  | std_logic        | serial in  |
| Debug_Rst <sup>1</sup>        | Reset signal from MDM, active high. Should be held for at least 1 Clk clock cycle. | std_logic        | input      |
| Dbg_Trig_In <sup>2</sup>      | Cross trigger event input to MDM                                                   | std_logic_vector | output     |
| Dbg_Trig_Ack_In <sup>2</sup>  | Cross trigger event input acknowledge from MDM                                     | std_logic_vector | input      |
| Dbg_Trig_Out <sup>2</sup>     | Cross trigger action output from MDM                                               | std_logic_vector | input      |
| Dbg_Trig_Ack_Out <sup>2</sup> | Cross trigger action output acknowledge to MDM                                     | std_logic_vector | output     |

**Table 3-15: MicroBlaze Debug Signals**

| Signal Name                  | Description                               | VHDL Type        | Kind         |
|------------------------------|-------------------------------------------|------------------|--------------|
| Dbg_Trace_Data <sup>3</sup>  | External Program Trace data output to MDM | std_logic_vector | output       |
| Dbg_Trace_Valid <sup>3</sup> | External Program Trace valid to MDM       | std_logic        | output       |
| Dbg_Trace_Ready <sup>3</sup> | External Program Trace ready from MDM     | std_logic        | input        |
| Dbg_Trace_Clk <sup>3</sup>   | External Program Trace clock from MDM     | std_logic        | input        |
| Dbg_ARADDR <sup>4</sup>      | Read address from MDM                     | std_logic_vector | parallel in  |
| Dbg_ARREADY <sup>4</sup>     | Read address ready to MDM                 | std_logic        | parallel out |
| Dbg_ARVALID <sup>4</sup>     | Read address valid from MDM               | std_logic        | parallel in  |
| Dbg_AWADDR <sup>4</sup>      | Write address from MDM                    | std_logic_vector | parallel in  |
| Dbg_AWREADY <sup>4</sup>     | Write address ready to MDM                | std_logic        | parallel out |
| Dbg_AWVALID <sup>4</sup>     | Write address valid from MDM              | std_logic        | parallel in  |
| Dbg_BREADY <sup>4</sup>      | Write response ready to MDM               | std_logic        | parallel out |
| Dbg_BRESP <sup>4</sup>       | Write response to MDM                     | std_logic_vector | parallel out |
| Dbg_BVALID <sup>4</sup>      | Write response valid from MDM             | std_logic        | parallel in  |
| Dbg_RDATA <sup>4</sup>       | Read data to MDM                          | std_logic_vector | parallel out |
| Dbg_RREADY <sup>4</sup>      | Read data ready to MDM                    | std_logic        | parallel out |
| Dbg_RRESP <sup>4</sup>       | Read data response to MDM                 | std_logic_vector | parallel out |
| Dbg_RVALID <sup>4</sup>      | Read data valid from MDM                  | std_logic        | parallel in  |
| Dbg_WDATA <sup>4</sup>       | Write data from MDM                       | std_logic_vector | parallel in  |
| Dbg_WREADY <sup>4</sup>      | Write data ready to MDM                   | std_logic        | parallel out |
| Dbg_WVALID <sup>4</sup>      | Write data valid from MDM                 | std_logic        | parallel in  |
| DEBUG_ACLK <sup>4</sup>      | Debug clock, must be same as Clk          | std_logic        | parallel in  |
| DEBUG_ARESET <sup>4</sup>    | Debug reset, must be same as Reset        | std_logic        | parallel in  |

1. Updated for MicroBlaze v7.00: Dbg\_Shift added and Debug\_Rst included in DEBUG bus
2. Updated for MicroBlaze v9.3: Dbg\_Trig signals added to DEBUG bus
3. Updated for MicroBlaze v9.4: External Program Trace signal added to DEBUG bus
4. Updated for MicroBlaze v10.0: Parallel debug signals added to DEBUG bus

## Trace Interface Description

The MicroBlaze core exports a number of internal signals for trace purposes. This signal interface is not standardized and new revisions of the processor may not be backward compatible for signal selection or functionality. It is recommended that you not design custom logic for these signals, but rather to use them via Xilinx provided analysis IP. The trace signals are grouped in the TRACE bus. The current set of trace signals were last updated for MicroBlaze v7.30 and are listed in [Table 3-16](#).

The mapping of the MSR bits is shown in [Table 3-17](#). For a complete description of the Machine Status Register, see "[Special Purpose Registers](#)".

The Trace exception types are listed in [Table 3-18](#). All unused Trace exception types are reserved.

**Table 3-16: MicroBlaze Trace Signals**

| Signal Name                          | Description                                                                              | VHDL Type                               | Direction |
|--------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------|-----------|
| Trace_Valid_Instr                    | Valid instruction on trace port.                                                         | std_logic                               | output    |
| Trace_Instruction <sup>1</sup>       | Instruction code                                                                         | std_logic_vector (0 to 31)              | output    |
| Trace_PC <sup>1</sup>                | Program counter                                                                          | std_logic_vector (0 to 31)              | output    |
| Trace_Reg_Write <sup>1</sup>         | Instruction writes to the register file                                                  | std_logic                               | output    |
| Trace_Reg_Addr <sup>1</sup>          | Destination register address                                                             | std_logic_vector (0 to 4)               | output    |
| Trace_MSR_Reg <sup>1</sup>           | Machine status register. The mapping of the register bits is documented below.           | std_logic_vector (0 to 14) <sup>2</sup> | output    |
| Trace_PID_Reg <sup>1</sup>           | Process identifier register                                                              | std_logic_vector (0 to 7)               | output    |
| Trace_New_Reg_Value <sup>1</sup>     | Destination register update value                                                        | std_logic_vector (0 to 31)              | output    |
| Trace_Exception_Taken <sup>1,2</sup> | Instruction result in taken exception                                                    | std_logic                               | output    |
| Trace_Exception_Kind <sup>1</sup>    | Exception type. The description for the exception type is documented below.              | std_logic_vector (0 to 4) <sup>2</sup>  | output    |
| Trace_Jump_Taken <sup>1</sup>        | Branch instruction evaluated true, that is taken                                         | std_logic                               | output    |
| Trace_Jump_Hit <sup>1,3</sup>        | Branch Target Cache hit                                                                  | std_logic                               | output    |
| Trace_Delay_Slot <sup>1</sup>        | Instruction is in delay slot of a taken branch                                           | std_logic                               | output    |
| Trace_Data_Access <sup>1</sup>       | Valid D-side memory access                                                               | std_logic                               | output    |
| Trace_Data_Address <sup>1</sup>      | Address for D-side memory access, where N = 32 - 64, determined by parameter C_ADDR_SIZE | std_logic_vector (0 to N-1)             | output    |
| Trace_Data_Write_Value <sup>1</sup>  | Value for D-side memory write access                                                     | std_logic_vector (0 to 31)              | output    |
| Trace_Data_Byte_Enable <sup>1</sup>  | Byte enables for D-side memory access                                                    | std_logic_vector (0 to 3)               | output    |

Table 3-16: MicroBlaze Trace Signals (Cont'd)

| Signal Name                    | Description                                                                                                 | VHDL Type | Direction |
|--------------------------------|-------------------------------------------------------------------------------------------------------------|-----------|-----------|
| Trace_Data_Read <sup>1</sup>   | D-side memory access is a read                                                                              | std_logic | output    |
| Trace_Data_Write <sup>1</sup>  | D-side memory access is a write                                                                             | std_logic | output    |
| Trace_DCache_Req               | Data memory address is within D-Cache range                                                                 | std_logic | output    |
| Trace_DCache_Hit               | Data memory address is present in D-Cache                                                                   | std_logic | output    |
| Trace_DCache_Rdy               | Data memory address is within D-Cache range and the access is completed                                     | std_logic | output    |
| Trace_DCache_Read <sup>4</sup> | The D-Cache request is a read                                                                               | std_logic | output    |
| Trace_ICache_Req               | Instruction memory address is within I-Cache range, and the cache is enabled in the Machine Status Register | std_logic | output    |
| Trace_ICache_Hit               | Instruction memory address is present in I-Cache                                                            | std_logic | output    |
| Trace_ICache_Rdy               | Instruction memory address is within I-Cache range and the access is completed                              | std_logic | output    |
| Trace_OF_PipeRun               | Pipeline advance for Decode stage                                                                           | std_logic | output    |
| Trace_EX_PipeRun <sup>3</sup>  | Pipeline advance for Execution stage                                                                        | std_logic | output    |
| Trace_MEM_PipeRun <sup>3</sup> | Pipeline advance for Memory stage                                                                           | std_logic | output    |
| Trace_MB_Halted                | Pipeline is halted by debug                                                                                 | std_logic | output    |

1. Valid only when Trace\_Valid\_Instr = 1
2. Valid only when Trace\_Exception\_Taken = 1
3. Not used with area optimization feature
4. Valid only when Trace\_DCache\_Req = 1

Table 3-17: Mapping of Trace MSR

| Trace_MSR_Reg | Machine Status Register |      |                                   |
|---------------|-------------------------|------|-----------------------------------|
| Bit           | Bit                     | Name | Description                       |
| 0             | 17                      | VMS  | Virtual Protected Mode Save       |
| 1             | 18                      | VM   | Virtual Protected Mode            |
| 2             | 19                      | UMS  | User Mode Save                    |
| 3             | 20                      | UM   | User Mode                         |
| 4             | 21                      | PVR  | Processor Version Register exists |
| 5             | 22                      | EIP  | Exception In Progress             |
| 6             | 23                      | EE   | Exception Enable                  |
| 7             | 24                      | DCE  | Data Cache Enable                 |

Table 3-17: Mapping of Trace MSR

| Trace_MSR_Reg | Machine Status Register |          |                                       |
|---------------|-------------------------|----------|---------------------------------------|
| Bit           | Bit                     | Name     | Description                           |
| 8             | 25                      | DZO      | Division by Zero or Division Overflow |
| 9             | 26                      | ICE      | Instruction Cache Enable              |
| 10            | 27                      | FSL      | AXI4-Stream Error                     |
| 11            | 28                      | BIP      | Break in Progress                     |
| 12            | 29                      | C        | Arithmetic Carry                      |
| 13            | 30                      | IE       | Interrupt Enable                      |
| 14            | 31                      | Reserved | Reserved                              |

Table 3-18: Type of Trace Exception

| Trace_Exception_Kind [0:4] | Description                      |
|----------------------------|----------------------------------|
| 00000                      | Stream exception                 |
| 00001                      | Unaligned exception              |
| 00010                      | Illegal Opcode exception         |
| 00011                      | Instruction Bus exception        |
| 00100                      | Data Bus exception               |
| 00101                      | Divide exception                 |
| 00110                      | FPU exception                    |
| 00111                      | Privileged instruction exception |
| 01010                      | Interrupt                        |
| 01011                      | External non maskable break      |
| 01100                      | External maskable break          |
| 10000                      | Data storage exception           |
| 10001                      | Instruction storage exception    |
| 10010                      | Data TLB miss exception          |
| 10011                      | Instruction TLB miss exception   |

## MicroBlaze Core Configurability

The MicroBlaze core has been developed to support a high degree of user configurability. This allows tailoring of the processor to meet specific cost/performance requirements.

Configuration is done via parameters that typically enable, size, or select certain processor features. For example, the instruction cache is enabled by setting the `C_USE_ICACHE` parameter. The size of the instruction cache, and the cacheable memory range, are all configurable using: `C_CACHE_BYTE_SIZE`, `C_ICACHE_BASEADDR`, and `C_ICACHE_HIGHADDR` respectively.

Parameters valid for the latest version of MicroBlaze are listed in [Table 3-19](#). Not all of these are recognized by older versions of MicroBlaze; however, the configurability is fully backward compatible.

**Note:** Shaded rows indicate that the parameter has a fixed value and *cannot* be modified.

Table 3-19: Configuration Parameters

| Parameter Name                           | Feature/Description                                                                 | Allowable Values                     | Default Value | Tool Assigned | VHDL Type        |
|------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------|---------------|---------------|------------------|
| <code>C_FAMILY</code>                    | Target Family                                                                       | Listed in <a href="#">Table 3-20</a> | virtex7       | yes           | string           |
| <code>C_DATA_SIZE</code>                 | Data Size                                                                           | 32                                   | 32            | NA            | integer          |
| <code>C_ADDR_SIZE</code>                 | Address Size                                                                        | 32-64                                | 32            | NA            | integer          |
| <code>C_DYNAMIC_BUS_SIZING</code>        | Legacy                                                                              | 1                                    | 1             | NA            | integer          |
| <code>C_SCO</code>                       | Xilinx internal                                                                     | 0                                    | 0             | NA            | integer          |
| <code>C_AREA_OPTIMIZED</code>            | Select implementation optimization:<br>0 = Performance<br>1 = Area<br>2 = Frequency | 0, 1, 2                              | 0             |               | integer          |
| <code>C_OPTIMIZATION</code>              | Reserved for future use                                                             | 0                                    | 0             | NA            | integer          |
| <code>C_INTERCONNECT</code>              | Select interconnect<br>2 = AXI4 only<br>3 = AXI4 and ACE                            | 2, 3                                 | 2             |               | integer          |
| <code>C_ENDIANNES</code>                 | Select endianness<br>1 = Little Endian                                              | 1                                    | 1             | yes           | integer          |
| <code>C_BASE_VECTORS</code> <sup>1</sup> | Configurable base vectors                                                           | 0x00000000-0xffffffff                | 0x00000000    |               | std_logic_vector |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name                                                                                               | Feature/Description                                                            | Allowable Values                       | Default Value | Tool Assigned | VHDL Type                  |
|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------|---------------|---------------|----------------------------|
| C_FAULT_TOLERANT                                                                                             | Implement fault tolerance                                                      | 0, 1                                   | 0             | yes           | integer                    |
| C_ECC_USE_CE_EXCEPTION                                                                                       | Generate exception for correctable ECC error                                   | 0,1                                    | 0             |               | integer                    |
| C_LOCKSTEP_SLAVE                                                                                             | Lockstep Slave                                                                 | 0, 1                                   | 0             |               | integer                    |
| C_AVOID_PRIMITIVES                                                                                           | Disallow FPGA primitives<br>0 = None<br>1 = SRL<br>2 = LUTRAM<br>3 = Both      | 0, 1, 2, 3                             | 0             |               | integer                    |
| C_PVR                                                                                                        | Processor version register mode selection<br>0 = None<br>1 = Basic<br>2 = Full | 0, 1, 2                                | 0             |               | integer                    |
| C_PVR_USER1                                                                                                  | Processor version register USER1 constant                                      | 0x00-0xff                              | 0x00          |               | std_logic_vector (0 to 7)  |
| C_PVR_USER2                                                                                                  | Processor version register USER2 constant                                      | 0x00000000-0xffffffff                  | 0x00000000    |               | std_logic_vector (0 to 31) |
| C_RESET_MSR_IE<br>C_RESET_MSR_BIP<br>C_RESET_MSR_ICE<br>C_RESET_MSR_DCE<br>C_RESET_MSR_EE<br>C_RESET_MSR_EIP | Reset value for MSR register bits IE, BIP, ICE, DCE, EE, and EIP               | Any combination of the individual bits | 0x0000        |               | std_logic                  |
| C_INSTANCE                                                                                                   | Instance Name                                                                  | Any instance name                      | micro blaze   | yes           | string                     |
| C_D_AXI                                                                                                      | Data side AXI interface                                                        | 0, 1                                   | 0             |               | integer                    |
| C_D_LMB                                                                                                      | Data side LMB interface                                                        | 0, 1                                   | 1             |               | integer                    |
| C_I_AXI                                                                                                      | Instruction side AXI interface                                                 | 0, 1                                   | 0             |               | integer                    |
| C_I_LMB                                                                                                      | Instruction side LMB interface                                                 | 0, 1                                   | 1             |               | integer                    |
| C_USE_BARREL                                                                                                 | Include barrel shifter                                                         | 0, 1                                   | 0             |               | integer                    |
| C_USE_DIV                                                                                                    | Include hardware divider                                                       | 0, 1                                   | 0             |               | integer                    |



Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name          | Feature/Description                                                           | Allowable Values | Default Value | Tool Assigned | VHDL Type |
|-------------------------|-------------------------------------------------------------------------------|------------------|---------------|---------------|-----------|
| C_USE_HW_MUL            | Include hardware multiplier<br>0 = None<br>1 = Mul32<br>2 = Mul64             | 0, 1, 2          | 1             |               | integer   |
| C_USE_FPU               | Include hardware floating point unit<br>0 = None<br>1 = Basic<br>2 = Extended | 0, 1, 2          | 0             |               | integer   |
| C_USE_MSR_INSTR         | Enable use of instructions: MSRSET and MSRCLR                                 | 0, 1             | 1             |               | integer   |
| C_USE_PCOMP_INSTR       | Enable use of instructions: CLZ, PCMPBF, PCMPEQ, and PCMPNE                   | 0, 1             | 1             |               | integer   |
| C_USE_REORDER_INSTR     | Enable use of instructions: Reverse load, reverse store, and swap             | 0, 1             | 1             |               | integer   |
| C_UNALIGNED_EXCEPTIONS  | Enable exception handling for unaligned data accesses                         | 0, 1             | 0             |               | integer   |
| C_ILL_OPCODE_EXCEPTION  | Enable exception handling for illegal opcode                                  | 0, 1             | 0             |               | integer   |
| C_M_AXI_I_BUS_EXCEPTION | Enable exception handling for M_AXI_I bus error                               | 0, 1             | 0             |               | integer   |
| C_M_AXI_D_BUS_EXCEPTION | Enable exception handling for M_AXI_D bus error                               | 0, 1             | 0             |               | integer   |
| C_DIV_ZERO_EXCEPTION    | Enable exception handling for division by zero or division overflow           | 0, 1             | 0             |               | integer   |
| C_FPU_EXCEPTION         | Enable exception handling for hardware floating point unit exceptions         | 0, 1             | 0             |               | integer   |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name           | Feature/Description                                                | Allowable Values                                       | Default Value | Tool Assigned | VHDL Type |
|--------------------------|--------------------------------------------------------------------|--------------------------------------------------------|---------------|---------------|-----------|
| C_OPCODE_0x0_ILLEGAL     | Detect opcode 0x0 as an illegal instruction                        | 0,1                                                    | 0             |               | integer   |
| C_FSL_EXCEPTION          | Enable exception handling for Stream Links                         | 0,1                                                    | 0             |               | integer   |
| C_ECC_USE_CE_EXCEPTION   | Generate Bus Error Exceptions for correctable errors               | 0,1                                                    | 0             |               | integer   |
| C_USE_STACK_PROTECTION   | Generate exception for stack overflow or stack underflow           | 0,1                                                    | 0             |               | integer   |
| C_IMPRECISE_EXCEPTIONS   | Allow imprecise exceptions for ECC errors in LMB memory            | 0,1                                                    | 0             |               | integer   |
| C_DEBUG_ENABLED          | MDM Debug interface<br>0 = None<br>1 = Basic<br>2 = Extended       | 0,1,2                                                  | 1             |               | integer   |
| C_NUMBER_OF_PC_BRK       | Number of hardware breakpoints                                     | 0-8                                                    | 1             |               | integer   |
| C_NUMBER_OF_RD_ADDR_BRK  | Number of read address watchpoints                                 | 0-4                                                    | 0             |               | integer   |
| C_NUMBER_OF_WR_ADDR_BRK  | Number of write address watchpoints                                | 0-4                                                    | 0             |               | integer   |
| C_DEBUG_EVENT_COUNTERS   | Number of Performance Monitor event counters                       | 0-48                                                   | 5             |               | integer   |
| C_DEBUG_LATENCY_COUNTERS | Number of Performance Monitor latency counters                     | 0-7                                                    | 1             |               | integer   |
| C_DEBUG_COUNTER_WIDTH    | Performance Monitor counter width                                  | 32,48,64                                               | 32            |               | integer   |
| C_DEBUG_TRACE_SIZE       | Trace Buffer size<br>Embedded: 0, ≥ 8192<br>External: 0, 32 - 8192 | 0, 32, 64, 128, 256, 8192, 16384, 32768, 65536, 131072 | 8192          |               | integer   |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name            | Feature/Description                                                             | Allowable Values                           | Default Value  | Tool Assigned | VHDL Type        |
|---------------------------|---------------------------------------------------------------------------------|--------------------------------------------|----------------|---------------|------------------|
| C_DEBUG_PROFILE_SIZE      | Profile Buffer size                                                             | 0, 4096, 8192, 16384, 32768, 65536, 131072 | 0              |               | integer          |
| C_DEBUG_EXTERNAL_TRACE    | External Program Trace                                                          | 0,1                                        | 0              | yes           | integer          |
| C_DEBUG_INTERFACE         | Debug Interface:<br>0 = Debug Serial<br>1 = Debug Parallel<br>2 = AXI4-Lite     | 0,1,2                                      | 0              |               | integer          |
| C_ASYNC_INTERRUPT         | Asynchronous Interrupt                                                          | 0,1                                        | 0              | yes           | integer          |
| C_ASYNC_WAKEUP            | Asynchronous Wakeup                                                             | 00,01,10,11                                | 00             | yes           | integer          |
| C_INTERRUPT_IS_EDGE       | Level/Edge Interrupt                                                            | 0, 1                                       | 0              | yes           | integer          |
| C_EDGE_IS_POSITIVE        | Negative/Positive Edge Interrupt                                                | 0, 1                                       | 1              | yes           | integer          |
| C_FSL_LINKS               | Number of AXI-Stream interfaces                                                 | 0-16                                       | 0              |               | integer          |
| C_USE_EXTENDED_FSL_INSTR  | Enable use of extended stream instructions                                      | 0, 1                                       | 0              |               | integer          |
| C_ICACHE_BASEADDR         | Instruction cache base address                                                  | 0x0 - 0xFFFFFFFF<br>FFFFFFFF               | 0x0            |               | std_logic_vector |
| C_ICACHE_HIGHADDR         | Instruction cache high address                                                  | 0x0 - 0xFFFFFFFF<br>FFFFFFFF               | 0x3FFFF<br>FFF |               | std_logic_vector |
| C_USE_ICACHE              | Instruction cache                                                               | 0, 1                                       | 0              |               | integer          |
| C_ALLOW_ICACHE_WR         | Instruction cache write enable                                                  | 0, 1                                       | 1              |               | integer          |
| C_ICACHE_LINE_LEN         | Instruction cache line length                                                   | 4, 8, 16                                   | 4              |               | integer          |
| C_ICACHE_ALWAYS_USED      | Instruction cache interface used for all memory accesses in the cacheable range | 0, 1                                       | 1              |               | integer          |
| C_ICACHE_FORCE_TAG_LUTRAM | Instruction cache tag always implemented with distributed RAM                   | 0, 1                                       | 0              |               | integer          |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name            | Feature/Description                                                                | Allowable Values                                                            | Default Value  | Tool Assigned | VHDL Type        |
|---------------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|----------------|---------------|------------------|
| C_ICACHE_STREAMS          | Instruction cache streams                                                          | 0, 1                                                                        | 0              |               | integer          |
| C_ICACHE_VICTIMS          | Instruction cache victims                                                          | 0, 2, 4, 8                                                                  | 0              |               | integer          |
| C_ICACHE_DATA_WIDTH       | Instruction cache data width<br>0 = 32 bits<br>1 = Full cache line<br>2 = 512 bits | 0, 1, 2                                                                     | 0              |               | integer          |
| C_ADDR_TAG_BITS           | Instruction cache address tags                                                     | 0-25                                                                        | 17             | yes           | integer          |
| C_CACHE_BYTE_SIZE         | Instruction cache size                                                             | 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768, 65536 <sup>2</sup> | 8192           |               | integer          |
| C_DCACHE_BASEADDR         | Data cache base address                                                            | 0x0 - 0xFFFFFFFF<br>FFFFFFFF                                                | 0x0            |               | std_logic_vector |
| C_DCACHE_HIGHADDR         | Data cache high address                                                            | 0x0 - 0xFFFFFFFF<br>FFFFFFFF                                                | 0x3FFFF<br>FFF |               | std_logic_vector |
| C_USE_DCACHE              | Data cache                                                                         | 0, 1                                                                        | 0              |               | integer          |
| C_ALLOW_DCACHE_WR         | Data cache write enable                                                            | 0, 1                                                                        | 1              |               | integer          |
| C_DCACHE_LINE_LEN         | Data cache line length                                                             | 4, 8, 16                                                                    | 4              |               | integer          |
| C_DCACHE_ALWAYS_USED      | Data cache interface used for all accesses in the cacheable range                  | 0, 1                                                                        | 1              |               | integer          |
| C_DCACHE_FORCE_TAG_LUTRAM | Data cache tag always implemented with distributed RAM                             | 0, 1                                                                        | 0              |               | integer          |
| C_DCACHE_USE_WRITEBACK    | Data cache write-back storage policy used                                          | 0, 1                                                                        | 0              |               | integer          |
| C_DCACHE_VICTIMS          | Data cache victims                                                                 | 0, 2, 4, 8                                                                  | 0              |               | integer          |
| C_DCACHE_DATA_WIDTH       | Data cache data width<br>0 = 32 bits<br>1 = Full cache line<br>2 = 512 bits        | 0, 1, 2                                                                     | 0              |               | integer          |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name                      | Feature/Description                                                                                                    | Allowable Values                                                            | Default Value | Tool Assigned | VHDL Type |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|---------------|---------------|-----------|
| C_DCACHE_ADDR_TAG                   | Data cache address tags                                                                                                | 0-25                                                                        | 17            | yes           | integer   |
| C_DCACHE_BYTE_SIZE                  | Data cache size                                                                                                        | 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768, 65536 <sup>2</sup> | 8192          |               | integer   |
| C_USE_MMU <sup>3</sup>              | Memory Management:<br>0 = None<br>1 = User Mode<br>2 = Protection<br>3 = Virtual                                       | 0, 1, 2, 3                                                                  | 0             |               | integer   |
| C_MMU_DTLB_SIZE <sup>3</sup>        | Data shadow Translation Look-Aside Buffer size                                                                         | 1, 2, 4, 8                                                                  | 4             |               | integer   |
| C_MMU_ITLB_SIZE <sup>3</sup>        | Instruction shadow Translation Look-Aside Buffer size                                                                  | 1, 2, 4, 8                                                                  | 2             |               | integer   |
| C_MMU_TLB_ACCESS <sup>3</sup>       | Access to memory management special registers:<br>0 = Minimal<br>1 = Read<br>2 = Write<br>3 = Full                     | 0, 1, 2, 3                                                                  | 3             |               | integer   |
| C_MMU_ZONES <sup>3</sup>            | Number of memory protection zones                                                                                      | 0-16                                                                        | 16            |               | integer   |
| C_MMU_PRIVILEGED_INSTR <sup>3</sup> | Privileged instructions<br>0 = Full protection<br>1 = Allow stream instrs<br>2 = Allow extended addr<br>3 = Allow both | 0,1,2,3                                                                     | 0             |               | integer   |
| C_USE_INTERRUPT                     | Enable interrupt handling<br>0 = No interrupt<br>1 = Standard interrupt<br>2 = Low-latency interrupt                   | 0, 1, 2                                                                     | 1             | yes           | integer   |
| C_USE_EXT_BRK                       | Enable external break handling                                                                                         | 0,1                                                                         | 0             | yes           | integer   |
| C_USE_EXT_NM_BRK                    | Enable external non-maskable break handling                                                                            | 0,1                                                                         | 0             | yes           | integer   |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name                          | Feature/Description                                                                                                                                                        | Allowable Values | Default Value | Tool Assigned | VHDL Type |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|---------------|---------------|-----------|
| C_USE_NON_SECURE                        | Use corresponding non-secure input                                                                                                                                         | 0-15             | 0             | yes           | integer   |
| C_USE_BRANCH_TARGET_CACHE <sup>3</sup>  | Enable Branch Target Cache                                                                                                                                                 | 0,1              | 0             |               | integer   |
| C_BRANCH_TARGET_CACHE_SIZE <sup>3</sup> | Branch Target Cache size:<br>0 = Default<br>1 = 8 entries<br>2 = 16 entries<br>3 = 32 entries<br>4 = 64 entries<br>5 = 512 entries<br>6 = 1024 entries<br>7 = 2048 entries | 0-7              | 0             |               | integer   |
| C_M_AXI_DP_THREAD_ID_WIDTH              | Data side AXI thread ID width                                                                                                                                              | 1                | 1             |               | integer   |
| C_M_AXI_DP_DATA_WIDTH                   | Data side AXI data width                                                                                                                                                   | 32               | 32            |               | integer   |
| C_M_AXI_DP_ADDR_WIDTH                   | Data side AXI address width                                                                                                                                                | 32-64            | 32            | yes           | integer   |
| C_M_AXI_DP_SUPPORTS_THREADS             | Data side AXI uses threads                                                                                                                                                 | 0                | 0             |               | integer   |
| C_M_AXI_DP_SUPPORTS_READ                | Data side AXI support for read accesses                                                                                                                                    | 1                | 1             |               | integer   |
| C_M_AXI_DP_SUPPORTS_WRITE               | Data side AXI support for write accesses                                                                                                                                   | 1                | 1             |               | integer   |
| C_M_AXI_DP_SUPPORTS_NARROW_BURST        | Data side AXI narrow burst support                                                                                                                                         | 0                | 0             |               | integer   |
| C_M_AXI_DP_PROTOCOL                     | Data side AXI protocol                                                                                                                                                     | AXI4, AXI4LITE   | AXI4LITE      | yes           | string    |
| C_M_AXI_DP_EXCLUSIVE_ACCESS             | Data side AXI exclusive access support                                                                                                                                     | 0,1              | 0             |               | integer   |
| C_M_AXI_IP_THREAD_ID_WIDTH              | Instruction side AXI thread ID width                                                                                                                                       | 1                | 1             |               | integer   |
| C_M_AXI_IP_DATA_WIDTH                   | Instruction side AXI data width                                                                                                                                            | 32               | 32            |               | integer   |
| C_M_AXI_IP_ADDR_WIDTH                   | Instruction side AXI address width                                                                                                                                         | 32-64            | 32            | yes           | integer   |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name                   | Feature/Description                             | Allowable Values      | Default Value | Tool Assigned | VHDL Type |
|----------------------------------|-------------------------------------------------|-----------------------|---------------|---------------|-----------|
| C_M_AXI_IP_SUPPORTS_THREADS      | Instruction side AXI uses threads               | 0                     | 0             |               | integer   |
| C_M_AXI_IP_SUPPORTS_READ         | Instruction side AXI support for read accesses  | 1                     | 1             |               | integer   |
| C_M_AXI_IP_SUPPORTS_WRITE        | Instruction side AXI support for write accesses | 0                     | 0             |               | integer   |
| C_M_AXI_IP_SUPPORTS_NARROW_BURST | Instruction side AXI narrow burst support       | 0                     | 0             |               | integer   |
| C_M_AXI_IP_PROTOCOL              | Instruction side AXI protocol                   | AXI4LITE              | AXI4 LITE     |               | string    |
| C_M_AXI_DC_THREAD_ID_WIDTH       | Data cache AXI ID width                         | 1                     | 1             |               | integer   |
| C_M_AXI_DC_DATA_WIDTH            | Data cache AXI data width                       | 32, 64, 128, 256, 512 | 32            |               | integer   |
| C_M_AXI_DC_ADDR_WIDTH            | Data cache AXI address width                    | 32-64                 | 32            | yes           | integer   |
| C_M_AXI_DC_SUPPORTS_THREADS      | Data cache AXI uses threads                     | 0                     | 0             |               | integer   |
| C_M_AXI_DC_SUPPORTS_READ         | Data cache AXI support for read accesses        | 1                     | 1             |               | integer   |
| C_M_AXI_DC_SUPPORTS_WRITE        | Data cache AXI support for write accesses       | 1                     | 1             |               | integer   |
| C_M_AXI_DC_SUPPORTS_NARROW_BURST | Data cache AXI narrow burst support             | 0                     | 0             |               | integer   |
| C_M_AXI_DC_SUPPORTS_USER_SIGNALS | Data cache AXI user signal support              | 1                     | 1             |               | integer   |
| C_M_AXI_DC_PROTOCOL              | Data cache AXI protocol                         | AXI4                  | AXI4          |               | string    |
| C_M_AXI_DC_AWUSER_WIDTH          | Data cache AXI user width                       | 5                     | 5             |               | integer   |
| C_M_AXI_DC_ARUSER_WIDTH          | Data cache AXI user width                       | 5                     | 5             |               | integer   |
| C_M_AXI_DC_WUSER_WIDTH           | Data cache AXI user width                       | 1                     | 1             |               | integer   |

Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name                   | Feature/Description                              | Allowable Values      | Default Value | Tool Assigned | VHDL Type |
|----------------------------------|--------------------------------------------------|-----------------------|---------------|---------------|-----------|
| C_M_AXI_DC_RUSER_WIDTH           | Data cache AXI user width                        | 1                     | 1             |               | integer   |
| C_M_AXI_DC_BUSER_WIDTH           | Data cache AXI user width                        | 1                     | 1             |               | integer   |
| C_M_AXI_DC_EXCLUSIVE_ACCESS      | Data cache AXI exclusive access support          | 0,1                   | 0             |               | integer   |
| C_M_AXI_DC_USER_VALUE            | Data cache AXI user value                        | 0-31                  | 31            |               | integer   |
| C_M_AXI_IC_THREAD_ID_WIDTH       | Instruction cache AXI ID width                   | 1                     | 1             |               | integer   |
| C_M_AXI_IC_DATA_WIDTH            | Instruction cache AXI data width                 | 32, 64, 128, 256, 512 | 32            |               | integer   |
| C_M_AXI_IC_ADDR_WIDTH            | Instruction cache AXI address width              | 32-64                 | 32            | yes           | integer   |
| C_M_AXI_IC_SUPPORTS_THREADS      | Instruction cache AXI uses threads               | 0                     | 0             |               | integer   |
| C_M_AXI_IC_SUPPORTS_READ         | Instruction cache AXI support for read accesses  | 1                     | 1             |               | integer   |
| C_M_AXI_IC_SUPPORTS_WRITE        | Instruction cache AXI support for write accesses | 0                     | 0             |               | integer   |
| C_M_AXI_IC_SUPPORTS_NARROW_BURST | Instruction cache AXI narrow burst support       | 0                     | 0             |               | integer   |
| C_M_AXI_IC_SUPPORTS_USER_SIGNALS | Instruction cache AXI user signal support        | 1                     | 1             |               | integer   |
| C_M_AXI_IC_PROTOCOL              | Instruction cache AXI protocol                   | AXI4                  | AXI4          |               | string    |
| C_M_AXI_IC_AWUSER_WIDTH          | Instruction cache AXI user width                 | 5                     | 5             |               | integer   |
| C_M_AXI_IC_ARUSER_WIDTH          | Instruction cache AXI user width                 | 5                     | 5             |               | integer   |
| C_M_AXI_IC_WUSER_WIDTH           | Instruction cache AXI user width                 | 1                     | 1             |               | integer   |
| C_M_AXI_IC_RUSER_WIDTH           | Instruction cache AXI user width                 | 1                     | 1             |               | integer   |



Table 3-19: Configuration Parameters (Cont'd)

| Parameter Name          | Feature/Description                           | Allowable Values | Default Value | Tool Assigned | VHDL Type |
|-------------------------|-----------------------------------------------|------------------|---------------|---------------|-----------|
| C_M_AXI_IC_BUSER_WIDTH  | Instruction cache AXI user width              | 1                | 1             |               | integer   |
| C_M_AXI_IC_USER_VALUE   | Instruction cache AXI user value              | 0-31             | 31            |               | integer   |
| C_STREAM_INTERCONNECT   | Select AXI4-Stream interconnect               | 0,1              | 0             |               | integer   |
| C_Mn_AXIS_PROTOCOL      | AXI4-Stream protocol                          | GENERIC          | GENERIC       |               | string    |
| C_Sn_AXIS_PROTOCOL      | AXI4-Stream protocol                          | GENERIC          | GENERIC       |               | string    |
| C_Mn_AXIS_DATA_WIDTH    | AXI4-Stream master data width                 | 32               | 32            | NA            | integer   |
| C_Sn_AXIS_DATA_WIDTH    | AXI4-Stream slave data width                  | 32               | 32            | NA            | integer   |
| C_NUM_SYNC_FF_CLK       | Reset and Wakeup[0:1] synchronization stages  | 0-               | 2             |               | integer   |
| C_NUM_SYNC_FF_CLK_IRQ   | Interrupt input signal synchronization stages | 0-               | 1             |               | integer   |
| C_NUM_SYNC_FF_CLK_DEBUG | Dbg_ serial signal synchronization stages     | 0-               | 2             |               | integer   |
| C_NUM_SYNC_FF_DBG_CLK   | Internal synchronization stages to Dbg_Clk    | 0-               | 1             |               | integer   |

1. The 7 least significant bits must all be 0.
2. Not all sizes are permitted in all architectures. The cache uses 0 - 32 RAMB primitives (0 if cache size is less than 2048).
3. Not available when C\_AREA\_OPTIMIZED is set to 1 (Area).

Table 3-20: Parameter C\_FAMILY Allowable Values

|          | Allowable Values                                        |
|----------|---------------------------------------------------------|
| Artix®   | aartix7 artix7 artix7l qartix7 qartix7l                 |
| Kintex®  | kintex7 kintex7l qkintex7 qkintex7l kintexu kintexuplus |
| Spartan® | spartan7                                                |
| Virtex®  | qvirtex7 virtex7 virtexu virtexuplus virtexuplusHBM     |
| Zynq®    | azynq zynq qzynq zynquplus zynquplusRFSOC               |

## MicroBlaze Application Binary Interface

This chapter describes MicroBlaze™ Application Binary Interface (ABI), which is important for developing software in assembly language for the soft processor. The MicroBlaze GNU compiler follows the conventions described in this document. Any code written by assembly programmers should also follow the same conventions to be compatible with the compiler generated code. Interrupt and Exception handling is also explained briefly.

### Data Types

The data types used by MicroBlaze assembly programs are shown in [Table 4-1](#). Data types such as data8, data16, and data32 are used in place of the usual byte, half-word, and word/register.

**Table 4-1: Data Types in MicroBlaze Assembly Programs**

| MicroBlaze data types<br>(for assembly programs) | Corresponding ANSI C data types | Size (bytes) |
|--------------------------------------------------|---------------------------------|--------------|
| data8                                            | char                            | 1            |
| data16                                           | short                           | 2            |
| data32                                           | int                             | 4            |
| data32                                           | long int                        | 4            |
| data32                                           | float                           | 4            |
| data32                                           | enum                            | 4            |
| data16/data32                                    | pointer <sup>1</sup>            | 2/4          |

1. Pointers to small data areas, which can be accessed by global pointers are data16.

## Register Usage Conventions

The register usage convention for MicroBlaze is given in [Table 4-2](#).

**Table 4-2: Register Usage Conventions**

| Register | Type                            | Enforcement | Purpose                                                                                                                                                                                  |
|----------|---------------------------------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| R0       | Dedicated                       | HW          | Value 0                                                                                                                                                                                  |
| R1       | Dedicated                       | SW          | Stack Pointer                                                                                                                                                                            |
| R2       | Dedicated                       | SW          | Read-only small data area anchor                                                                                                                                                         |
| R3-R4    | Volatile                        | SW          | Return Values/Temporaries                                                                                                                                                                |
| R5-R10   | Volatile                        | SW          | Passing parameters/Temporaries                                                                                                                                                           |
| R11-R12  | Volatile                        | SW          | Temporaries                                                                                                                                                                              |
| R13      | Dedicated                       | SW          | Read-write small data area anchor                                                                                                                                                        |
| R14      | Dedicated                       | HW          | Return address for Interrupt                                                                                                                                                             |
| R15      | Dedicated                       | SW          | Return address for Sub-routine                                                                                                                                                           |
| R16      | Dedicated                       | HW          | Return address for Trap (Debugger)                                                                                                                                                       |
| R17      | Dedicated                       | HW/SW       | Return address for Exceptions<br>HW, if configured to support hardware exceptions, else SW                                                                                               |
| R18      | Dedicated                       | SW          | Reserved for Assembler/Compiler Temporaries                                                                                                                                              |
| R19      | Non-volatile                    | SW          | Must be saved across function calls. Callee-save                                                                                                                                         |
| R20      | Dedicated<br>or<br>Non-volatile | SW          | Reserved for storing a pointer to the Global Offset Table (GOT) in<br>Position Independent Code (PIC). Non-volatile in non-PIC code.<br>Must be saved across function calls. Callee-save |
| R21-R31  | Non-volatile                    | SW          | Must be saved across function calls. Callee-save                                                                                                                                         |
| RPC      | Special                         | HW          | Program counter                                                                                                                                                                          |
| RMSR     | Special                         | HW          | Machine Status Register                                                                                                                                                                  |
| REAR     | Special                         | HW          | Exception Address Register                                                                                                                                                               |
| RESR     | Special                         | HW          | Exception Status Register                                                                                                                                                                |
| RFSR     | Special                         | HW          | Floating Point Status Register                                                                                                                                                           |
| RBTR     | Special                         | HW          | Branch Target Register                                                                                                                                                                   |
| REDR     | Special                         | HW          | Exception Data Register                                                                                                                                                                  |
| RPID     | Special                         | HW          | Process Identifier Register                                                                                                                                                              |
| RZPR     | Special                         | HW          | Zone Protection Register                                                                                                                                                                 |
| RTLBLO   | Special                         | HW          | Translation Look-Aside Buffer Low Register                                                                                                                                               |
| RTLBHI   | Special                         | HW          | Translation Look-Aside Buffer High Register                                                                                                                                              |
| RTL BX   | Special                         | HW          | Translation Look-Aside Buffer Index Register                                                                                                                                             |
| RTLBSX   | Special                         | HW          | Translation Look-Aside Buffer Search Index                                                                                                                                               |
| RPVR0-12 | Special                         | HW          | Processor Version Register 0 through 12                                                                                                                                                  |

The architecture for MicroBlaze defines 32 general purpose registers (GPRs). These registers are classified as volatile, non-volatile, and dedicated.

- The volatile registers (also known as caller-save) are used as temporaries and do not retain values across the function calls. Registers R3 through R12 are volatile, of which R3 and R4 are used for returning values to the caller function, if any. Registers R5 through R10 are used for passing parameters between subroutines.
- Registers R19 through R31 retain their contents across function calls and are hence termed as non-volatile registers (a.k.a callee-save). The callee function is expected to save those non-volatile registers, which are being used. These are typically saved to the stack during the prologue and then reloaded during the epilogue.
- Certain registers are used as dedicated registers and programmers are not expected to use them for any other purpose.
  - .. Registers R14 through R17 are used for storing the return address from interrupts, sub-routines, traps, and exceptions in that order. Subroutines are called using the branch and link instruction, which saves the current Program Counter (PC) onto register R15.
  - .. Small data area pointers are used for accessing certain memory locations with 16-bit immediate value. These areas are discussed in the memory model section of this document. The read only small data area (SDA) anchor R2 (Read-Only) is used to access the constants such as literals. The other SDA anchor R13 (Read-Write) is used for accessing the values in the small data read-write section.
  - .. Register R1 stores the value of the stack pointer and is updated on entry and exit from functions.
  - .. Register R18 is used as a temporary register for assembler operations.
- MicroBlaze includes special purpose registers such as: program counter (rpc), machine status register (rmsr), exception status register (resr), exception address register (rear), floating point status register (rfsr), branch target register (rbtr), exception data register (redr), memory management registers (rpid, rzpr, rtlblo, rtlbhi, rtlbx, rtlbsx), and processor version registers (0-12). These registers are not mapped directly to the register file and hence the usage of these registers is different from the general purpose registers. The value of a special purpose registers can be transferred to or from a general purpose register by using `mts` and `mfs` instructions respectively.

## Stack Convention

The stack conventions used by MicroBlaze are detailed in [Table 4-3](#).

The shaded area in [Table 4-3](#) denotes a part of the stack frame for a caller function, while the unshaded area indicates the callee frame function. The ABI conventions of the stack frame define the protocol for passing parameters, preserving non-volatile register values, and allocating space for the local variables in a function.

Functions that contain calls to other subroutines are called as non-leaf functions. These non-leaf functions have to create a new stack frame area for its own use. When the program starts executing, the stack pointer has the maximum value. As functions are called, the stack pointer is decremented by the number of words required by every function for its stack frame. The stack pointer of a caller function always has a higher value as compared to the callee function.

**Table 4-3: Stack Convention**

|                   |                                                                                                                                                                     |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| High Address      |                                                                                                                                                                     |
|                   | Function Parameters for called sub-routine (Arg n .. Arg1)<br>(Optional: Maximum number of arguments required for any called procedure from the current procedure). |
| Old Stack Pointer | Link Register (R15)                                                                                                                                                 |
|                   | Callee Saved Register (R31....R19)<br>(Optional: Only those registers which are used by the current procedure are saved)                                            |
|                   | Local Variables for Current Procedure<br>(Optional: Present only if Locals defined in the procedure)                                                                |
|                   | Functional Parameters (Arg n .. Arg 1)<br>(Optional: Maximum number of arguments required for any called procedure from the current procedure)                      |
| New Stack Pointer | Link Register                                                                                                                                                       |
| Low Address       |                                                                                                                                                                     |

Consider an example where Func1 calls Func2, which in turn calls Func3. The stack representation at different instances is depicted in [Figure 4-1](#). After the call from Func 1 to Func 2, the value of the stack pointer (SP) is decremented. This value of SP is again decremented to accommodate the stack frame for Func3. On return from Func 3 the value of the stack pointer is increased to its original value in the function, Func 2.

Details of how the stack is maintained are shown in [Figure 4-1](#).

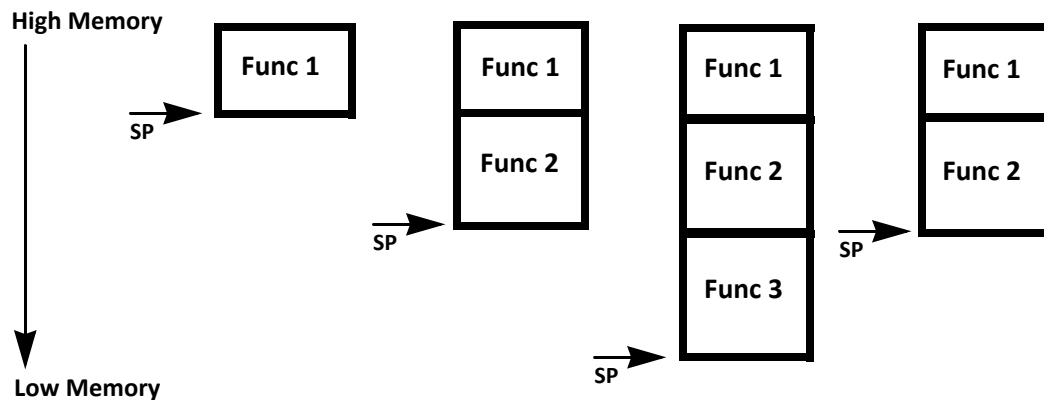


Figure 4-1: Stack Frame

Stack protection is available to ensure that the stack does not grow above the high limit or shrink below the low limit. The Stack High Register (SHR) and Stack Low Register (SLR) are used to enforce this, respectively. These registers are automatically initialized to the stack limits from linker symbols by the `crt0.o` initialization file.

Enabling stack protection in hardware can be useful to detect erroneous program behavior due to stack size issues, which can otherwise be very hard to debug.

## Calling Convention

The caller function passes parameters to the callee function using either the registers (R5 through R10) or on its own stack frame. The callee uses the stack area of the caller to store the parameters passed to the callee.

Refer to [Figure 4-1](#). The parameters for Func 2 are stored either in the registers R5 through R10 or on the stack frame allocated for Func 1.

If Func 2 has more than six integer parameters, the first six parameters can be passed in registers R5 through R10, whereas all subsequent parameters must be passed on the stack frame allocated for Func 1, starting at offset `SP + 28`.

---

## Memory Model

The memory model for MicroBlaze classifies the data into four different parts: Small Data Area, Data Area, Common Un-Initialized Area, and Literals or Constants.

### Small Data Area

Global initialized variables which are small in size are stored in this area. The threshold for deciding the size of the variable to be stored in the small data area is set to 8 bytes in the MicroBlaze C compiler (mb-gcc), but this can be changed by giving a command line option to the compiler. Details about this option are discussed in the *GNU Compiler Tools* chapter. 64 kilobytes of memory is allocated for the small data areas. The small data area is accessed using the read-write small data area anchor (R13) and a 16-bit offset. Allocating small variables to this area reduces the requirement of adding `IMM` instructions to the code for accessing global variables. Any variable in the small data area can also be accessed using an absolute address.

### Data Area

Comparatively large initialized variables are allocated to the data area, which can either be accessed using the read-write SDA anchor R13 or using the absolute address, depending on the command line option given to the compiler.

### Common Un-Initialized Area

Un-initialized global variables are allocated in the common area and can be accessed either using the absolute address or using the read-write small data area anchor R13.

### Literals or Constants

Constants are placed into the read-only small data area and are accessed using the read-only small data area anchor R2.

The compiler generates appropriate global pointers to act as base pointers. The actual values of the SDA anchors are decided by the linker, in the final linking stages. For more information on the various sections of the memory please refer to *MicroBlaze Linker Script Sections* in the *Embedded System Tools Reference Manual*. The compiler generates appropriate sections, depending on the command line options. Please refer to the *GNU Compiler Tools* chapter in the *Embedded System Tools Reference Manual* for more information about these options.

## Interrupt, Break and Exception Handling

MicroBlaze assumes certain address locations for handling interrupts and exceptions as indicated in Table 4-4. At these locations, code is written to jump to the appropriate handlers.

Table 4-4: Interrupt and Exception Handling

| On                                | Hardware jumps to                                | Software Labels       |
|-----------------------------------|--------------------------------------------------|-----------------------|
| Start / Reset                     | C_BASE_VECTORS + 0x0                             | _start                |
| User exception                    | C_BASE_VECTORS + 0x8                             | _exception_handler    |
| Interrupt                         | C_BASE_VECTORS + 0x10 <sup>1</sup>               | _interrupt_handler    |
| Break (HW/SW)                     | C_BASE_VECTORS + 0x18                            | -                     |
| Hardware exception                | C_BASE_VECTORS + 0x20                            | _hw_exception_handler |
| Reserved by Xilinx for future use | C_BASE_VECTORS + 0x28 -<br>C_BASE_VECTORS + 0x4F | -                     |

1. With low-latency interrupt mode, the vector address is supplied by the Interrupt Controller.

The code expected at these locations is as shown below. The `crt0.o` initialization file is passed by the `mb-gcc` compiler to the `mb-ld` linker for linking. This file sets the appropriate addresses of the exception handlers.

The following is code for passing control to Exception, Break and Interrupt handlers, assuming the default `C_BASE_VECTORS` value of 0x00000000:

```

0x00:  bri    __start1
0x04:  nop
0x08:  imm    high bits of address (user exception handler)
0x0c:  bri    _exception_handler
0x10:  imm    high bits of address (interrupt handler)
0x14:  bri    _interrupt_handler
0x18:  imm    high bits of address (break handler)
0x1c:  bri    low bits of address (break handler)
0x20:  imm    high bits of address (HW exception handler)
0x24:  bri    _hw_exception_handler

```

With low-latency interrupt mode, control is directly passed to the interrupt handler for each individual interrupt utilizing this mode. In this case, it is the responsibility of each handler to save and restore used registers. The MicroBlaze C compiler (`mb-gcc`) attribute **`fast_interrupt`** is available to allow this task to be performed by the compiler:

```
void interrupt_handler_name() __attribute__((fast_interrupt));
```

MicroBlaze allows exception and interrupt handler routines to be located at any address location addressable using 32 bits.

The user exception handler code starts with the label `_exception_handler`, the hardware exception handler starts with `_hw_exception_handler`, while the interrupt



handler code starts with the label `_interrupt_handler` for interrupts that do not use low-latency handlers.

In the current MicroBlaze system, there are dummy routines for interrupt, break and user exception handling, which you can change. In order to override these routines and link your own interrupt and exception handlers, you must define the handler code with specific attributes.

The interrupt handler code must be defined with attribute `interrupt_handler` to ensure that the compiler will generate code to save and restore used registers and emit an `rtid` instruction to return from the handler:

```
void function_name() __attribute__((interrupt_handler));
```

The break handler code must be defined with attribute **`break_handler`** to ensure that the compiler will generate code to save and restore used registers and emit an **`rtbd`** instruction to return from the handler:

```
void function_name() __attribute__((break_handler));
```

For more details about the use and syntax of the interrupt handler attribute, please refer to the *GNU Compiler Tools* chapter in the *Embedded System Tools Reference Manual*.

When software breakpoints are used in the Xilinx System Debugger (XSDB) tool or the Software Development Kit (SDK) tool, the Break (HW/SW) address location is reserved for handling the software breakpoint.

## MicroBlaze Instruction Set Architecture

This chapter provides a detailed guide to the Instruction Set Architecture of MicroBlaze™.

### Notation

The symbols used throughout this chapter are defined in [Table 5-1](#).

**Table 5-1: Symbol Notation**

| Symbol | Meaning                          |
|--------|----------------------------------|
| +      | Add                              |
| -      | Subtract                         |
| ×      | Multiply                         |
| /      | Divide                           |
| ^      | Bitwise logical AND              |
| ∨      | Bitwise logical OR               |
| ⊕      | Bitwise logical XOR              |
| x      | Bitwise logical complement of x  |
| ←      | Assignment                       |
| >>     | Right shift                      |
| <<     | Left shift                       |
| rx     | Register x                       |
| x[i]   | Bit i in register x              |
| x[i:j] | Bits i through j in register x   |
| =      | Equal comparison                 |
| ≠      | Not equal comparison             |
| >      | Greater than comparison          |
| >=     | Greater than or equal comparison |
| <      | Less than comparison             |
| <=     | Less than or equal comparison    |
|        | Signal choice                    |

Table 5-1: Symbol Notation (Cont'd)

| Symbol                    | Meaning                                                                          |
|---------------------------|----------------------------------------------------------------------------------|
| sext( <i>x</i> )          | Sign-extend <i>x</i>                                                             |
| Mem( <i>x</i> )           | Memory location at address <i>x</i>                                              |
| FSL <i>x</i>              | AXI4-Stream interface <i>x</i>                                                   |
| LSW( <i>x</i> )           | Least Significant Word of <i>x</i>                                               |
| isDnz( <i>x</i> )         | Floating point: true if <i>x</i> is denormalized                                 |
| isInfinite( <i>x</i> )    | Floating point: true if <i>x</i> is $+\infty$ or $-\infty$                       |
| isPosInfinite( <i>x</i> ) | Floating point: true if <i>x</i> is $+\infty$                                    |
| isNegInfinite( <i>x</i> ) | Floating point: true if <i>x</i> is $-\infty$                                    |
| isNaN( <i>x</i> )         | Floating point: true if <i>x</i> is a quiet or signalling NaN                    |
| isZero( <i>x</i> )        | Floating point: true if <i>x</i> is +0 or -0                                     |
| isQuietNaN( <i>x</i> )    | Floating point: true if <i>x</i> is a quiet NaN                                  |
| isSigNaN( <i>x</i> )      | Floating point: true if <i>x</i> is a signaling NaN                              |
| signZero( <i>x</i> )      | Floating point: return +0 for <i>x</i> > 0, and -0 if <i>x</i> < 0               |
| signInfinite( <i>x</i> )  | Floating point: return $+\infty$ for <i>x</i> > 0, and $-\infty$ if <i>x</i> < 0 |

## Formats

MicroBlaze uses two instruction formats: Type A and Type B.

### *Type A*

Type A is used for register-register instructions. It contains the opcode, one destination and two source registers.

| Opcode | Destination Reg | Source Reg A | Source Reg B | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
|--------|-----------------|--------------|--------------|----|---|---|---|---|---|---|---|---|---|---|----|
| 0      | 6               | 11           | 16           | 21 |   |   |   |   |   |   |   |   |   |   | 31 |

### *Type B*

Type B is used for register-immediate instructions. It contains the opcode, one destination and one source registers, and a source 16-bit immediate value.

| Opcode | Destination Reg | Source Reg A | Immediate Value |    |
|--------|-----------------|--------------|-----------------|----|
| 0      | 6               | 11           | 16              | 31 |

## Instructions

This section provides descriptions of MicroBlaze instructions. Instructions are listed in alphabetical order. For each instruction Xilinx provides the mnemonic, encoding, a description, pseudocode of its semantics, and a list of registers that it modifies.

**add** Arithmetic Add

|       |            |                               |
|-------|------------|-------------------------------|
| add   | rD, rA, rB | Add                           |
| addc  | rD, rA, rB | Add with Carry                |
| addk  | rD, rA, rB | Add and Keep Carry            |
| addkc | rD, rA, rB | Add with Carry and Keep Carry |

|             |    |    |    |                         |
|-------------|----|----|----|-------------------------|
| 0 0 0 K C 0 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

The sum of the contents of registers rA and rB, is placed into register rD.

Bit 3 of the instruction (labeled as K in the figure) is set to one for the mnemonic addk. Bit 4 of the instruction (labeled as C in the figure) is set to one for the mnemonic addc. Both bits are set to one for the mnemonic addkc.

When an add instruction has bit 3 set (addk, addkc), the carry flag will keep its previous value regardless of the outcome of the execution of the instruction. If bit 3 is cleared (add, addc), then the carry flag will be affected by the execution of the instruction.

When bit 4 of the instruction is set to one (addc, addkc), the content of the carry flag (MSR[C]) affects the execution of the instruction. When bit 4 is cleared (add, addk), the content of the carry flag does not affect the execution of the instruction (providing a normal addition).

## Pseudocode

```

if C = 0 then
    (rD) ← (rA) + (rB)
else
    (rD) ← (rA) + (rB) + MSR[C]
if K = 0 then
    MSR[C] ← CarryOut

```

### ***Registers Altered***

- rD
- MSR[C]

## Latency

1 cycle

### Note

The C bit in the instruction opcode is not the same as the carry bit in the MSR.

The "add r0, r0, r0" (= 0x00000000) instruction is never used by the compiler and usually indicates uninitialized memory. If you are using illegal instruction exceptions you can trap these instructions by setting the MicroBlaze parameter C\_OPCODE\_0x0\_ILLEGAL=1.

## addi Arithmetic Add Immediate

|        |             |                                         |
|--------|-------------|-----------------------------------------|
| addi   | rD, rA, IMM | Add Immediate                           |
| addic  | rD, rA, IMM | Add Immediate with Carry                |
| addik  | rD, rA, IMM | Add Immediate and Keep Carry            |
| addikc | rD, rA, IMM | Add Immediate with Carry and Keep Carry |

| 0 | 0 | 1 | K | C | 0 | rD | rA | IMM |
|---|---|---|---|---|---|----|----|-----|
| 0 |   |   |   |   | 6 | 1  | 1  | 3   |
|   |   |   |   |   |   | 1  | 6  | 1   |

### Description

The sum of the contents of registers rA and the value in the IMM field, sign-extended to 32 bits, is placed into register rD. Bit 3 of the instruction (labeled as K in the figure) is set to one for the mnemonic addik. Bit 4 of the instruction (labeled as C in the figure) is set to one for the mnemonic addic. Both bits are set to one for the mnemonic addikc.

When an addi instruction has bit 3 set (addik, addikc), the carry flag will keep its previous value regardless of the outcome of the execution of the instruction. If bit 3 is cleared (addi, addic), then the carry flag will be affected by the execution of the instruction.

When bit 4 of the instruction is set to one (addic, addikc), the content of the carry flag (MSR[C]) affects the execution of the instruction. When bit 4 is cleared (addi, addik), the content of the carry flag does not affect the execution of the instruction (providing a normal addition).

### Pseudocode

```

if C = 0 then
    (rD) ← (rA) + sext(IMM)
else
    (rD) ← (rA) + sext(IMM) + MSR[C]
if K = 0 then
    MSR[C] ← CarryOut

```

### Registers Altered

- rD
- MSR[C]

### Latency

1 cycle

### Notes

The C bit in the instruction opcode is not the same as the carry bit in the MSR.

By default, Type B Instructions take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” [page 228](#) for details on using 32-bit immediate values.

## and Logical AND

and  $r_D, r_A, r_B$

| 1 0 0 0 0 1 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
|-------------|----|----|----|-------------------------|
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

The contents of register rA are ANDed with the contents of register rB; the result is placed into register rD.

## Pseudocode

$$(rD) \leftarrow (rA) \wedge (rB)$$

### Registers Altered

- rD

## Latency

1 cycle

## andi Logical AND with Immediate

andi                      rD, rA, IMM

| 1 | 0 | 1 | 0 | 0 | 1 | rD | rA | IMM |
|---|---|---|---|---|---|----|----|-----|
| 0 |   |   |   |   | 6 | 1  | 1  | 3   |
|   |   |   |   |   |   | 1  | 6  | 1   |

### Description

The contents of register rA are ANDed with the value of the IMM field, sign-extended to 32 bits; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \wedge \text{sext}(IMM)$$

### Registers Altered

- rD

### Latency

1 cycle

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "imm," [page 228](#) for details on using 32-bit immediate values.



## andn Logical AND NOT

andn rD, rA, rB

|             |    |    |    |                     |
|-------------|----|----|----|---------------------|
| 1 0 0 0 1 1 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1  | 1  | 2                   |
|             |    | 1  | 6  | 1                   |
|             |    |    |    | 3                   |
|             |    |    |    | 1                   |

### Description

The contents of register rA are ANDed with the logical complement of the contents of register rB; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \wedge (\overline{rB})$$

### Registers Altered

- rD

### Latency

1 cycle

## andni Logical AND NOT with Immediate

andni            rD, rA, IMM

| 1 | 0 | 1 | 0 | 1 | 1 | rD | rA | IMM |
|---|---|---|---|---|---|----|----|-----|
| 0 |   |   |   |   | 6 | 1  | 1  | 3   |
|   |   |   |   |   |   | 1  | 6  | 1   |

### Description

The IMM field is sign-extended to 32 bits. The contents of register rA are ANDed with the logical complement of the extended IMM field; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \wedge (\overline{\text{sext}(\text{IMM})})$$

### Registers Altered

- rD

### Latency

1 cycle

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "imm," [page 228](#) for details on using 32-bit immediate values.

## beq Branch if Equal

|      |        |                            |
|------|--------|----------------------------|
| beq  | rA, rB | Branch if Equal            |
| beqd | rA, rB | Branch if Equal with Delay |

|             |           |    |    |                         |
|-------------|-----------|----|----|-------------------------|
| 1 0 0 1 1 1 | D 0 0 0 0 | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6         | 1  | 1  | 2                       |
|             |           | 1  | 6  | 1                       |
|             |           |    |    | 3                       |
|             |           |    |    | 1                       |

### Description

Branch if rA is equal to 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address  $PC + rB$ .

The mnemonic beq<sub>d</sub> will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

## Pseudocode

```

If rA = 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

## Latency

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### Note

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## beqi Branch Immediate if Equal

|       |         |                                      |
|-------|---------|--------------------------------------|
| beqi  | rA, IMM | Branch Immediate if Equal            |
| beqid | rA, IMM | Branch Immediate if Equal with Delay |

|             |           |        |                  |
|-------------|-----------|--------|------------------|
| 1 0 1 1 1 1 | D 0 0 0 0 | rA     | IMM              |
| 0           | 6         | 1<br>1 | 1<br>6<br>3<br>1 |

### Description

Branch if rA is equal to 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic beqid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA = 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## **bge** Branch if Greater or Equal

|      |        |                                       |
|------|--------|---------------------------------------|
| bge  | rA, rB | Branch if Greater or Equal            |
| bged | rA, rB | Branch if Greater or Equal with Delay |

|                    |                  |           |           |                            |
|--------------------|------------------|-----------|-----------|----------------------------|
| <b>1 0 0 1 1 1</b> | <b>D 0 1 0 1</b> | <b>rA</b> | <b>rB</b> | <b>0 0 0 0 0 0 0 0 0 0</b> |
| 0                  | 6                | 1<br>1    | 1<br>6    | 2<br>1                     |
|                    |                  |           |           | 3<br>1                     |

### **Description**

Branch if rA is greater or equal to 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address PC + rB.

The mnemonic bged will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### **Pseudocode**

```

If rA >= 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### **Registers Altered**

- PC

### **Latency**

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### **Note**

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## bgei Branch Immediate if Greater or Equal

|       |         |                                                 |
|-------|---------|-------------------------------------------------|
| bgei  | rA, IMM | Branch Immediate if Greater or Equal            |
| bgeid | rA, IMM | Branch Immediate if Greater or Equal with Delay |

| 1 0 1 1 1 1 | D 0 1 0 1 | rA | IMM |
|-------------|-----------|----|-----|
| 0           | 6         | 1  | 1   |
|             |           | 1  | 6   |
|             |           |    | 3   |
|             |           |    | 1   |

### Description

Branch if rA is greater or equal to 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic bgeid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA >= 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## **bgt** Branch if Greater Than

|      |        |                                   |
|------|--------|-----------------------------------|
| bgt  | rA, rB | Branch if Greater Than            |
| bgtD | rA, rB | Branch if Greater Than with Delay |

|                    |                  |           |           |                            |
|--------------------|------------------|-----------|-----------|----------------------------|
| <b>1 0 0 1 1 1</b> | <b>D 0 1 0 0</b> | <b>rA</b> | <b>rB</b> | <b>0 0 0 0 0 0 0 0 0 0</b> |
| 0                  | 6                | 1         | 1         | 2                          |
|                    |                  | 1         | 6         | 1                          |
|                    |                  |           |           | 3                          |
|                    |                  |           |           | 1                          |

### **Description**

Branch if rA is greater than 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address PC + rB.

The mnemonic bgtD will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### **Pseudocode**

```

If rA > 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### **Registers Altered**

- PC

### **Latency**

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### **Note**

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## **bgti** Branch Immediate if Greater Than

|       |         |                                             |
|-------|---------|---------------------------------------------|
| bgti  | rA, IMM | Branch Immediate if Greater Than            |
| bgtid | rA, IMM | Branch Immediate if Greater Than with Delay |

|                    |                  |           |                  |
|--------------------|------------------|-----------|------------------|
| <b>1 0 1 1 1 1</b> | <b>D 0 1 0 0</b> | <b>rA</b> | <b>IMM</b>       |
| 0                  | 6                | 1<br>1    | 1<br>6<br>3<br>1 |

### **Description**

Branch if rA is greater than 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic bgtid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### **Pseudocode**

```

If rA > 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### **Registers Altered**

- PC

### **Latency**

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### **Note**

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.



## ble Branch if Less or Equal

|      |        |                                    |
|------|--------|------------------------------------|
| ble  | rA, rB | Branch if Less or Equal            |
| bled | rA, rB | Branch if Less or Equal with Delay |

|             |           |    |    |                     |
|-------------|-----------|----|----|---------------------|
| 1 0 0 1 1 1 | D 0 0 1 1 | rA | rB | 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6         | 1  | 1  | 2                   |
|             |           | 1  | 6  | 1                   |
|             |           |    |    | 3                   |
|             |           |    |    | 1                   |

### Description

Branch if rA is less or equal to 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address PC + rB.

The mnemonic bled will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA <= 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### Note

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## blei Branch Immediate if Less or Equal

|       |         |                                              |
|-------|---------|----------------------------------------------|
| blei  | rA, IMM | Branch Immediate if Less or Equal            |
| bleid | rA, IMM | Branch Immediate if Less or Equal with Delay |

|                    |                  |           |                  |
|--------------------|------------------|-----------|------------------|
| <b>1 0 1 1 1 1</b> | <b>D 0 0 1 1</b> | <b>rA</b> | <b>IMM</b>       |
| 0                  | 6                | 1<br>1    | 1<br>6<br>3<br>1 |

### Description

Branch if rA is less or equal to 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic bleid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA <= 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## blt Branch if Less Than

|      |        |                                |
|------|--------|--------------------------------|
| blt  | rA, rB | Branch if Less Than            |
| bltd | rA, rB | Branch if Less Than with Delay |

|             |           |    |    |                         |
|-------------|-----------|----|----|-------------------------|
| 1 0 0 1 1 1 | D 0 0 1 0 | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6         | 1  | 1  | 2                       |
|             |           | 1  | 6  | 1                       |
|             |           |    |    | 3                       |
|             |           |    |    | 1                       |

### Description

Branch if rA is less than 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address PC + rB.

The mnemonic bltd will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA < 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### Note

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## **blti** Branch Immediate if Less Than

|       |         |                                          |
|-------|---------|------------------------------------------|
| blti  | rA, IMM | Branch Immediate if Less Than            |
| bltid | rA, IMM | Branch Immediate if Less Than with Delay |

|                    |                  |           |                  |
|--------------------|------------------|-----------|------------------|
| <b>1 0 1 1 1 1</b> | <b>D 0 0 1 0</b> | <b>rA</b> | <b>IMM</b>       |
| 0                  | 6                | 1<br>1    | 1<br>6<br>3<br>1 |

### **Description**

Branch if rA is less than 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic bltid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### **Pseudocode**

```

If rA < 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### **Registers Altered**

- PC

### **Latency**

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### **Note**

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## bne Branch if Not Equal

|      |        |                                |
|------|--------|--------------------------------|
| bne  | rA, rB | Branch if Not Equal            |
| bned | rA, rB | Branch if Not Equal with Delay |

|             |           |    |    |                     |
|-------------|-----------|----|----|---------------------|
| 1 0 0 1 1 1 | D 0 0 0 1 | rA | rB | 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6         | 1  | 1  | 2                   |
|             |           | 1  | 6  | 1                   |
|             |           |    |    | 3                   |
|             |           |    |    | 1                   |

### Description

Branch if rA not equal to 0, to the instruction located in the offset value of rB. The target of the branch will be the instruction at address PC + rB.

The mnemonic bned will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA ≠ 0 then
    PC ← PC + rB
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set)

### Note

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## bnei Branch Immediate if Not Equal

|       |         |                                          |
|-------|---------|------------------------------------------|
| bnei  | rA, IMM | Branch Immediate if Not Equal            |
| bneid | rA, IMM | Branch Immediate if Not Equal with Delay |

| 1 0 1 1 1 1 | D 0 0 0 1 | rA | IMM |
|-------------|-----------|----|-----|
| 0           | 6         | 1  | 1   |
|             |           | 1  | 6   |
|             |           |    | 3   |
|             |           |    | 1   |

### Description

Branch if rA not equal to 0, to the instruction located in the offset value of IMM. The target of the branch will be the instruction at address PC + IMM.

The mnemonic bneid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

If rA ≠ 0 then
    PC ← PC + sext(IMM)
else
    PC ← PC + 4
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- PC

### Latency

- 1 cycle (if branch is not taken, or successful branch prediction occurs)
- 2 cycles (if branch is taken and the D bit is set)
- 3 cycles (if branch is taken and the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## br Unconditional Branch

|       |        |                                     |
|-------|--------|-------------------------------------|
| br    | rB     | Branch                              |
| bra   | rB     | Branch Absolute                     |
| brd   | rB     | Branch with Delay                   |
| brad  | rB     | Branch Absolute with Delay          |
| brld  | rD, rB | Branch and Link with Delay          |
| brald | rD, rB | Branch Absolute and Link with Delay |

|             |    |           |    |                     |
|-------------|----|-----------|----|---------------------|
| 1 0 0 1 1 0 | rD | D A L 0 0 | rB | 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1         | 1  | 2                   |
|             |    | 1         | 6  | 1                   |
|             |    |           |    | 3                   |
|             |    |           |    | 1                   |

### Description

Branch to the instruction located at address determined by rB.

The mnemonics brld and brald will set the L bit. If the L bit is set, linking will be performed. The current value of PC will be stored in rD.

The mnemonics bra, brad and brald will set the A bit. If the A bit is set, it means that the branch is to an absolute value and the target is the value in rB, otherwise, it is a relative branch and the target will be PC + rB.

The mnemonics brd, brad, brld and brald will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction.

If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

### Pseudocode

```

if L = 1 then
    (rD) ← PC
if A = 1 then
    PC ← (rB)
else
    PC ← PC + (rB)
if D = 1 then
    allow following instruction to complete execution

```

### Registers Altered

- rD
- PC

### Latency

- 2 cycles (if the D bit is set)
- 3 cycles (if the D bit is not set)

**Note**

The instructions brl and bral are not available. A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.



## **bri**    **Unconditional Branch Immediate**

|        |         |                                               |
|--------|---------|-----------------------------------------------|
| bri    | IMM     | Branch Immediate                              |
| brai   | IMM     | Branch Absolute Immediate                     |
| brid   | IMM     | Branch Immediate with Delay                   |
| braid  | IMM     | Branch Absolute Immediate with Delay          |
| brlid  | rD, IMM | Branch and Link Immediate with Delay          |
| bralid | rD, IMM | Branch Absolute and Link Immediate with Delay |

|                    |           |                  |            |
|--------------------|-----------|------------------|------------|
| <b>1 0 1 1 1 0</b> | <b>rD</b> | <b>D A L 0 0</b> | <b>IMM</b> |
| 0                  | 6         | 1                | 1          |
|                    |           | 1                | 6          |
|                    |           |                  | 3          |
|                    |           |                  | 1          |

### **Description**

Branch to the instruction located at address determined by IMM, sign-extended to 32 bits.

The mnemonics brlid and bralid will set the L bit. If the L bit is set, linking will be performed. The current value of PC will be stored in rD.

The mnemonics brai, braid and bralid will set the A bit. If the A bit is set, it means that the branch is to an absolute value and the target is the value in IMM, otherwise, it is a relative branch and the target will be PC + IMM.

The mnemonics brid, braid, brlid and bralid will set the D bit. The D bit determines whether there is a branch delay slot or not. If the D bit is set, it means that there is a delay slot and the instruction following the branch (that is, in the branch delay slot) is allowed to complete execution before executing the target instruction. If the D bit is not set, it means that there is no delay slot, so the instruction to be executed after the branch is the target instruction.

As a special case, when MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) and "bralid rD, C\_BASE\_VECTORS+0x8" is used to perform a User Vector Exception, the Machine Status Register bits User Mode and Virtual Mode are cleared.

### **Pseudocode**

```

if L = 1 then
    (rD) ← PC
if A = 1 then
    PC ← sext(IMM)
else
    PC ← PC + sext(IMM)
if D = 1 then
    allow following instruction to complete execution
if D = 1 and A = 1 and L = 1 and IMM = C_BASE_VECTORS+0x8 then
    MSR[UMS] ← MSR[UM]
    MSR[VMS] ← MSR[VM]
    MSR[UM] ← 0
    MSR[VM] ← 0

```

**Registers Altered**

- rD
- PC
- MSR[UM], MSR[VM]

**Latency**

- 1 cycle (if successful branch prediction occurs)
- 2 cycles (if the D bit is set)
- 3 cycles (if the D bit is not set, or a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

**Notes**

The instructions brli and brali are not available.

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” [page 228](#) for details on using 32-bit immediate values.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

**brk** Break

brk                      rD, rB

|             |    |           |    |                     |
|-------------|----|-----------|----|---------------------|
| 1 0 0 1 1 0 | rD | 0 1 1 0 0 | rB | 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 11        | 16 | 21                  |
|             |    |           |    | 31                  |

### **Description**

Branch and link to the instruction located at address value in rB. The current value of PC will be stored in rD. The BIP flag in the MSR will be set, and the reservation bit will be cleared.

When MicroBlaze is configured to use an MMU (`C_USE_MMU >= 1`) this instruction is privileged. This means that if the instruction is attempted in User Mode (`MSR[UM] = 1`) a Privileged Instruction exception occurs.

## Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    (rD) ← PC
    PC ← (rB)
    MSR[BIP] ← 1
    Reservation ← 0

```

### Registers Altered

- rD
- PC
- MSR[BIP]
- ESR[EC], in case a privileged instruction exception is generated

## Latency

- 3 cycles

## brki Break Immediate

brki                      rD, IMM

|   |   |   |   |   |   |    |   |   |   |   |   |     |
|---|---|---|---|---|---|----|---|---|---|---|---|-----|
| 1 | 0 | 1 | 1 | 1 | 0 | rD | 0 | 1 | 1 | 0 | 0 | IMM |
| 0 |   |   |   |   |   | 6  |   |   |   |   |   | 31  |

### Description

Branch and link to the instruction located at address value in IMM, sign-extended to 32 bits. The current value of PC will be stored in rD. The BIP flag in the MSR will be set, and the reservation bit will be cleared.

When MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) this instruction is privileged, except as a special case when “brki rD, C\_BASE\_VECTORS+0x8” or “brki rD, C\_BASE\_VECTORS+0x18” is used to perform a Software Break. This means that, apart from the special case, if the instruction is attempted in User Mode ( $MSR[UM] = 1$ ) a Privileged Instruction exception occurs.

As a special case, when MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) and “brki rD, C\_BASE\_VECTORS+0x8” or “brki rD, C\_BASE\_VECTORS+0x18” is used to perform a Software Break, the Machine Status Register bits User Mode and Virtual Mode are cleared.

### Pseudocode

```

if MSR[UM] and IMM ≠ C_BASE_VECTORS+0x8 and IMM ≠ C_BASE_VECTORS+0x18 then
    ESR[EC] ← 00111
else
    (rD) ← PC
    PC ← sext(IMM)
    MSR[BIP] ← 1
    Reservation ← 0
    if IMM = C_BASE_VECTORS+0x8 or IMM = C_BASE_VECTORS+0x18 then
        MSR[UMS] ← MSR[UM] MSR[UM] ← 0
        MSR[VMS] ← MSR[VM] MSR[VM] ← 0

```

### Registers Altered

- rD, unless an exception is generated, in which case the register is unchanged
- PC
- MSR[BIP], MSR[UM], MSR[VM]
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 3 cycles

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

As a special case, the imm instruction does not override a Software Break “brki rD, 0x18” when  $C\_DEBUG\_ENABLED$  is greater than zero, irrespective of the value of  $C\_BASE\_VECTORS$ , to allow Software Break after an imm instruction.

## bs Barrel Shift

|      |            |                                 |
|------|------------|---------------------------------|
| bsrl | rD, rA, rB | Barrel Shift Right Logical      |
| bsra | rD, rA, rB | Barrel Shift Right Arithmetical |
| bsll | rD, rA, rB | Barrel Shift Left Logical       |

| 0 1 0 0 0 1 | rD | rA     | rB     | S T 0 0 0 0 0 0 0 0 |
|-------------|----|--------|--------|---------------------|
| 0           | 6  | 1<br>1 | 1<br>6 | 2<br>1              |
|             |    |        |        | 3<br>1              |

### Description

Shifts the contents of register rA by the amount specified in register rB and puts the result in register rD.

The mnemonic bsll sets the S bit (Side bit). If the S bit is set, the barrel shift is done to the left. The mnemonics bsrl and bsra clear the S bit and the shift is done to the right.

The mnemonic bsra will set the T bit (Type bit). If the T bit is set, the barrel shift performed is Arithmetical. The mnemonics bsrl and bsll clear the T bit and the shift performed is Logical.

### Pseudocode

```

if S = 1 then
    (rD) ← (rA) << (rB)[27:31]
else
    if T = 1 then
        if ((rB)[27:31]) ≠ 0 then
            (rD)[0:(rB)[27:31]-1] ← (rA)[0]
            (rD)[(rB)[27:31]:31] ← (rA) >> (rB)[27:31]
        else
            (rD) ← (rA)
    else
        (rD) ← (rA) >> (rB)[27:31]

```

### Registers Altered

- rD

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

These instructions are optional. To use them, MicroBlaze has to be configured to use barrel shift instructions (C\_USE\_BARREL=1).

## bsi Barrel Shift Immediate

|       |                                               |                                           |
|-------|-----------------------------------------------|-------------------------------------------|
| bsrli | rD, rA, IMM                                   | Barrel Shift Right Logical Immediate      |
| bsrai | rD, rA, IMM                                   | Barrel Shift Right Arithmetical Immediate |
| bslli | rD, rA, IMM                                   | Barrel Shift Left Logical Immediate       |
| bsefi | rD, rA, IMM <sub>W</sub> , IMM <sub>S</sub>   | Barrel Shift Extract Field Immediate      |
| bsifi | rD, rA, Width <sup>1</sup> , IMM <sub>S</sub> | Barrel Shift Insert Field Immediate       |

1. Width = IMM<sub>W</sub> - IMM<sub>S</sub> + 1

|             |  |  |  |  |  |    |  |    |  |           |  |  |  |  |             |  |  |  |  |     |  |    |  |
|-------------|--|--|--|--|--|----|--|----|--|-----------|--|--|--|--|-------------|--|--|--|--|-----|--|----|--|
| 0 1 1 0 0 1 |  |  |  |  |  | rD |  | rA |  | 0 0 0 0 0 |  |  |  |  | S T 0 0 0 0 |  |  |  |  | IMM |  |    |  |
| 0           |  |  |  |  |  | 6  |  | 11 |  | 16        |  |  |  |  | 21          |  |  |  |  | 27  |  | 31 |  |

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### Description

The first three instructions shift the contents of register rA by the amount specified by IMM and put the result in register rD.

Barrel Shift Extract Field extracts a bit field from register rA and puts the result in register rD. The bit field width is specified by IMM<sub>W</sub> and the shift amount is specified by IMM<sub>S</sub>. The bit field width must be in the range 1 - 31, and the condition IMM<sub>W</sub> + IMM<sub>S</sub> ≤ 32 must apply.

Barrel Shift Insert Field inserts a bit field from register rA into register rD, modifying the existing value in register rD. The bit field width is defined by IMM<sub>W</sub> - IMM<sub>S</sub> + 1, and the shift amount is specified by IMM<sub>S</sub>. The condition IMM<sub>W</sub> ≥ IMM<sub>S</sub> must apply.

The mnemonic bsll sets the S bit (Side bit). If the S bit is set, the barrel shift is done to the left. The mnemonics bsrl and bsra clear the S bit and the shift is done to the right.

The mnemonic bsra sets the T bit (Type bit). If the T bit is set, the barrel shift performed is Arithmetical. The mnemonics bsrl and bsll clear the T bit and the shift performed is Logical.

The mnemonic bsefi sets the E bit (Extract bit). In this case the S and T bits are not used.

The mnemonic bsifi sets the I bit (Insert bit). In this case the S and T bits are not used.

## Pseudocode

```

if E = 1 then
    (rD)[0:31-IMMW] ← 0
    (rD)[32-IMMW:31] ← (rA) >> IMMS
else if I = 1 then
    mask ← (0xffffffff << (IMMW + 1)) ⊕ (0xffffffff << IMMS)
    (rD) ← ((rA) << IMMS) ∧ mask) ∨ ((rD) ∧  $\overline{\text{mask}}$ )
else if S = 1 then
    (rD) ← (rA) << IMM
else if T = 1 then
    if IMM ≠ 0 then
        (rD)[0:IMM-1] ← (rA)[0]
        (rD)[IMM:31] ← (rA) >> IMM
    else
        (rD) ← (rA)
else
    (rD) ← (rA) >> IMM

```

## Registers Altered

- rD

## Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

## Notes

These are not Type B Instructions. There is no effect from a preceding imm instruction.

These instructions are optional. To use them, MicroBlaze has to be configured to use barrel shift instructions (C\_USE\_BARREL=1).

The assembler code “bsifi rD, rA, width, shift” denotes the actual bit field width, not the IMM<sub>W</sub> field, which is computed by IMM<sub>W</sub> = shift + width - 1.

## clz Count Leading Zeros

clz                      rD, rA                      Count leading zeros in rA

|             |    |    |           |                       |
|-------------|----|----|-----------|-----------------------|
| 1 0 0 1 0 0 | rD | rA | 0 0 0 0 0 | 0 0 0 1 1 1 0 0 0 0 0 |
| 0           | 6  | 1  | 1         | 2                     |
|             |    | 1  | 6         | 1                     |
|             |    |    |           | 3                     |
|             |    |    |           | 1                     |

### Description

This instruction counts the number of leading zeros in register rA starting from the most significant bit. The result is a number between 0 and 32, stored in register rD.

The result in rD is 32 when rA is 0, and it is 0 if rA is 0xFFFFFFFF.

### Pseudocode

```

n ← 0
while (rA)[n] = 0
    n ← n + 1
(rD) ← n

```

### Registers Altered

- rD

### Latency

- 1 cycle

### Notes

This instruction is only available when the parameter C\_USE\_PCOMP\_INSTR is set to 1.



## cmp Integer Compare

|      |            |                               |
|------|------------|-------------------------------|
| cmp  | rD, rA, rB | compare rB with rA (signed)   |
| cmpu | rD, rA, rB | compare rB with rA (unsigned) |

| 0 0 0 1 0 1 | rD | rA | rB | 0 0 0 0 0 0 0 0 U 1 |
|-------------|----|----|----|---------------------|
| 0           | 6  | 1  | 1  | 2                   |
|             |    | 1  | 6  | 1                   |

### Description

The contents of register rA is subtracted from the contents of register rB and the result is placed into register rD.

The MSB bit of rD is adjusted to shown true relation between rA and rB. If the U bit is set, rA and rB is considered unsigned values. If the U bit is clear, rA and rB is considered signed values.

### Pseudocode

$$(rD) \leftarrow (rB) + \overline{(rA)} + 1$$

$$(rD) \text{ (MSB)} \leftarrow (rA) > (rB)$$

### Registers Altered

- rD

### Latency

- 1 cycle

## fadd Floating Point Arithmetic Add

|      |            |     |
|------|------------|-----|
| fadd | rD, rA, rB | Add |
|------|------------|-----|

|   |   |   |   |   |   |    |    |    |    |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|---|---|---|---|---|---|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |   |   |   |   |   |   | 31 |

### Description

The floating point sum of registers rA and rB, is placed into register rD.

## Pseudocode

```

if isDnz(rA) or isDnz(rB) then
    (rD) ← 0xFFC00000
    FSR[DO] ← 1
    ESR[EC] ← 00110
else if isSigNaN(rA) or isSigNaN(rB) or
    (isPosInfinite(rA) and isNegInfinite(rB)) or
    (isNegInfinite(rA) and isPosInfinite(rB)) then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else if isQuietNaN(rA) or isQuietNaN(rB) then
    (rD) ← 0xFFC00000
else if isDnz((rA)+(rB)) then
    (rD) ← signZero((rA)+(rB))
    FSR[UF] ← 1
    ESR[EC] ← 00110
else if isNaN((rA)+(rB)) then
    (rD) ← signInfinite((rA)+(rB))
    FSR[OF] ← 1
    ESR[EC] ← 00110
else
    (rD) ← (rA) + (rB)

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,UF,OF,DO]

## Latency

- 4 cycles with C\_AREA\_OPTIMIZED=0
- 6 cycles with C\_AREA\_OPTIMIZED=1
- 1 cycle with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is greater than 0.

## frsub Reverse Floating Point Arithmetic Subtraction

|       |            |                  |
|-------|------------|------------------|
| frsub | rD, rA, rB | Reverse subtract |
|-------|------------|------------------|

|   |   |   |   |   |   |    |    |    |    |   |   |   |    |   |   |   |   |    |  |  |  |  |  |  |  |    |
|---|---|---|---|---|---|----|----|----|----|---|---|---|----|---|---|---|---|----|--|--|--|--|--|--|--|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 0  | 0 | 0 | 1 | 0  | 0 | 0 | 0 | 0 | 0  |  |  |  |  |  |  |  |    |
| 0 |   |   |   |   |   | 6  |    |    | 11 |   |   |   | 16 |   |   |   |   | 21 |  |  |  |  |  |  |  | 31 |

### Description

The floating point value in rA is subtracted from the floating point value in rB and the result is placed into register rD.

## Pseudocode

```

if isDnz(rA) or isDnz(rB) then
    (rD) ← 0xFFC00000
    FSR[DO] ← 1
    ESR[EC] ← 00110
else if (isSigNaN(rA) or isSigNaN(rB) or
        (isPosInfinite(rA) and isPosInfinite(rB)) or
        (isNegInfinite(rA) and isNegInfinite(rB))) then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else if isQuietNaN(rA) or isQuietNaN(rB) then
    (rD) ← 0xFFC00000
else if isDnz((rB)-(rA)) then
    (rD) ← signZero((rB)-(rA))
    FSR[UF] ← 1
    ESR[EC] ← 00110
else if isNaN((rB)-(rA)) then
    (rD) ← signInfinite((rB)-(rA))
    FSR[OF] ← 1
    ESR[EC] ← 00110
else
    (rD) ← (rB) - (rA)

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,UF,OF,DO]

## Latency

- 4 cycles with C\_AREA\_OPTIMIZED=0
- 6 cycles with C\_AREA\_OPTIMIZED=1
- 1 cycle with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is greater than 0.

## fmul Floating Point Arithmetic Multiplication

|      |            |          |
|------|------------|----------|
| fmul | rD, rA, rB | Multiply |
|------|------------|----------|

[illegible]

### Description

The floating point value in rA is multiplied with the floating point value in rB and the result is placed into register rD.

## Pseudocode

```

if isDnz(rA) or isDnz(rB) then
    (rD) ← 0xFFC00000
    FSR[DO] ← 1
    ESR[EC] ← 00110
else
    if isSigNaN(rA) or isSigNaN(rB) or (isZero(rA) and isInfinite(rB)) or
       (isZero(rB) and isInfinite(rA)) then
        (rD) ← 0xFFC00000
        FSR[IO] ← 1
        ESR[EC] ← 00110
    else if isQuietNaN(rA) or isQuietNaN(rB) then
        (rD) ← 0xFFC00000
    else if isDnz((rB)*(rA)) then
        (rD) ← signZero((rA)*(rB))
        FSR[UF] ← 1
        ESR[EC] ← 00110
    else if isNaN((rB)*(rA)) then
        (rD) ← signInfinite((rB)*(rA))
        FSR[OF] ← 1
        ESR[EC] ← 00110
    else
        (rD) ← (rB) * (rA)

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,UF,OF,DO]

## Latency

- 4 cycles with C\_AREA\_OPTIMIZED=0
- 6 cycles with C\_AREA\_OPTIMIZED=1
- 1 cycle with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is greater than 0.

**fdiv** Floating Point Arithmetic Division

fdiv                  rD, rA, rB        Divide

|   |   |   |   |   |   |    |    |    |    |   |   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|---|---|---|---|---|---|---|---|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 0  | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |    |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |   |   |   |   |   |   |   |   | 31 |

### Description

The floating point value in rB is divided by the floating point value in rA and the result is placed into register rD.

## Pseudocode

```

if isDnz(rA) or isDnz(rB) then
    (rD)  $\leftarrow$  0xFFC00000
    FSR[DO]  $\leftarrow$  1
    ESR[EC]  $\leftarrow$  00110
else
    if isSigNaN(rA) or isSigNaN(rB) or (isZero(rA) and isZero(rB)) or
       (isInfinite(rA) and isInfinite(rB)) then
        (rD)  $\leftarrow$  0xFFC00000
        FSR[IO]  $\leftarrow$  1
        ESR[EC]  $\leftarrow$  00110
    else if isQuietNaN(rA) or isQuietNaN(rB) then
        (rD)  $\leftarrow$  0xFFC00000
    else if isZero(rA) and not isInfinite(rB) then
        (rD)  $\leftarrow$  signInfinite((rB)/(rA))
        FSR[DZ]  $\leftarrow$  1
        ESR[EC]  $\leftarrow$  00110
    else if isDnz((rB) / (rA)) then
        (rD)  $\leftarrow$  signZero((rB) / (rA))
        FSR[UF]  $\leftarrow$  1
        ESR[EC]  $\leftarrow$  00110
    else if isNaN((rB)/(rA)) then
        (rD)  $\leftarrow$  signInfinite((rB) / (rA))
        FSR[OF]  $\leftarrow$  1
        ESR[EC]  $\leftarrow$  00110
    else
        (rD)  $\leftarrow$  (rB) / (rA)

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,UF,OF,DO,DZ]

## Latency

- 28 cycles with C\_AREA\_OPTIMIZED=0, 30 cycles with C\_AREA\_OPTIMIZED=1, 24 cycles with C\_AREA\_OPTIMIZED=2

**Note**

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is greater than 0.

## fcmp Floating Point Number Comparison

|         |            |                                            |
|---------|------------|--------------------------------------------|
| fcmp.un | rD, rA, rB | Unordered floating point comparison        |
| fcmp.lt | rD, rA, rB | Less-than floating point comparison        |
| fcmp.eq | rD, rA, rB | Equal floating point comparison            |
| fcmp.le | rD, rA, rB | Less-or-Equal floating point comparison    |
| fcmp.gt | rD, rA, rB | Greater-than floating point comparison     |
| fcmp.ne | rD, rA, rB | Not-Equal floating point comparison        |
| fcmp.ge | rD, rA, rB | Greater-or-Equal floating point comparison |

|   |   |   |   |   |   |    |    |    |    |   |   |   |       |    |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|---|-------|----|---|---|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 0  | 1 | 0 | 0 | OpSel | 0  | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |   | 25    | 28 |   |   | 31 |

### Description

The floating point value in rB is compared with the floating point value in rA and the comparison result is placed into register rD. The OpSel field in the instruction code determines the type of comparison performed.

### Pseudocode

```

if isDnz(rA) or isDnz(rB) then
    (rD) ← 0
    FSR[DO] ← 1
    ESR[EC] ← 00110
else
    {read out behavior from Table 5-2}

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,DO]

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### Note

These instructions are only available when the MicroBlaze parameter C\_USE\_FPU is greater than 0.

Table 5-2, page 219 lists the floating point comparison operations.

Table 5-2: Floating Point Comparison Operation

| Comparison Type  |       | Operand Relationship |             |             |                                            |                                            |
|------------------|-------|----------------------|-------------|-------------|--------------------------------------------|--------------------------------------------|
| Description      | OpSel | (rB) > (rA)          | (rB) < (rA) | (rB) = (rA) | isSigNaN(rA) or<br>isSigNaN(rB)            | isQuietNaN(rA) or<br>isQuietNaN(rB)        |
| Unordered        | 000   | (rD) ← 0             | (rD) ← 0    | (rD) ← 0    | (rD) ← 1<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 1                                   |
| Less-than        | 001   | (rD) ← 0             | (rD) ← 1    | (rD) ← 0    | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 |
| Equal            | 010   | (rD) ← 0             | (rD) ← 0    | (rD) ← 1    | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 0                                   |
| Less-or-equal    | 011   | (rD) ← 0             | (rD) ← 1    | (rD) ← 1    | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 |
| Greater-than     | 100   | (rD) ← 1             | (rD) ← 0    | (rD) ← 0    | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 |
| Not-equal        | 101   | (rD) ← 1             | (rD) ← 1    | (rD) ← 0    | (rD) ← 1<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 1                                   |
| Greater-or-equal | 110   | (rD) ← 1             | (rD) ← 0    | (rD) ← 1    | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 | (rD) ← 0<br>FSR[IO] ← 1<br>ESR[EC] ← 00110 |

## flt Floating Point Convert Integer to Float

flt                      rD, rA

|   |   |   |   |   |   |    |    |   |    |   |   |   |    |   |   |   |   |   |    |  |  |  |  |  |    |
|---|---|---|---|---|---|----|----|---|----|---|---|---|----|---|---|---|---|---|----|--|--|--|--|--|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | 0 | 0  | 1 | 0 | 1 | 0  | 0 | 0 | 0 | 0 | 0 | 0  |  |  |  |  |  |    |
| 0 |   |   |   |   |   | 6  |    |   | 11 |   |   |   | 16 |   |   |   |   |   | 21 |  |  |  |  |  | 31 |

### Description

Converts the signed integer in register rA to floating point and puts the result in register rD. This is a 32-bit rounding signed conversion that will produce a 32-bit floating point result.

## Pseudocode

$$(rD) \leftarrow \text{float} ((rA))$$

### Registers Altered

- rD

## Latency

- 4 cycles with C\_AREA\_OPTIMIZED=0
- 6 cycles with C\_AREA\_OPTIMIZED=1
- 1 cycle with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is set to 2 (Extended).



## fint Floating Point Convert Float to Integer

fint                      rD, rA

[illegible]

### Description

Converts the floating point number in register rA to a signed integer and puts the result in register rD. This is a 32-bit signed conversion that will produce a 32-bit integer result.

## Pseudocode

```

if isDnz(rA) then
    (rD) ← 0xFFC00000
    FSR[DO] ← 1
    ESR[EC] ← 00110
else if isNaN(rA) then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else if isInf(rA) or (rA) < -231 or (rA) > 231 - 1 then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else
    (rD) ← int ((rA))

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,DO]

## Latency

- 5 cycles with C\_AREA\_OPTIMIZED=0
- 7 cycles with C\_AREA\_OPTIMIZED=1
- 2 cycles with C\_AREA\_OPTIMIZED=2

**Note**

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is set to 2 (Extended).

## fsqrt Floating Point Arithmetic Square Root

|       |        |             |
|-------|--------|-------------|
| fsqrt | rD, rA | Square Root |
|-------|--------|-------------|

|   |   |   |   |   |   |    |    |   |    |   |   |   |    |   |   |   |   |   |    |  |  |  |  |  |    |
|---|---|---|---|---|---|----|----|---|----|---|---|---|----|---|---|---|---|---|----|--|--|--|--|--|----|
| 0 | 1 | 0 | 1 | 1 | 0 | rD | rA | 0 | 0  | 1 | 1 | 1 | 0  | 0 | 0 | 0 | 0 | 0 | 0  |  |  |  |  |  |    |
| 0 |   |   |   |   |   | 6  |    |   | 11 |   |   |   | 16 |   |   |   |   |   | 21 |  |  |  |  |  | 31 |

### Description

Performs a floating point square root on the value in rA and puts the result in register rD.

## Pseudocode

```

if isDnz(rA) then
    (rD) ← 0xFFC00000
    FSR[DO] ← 1
    ESR[EC] ← 00110
else if isSigNaN(rA) then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else if isQuietNaN(rA) then
    (rD) ← 0xFFC00000
else if (rA) < 0 then
    (rD) ← 0xFFC00000
    FSR[IO] ← 1
    ESR[EC] ← 00110
else if (rA) = -0 then
    (rD) ← -0
else
    (rD) ← sqrt ((rA))

```

### Registers Altered

- rD, unless an FP exception is generated, in which case the register is unchanged
- ESR[EC], if an FP exception is generated
- FSR[IO,DO]

## Latency

- 27 cycles with C\_AREA\_OPTIMIZED=0
- 29 cycles with C\_AREA\_OPTIMIZED=1
- 23 cycles with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only available when the MicroBlaze parameter `C_USE_FPU` is set to 2 (Extended).

## get **get from stream interface**

|          |          |                                                                                                                    |
|----------|----------|--------------------------------------------------------------------------------------------------------------------|
| tneaget  | rD, FSLx | get data from link x<br>t = test-only<br>n = non-blocking<br>e = exception if control bit set<br>a = atomic        |
| tnecaget | rD, FSLx | get control from link x<br>t = test-only<br>n = non-blocking<br>e = exception if control bit not set<br>a = atomic |

|   |   |   |   |   |   |    |   |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |      |    |
|---|---|---|---|---|---|----|---|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|------|----|
| 0 | 1 | 1 | 0 | 1 | 1 | rD | 0 | 0 | 0 | 0 | 0 | 0 | n  | c | t | a | e | 0 | 0 | 0 | 0 | 0 | 0 | FSLx |    |
| 0 |   |   |   |   |   | 6  |   |   |   |   |   |   | 11 |   |   |   |   |   |   |   |   |   |   | 28   | 31 |

### Description

MicroBlaze will read from the link x interface and place the result in register rD. If the available number of links set by C\_FSL\_LINKS is less than or equal to FSLx, link 0 is used.

The get instruction has 32 variants.

The blocking versions (when 'n' bit is '0') will stall MicroBlaze until the data from the interface is valid. The non-blocking versions will not stall MicroBlaze and will set carry to '0' if the data was valid and to '1' if the data was invalid. In case of an invalid access the destination register contents is undefined.

All data get instructions (when 'c' bit is '0') expect the control bit from the interface to be '0'. If this is not the case, the instruction will set MSR[FSL] to '1'. All control get instructions (when 'c' bit is '1') expect the control bit from the interface to be '1'. If this is not the case, the instruction will set MSR[FSL] to '1'.

The exception versions (when 'e' bit is '1') will generate an exception if there is a control bit mismatch. In this case ESR is updated with EC set to the exception cause and ESS set to the link index. The target register, rD, is not updated when an exception is generated, instead the data is stored in EDR.

The test versions (when 't' bit is '1') will be handled as the normal case, except that the read signal to the link is not asserted.

Atomic versions (when 'a' bit is '1') are not interruptible. This means that a sequence of atomic instructions can be grouped together without an interrupt breaking the program flow. However, note that exceptions may still occur.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) and not explicitly allowed by setting C\_MMU\_PRIVILEGED\_INSTR to 1 these instructions are privileged. This means that if these instructions are attempted in User Mode (MSR[UM]=1) a Privileged Instruction exception occurs.

### ***Pseudocode***

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    x ← FSLx
    if x ≥ C_FSL_LINKS then
        x ← 0
    (rD) ← Sx_AXIS_TDATA
    if (n = 1) then
        MSR[Carry] ←  $\overline{Sx\_AXIS\_TVALID}$ 
    if Sx_AXIS_TLAST ≠ c and Sx_AXIS_TVALID then
        MSR[FSL] ← 1
        if (e = 1) then
            ESR[EC] ← 00000
            ESR[ESS] ← instruction bits [28:31]
            EDR ← Sx_AXIS_TDATA

```

### ***Registers Altered***

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[FSL]
- MSR[Carry]
- ESR[EC], in case a stream exception or a privileged instruction exception is generated
- ESR[ESS], in case a stream exception is generated
- EDR, in case a stream exception is generated

### ***Latency***

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

The blocking versions of this instruction will stall the pipeline of MicroBlaze until the instruction can be completed. Interrupts are served when the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1, and the instruction is not atomic.

### ***Note***

To refer to an FSLx interface in assembly language, use rfsl0, rfsl1, ... rfsl15.

The blocking versions of this instruction should not be placed in a delay slot when the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1, since this prevents interrupts from being served.

For non-blocking versions, an rsubc instruction can be used to decrement an index variable.

The 'e' bit does not have any effect unless C\_FSL\_EXCEPTION is set to 1.

These instructions are only available when the MicroBlaze parameter C\_FSL\_LINKS is greater than 0.

The extended instructions (exception, test and atomic versions) are only available when the MicroBlaze parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1.

It is not recommended to allow these instructions in user mode, unless absolutely necessary for performance reasons, since that removes all hardware protection preventing incorrect use of a link.

## getd get from stream interface dynamic

|           |        |                                                                                                                            |
|-----------|--------|----------------------------------------------------------------------------------------------------------------------------|
| tneagetd  | rD, rB | get data from link rB[28:31]<br>t = test-only<br>n = non-blocking<br>e = exception if control bit set<br>a = atomic        |
| tnecagetd | rD, rB | get control from link rB[28:31]<br>t = test-only<br>n = non-blocking<br>e = exception if control bit not set<br>a = atomic |

|   |   |   |   |   |   |    |   |   |   |   |   |    |   |   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|----|
| 0 | 1 | 0 | 0 | 1 | 1 | rD | 0 | 0 | 0 | 0 | 0 | rB | 0 | n | c | t | a | e | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  |   |   |   |   |   | 11 |   |   |   |   |   |   |   |   |   |   | 31 |

### Description

MicroBlaze will read from the interface defined by the four least significant bits in rB and place the result in register rD. If the available number of links set by C\_FSL\_LINKS is less than or equal to the four least significant bits in rB, link 0 is used.

The getd instruction has 32 variants.

The blocking versions (when 'n' bit is '0') will stall MicroBlaze until the data from the interface is valid. The non-blocking versions will not stall MicroBlaze and will set carry to '0' if the data was valid and to '1' if the data was invalid. In case of an invalid access the destination register contents is undefined.

All data get instructions (when 'c' bit is '0') expect the control bit from the interface to be '0'. If this is not the case, the instruction will set MSR[FSL] to '1'. All control get instructions (when 'c' bit is '1') expect the control bit from the interface to be '1'. If this is not the case, the instruction will set MSR[FSL] to '1'.

The exception versions (when 'e' bit is '1') will generate an exception if there is a control bit mismatch. In this case ESR is updated with EC set to the exception cause and ESS set to the link index. The target register, rD, is not updated when an exception is generated, instead the data is stored in EDR.

The test versions (when 't' bit is '1') will be handled as the normal case, except that the read signal to the link is not asserted.

Atomic versions (when 'a' bit is '1') are not interruptible. This means that a sequence of atomic instructions can be grouped together without an interrupt breaking the program flow. However, note that exceptions may still occur.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) and not explicitly allowed by setting C\_MMU\_PRIVILEGED\_INSTR to 1 these instructions are privileged. This means that if these instructions are attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

### ***Pseudocode***

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    x ← rB[28:31]
    if x >= C_FSL_LINKS then
        x ← 0
    (rD) ← Sx_AXIS_TDATA
    if (n = 1) then
        MSR[Carry] ←  $\overline{Sx\_AXIS\_TVALID}$ 
    if Sx_AXIS_TLAST ≠ c and Sx_AXIS_TVALID then
        MSR[FSL] ← 1
        if (e = 1) then
            ESR[EC] ← 00000
            ESR[ESS] ← rB[28:31]
            EDR ← Sx_AXIS_TDATA

```

### ***Registers Altered***

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[FSL]
- MSR[Carry]
- ESR[EC], in case a stream exception or a privileged instruction exception is generated
- ESR[ESS], in case a stream exception is generated
- EDR, in case a stream exception is generated

### ***Latency***

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

The blocking versions of this instruction will stall the pipeline of MicroBlaze until the instruction can be completed. Interrupts are served unless the instruction is atomic, which ensures that the instruction cannot be interrupted.

### ***Note***

The blocking versions of this instruction should not be placed in a delay slot, since this prevents interrupts from being served.

For non-blocking versions, an rsubc instruction can be used to decrement an index variable.

The 'e' bit does not have any effect unless C\_FSL\_EXCEPTION is set to 1.

These instructions are only available when the MicroBlaze parameter C\_FSL\_LINKS is greater than 0 and the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1.

It is not recommended to allow these instructions in user mode, unless absolutely necessary for performance reasons, since that removes all hardware protection preventing incorrect use of a link.

## idiv Integer Divide

idiv            rD, rA, rB        divide rB by rA (signed)  
idivu          rD, rA, rB        divide rB by rA (unsigned)

| 0 1 0 0 1 0 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 U 0 |   |
|-------------|----|----|----|-------------------------|---|
| 0           | 6  | 1  | 1  | 2                       | 3 |
|             |    | 1  | 6  | 1                       | 1 |

### Description

The contents of register rB is divided by the contents of register rA and the result is placed into register rD.

If the U bit is set, rA and rB are considered unsigned values. If the U bit is clear, rA and rB are considered signed values.

If the value of rA is 0 (divide by zero), the DZO bit in MSR will be set and the value in rD will be 0, unless an exception is generated.

If the U bit is clear, the value of rA is -1, and the value of rB is -2147483648 (divide overflow), the DZO bit in MSR will be set and the value in rD will be -2147483648, unless an exception is generated.

### Pseudocode

```

if (rA) = 0 then
    (rD) <- 0
    MSR[DZO] <- 1
    ESR[EC] <- 00101
    ESR[DEC] <- 0
else if U = 0 and (rA) = -1 and (rB) = -2147483648 then
    (rD) <- -2147483648
    MSR[DZO] <- 1
    ESR[EC] <- 00101
    ESR[DEC] <- 1
else
    (rD) ← (rB) / (rA)

```

### Registers Altered

- rD, unless a divide exception is generated, in which case the register is unchanged
- MSR[DZO], if divide by zero or divide overflow occurs
- ESR[EC], if divide by zero or divide overflow occurs

### Latency

- 1 cycle if (rA) = 0, otherwise 34 cycles with C\_AREA\_OPTIMIZED=0
- 1 cycle if (rA) = 0, otherwise 35 cycles with C\_AREA\_OPTIMIZED=1
- 1 cycle if (rA) = 0, otherwise 30 cycles with C\_AREA\_OPTIMIZED=2

### Note

This instruction is only valid if MicroBlaze is configured to use a hardware divider (C\_USE\_DIV = 1).

## imm Immediate

imm                      IMM

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |     |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|
| 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | IMM |
| 0 |   |   |   |   | 6 |   |   |   |   | 1 |   |   |   | 1 |   | 3   |
|   |   |   |   |   |   |   |   |   |   | 1 |   |   |   | 6 |   | 1   |

### Description

The instruction imm loads the IMM value into a temporary register. It also locks this value so it can be used by the following instruction and form a 32-bit immediate value.

The instruction imm is used in conjunction with Type B instructions. Since Type B instructions have only a 16-bit immediate value field, a 32-bit immediate value cannot be used directly. However, 32-bit immediate values can be used in MicroBlaze. By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. The imm instruction locks the 16-bit IMM value temporarily for the next instruction. A Type B instruction that immediately follows the imm instruction will then form a 32-bit immediate value from the 16-bit IMM value of the imm instruction (upper 16 bits) and its own 16-bit immediate value field (lower 16 bits). If no Type B instruction follows the imm instruction, the locked value gets unlocked and becomes useless.

### Latency

- 1 cycle

### Notes

The imm instruction and the Type B instruction following it are atomic; consequently, no interrupts are allowed between them.

The assembler provided by Xilinx automatically detects the need for imm instructions. When a 32-bit IMM value is specified in a Type B instruction, the assembler converts the IMM value to a 16-bit one to assemble the instruction and inserts an imm instruction before it in the executable file.



## lbu Load Byte Unsigned

|       |            |
|-------|------------|
| lbu   | rD, rA, rB |
| lbur  | rD, rA, rB |
| lbuea | rD, rA, rB |

|   |   |   |   |   |   |   |    |  |    |  |    |    |   |   |   |    |   |   |   |   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|---|----|--|----|--|----|----|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|---|----|
| 1 | 1 | 0 | 0 | 0 | 0 |   | rD |  | rA |  | rB |    | 0 | R | 0 | EA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |    |
| 0 |   |   |   |   |   | 6 |    |  | 11 |  |    | 16 |   |   |   | 21 |   |   |   |   |   |   |   |   |   |   |   |   | 31 |

### Description

Loads a byte (8 bits) from the memory location that results from adding the contents of registers rA and rB. The data is placed in the least significant byte of register rD and the other three bytes in rD are cleared.

If the R bit is set, a byte reversed memory location is used, loading data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

### Pseudocode

```

if EA = 1 then
    Addr ← (rA) & (rB)
else
    Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else
    (rD)[24:31] ← Mem(Addr)
    (rD)[0:23] ← 0

```

**Registers Altered**

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if an exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

The byte reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).

## lbui Load Byte Unsigned Immediate

lbui                      rD, rA, IMM

|   |   |   |   |   |   |    |    |     |
|---|---|---|---|---|---|----|----|-----|
| 1 | 1 | 1 | 0 | 0 | 0 | rD | rA | IMM |
| 0 |   |   |   |   | 6 | 11 | 16 | 31  |

### Description

Loads a byte (8 bits) from the memory location that results from adding the contents of register rA with the value in IMM, sign-extended to 32 bits. The data is placed in the least significant byte of register rD and the other three bytes in rD are cleared.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled.

### Pseudocode

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else
    (rD)[24:31] ← Mem(Addr)
    (rD)[0:23] ← 0

```

### Registers Altered

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if an exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

## lhu Load Halfword Unsigned

lhu            rD, rA, rB  
lhur            rD, rA, rB  
lhuea          rD, rA, rB

|          |          |          |          |          |          |           |           |           |          |          |          |           |          |          |          |          |          |          |          |          |
|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|----------|----------|----------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| <b>1</b> | <b>1</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>1</b> | <b>rD</b> | <b>rA</b> | <b>rB</b> | <b>0</b> | <b>R</b> | <b>0</b> | <b>EA</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> |
| 0        |          |          |          |          | 6        |           | 11        |           | 16       |          | 21       |           |          |          |          |          |          |          |          | 31       |

### Description

Loads a halfword (16 bits) from the halfword aligned memory location that results from adding the contents of registers rA and rB. The data is placed in the least significant halfword of register rD and the most significant halfword in rD is cleared.

If the R bit is set, a halfword reversed memory location is used and the two bytes in the halfword are reversed, loading data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled.

An unaligned data access exception occurs if the least significant bit in the address is not zero.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

### Pseudocode

```

if EA = 1 then
    Addr ← (rA) & (rB)
else
    Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 0; ESR[S] ← 0; ESR[Rx] ← rD
else if (VM = 0 and R = 1) or
    (VM = 1 and R = 1 and E = 1) or
    (VM = 1 and R = 0 and E = 0) then
    (rD)[16:23] ← Mem(Addr); (rD)[24:31] ← Mem(Addr+1); (rD)[0:15] ← 0
else
    (rD)[16:23] ← Mem(Addr+1); (rD)[24:31] ← Mem(Addr); (rD)[0:15] ← 0

```

**Registers Altered**

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if an exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

The halfword reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).

## lhui Load Halfword Unsigned Immediate

lhui                      rD, rA, IMM

|   |   |   |   |   |   |    |    |     |
|---|---|---|---|---|---|----|----|-----|
| 1 | 1 | 1 | 0 | 0 | 1 | rD | rA | IMM |
| 0 |   |   |   |   | 6 | 11 | 16 | 31  |

### Description

Loads a halfword (16 bits) from the halfword aligned memory location that results from adding the contents of register rA and the value in IMM, sign-extended to 32 bits. The data is placed in the least significant halfword of register rD and the most significant halfword in rD is cleared.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB. A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled. An unaligned data access exception occurs if the least significant bit in the address is not zero.

### Pseudocode

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 0; ESR[S] ← 0; ESR[Rx] ← rD
else
    (rD)[16:31] ← Mem(Addr)
    (rD)[0:15] ← 0

```

### Registers Altered

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

### Latency

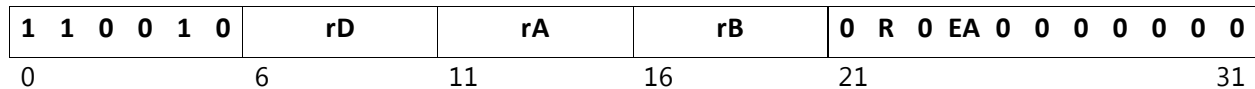
- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

## **lw**    **Load Word**

lw                    rD, rA, rB  
lwr                    rD, rA, rB  
lwea                   rD, rA, rB



### **Description**

Loads a word (32 bits) from the word aligned memory location that results from adding the contents of registers rA and rB. The data is placed in register rD.

If the R bit is set, the bytes in the loaded word are reversed , loading data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled.

An unaligned data access exception occurs if the two least significant bits in the address are not zero.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

### **Pseudocode**

```

if EA = 1 then
    Addr ← (rA) & (rB)
else
    Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[30:31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 1; ESR[S] ← 0; ESR[Rx] ← rD
else
    (rD) ← Mem(Addr)

```

**Registers Altered**

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

The word reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).



## **lwi** Load Word Immediate

lwi                      rD, rA, IMM

|          |          |          |          |          |          |           |           |            |
|----------|----------|----------|----------|----------|----------|-----------|-----------|------------|
| <b>1</b> | <b>1</b> | <b>1</b> | <b>0</b> | <b>1</b> | <b>0</b> | <b>rD</b> | <b>rA</b> | <b>IMM</b> |
| 0        |          |          |          |          | 6        | 11        | 16        | 31         |

### **Description**

Loads a word (32 bits) from the word aligned memory location that results from adding the contents of register rA and the value IMM, sign-extended to 32 bits. The data is placed in register rD. A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB. A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled. An unaligned data access exception occurs if the two least significant bits in the address are not zero.

### **Pseudocode**

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[30:31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 1; ESR[S] ← 0; ESR[Rx] ← rD
else
    (rD) ← Mem(Addr)

```

### **Registers Altered**

- rD, unless an exception is generated, in which case the register is unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

### **Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### **Note**

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

**lwx** Load Word Exclusive

lwx                      rD, rA, rB

|             |    |    |    |                         |
|-------------|----|----|----|-------------------------|
| 1 1 0 0 1 0 | rD | rA | rB | 1 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 11 | 16 | 21                      |
|             |    |    |    | 31                      |

### Description

Loads a word (32 bits) from the word aligned memory location that results from adding the contents of registers rA and rB. The data is placed in register rD, and the reservation bit is set. If an AXI4 interconnect with exclusive access enabled is used, and the interconnect response is not EXOKAY, the carry flag (MSR[C]) is set; otherwise the carry flag is cleared.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if access is prevented by a no-access-allowed zone protection. This only applies to accesses with user mode and virtual protected mode enabled.

An unaligned data access exception will not occur, even if the two least significant bits in the address are not zero.

A data bus exception can occur when an AXI4 interconnect with exclusive access enabled is used, and the interconnect response is not EXOKAY, which means that an exclusive access cannot be handled.

Enabling AXI exclusive access ensures that the operation is protected from other bus masters, but requires that the addressed slave supports exclusive access. When exclusive access is not enabled, only the internal reservation bit is used. Exclusive access is enabled using the two parameters C\_M\_AXI\_DP\_EXCLUSIVE\_ACCESS and C\_M\_AXI\_DC\_EXCLUSIVE\_ACCESS for the peripheral and cache interconnect, respectively.

## Pseudocode

```

Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 0
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[UM] = 1 and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 0; ESR[DIZ] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if AXI_Exclusive(Addr) and AXI_Response ≠ EXOKAY and MSR[EE] then
    ESR[EC] ← 00100; ESR[ECC] ← 0;
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else
    (rD) ← Mem(Addr); Reservation ← 1;
    if AXI_Exclusive(Addr) and AXI_Response ≠ EXOKAY then
        MSR[C] ← 1
    else
        MSR[C] ← 0

```

**Registers Altered**

- rD and MSR[C], unless an exception is generated, in which case they are unchanged
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

**Latency**

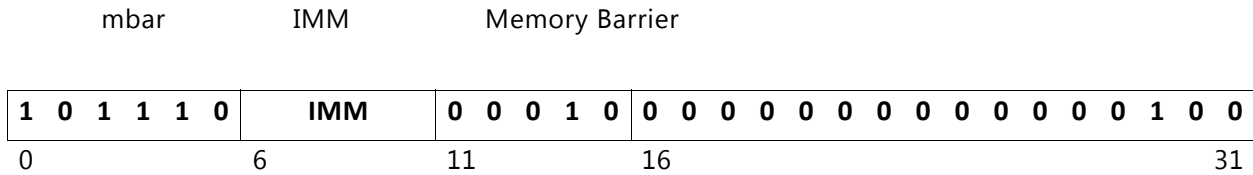
- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

This instruction is used together with SWX to implement exclusive access, such as semaphores and spinlocks.

The carry flag (MSR[C]) may not be set immediately (dependent on pipeline stall behavior). The LWX instruction should not be immediately followed by an MSRCLR, MSRSET, MTS, or SRC instruction, to ensure the correct value of the carry flag is obtained.

## mbar Memory Barrier



### Description

This instruction ensures that outstanding memory accesses on memory interfaces are completed before any subsequent instructions are executed. This is necessary to guarantee that self-modifying code is handled correctly, and that a DMA transfer can be safely started.

With self-modifying code, it is necessary to first use an MBAR instruction to wait for data accesses, which can be done by setting IMM to 1, and then use another MBAR instruction to clear the Branch Target Cache and empty the instruction prefetch buffer, which can be done by setting IMM to 2.

To ensure that data to be read by a DMA unit has been written to memory, it is only necessary to wait for data accesses, which can be done by setting IMM to 1.

When MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) this instruction is privileged when the most significant bit in IMM is set to 1. This means that if the instruction is attempted in User Mode ( $MSR[UM] = 1$ ) a Privileged Instruction exception occurs.

When the two most significant bits in IMM are set to 10 (Sleep), 01 (Hibernate), or 11 (Suspend) and no exception occurs, MicroBlaze enters sleep mode after all outstanding accesses have been completed, and sets the Sleep, Hibernate or Suspend output signal respectively to indicate this. The pipeline is halted, and MicroBlaze will not continue execution until a bit in the Wakeup input signal is asserted.

### Pseudocode

```

if (IMM & 1) = 0 then
    wait for instruction side memory accesses
if (IMM & 2) = 0 then
    wait for data side memory accesses
PC ← PC + 4
if (IMM & 24) != 0 then
    enter sleep mode

```

### Registers Altered

- PC
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 2 + N cycles when  $C\_INTERCONNECT = 2$  (AXI)
- 8 + N cycles when  $C\_INTERCONNECT = 3$  (ACE)

N is the number of cycles to wait for memory accesses to complete

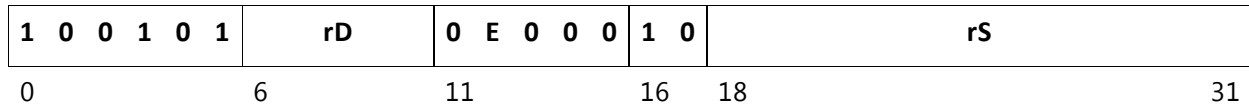
### Notes

This instruction must not be preceded by an imm instruction, and must not be placed in a delay slot.

The assembler pseudo-instructions sleep, hibernate, and suspend can be used instead of "mbar 16", "mbar 8", and "mbar 24" respectively to enter sleep mode.

## mfs Move From Special Purpose Register

mfs            rD, rS  
mfse          rD, rS



### Description

Copies the contents of the special purpose register rS into register rD. The special purpose registers TLBLO and TLBHI are used to copy the contents of the Unified TLB entry indexed by TLBX.

If the E bit is set, the extended part of the special register is moved. The EAR, PVR[8] and PVR[9] registers have extended parts when extended addressing is enabled (C\_ADDR\_SIZE > 32), and the TLBLO, PVR[6] and PVR[7] registers have extended parts when Physical Address Extension (PAE) is enabled.

### Pseudocode

```

if E = 1 then
  switch (rS):
    case 0x0003 : (rD) ← EAR[0:C_ADDR_SIZE-32-1]
    case 0x1003 : (rD) ← TLBLO[0:C_ADDR_SIZE-32-1]
    case 0x2006 : (rD) ← PVR6[0:C_ADDR_SIZE-32-1]
    case 0x2007 : (rD) ← PVR7[0:C_ADDR_SIZE-32-1]
    case 0x2008 : (rD) ← PVR8[0:C_ADDR_SIZE-32-1]
    case 0x2009 : (rD) ← PVR9[0:C_ADDR_SIZE-32-1]
    default : (rD) ← Undefined
else
  switch (rS):
    case 0x0000 : (rD) ← PC
    case 0x0001 : (rD) ← MSR
    case 0x0003 : (rD) ← EAR[C_ADDR_SIZE-32:C_ADDR_SIZE-1]
    case 0x0005 : (rD) ← ESR
    case 0x0007 : (rD) ← FSR
    case 0x000B : (rD) ← BTR
    case 0x000D : (rD) ← EDR
    case 0x0800 : (rD) ← SLR
    case 0x0802 : (rD) ← SHR
    case 0x1000 : (rD) ← PID
    case 0x1001 : (rD) ← ZPR
    case 0x1002 : (rD) ← TLBX
    case 0x1003 : (rD) ← TLBLO[C_ADDR_SIZE-32:C_ADDR_SIZE-1]
    case 0x1004 : (rD) ← TLBHI
    case 0x200x : (rD) ← PVRx[C_ADDR_SIZE-32:C_ADDR_SIZE-1] (where x = 0 to 12)
    default : (rD) ← Undefined

```

### Registers Altered

- rD

## Latency

- 1 cycle

## Notes

To refer to special purpose registers in assembly language, use `rpc` for PC, `rmsr` for MSR, `rear` for EAR, `resr` for ESR, `rfsr` for FSR, `rbtr` for BTR, `redr` for EDR, `rslr` for SLR, `rshr` for SHR, `rpil` for PID, `rzpr` for ZPR, `rtlblo` for TLBLO, `rtlbhi` for TLBHI, `rtlbx` for TLBX, and `rpvr0` - `rpvr12` for PVR0 - PVR12.

The value read from MSR may not include effects of the immediately preceding instruction (dependent on pipeline stall behavior). An instruction that does not affect MSR must precede the MFS instruction to guarantee correct MSR value.

The value read from FSR may not include effects of the immediately preceding instruction (dependent on pipeline stall behavior). An instruction that does not affect FSR must precede the MFS instruction to guarantee correct FSR value.

EAR, ESR and BTR are only valid as operands when at least one of the MicroBlaze `C_*_EXCEPTION` parameters are set to 1.

EDR is only valid as operand when the parameter `C_FSL_EXCEPTION` is set to 1 and the parameter `C_FSL_LINKS` is greater than 0.

FSR is only valid as an operand when the `C_USE_FPU` parameter is greater than 0.

SLR and SHR are only valid as an operand when the `C_USE_STACK_PROTECTION` parameter is set to 1.

PID, ZPR, TLBLO and TLBHI are only valid as operands when the parameter `C_USE_MMU` > 1 (User Mode) and the parameter `C_MMU_TLB_ACCESS` = 1 (Read) or 3 (Full).

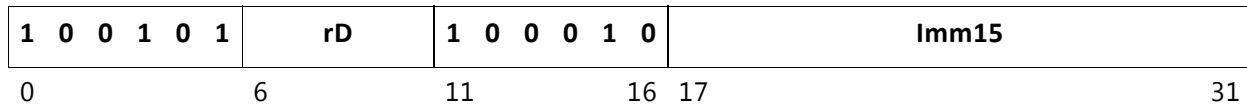
TLBX is only valid as operand when the parameter `C_USE_MMU` > 1 (User Mode) and the parameter `C_MMU_TLB_ACCESS` > 0 (Minimal).

PVR0 is only valid as an operand when `C_PVR` is 1 (Basic) or 2 (Full), and PVR1 - PVR12 are only valid as operands when `C_PVR` is set to 2 (Full).

The extended instruction is only valid if MicroBlaze is configured to use extended address (`C_ADDR_SIZE` > 32).

## msrclr **Read MSR and clear bits in MSR**

msrclr            rD, Imm



### Description

Copies the contents of the special purpose register MSR into register rD.

Bit positions in the IMM value that are 1 are cleared in the MSR. Bit positions that are 0 in the IMM value are left untouched.

When MicroBlaze is configured to use an MMU (`C_USE_MMU >= 1`) this instruction is privileged for all IMM values except those only affecting C. This means that if the instruction is attempted in User Mode (`MSR[UM] = 1`) in this case a Privileged Instruction exception occurs.

### Pseudocode

```

if MSR[UM] = 1 and IMM ≠ 0x4 then
    ESR[EC] ← 00111
else
    (rD) ← (MSR)
    (MSR) ← (MSR) ∧ ( $\overline{\text{IMM}}$ )

```

### Registers Altered

- rD
- MSR
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 1 cycle

### Notes

MSRCLR will affect the Carry bit immediately while the remaining bits will take effect one cycle after the instruction has been executed. When clearing the IE bit, it is guaranteed that the processor will not react to any interrupt for the subsequent instructions.

The value read from MSR may not include effects of the immediately preceding instruction (dependent on pipeline stall behavior). An instruction that does not affect MSR must precede the MSRCLR instruction to guarantee correct MSR value. This applies to both the value copied to register rD and the changed MSR value itself.

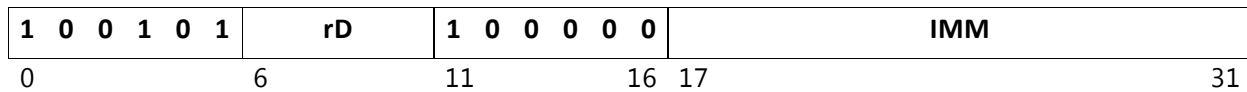
The immediate values has to be less than 215 when `C_USE_MMU >= 1` (User Mode), and less than 214 otherwise. Only bits 17 to 31 of the MSR can be cleared when `C_USE_MMU >= 1` (User Mode), and bits 18 to 31 otherwise.

This instruction is only available when the parameter `C_USE_MSR_INSTR` is set to 1.

When clearing `MSR[VM]` the instruction must always be followed by a synchronizing branch instruction, for example BRI 4.

## msrset Read MSR and set bits in MSR

msrset            rD, Imm



### Description

Copies the contents of the special purpose register MSR into register rD. Bit positions in the IMM value that are 1 are set in the MSR. Bit positions that are 0 in the IMM value are left untouched.

When MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) this instruction is privileged for all IMM values except those only affecting C. This means that if the instruction is attempted in User Mode ( $MSR[UM] = 1$ ) in this case a Privileged Instruction exception occurs.

With low-latency interrupt mode ( $C\_USE\_INTERRUPT = 2$ ), the Interrupt\_Ack output port is set to 11 if the  $MSR[IE]$  bit is set by executing this instruction.

### Pseudocode

```

if MSR[UM] = 1 and IMM ≠ 0x4 then
    ESR[EC] ← 00111
else
    (rD) ← (MSR)
    (MSR) ← (MSR) ∨ (IMM)
    if (IMM) & 2
        Interrupt_Ack ← 11

```

### Registers Altered

- rD
- MSR
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 1 cycle

### Notes

MSRSET will affect the Carry bit immediately while the remaining bits will take effect one cycle after the instruction has been executed. When setting the EIP or BIP bit, it is guaranteed that the processor will not react to any interrupt or normal hardware break for the subsequent instructions.

The value read from MSR may not include effects of the immediately preceding instruction (dependent on pipeline stall behavior). An instruction that does not affect MSR must precede the MSRSET instruction to guarantee correct MSR value. This applies to both the value copied to register rD and the changed MSR value itself.

The immediate values has to be less than 215 when  $C\_USE\_MMU \geq 1$  (User Mode), and less than 214 otherwise. Only bits 17 to 31 of the MSR can be set when  $C\_USE\_MMU \geq 1$  (User Mode), and bits 18 to 31 otherwise.

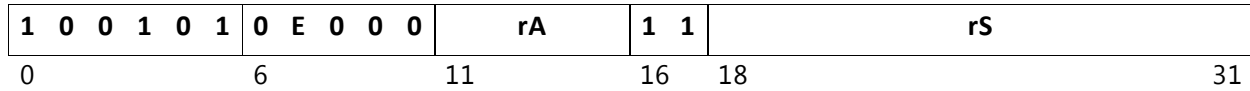
This instruction is only available when the parameter  $C\_USE\_MSR\_INSTR$  is set to 1.

When setting  $MSR[VM]$  the instruction must always be followed by a synchronizing branch instruction, for example BRI 4.



## mts **Move To Special Purpose Register**

mts            rS, rA  
mtse          rS, rA



### Description

Copies the contents of register rD into the special purpose register rS. The special purpose registers TLBLO and TLBHI are used to copy to the Unified TLB entry indexed by TLBX.

If the E bit is set, the extended part of the special register is moved. The TLBLO register has an extended part when the Physical Address Extension (PAE) is enabled.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) this instruction is privileged. This means that if the instruction is attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

With low-latency interrupt mode (C\_USE\_INTERRUPT = 2), the Interrupt\_Ack output port is set to 11 if the MSR[IE] bit is set by executing this instruction.

### Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    if E = 1 then
        if (rS) = 0x1003 then
            TLBLO[0:C_ADDR_SIZE-32-1] ← (rA)
        else
            switch (rS)
            case 0x0001 : MSR ← (rA)
            case 0x0007 : FSR ← (rA)
            case 0x0800 : SLR ← (rA)
            case 0x0802 : SHR ← (rA)
            case 0x1000 : PID ← (rA)
            case 0x1001 : ZPR ← (rA)
            case 0x1002 : TLBX ← (rA)
            case 0x1003 : TLBLO[C_ADDR_SIZE-32:C_ADDR_SIZE-1] ← (rA)
            case 0x1004 : TLBHI ← (rA)
            case 0x1005 : TLBSX ← (rA)
            if (rS) = 0x0001 and (rA) & 2
                Interrupt_Ack ← 11
    
```

### Registers Altered

- rS
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 1 cycle

## Notes

When writing MSR using MTS, all bits take effect one cycle after the instruction has been executed. An MTS instruction writing MSR should never be followed back-to-back by an instruction that uses the MSR content. When clearing the IE bit, it is guaranteed that the processor will not react to any interrupt for the subsequent instructions. When setting the EIP or BIP bit, it is guaranteed that the processor will not react to any interrupt or normal hardware break for the subsequent instructions.

To refer to special purpose registers in assembly language, use `rmsr` for MSR, `rfsr` for FSR, `rsrlr` for SLR, `rshr` for SHR, `rpil` for PID, `rzpr` for ZPR, `rtlblo` for TLBLO, `rtlbhi` for TLBHI, `rtlbx` for TLBX, and `rtlbox` for TLBSX.

The PC, ESR, EAR, BTR, EDR and PVR0 - PVR12 cannot be written by the MTS instruction.

The FSR is only valid as a destination if the MicroBlaze parameter `C_USE_FPU` is greater than 0.

The SLR and SHR are only valid as a destination if the MicroBlaze parameter `C_USE_STACK_PROTECTION` is set to 1.

PID, ZPR and TLBSX are only valid as destinations when the parameter `C_USE_MMU > 1` (User Mode) and the parameter `C_MMU_TLB_ACCESS > 1` (Read). TLBLO, TLBHI and TLBX are only valid as destinations when the parameter `C_USE_MMU > 1` (User Mode).

When changing MSR[VM] or PID the instruction must always be followed by a synchronizing branch instruction, for example BRI 4.

After writing to TLBHI in order to invalidate one or more UTLB entries, an MBAR 1 instruction must be issued to ensure that coherency is preserved in a coherent multi-processor system.

When PAE is enabled, the entire TLBLO register must be written, by first using the extended instruction to write the most significant bits immediately followed by the least significant bits.

The extended instruction is only valid if MicroBlaze is configured to use the MMU in virtual mode (`C_USE_MMU = 3`) and extended address (`C_ADDR_SIZE > 32`).

## mul Multiply

mul rD, rA, rB

|             |    |    |    |                         |
|-------------|----|----|----|-------------------------|
| 0 1 0 0 0 0 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

Multiplies the contents of registers rA and rB and puts the result in register rD. This is a 32-bit by 32-bit multiplication that will produce a 64-bit result. The least significant word of this value is placed in rD. The most significant word is discarded.

### Pseudocode

$$(rD) \leftarrow \text{LSW}((rA) \times (rB))$$

### Registers Altered

- rD

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### Note

This instruction is only valid if the target architecture has multiplier primitives, and if present, the MicroBlaze parameter C\_USE\_HW\_MUL is greater than 0.

## mulh Multiply High

mulh                      rD, rA, rB

|   |   |   |   |   |   |   |           |  |           |  |           |  |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|-----------|--|-----------|--|-----------|--|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 | 0 |   | <b>rD</b> |  | <b>rA</b> |  | <b>rB</b> |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0 |   |   |   |   |   | 6 |           |  | 1         |  | 1         |  | 2 |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |   |           |  | 1         |  | 6         |  | 1 |   |   |   |   |   |   |   |   |   | 1 |

### Description

Multiplies the contents of registers rA and rB and puts the result in register rD. This is a 32-bit by 32-bit signed multiplication that will produce a 64-bit result. The most significant word of this value is placed in rD. The least significant word is discarded.

### Pseudocode

$$(rD) \leftarrow \text{MSW}((rA) \times (rB)), \text{ signed}$$

### Registers Altered

- rD

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### Note

This instruction is only valid if the target architecture has multiplier primitives, and if present, the MicroBlaze parameter C\_USE\_HW\_MUL is set to 2 (Mul64).

When MULH is used, bit 30 and 31 in the MUL instruction must be zero to distinguish between the two instructions. In previous versions of MicroBlaze, these bits were defined as zero, but the actual values were not relevant.

## mulhu Multiply High Unsigned

mulhu      rD, rA, rB

|   |   |   |   |   |   |   |    |  |    |  |    |  |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|----|--|----|--|----|--|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 | 0 |   | rD |  | rA |  | rB |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 0 |   |   |   |   |   | 6 |    |  | 1  |  | 1  |  | 2 |   |   |   |   |   |   |   |   | 3 |   |
|   |   |   |   |   |   |   |    |  | 1  |  | 6  |  | 1 |   |   |   |   |   |   |   |   | 1 |   |

### Description

Multiplies the contents of registers rA and rB and puts the result in register rD. This is a 32-bit by 32-bit unsigned multiplication that will produce a 64-bit unsigned result. The most significant word of this value is placed in rD. The least significant word is discarded.

### Pseudocode

$$(rD) \leftarrow \text{MSW}((rA) \times (rB)), \text{ unsigned}$$

### Registers Altered

- rD

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### Note

This instruction is only valid if the target architecture has multiplier primitives, and if present, the MicroBlaze parameter C\_USE\_HW\_MUL is set to 2 (Mul64).

When MULHU is used, bit 30 and 31 in the MUL instruction must be zero to distinguish between the two instructions. In previous versions of MicroBlaze, these bits were defined as zero, but the actual values were not relevant.

## **mulhsu** Multiply High Signed Unsigned

mulhsu      rD, rA, rB

|                    |           |           |           |                                |
|--------------------|-----------|-----------|-----------|--------------------------------|
| <b>0 1 0 0 0 0</b> | <b>rD</b> | <b>rA</b> | <b>rB</b> | <b>0 0 0 0 0 0 0 0 0 0 1 0</b> |
| 0                  | 6         | 1         | 1         | 2                              |
|                    |           | 1         | 6         | 1                              |
|                    |           |           |           | 3                              |
|                    |           |           |           | 1                              |

### **Description**

Multiplies the contents of registers rA and rB and puts the result in register rD. This is a 32-bit signed by 32-bit unsigned multiplication that will produce a 64-bit signed result. The most significant word of this value is placed in rD. The least significant word is discarded.

### **Pseudocode**

$(rD) \leftarrow \text{MSW}((rA), \text{signed} \times (rB), \text{unsigned}), \text{signed}$

### **Registers Altered**

- rD

### **Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### **Note**

This instruction is only valid if the target architecture has multiplier primitives, and if present, the MicroBlaze parameter C\_USE\_HW\_MUL is set to 2 (Mul64).

When MULHSU is used, bit 30 and 31 in the MUL instruction must be zero to distinguish between the two instructions. In previous versions of MicroBlaze, these bits were defined as zero, but the actual values were not relevant.

## muli Multiply Immediate

muli rD, rA, IMM

| 0 | 1 | 1 | 0 | 0 | 0 | rD | rA     | IMM              |
|---|---|---|---|---|---|----|--------|------------------|
| 0 |   |   |   |   |   | 6  | 1<br>1 | 1<br>6<br>3<br>1 |

### Description

Multiplies the contents of registers rA and the value IMM, sign-extended to 32 bits; and puts the result in register rD. This is a 32-bit by 32-bit multiplication that will produce a 64-bit result. The least significant word of this value is placed in rD. The most significant word is discarded.

### Pseudocode

$$(rD) \leftarrow \text{LSW}((rA) \times \text{sext}(IMM))$$

### Registers Altered

- rD

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles with C\_AREA\_OPTIMIZED=1

### Notes

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "[imm](#)," [page 228](#) for details on using 32-bit immediate values.

This instruction is only valid if the target architecture has multiplier primitives, and if present, the MicroBlaze parameter C\_USE\_HW\_MUL is greater than 0.

**or**

## Logical OR

or  $r_D, r_A, r_B$

| 1 0 0 0 0 0 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
|-------------|----|----|----|-------------------------|
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

The contents of register rA are ORed with the contents of register rB; the result is placed into register rD.

## Pseudocode

$$(rD) \leftarrow (rA) \vee (rB)$$

### ***Registers Altered***

- rD

## Latency

- 1 cycle

**Note**

The assembler pseudo-instruction `nop` is implemented as `"or r0, r0, r0"`.



## ori Logical OR with Immediate

ori rD, rA, IMM

| 1 | 0 | 1 | 0 | 0 | 0 | rD | rA     | IMM              |
|---|---|---|---|---|---|----|--------|------------------|
| 0 |   |   |   |   |   | 6  | 1<br>1 | 1<br>6<br>3<br>1 |

### Description

The contents of register rA are ORed with the extended IMM field, sign-extended to 32 bits; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \vee \text{sext}(IMM)$$

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "imm," page 228 for details on using 32-bit immediate values.

## pcmpbf Pattern Compare Byte Find

|        |            |                                                        |
|--------|------------|--------------------------------------------------------|
| pcmpbf | rD, rA, rB | byte-wise comparison returning position of first match |
|--------|------------|--------------------------------------------------------|

| 1 0 0 0 0 0 | rD | rA | rB | 1 0 0 0 0 0 0 0 0 0 0 0 |
|-------------|----|----|----|-------------------------|
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

The contents of register rA is bitwise compared with the contents in register rB.

- rD is loaded with the position of the first matching byte pair, starting with MSB as position 1, and comparing until LSB as position 4
- If none of the byte pairs match, rD is set to 0

## Pseudocode

```

if rB[0:7] = rA[0:7] then
    (rD) ← 1
else
    if rB[8:15] = rA[8:15] then
        (rD) ← 2
    else
        if rB[16:23] = rA[16:23] then
            (rD) ← 3
        else
            if rB[24:31] = rA[24:31] then
                (rD) ← 4
            else
                (rD) ← 0

```

### Registers Altered

- rD

## Latency

- 1 cycle

### Note

This instruction is only available when the parameter `C_USE_PCOMP_INSTR` is set to 1.

## pcmpeq Pattern Compare Equal

pcmpeq      rD, rA, rB      equality comparison with a positive boolean result

|             |    |    |    |                     |
|-------------|----|----|----|---------------------|
| 1 0 0 0 1 0 | rD | rA | rB | 1 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1  | 1  | 2                   |
|             |    | 1  | 6  | 1                   |
|             |    |    |    | 3                   |
|             |    |    |    | 1                   |

### Description

The contents of register rA is compared with the contents in register rB.

- rD is loaded with 1 if they match, and 0 if not

### Pseudocode

```
if (rB) = (rA) then
    (rD) ← 1
else
    (rD) ← 0
```

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

This instruction is only available when the parameter C\_USE\_PCMP\_INSTR is set to 1.

## pcmpne Pattern Compare Not Equal

pcmpne      rD, rA, rB      equality comparison with a negative boolean result

|                    |           |           |           |                                |
|--------------------|-----------|-----------|-----------|--------------------------------|
| <b>1 0 0 0 1 1</b> | <b>rD</b> | <b>rA</b> | <b>rB</b> | <b>1 0 0 0 0 0 0 0 0 0 0 0</b> |
| 0                  | 6         | 1         | 1         | 2                              |
|                    |           | 1         | 6         | 1                              |
|                    |           |           |           | 3                              |
|                    |           |           |           | 1                              |

### Description

The contents of register rA is compared with the contents in register rB.

- rD is loaded with 0 if they match, and 1 if not

### Pseudocode

```

if (rB) = (rA) then
    (rD) ← 0
else
    (rD) ← 1

```

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

This instruction is only available when the parameter C\_USE\_PCMP\_INSTR is set to 1.

## put Put to stream interface

|         |          |                                                                   |
|---------|----------|-------------------------------------------------------------------|
| naput   | rA, FSLx | put data to link x<br>n = non-blocking<br>a = atomic              |
| tnaput  | FSLx     | put data to link x test-only<br>n = non-blocking<br>a = atomic    |
| ncaput  | rA, FSLx | put control to link x<br>n = non-blocking<br>a = atomic           |
| tncaput | FSLx     | put control to link x test-only<br>n = non-blocking<br>a = atomic |

|   |   |   |   |   |   |   |   |   |   |   |    |   |   |   |   |    |   |   |   |   |   |   |   |    |      |
|---|---|---|---|---|---|---|---|---|---|---|----|---|---|---|---|----|---|---|---|---|---|---|---|----|------|
| 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | rA | 1 | n | c | t | a  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  | FSLx |
| 0 |   |   |   |   |   | 6 |   |   |   |   | 11 |   |   |   |   | 16 |   |   |   |   |   |   |   | 28 | 31   |

### Description

MicroBlaze will write the value from register rA to the link x interface. If the available number of links set by C\_FSL\_LINKS is less than or equal to FSLx, link 0 is used.

The put instruction has 16 variants.

The blocking versions (when 'n' is '0') will stall MicroBlaze until there is space available in the interface. The non-blocking versions will not stall MicroBlaze and will set carry to '0' if space was available and to '1' if no space was available.

All data put instructions (when 'c' is '0') will set the control bit to the interface to '0' and all control put instructions (when 'c' is '1') will set the control bit to '1'.

The test versions (when 't' bit is '1') will be handled as the normal case, except that the write signal to the link is not asserted (thus no source register is required).

Atomic versions (when 'a' bit is '1') are not interruptible. This means that a sequence of atomic instructions can be grouped together without an interrupt breaking the program flow. However, note that exceptions may still occur.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) and not explicitly allowed by setting C\_MMU\_PRIVILEGED\_INSTR to 1 these instructions are privileged. This means that if these instructions are attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

### ***Pseudocode***

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    x ← FSLx
    if x >= C_FSL_LINKS then
        x ← 0
    Mx_AXIS_TDATA ← (rA)
    if (n = 1) then
        MSR[Carry] ← Mx_AXIS_TVALID ∧  $\overline{\text{Mx\_AXIS\_TREADY}}$ 
    Mx_AXIS_TLAST ← C

```

### ***Registers Altered***

- MSR[Carry]
- ESR[EC], in case a privileged instruction exception is generated

### ***Latency***

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

The blocking versions of this instruction will stall the pipeline of MicroBlaze until the instruction can be completed. Interrupts are served when the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1, and the instruction is not atomic.

### ***Note***

To refer to an FSLx interface in assembly language, use rfsl0, rfsl1, ... rfsl15.

The blocking versions of this instruction should not be placed in a delay slot when the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1, since this prevents interrupts from being served.

These instructions are only available when the MicroBlaze parameter C\_FSL\_LINKS is greater than 0.

The extended instructions (test and atomic versions) are only available when the MicroBlaze parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1.

It is not recommended to allow these instructions in user mode, unless absolutely necessary for performance reasons, since that removes all hardware protection preventing incorrect use of a link.

## putd Put to stream interface dynamic

|          |        |                                                                           |
|----------|--------|---------------------------------------------------------------------------|
| naputd   | rA, rB | put data to link rB[28:31]<br>n = non-blocking<br>a = atomic              |
| tnaputd  | rB     | put data to link rB[28:31] test-only<br>n = non-blocking<br>a = atomic    |
| ncaputd  | rA, rB | put control to link rB[28:31]<br>n = non-blocking<br>a = atomic           |
| tncaputd | rB     | put control to link rB[28:31] test-only<br>n = non-blocking<br>a = atomic |

|   |   |   |   |   |   |   |   |   |   |   |    |    |    |   |   |   |   |    |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|---|---|---|---|---|----|----|----|---|---|---|---|----|---|---|---|---|---|---|---|---|----|
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | rA | rB | 1  | n | c | t | a | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6 |   |   |   |   | 11 |    | 16 |   |   |   |   | 21 |   |   |   |   |   |   |   |   | 31 |

### Description

MicroBlaze will write the value from register rA to the link interface defined by the four least significant bits in rB. If the available number of links set by C\_FSL\_LINKS is less than or equal to the four least significant bits in rB, link 0 is used.

The putd instruction has 16 variants.

The blocking versions (when 'n' is '0') will stall MicroBlaze until there is space available in the interface. The non-blocking versions will not stall MicroBlaze and will set carry to '0' if space was available and to '1' if no space was available.

All data putd instructions (when 'c' is '0') will set the control bit to the interface to '0' and all control putd instructions (when 'c' is '1') will set the control bit to '1'.

The test versions (when 't' bit is '1') will be handled as the normal case, except that the write signal to the link is not asserted (thus no source register is required).

Atomic versions (when 'a' bit is '1') are not interruptible. This means that a sequence of atomic instructions can be grouped together without an interrupt breaking the program flow. However, note that exceptions may still occur.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) and not explicitly allowed by setting C\_MMU\_PRIVILEGED\_INSTR to 1 these instructions are privileged. This means that if these instructions are attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

### Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    x ← rB[28:31]
    if x ≥ C_FSL_LINKS then
        x ← 0
    Mx_AXIS_TDATA ← (rA)
    if (n = 1) then
        MSR[Carry] ← Mx_AXIS_TVALID ∧  $\overline{\text{Mx\_AXIS\_TREADY}}$ 
    Mx_AXIS_TLAST ← C

```

### Registers Altered

- MSR[Carry]
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

The blocking versions of this instruction will stall the pipeline of MicroBlaze until the instruction can be completed. Interrupts are served unless the instruction is atomic, which ensures that the instruction cannot be interrupted.

### Note

The blocking versions of this instruction should not be placed in a delay slot, since this prevents interrupts from being served.

These instructions are only available when the MicroBlaze parameter C\_FSL\_LINKS is greater than 0 and the parameter C\_USE\_EXTENDED\_FSL\_INSTR is set to 1.

It is not recommended to allow these instructions in user mode, unless absolutely necessary for performance reasons, since that removes all hardware protection preventing incorrect use of a link.



## **rsub** Arithmetic Reverse Subtract

|        |            |                                    |
|--------|------------|------------------------------------|
| rsub   | rD, rA, rB | Subtract                           |
| rsubc  | rD, rA, rB | Subtract with Carry                |
| rsubk  | rD, rA, rB | Subtract and Keep Carry            |
| rsubkc | rD, rA, rB | Subtract with Carry and Keep Carry |

|                    |           |           |           |                                |
|--------------------|-----------|-----------|-----------|--------------------------------|
| <b>0 0 0 K C 1</b> | <b>rD</b> | <b>rA</b> | <b>rB</b> | <b>0 0 0 0 0 0 0 0 0 0 0 0</b> |
| 0                  | 6         | 1         | 1         | 2                              |
|                    |           | 1         | 6         | 1                              |
|                    |           |           |           | 3                              |
|                    |           |           |           | 1                              |

### **Description**

The contents of register rA is subtracted from the contents of register rB and the result is placed into register rD. Bit 3 of the instruction (labeled as K in the figure) is set to one for the mnemonic rsubk. Bit 4 of the instruction (labeled as C in the figure) is set to one for the mnemonic rsubc. Both bits are set to one for the mnemonic rsubkc.

When an rsub instruction has bit 3 set (rsubk, rsubkc), the carry flag will Keep its previous value regardless of the outcome of the execution of the instruction. If bit 3 is cleared (rsub, rsubc), then the carry flag will be affected by the execution of the instruction.

When bit 4 of the instruction is set to one (rsubc, rsubkc), the content of the carry flag (MSR[C]) affects the execution of the instruction. When bit 4 is cleared (rsub, rsubk), the content of the carry flag does not affect the execution of the instruction (providing a normal subtraction).

### **Pseudocode**

```

if C = 0 then
    (rD) ← (rB) +  $\overline{(rA)}$  + 1
else
    (rD) ← (rB) +  $\overline{(rA)}$  + MSR[C]
if K = 0 then
    MSR[C] ← CarryOut

```

### **Registers Altered**

- rD
- MSR[C]

### **Latency**

- 1 cycle

### **Notes**

In subtractions, Carry = (Borrow). When the Carry is set by a subtraction, it means that there is no Borrow, and when the Carry is cleared, it means that there is a Borrow.

## **rsubi**    Arithmetic Reverse Subtract Immediate

|         |             |                                              |
|---------|-------------|----------------------------------------------|
| rsubi   | rD, rA, IMM | Subtract Immediate                           |
| rsubic  | rD, rA, IMM | Subtract Immediate with Carry                |
| rsubik  | rD, rA, IMM | Subtract Immediate and Keep Carry            |
| rsubikc | rD, rA, IMM | Subtract Immediate with Carry and Keep Carry |

| 0 | 0 | 1 | K | C | 1 | rD | rA | IMM |
|---|---|---|---|---|---|----|----|-----|
| 0 |   |   |   |   | 6 | 1  | 1  | 3   |
|   |   |   |   |   |   | 1  | 6  | 1   |

### **Description**

The contents of register rA is subtracted from the value of IMM, sign-extended to 32 bits, and the result is placed into register rD. Bit 3 of the instruction (labeled as K in the figure) is set to one for the mnemonic rsubik. Bit 4 of the instruction (labeled as C in the figure) is set to one for the mnemonic rsubic. Both bits are set to one for the mnemonic rsubikc.

When an rsubi instruction has bit 3 set (rsubik, rsubikc), the carry flag will Keep its previous value regardless of the outcome of the execution of the instruction. If bit 3 is cleared (rsubi, rsubic), then the carry flag will be affected by the execution of the instruction. When bit 4 of the instruction is set to one (rsubic, rsubikc), the content of the carry flag (MSR[C]) affects the execution of the instruction. When bit 4 is cleared (rsubi, rsubik), the content of the carry flag does not affect the execution of the instruction (providing a normal subtraction).

### **Pseudocode**

```

if C = 0 then
    (rD) ← sext(IMM) + ( $\overline{rA}$ ) + 1
else
    (rD) ← sext(IMM) + ( $\overline{rA}$ ) + MSR[C]
if K = 0 then
    MSR[C] ← CarryOut

```

### **Registers Altered**

- rD
- MSR[C]

### **Latency**

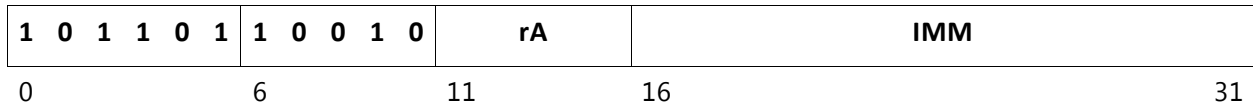
- 1 cycle

### **Notes**

In subtractions, Carry = (Borrow). When the Carry is set by a subtraction, it means that there is no Borrow, and when the Carry is cleared, it means that there is a Borrow. By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "[imm](#)," [page 228](#) for details on using 32-bit immediate values.

## rtbd Return from Break

rtbd                      rA, IMM



### Description

Return from break will branch to the location specified by the contents of rA plus the IMM field, sign-extended to 32 bits. It will also enable breaks after execution by clearing the BIP flag in the MSR.

This instruction always has a delay slot. The instruction following the RTBD is always executed before the branch target. That delay slot instruction has breaks disabled.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) this instruction is privileged. This means that if the instruction is attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

### Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    PC ← (rA) + sext(IMM)
    allow following instruction to complete execution
    MSR[BIP] ← 0
    MSR[UM] ← MSR[UMS]
    MSR[VM] ← MSR[VMS]

```

### Registers Altered

- PC
- MSR[BIP], MSR[UM], MSR[VM]
- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 2 cycles

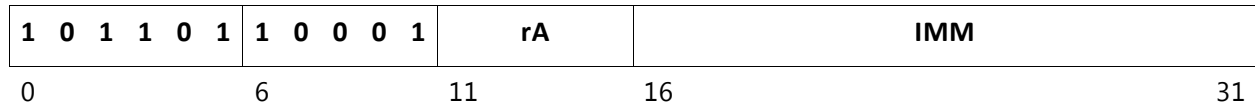
### Note

Convention is to use general purpose register r16 as rA.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## **rtid** Return from Interrupt

rtid                      rA, IMM



### **Description**

Return from interrupt will branch to the location specified by the contents of rA plus the IMM field, sign-extended to 32 bits. It will also enable interrupts after execution.

This instruction always has a delay slot. The instruction following the RTID is always executed before the branch target. That delay slot instruction has interrupts disabled.

When MicroBlaze is configured to use an MMU (C\_USE\_MMU >= 1) this instruction is privileged. This means that if the instruction is attempted in User Mode (MSR[UM] = 1) a Privileged Instruction exception occurs.

With low-latency interrupt mode (C\_USE\_INTERRUPT = 2), the Interrupt\_Ack output port is set to 10 when this instruction is executed, and subsequently to 11 when the MSR[IE] bit is set.

### **Pseudocode**

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    PC ← (rA) + sext(IMM)
    Interrupt_Ack ← 10
    allow following instruction to complete execution
    MSR[IE] ← 1
    MSR[UM] ← MSR[UMS]
    MSR[VM] ← MSR[VMS]
    Interrupt_Ack ← 11

```

### **Registers Altered**

- PC
- MSR[IE], MSR[UM], MSR[VM]
- ESR[EC], in case a privileged instruction exception is generated

### **Latency**

- 2 cycles

### **Note**

Convention is to use general purpose register r14 as rA.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## rted Return from Exception

rted                      rA, IMM

|   |   |   |   |   |   |   |   |   |   |    |    |     |  |    |  |
|---|---|---|---|---|---|---|---|---|---|----|----|-----|--|----|--|
| 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0  | rA | IMM |  |    |  |
| 0 |   |   |   |   |   | 6 |   |   |   | 11 |    | 16  |  | 31 |  |

### Description

Return from exception will branch to the location specified by the contents of rA plus the IMM field, sign-extended to 32 bits. The instruction will also enable exceptions after execution.

This instruction always has a delay slot. The instruction following the RTED is always executed before the branch target.

When MicroBlaze is configured to use an MMU ( $C\_USE\_MMU \geq 1$ ) this instruction is privileged. This means that if the instruction is attempted in User Mode ( $MSR[UM] = 1$ ) a Privileged Instruction exception occurs.

### Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    PC ← (rA) + sext(IMM)
    allow following instruction to complete execution
    MSR[EE] ← 1
    MSR[EIP] ← 0
    MSR[UM] ← MSR[UMS]
    MSR[VM] ← MSR[VMS]
    ESR ← 0

```

### Registers Altered

- PC
- MSR[EE], MSR[EIP], MSR[UM], MSR[VM]
- ESR

### Latency

- 2 cycles

### Note

Convention is to use general purpose register r17 as rA. This instruction requires that one or more of the MicroBlaze parameters  $C\_*\_EXCEPTION$  are set to 1 or that  $C\_USE\_MMU > 0$ .

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

The instruction should normally not be used when MSR[EE] is set, since if the instruction in the delay slot would cause an exception, the exception handler would be entered with exceptions enabled.

Code returning from an exception must first check if MSR[DS] is set, and in that case return to the address in BTR.

## rtsd **Return from Subroutine**

rtsd                      rA, IMM

|          |          |          |          |          |          |          |          |          |          |           |                  |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|------------------|
| <b>1</b> | <b>0</b> | <b>1</b> | <b>1</b> | <b>0</b> | <b>1</b> | <b>1</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>rA</b> | <b>IMM</b>       |
| 0        |          |          |          |          |          | 6        |          |          |          | 1<br>1    | 1<br>6<br>3<br>1 |

### Description

Return from subroutine will branch to the location specified by the contents of rA plus the IMM field, sign-extended to 32 bits.

This instruction always has a delay slot. The instruction following the RTSD is always executed before the branch target.

### Pseudocode

```
PC ← (rA) + sext(IMM)
allow following instruction to complete execution
```

### Registers Altered

- PC

### Latency

- 1 cycle (if successful branch prediction occurs)
- 2 cycles (with Branch Target Cache disabled)
- 3 cycles (if branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=0)
- 7-9 cycles (if a branch prediction mispredict occurs with C\_AREA\_OPTIMIZED=2)

### Note

Convention is to use general purpose register r15 as rA.

A delay slot must not be used by the following: imm, branch, or break instructions. Interrupts and external hardware breaks are deferred until after the delay slot branch has been completed.

## sb Store Byte

sb            rD, rA, rB  
sbr           rD, rA, rB  
sbea          rD, rA, rB

|   |   |   |   |   |   |    |    |    |    |   |   |    |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|----|---|---|---|---|---|---|----|
| 1 | 1 | 0 | 1 | 0 | 0 | rD | rA | rB | 0  | R | 0 | EA | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |    |   |   |   |   |   |   | 31 |

### Description

Stores the contents of the least significant byte of register rD, into the memory location that results from adding the contents of registers rA and rB.

If the R bit is set, a byte reversed memory location is used, storing data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

### Pseudocode

```

if EA = 1 then
    Addr ← (rA) & (rB)
else
    Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else
    Mem(Addr) ← (rD)[24:31]
```

### Registers Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if an exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

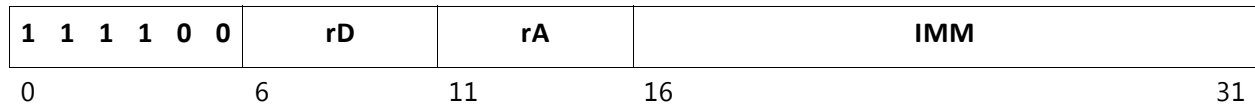
The byte reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).



## sbi **Store Byte Immediate**

sbi                      rD, rA, IMM



### Description

Stores the contents of the least significant byte of register rD, into the memory location that results from adding the contents of register rA and the value IMM, sign-extended to 32 bits.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

### Pseudocode

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else
    Mem(Addr) ← (rD)[24:31]
```

### Registers Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if an exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "imm," page 228 for details on using 32-bit immediate values.

## sext16 Sign Extend Halfword

sext16      rD, rA

|   |   |   |   |   |   |    |  |  |  |  |  |    |  |  |  |  |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|----|--|--|--|--|--|----|--|--|--|--|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | rD |  |  |  |  |  | rA |  |  |  |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 0 |   |   |   |   |   | 6  |  |  |  |  |  | 1  |  |  |  |  |  | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |    |  |  |  |  |  | 1  |  |  |  |  |  | 6 |   |   |   |   |   |   |   |   |   |   |   |   |   | 1 |

### Description

This instruction sign-extends a halfword (16 bits) into a word (32 bits). Bit 16 in rA will be copied into bits 0-15 of rD. Bits 16-31 in rA will be copied into bits 16-31 of rD.

### Pseudocode

```
(rD)[0:15] ← (rA)[16]
(rD)[16:31] ← (rA)[16:31]
```

### Registers Altered

- rD

### Latency

- 1 cycle

## sext8 Sign Extend Byte

sext8      rD, rA

|   |   |   |   |   |   |    |  |  |  |  |  |    |  |  |  |  |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|----|--|--|--|--|--|----|--|--|--|--|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | rD |  |  |  |  |  | rA |  |  |  |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 |   |   |   |   |   | 6  |  |  |  |  |  | 1  |  |  |  |  |  | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |    |  |  |  |  |  | 1  |  |  |  |  |  | 6 |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 1 |

### Description

This instruction sign-extends a byte (8 bits) into a word (32 bits). Bit 24 in rA will be copied into bits 0-23 of rD. Bits 24-31 in rA will be copied into bits 24-31 of rD.

### Pseudocode

```
(rD)[0:23] ← (rA)[24]
(rD)[24:31] ← (rA)[24:31]
```

### Registers Altered

- rD

### Latency

- 1 cycle

## sh Store Halfword

|      |            |
|------|------------|
| sh   | rD, rA, rB |
| shr  | rD, rA, rB |
| shea | rD, rA, rB |

|             |    |    |    |                        |
|-------------|----|----|----|------------------------|
| 1 1 0 1 0 1 | rD | rA | rB | 0 R 0 EA 0 0 0 0 0 0 0 |
| 0           | 6  | 11 | 16 | 21                     |
|             |    |    |    | 31                     |

### Description

Stores the contents of the least significant halfword of register rD, into the halfword aligned memory location that results from adding the contents of registers rA and rB.

If the R bit is set, a halfword reversed memory location is used and the two bytes in the halfword are reversed, storing data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

An unaligned data access exception occurs if the least significant bit in the address is not zero.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

## Pseudocode

```

if EA = 1 then
    Addr  $\leftarrow$  (rA) & (rB)
else
    Addr  $\leftarrow$  (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC]  $\leftarrow$  10010; ESR[S]  $\leftarrow$  1
    MSR[UMS]  $\leftarrow$  MSR[UM]; MSR[VMS]  $\leftarrow$  MSR[VM]; MSR[UM]  $\leftarrow$  0; MSR[VM]  $\leftarrow$  0
else if Access_Protected(Addr) and MSR[VM] = 1 then
    ESR[EC]  $\leftarrow$  10000; ESR[S]  $\leftarrow$  1; ESR[DIZ]  $\leftarrow$  No-access-allowed
    MSR[UMS]  $\leftarrow$  MSR[UM]; MSR[VMS]  $\leftarrow$  MSR[VM]; MSR[UM]  $\leftarrow$  0; MSR[VM]  $\leftarrow$  0
else if Addr[31]  $\neq$  0 then
    ESR[EC]  $\leftarrow$  00001; ESR[W]  $\leftarrow$  0; ESR[S]  $\leftarrow$  1; ESR[Rx]  $\leftarrow$  rD
else
    Mem(Addr)  $\leftarrow$  (rD)[16:31]

```

### Registers Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

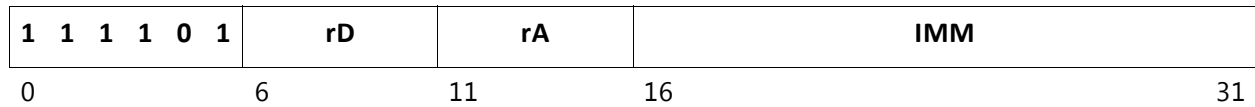
**Note**

The halfword reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).

## shi **Store Halfword Immediate**

shi                    rD, rA, IMM



### Description

Stores the contents of the least significant halfword of register rD, into the halfword aligned memory location that results from adding the contents of register rA and the value IMM, sign-extended to 32 bits.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB. A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode. An unaligned data access exception occurs if the least significant bit in the address is not zero.

### Pseudocode

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 0; ESR[S] ← 1; ESR[Rx] ← rD
else
    Mem(Addr) ← (rD)[16:31]

```

### Registers Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "[imm](#)," [page 228](#) for details on using 32-bit immediate values.

## sra Shift Right Arithmetic

sra                      rD, rA

|   |   |   |   |   |   |   |           |  |           |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|-----------|--|-----------|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 |   | <b>rD</b> |  | <b>rA</b> |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0 |   |   |   |   |   | 6 |           |  | 1         |  | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |   |           |  | 1         |  | 6 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 1 |

### Description

Shifts arithmetically the contents of register rA, one bit to the right, and places the result in rD. The most significant bit of rA (that is, the sign bit) placed in the most significant bit of rD. The least significant bit coming out of the shift chain is placed in the Carry flag.

### Pseudocode

```
(rD)[0] ← (rA)[0]
(rD)[1:31] ← (rA)[0:30]
MSR[C] ← (rA)[31]
```

### Registers Altered

- rD
- MSR[C]

### Latency

- 1 cycle

## src Shift Right with Carry

src rD, rA

|   |   |   |   |   |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|----|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | rD | rA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 0 |   |   |   |   | 6 |    | 1  | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |    | 1  | 6 |   |   |   |   |   |   |   |   |   |   |   |   |   | 1 |

### Description

Shifts the contents of register rA, one bit to the right, and places the result in rD. The Carry flag is shifted in the shift chain and placed in the most significant bit of rD. The least significant bit coming out of the shift chain is placed in the Carry flag.

### Pseudocode

```
(rD)[0] ← MSR[C]
(rD)[1:31] ← (rA)[0:30]
MSR[C] ← (rA)[31]
```

### Registers Altered

- rD
- MSR[C]

### Latency

- 1 cycle



## srl Shift Right Logical

srl                      rD, rA

|   |   |   |   |   |   |    |    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|----|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | rD | rA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 0 |   |   |   |   | 6 |    | 1  |   |   |   |   |   |   |   |   | 1 |   |   |   |   |   | 3 |
|   |   |   |   |   |   |    | 1  |   |   |   |   |   |   |   |   | 6 |   |   |   |   |   | 1 |

### Description

Shifts logically the contents of register rA, one bit to the right, and places the result in rD. A zero is shifted in the shift chain and placed in the most significant bit of rD. The least significant bit coming out of the shift chain is placed in the Carry flag.

### Pseudocode

```
(rD)[0] ← 0
(rD)[1:31] ← (rA)[0:30]
MSR[C] ← (rA)[31]
```

### Registers Altered

- rD
- MSR[C]

### Latency

- 1 cycle

## SW Store Word

sw            rD, rA, rB  
 swr          rD, rA, rB  
 swea        rD, rA, rB

|   |   |   |   |   |   |    |    |    |    |   |   |    |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|----|---|---|---|---|---|---|----|
| 1 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 0  | R | 0 | EA | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |    |   |   |   |   |   |   | 31 |

### Description

Stores the contents of register rD, into the word aligned memory location that results from adding the contents of registers rA and rB.

If the R bit is set, the bytes in the stored word are reversed, storing data with the opposite endianness of the endianness defined by the E bit (if virtual protected mode is enabled).

If the EA bit is set, an extended address is used, formed by concatenating rA and rB instead of adding them.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

An unaligned data access exception occurs if the two least significant bits in the address are not zero.

A privileged instruction error occurs if the EA bit is set, Physical Address Extension (PAE) is enabled, and the instruction is not explicitly allowed.

### Pseudocode

```

if EA = 1 then
  Addr ← (rA) & (rB)
else
  Addr ← (rA) + (rB)
if TLB_Miss(Addr) and MSR[VM] = 1 then
  ESR[EC] ← 10010; ESR[S] ← 1
  MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[VM] = 1 then
  ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
  MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[30:31] ≠ 0 then
  ESR[EC] ← 00001; ESR[W] ← 1; ESR[S] ← 1; ESR[Rx] ← rD
else
  Mem(Addr) ← (rD)[0:31]
```

### Registers Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

The word reversed instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

The extended address instruction is only valid if MicroBlaze is configured to use extended address (C\_ADDR\_SIZE > 32).

## swapb Swap Bytes

swapb      rD, rA

|             |    |    |                             |
|-------------|----|----|-----------------------------|
| 1 0 0 1 0 0 | rD | rA | 0 0 0 0 0 0 1 1 1 1 0 0 0 0 |
| 0           | 6  | 1  | 3                           |
|             |    | 1  | 1                           |

### Description

Swaps the contents of register rA treated as four bytes, and places the result in rD. This effectively converts the byte sequence in the register between endianness formats, either from little-endian to big-endian or vice versa.

### Pseudocode

```
(rD) [24:31] ← (rA) [0:7]
(rD) [16:23] ← (rA) [8:15]
(rD) [8:15] ← (rA) [16:23]
(rD) [0:7] ← (rA) [24:31]
```

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

This instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

## swaph Swap Halfwords

swaph      rD, rA

|   |   |   |   |   |   |  |    |  |    |  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|--|----|--|----|--|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 |  | rD |  | rA |  | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| 0 |   |   |   |   | 6 |  |    |  | 1  |  | 1 |   |   |   |   |   |   |   |   |   |   |   |   | 3 |   |
|   |   |   |   |   |   |  |    |  | 1  |  | 6 |   |   |   |   |   |   |   |   |   |   |   |   | 1 |   |

### Description

Swaps the contents of register rA treated as two halfwords, and places the result in rD. This effectively converts the two halfwords in the register between endianness formats, either from little-endian to big-endian or vice versa.

### Pseudocode

```
(rD)[0:15] ← (rA)[16:31]
(rD)[16:31] ← (rA)[0:15]
```

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

This instruction is only valid if MicroBlaze is configured to use reorder instructions (C\_USE\_REORDER\_INSTR = 1).

## swi Store Word Immediate

swi                      rD, rA, IMM

|          |          |          |          |          |          |           |           |            |
|----------|----------|----------|----------|----------|----------|-----------|-----------|------------|
| <b>1</b> | <b>1</b> | <b>1</b> | <b>1</b> | <b>1</b> | <b>0</b> | <b>rD</b> | <b>rA</b> | <b>IMM</b> |
| 0        |          |          |          |          | 6        | 11        | 16        | 31         |

### Description

Stores the contents of register rD, into the word aligned memory location that results from adding the contents of registers rA and the value IMM, sign-extended to 32 bits.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

An unaligned data access exception occurs if the two least significant bits in the address are not zero.

### Pseudocode

```

Addr ← (rA) + sext(IMM)
if TLB_Miss(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10010; ESR[S] ← 1
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Access_Protected(Addr) and MSR[VM] = 1 then
    ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
    MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
else if Addr[30:31] ≠ 0 then
    ESR[EC] ← 00001; ESR[W] ← 1; ESR[S] ← 1; ESR[Rx] ← rD
else
    Mem(Addr) ← (rD)[0:31]

```

### Register Altered

- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated
- ESR[W], ESR[Rx], if an unaligned data access exception is generated

### Latency

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction “imm,” page 228 for details on using 32-bit immediate values.

## SWX Store Word Exclusive

SWX                      rD, rA, rB

|   |   |   |   |   |   |    |    |    |    |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|----|----|----|----|---|---|---|---|---|---|---|---|----|
| 1 | 1 | 0 | 1 | 1 | 0 | rD | rA | rB | 1  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0  |
| 0 |   |   |   |   |   | 6  | 11 | 16 | 21 |   |   |   |   |   |   |   |   | 31 |

### Description

Conditionally stores the contents of register rD, into the word aligned memory location that results from adding the contents of registers rA and rB. If an AXI4 interconnect with exclusive access enabled is used, the store occurs if the interconnect response is EXOKAY, and the reservation bit is set; otherwise the store occurs when the reservation bit is set. The carry flag (MSR[C]) is set if the store does not occur, otherwise it is cleared. The reservation bit is cleared.

A data TLB miss exception occurs if virtual protected mode is enabled, and a valid translation entry corresponding to the address is not found in the TLB.

A data storage exception occurs if virtual protected mode is enabled, and access is prevented by no-access-allowed or read-only zone protection. No-access-allowed can only occur in user mode.

An unaligned data access exception will not occur even if the two least significant bits in the address are not zero.

Enabling AXI exclusive access ensures that the operation is protected from other bus masters, but requires that the addressed slave supports exclusive access. When exclusive access is not enabled, only the internal reservation bit is used. Exclusive access is enabled using the two parameters C\_M\_AXI\_DP\_EXCLUSIVE\_ACCESS and C\_M\_AXI\_DC\_EXCLUSIVE\_ACCESS for the peripheral and cache interconnect, respectively.

### Pseudocode

```

Addr ← (rA) + (rB)
if Reservation = 0 then
    MSR[C] ← 1
else
    if TLB_Miss(Addr) and MSR[VM] = 1 then
        ESR[EC] ← 10010; ESR[S] ← 1
        MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
    else if Access_Protected(Addr) and MSR[VM] = 1 then
        ESR[EC] ← 10000; ESR[S] ← 1; ESR[DIZ] ← No-access-allowed
        MSR[UMS] ← MSR[UM]; MSR[VMS] ← MSR[VM]; MSR[UM] ← 0; MSR[VM] ← 0
    else
        Reservation ← 0
        if AXI_Exclusive(Addr) and AXI_Response ≠ EXOKAY then
            MSR[C] ← 1
        else
            Mem(Addr) ← (rD)[0:31]
            MSR[C] ← 0

```

**Registers Altered**

- MSR[C], unless an exception is generated
- MSR[UM], MSR[VM], MSR[UMS], MSR[VMS], if a TLB miss exception or a data storage exception is generated
- ESR[EC], ESR[S], if an exception is generated
- ESR[DIZ], if a data storage exception is generated

**Latency**

- 1 cycle with C\_AREA\_OPTIMIZED=0 or 2
- 2 cycles with C\_AREA\_OPTIMIZED=1

**Note**

This instruction is used together with LWX to implement exclusive access, such as semaphores and spinlocks.

The carry flag (MSR[C]) may not be set immediately (dependent on pipeline stall behavior). The SWX instruction should not be immediately followed by an MSRCLR, MSRSET, MTS, or SRC instruction, to ensure the correct value of the carry flag is obtained.



## wdc Write to Data Cache

```
wdc          rA,rB
wdc.flush    rA,rB
wdc.clear    rA,rB
wdc.clear.ea rA,rB
wdc.ext.flush rA,rB
wdc.ext.clear rA,rB
```

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| 0 |   |   |   |   |   | 6 |   |   |   | 11 |    |   |   |   |   |   |   |   |   |   |   |   |   | 21 |  |  |  |  |  |  |  | 27 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | </ |

### Description

Write into the data cache tag to invalidate or flush a cache line. The mnemonic `wdc.flush` is used to set the F bit, `wdc.clear` is used to set the T bit, `wdc.clear.ea` is used to set the T and EA bits, `wdc.ext.flush` is used to set the E, F and T bits, and `wdc.ext.clear` is used to set the E and T bits.

When `C_DCACHE_USE_WRITEBACK` is set to 1:

- If the F bit is set, the instruction will flush and invalidate the cache line.
- Otherwise, the instruction will only invalidate the cache line and discard any data that has not been written to memory.
- If the T bit is set, only a cache line with a matching address is invalidated:
  - If the EA bit is set register rA concatenated with rB is the extended address of the affected cache line.
  - Otherwise, register rA added with rB is the address of the affected cache line.
  - The EA bit is only taken into account when the parameter `C_ADDR_SIZE > 32`.
- The E bit is not taken into account.
- The F and T bits cannot be used at the same time.

When `C_DCACHE_USE_WRITEBACK` is cleared to 0:

- If the E bit is not set, the instruction will invalidate the cache line. Register rA contains the address of the affected cache line, and the register rB value is not used.
- Otherwise, MicroBlaze will request that the matching address in an external cache should be invalidated or flushed, depending on the value of the F bit, and invalidate the internal affected cache line. Register rA added with rB is the address in the external cache, and of the affected cache line.
- The E bit is only taken into account when the parameter `C_INTERCONNECT` is set to 3 (ACE).

When MicroBlaze is configured to use an MMU (`C_USE_MMU >= 1`) the instruction is privileged. This means that if the instruction is attempted in User Mode (`MSR[UM] = 1`) a Privileged Instruction exception occurs.

## Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    if C_DCACHE_USE_WRITEBACK = 1 then
        if T = 1 and EA = 1 then
            address ← (rA) & (rB)
        else
            address ← (rA) + (rB)
    else if E = 0 then
        address ← (rA)
    else
        address ← (rA) + (rB)
    if C_DCACHE_LINE_LEN = 4 then
        cacheline_mask ← (1 << log2(C_DCACHE_BYTE_SIZE) - 4) - 1
        cacheline ← (DCache Line)[(address >> 4) ^ cacheline_mask]
        cacheline_addr ← address & 0xffffffff0
    if C_DCACHE_LINE_LEN = 8 then
        cacheline_mask ← (1 << log2(C_DCACHE_BYTE_SIZE) - 5) - 1
        cacheline ← (DCache Line)[(address >> 5) ^ cacheline_mask]
        cacheline_addr ← address & 0xffffffe0
    if C_DCACHE_LINE_LEN = 16 then
        cacheline_mask ← (1 << log2(C_DCACHE_BYTE_SIZE) - 6) - 1
        cacheline ← (DCache Line)[(address >> 6) ^ cacheline_mask]
        cacheline_addr ← address & 0xffffffc0
    if E = 0 and F = 1 and cacheline.Dirty then
        for i = 0 .. C_DCACHE_LINE_LEN - 1 loop
            if cacheline.Valid[i] then
                Mem(cacheline_addr + i * 4) ← cacheline.Data[i]
    if T = 0 then
        cacheline.Tag ← 0
    else if cacheline.Address = cacheline_addr then
        cacheline.Tag ← 0
    if E = 1 then
        if F = 1 then
            request external cache flush with address
        else
            request external cache invalidate with address

```

## Registers Altered

- ESR[EC], in case a privileged instruction exception is generated

## Latency

- 2 cycles for wdc.clear
- 2 cycles for wdc with C\_AREA\_OPTIMIZED=0 or 2
- 3 cycles for wdc with C\_AREA\_OPTIMIZED=0
- 2 + N cycles for wdc.flush, where N is the number of clock cycles required to flush the cache line to memory when necessary

## Note

The wdc, wdc.flush, wdc.clear and wdc.clear.ea instructions are independent of data cache enable (MSR[DCE]), and can be used either with the data cache enabled or disabled.

The wdc.clear and wdc.clear.ea instructions are intended to invalidate a specific area in memory, for example a buffer to be written by a Direct Memory Access device. Using this instruction ensures that

other cache lines are not inadvertently invalidated, erroneously discarding data that has not yet been written to memory.

The address of the affected cache line is always the physical address, independent of the parameter `C_USE_MMU` and whether the MMU is in virtual mode or real mode.

When using `wdc.flush` in a loop to flush the entire cache, the loop can be optimized by using `rA` as the cache base address and `rB` as the loop counter:

```

        addik      r5,r0,C_DCACHE_BASEADDR
        addik      r6,r0,C_DCACHE_BYTE_SIZE-C_DCACHE_LINE_LEN*4
loop:   wdc.flush  r5,r6
        bgtid      r6,loop
        addik      r6,r6,-C_DCACHE_LINE_LEN*4

```

When using `wdc.clear` in a loop to invalidate a memory area in the cache, the loop can be optimized by using `rA` as the memory area base address and `rB` as the loop counter:

```

        addik      r5,r0,memory_area_base_address
        addik      r6,r0,memory_area_byte_size-C_DCACHE_LINE_LEN*4
loop:   wdc.clear  r5,r6
        bgtid      r6,loop
        addik      r6,r6,-C_DCACHE_LINE_LEN*4

```

## wic Write to Instruction Cache

wic                      rA,rB

|   |   |   |   |   |   |   |   |   |   |   |    |    |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|----|----|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | rA | rB | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| 0 |   |   |   |   |   | 6 |   |   |   |   | 1  | 1  |   |   |   |   |   |   |   |   |   |   | 3 |
|   |   |   |   |   |   |   |   |   |   |   | 1  | 6  |   |   |   |   |   |   |   |   |   |   | 1 |

### Description

Write into the instruction cache tag to invalidate a cache line. The register rB value is not used. Register rA contains the address of the affected cache line.

When MicroBlaze is configured to use an MMU (`C_USE_MMU` >= 1) this instruction is privileged. This means that if the instruction is attempted in User Mode (`MSR[UM]` = 1) a Privileged Instruction exception occurs.

### Pseudocode

```

if MSR[UM] = 1 then
    ESR[EC] ← 00111
else
    if C_ICACHE_LINE_LEN = 4 then
        cacheline_mask ← (1 << log2(C_CACHE_BYTE_SIZE) - 4) - 1
        (ICache Line)[(Ra) >> 4] ∧ cacheline_mask].Tag ← 0
    if C_ICACHE_LINE_LEN = 8 then
        cacheline_mask ← (1 << log2(C_CACHE_BYTE_SIZE) - 5) - 1
        (ICache Line)[(Ra) >> 5] ∧ cacheline_mask].Tag ← 0
    if C_ICACHE_LINE_LEN = 16 then
        cacheline_mask ← (1 << log2(C_CACHE_BYTE_SIZE) - 6) - 1
        (ICache Line)[(Ra) >> 6] ∧ cacheline_mask].Tag ← 0

```

### Registers Altered

- ESR[EC], in case a privileged instruction exception is generated

### Latency

- 2 cycles

### Note

The WIC instruction is independent of instruction cache enable (`MSR[ICE]`), and can be used either with the instruction cache enabled or disabled.

The address of the affected cache line is the virtual address when the parameter `C_USE_MMU` = 3 (VIRTUAL) and the MMU is in virtual mode, otherwise it is the physical address.

## xor Logical Exclusive OR

xor                    rD, rA, rB

|             |    |    |    |                         |
|-------------|----|----|----|-------------------------|
| 1 0 0 0 1 0 | rD | rA | rB | 0 0 0 0 0 0 0 0 0 0 0 0 |
| 0           | 6  | 1  | 1  | 2                       |
|             |    | 1  | 6  | 1                       |
|             |    |    |    | 3                       |
|             |    |    |    | 1                       |

### Description

The contents of register rA are XORed with the contents of register rB; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \oplus (rB)$$

### Registers Altered

- rD

### Latency

- 1 cycle

## xori Logical Exclusive OR with Immediate

xori                      rD, rA, IMM

| 1 | 0 | 1 | 0 | 1 | 0 | rD | rA     | IMM              |
|---|---|---|---|---|---|----|--------|------------------|
| 0 |   |   |   |   |   | 6  | 1<br>1 | 1<br>6<br>3<br>1 |

### Description

The IMM field is extended to 32 bits by concatenating 16 0-bits on the left. The contents of register rA are XOR'ed with the extended IMM field; the result is placed into register rD.

### Pseudocode

$$(rD) \leftarrow (rA) \oplus \text{sext}(IMM)$$

### Registers Altered

- rD

### Latency

- 1 cycle

### Note

By default, Type B Instructions will take the 16-bit IMM field value and sign extend it to 32 bits to use as the immediate operand. This behavior can be overridden by preceding the Type B instruction with an imm instruction. See the instruction "[imm](#)," [page 228](#) for details on using 32-bit immediate values.

## Performance and Resource Utilization

### Performance

Performance characterization of this core has been done using the margin system methodology. The details of the margin system characterization methodology is described in ["IP Characterization and fMAX Margin System Methodology"](#) below.

### Maximum Frequencies

The maximum frequencies for the MicroBlaze™ core are provided in [Table A-1](#).

**Note:** Zynq®-7000 results are expected to be similar to 7 series results.

**Note:** Spartan®-7 results are expected to be similar to Artix®-7 results.

**Table A-1: Maximum Frequencies**

| Family              | F <sub>max</sub> (MHz) |
|---------------------|------------------------|
| Virtex®-7           | 399                    |
| Kintex®-7           | 399                    |
| Artix-7             | 264                    |
| Virtex UltraScale™  | 447                    |
| Kintex UltraScale   | 433                    |
| Virtex UltraScale+™ | 741                    |
| Kintex UltraScale+  | 730                    |
| Zynq UltraScale+    | 611                    |

## Resource Utilization

The MicroBlaze core resource utilization for various parameter configurations are measured for the following devices:

- Virtex-7 ([Table A-2](#))
- Kintex-7 ([Table A-3](#))
- Artix-7 ([Table A-4](#))
- Virtex UltraScale ([Table A-5](#))
- Kintex UltraScale ([Table A-6](#))
- Virtex UltraScale+ ([Table A-7](#))
- Kintex UltraScale+ ([Table A-8](#))
- Zynq UltraScale+ ([Table A-9](#))

**Note:** Zynq-7000 results are expected to be similar to 7 series results.

**Note:** Spartan-7 results are expected to be similar to Artix-7 results.

The parameter values for each of the measured configurations are shown in [Table A-10](#). The configurations directly correspond to the predefined templates in the MicroBlaze Configuration Wizard.

**Table A-2: Device Utilization - Virtex-7 FPGAs (XC7VX485T ffg1761-3)**

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 628              | 223  | 399                    |
| Maximum Performance    | 4148             | 3251 | 216                    |
| Maximum Frequency      | 1016             | 545  | 399                    |
| Linux with MMU         | 3502             | 3166 | 214                    |
| Low-end Linux with MMU | 2973             | 2563 | 231                    |
| Typical                | 2117             | 1725 | 250                    |
| Frequency Optimized    | 5965             | 5925 | 250                    |



Table A-3: Device Utilization - Kintex-7 FPGAs (XC7K325T ffg900-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 630              | 223  | 399                    |
| Maximum Performance    | 4119             | 3251 | 206                    |
| Maximum Frequency      | 1006             | 543  | 399                    |
| Linux with MMU         | 3506             | 3177 | 215                    |
| Low-end Linux with MMU | 2964             | 2567 | 218                    |
| Typical                | 2110             | 1729 | 249                    |
| Frequency Optimized    | 5974             | 5926 | 249                    |

Table A-4: Device Utilization - Artix-7 FPGAs (XC7A200T fbg676-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 627              | 224  | 264                    |
| Maximum Performance    | 4101             | 3251 | 160                    |
| Maximum Frequency      | 1014             | 543  | 264                    |
| Linux with MMU         | 3500             | 3169 | 147                    |
| Low-end Linux with MMU | 2954             | 2546 | 159                    |
| Typical                | 2109             | 1726 | 187                    |
| Frequency Optimized    | 5931             | 5908 | 159                    |

Table A-5: Device Utilization - Virtex UltraScale FPGAs (XCVU095 fvd1924-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 556              | 224  | 447                    |
| Maximum Performance    | 4133             | 3249 | 279                    |
| Maximum Frequency      | 1017             | 545  | 447                    |
| Linux with MMU         | 3472             | 3167 | 239                    |
| Low-end Linux with MMU | 2954             | 2546 | 258                    |
| Typical                | 2135             | 1725 | 293                    |
| Frequency Optimized    | 5990             | 5929 | 274                    |

Table A-6: Device Utilization - Kintex UltraScale FPGAs (XCKU040 ffva1156-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 556              | 226  | 433                    |
| Maximum Performance    | 4124             | 3261 | 278                    |
| Maximum Frequency      | 1012             | 545  | 433                    |
| Linux with MMU         | 3465             | 3166 | 254                    |
| Low-end Linux with MMU | 2946             | 2550 | 263                    |
| Typical                | 2135             | 1726 | 314                    |
| Frequency Optimized    | 6001             | 5920 | 286                    |

Table A-7: Device Utilization - Virtex UltraScale+ FPGAs (XCVU3P ffvc1517-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 556              | 217  | 741                    |
| Maximum Performance    | 4133             | 3260 | 398                    |
| Maximum Frequency      | 1017             | 543  | 741                    |
| Linux with MMU         | 3472             | 3195 | 380                    |
| Low-end Linux with MMU | 2954             | 2555 | 398                    |
| Typical                | 2135             | 1725 | 459                    |
| Frequency Optimized    | 5990             | 5923 | 433                    |

Table A-8: Device Utilization - Kintex UltraScale+ FPGAs (XCKU15P ffva1156-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 559              | 244  | 730                    |
| Maximum Performance    | 4202             | 3259 | 394                    |
| Maximum Frequency      | 1004             | 543  | 730                    |
| Linux with MMU         | 3503             | 3177 | 364                    |
| Low-end Linux with MMU | 2951             | 2561 | 401                    |
| Typical                | 2144             | 1733 | 465                    |
| Frequency Optimized    | 6046             | 5936 | 426                    |

Table A-9: Device Utilization - Zynq UltraScale+ FPGAs (XCZU9EG fvb1156-3)

| Configuration          | Device Resources |      |                        |
|------------------------|------------------|------|------------------------|
|                        | LUTs             | FFs  | F <sub>max</sub> (MHz) |
| Minimum Area           | 556              | 236  | 611                    |
| Maximum Performance    | 4196             | 3249 | 352                    |
| Maximum Frequency      | 1007             | 547  | 611                    |
| Linux with MMU         | 3530             | 3175 | 329                    |
| Low-end Linux with MMU | 2957             | 2546 | 333                    |
| Typical                | 2157             | 1733 | 413                    |
| Frequency Optimized    | 6070             | 5949 | 369                    |

Table A-10: Parameter Configurations

| Parameter               | Configuration Parameter Values |                     |                   |                |                        |         |       |
|-------------------------|--------------------------------|---------------------|-------------------|----------------|------------------------|---------|-------|
|                         | Minimum Area                   | Maximum Performance | Maximum Frequency | Linux with MMU | Low-end Linux with MMU | Typical |       |
| C_ALLOW_DCACHE_WR       | 1                              | 1                   | 1                 | 1              | 1                      | 1       | 1     |
| C_ALLOW_ICACHE_WR       | 1                              | 1                   | 1                 | 1              | 1                      | 1       | 1     |
| C_AREA_OPTIMIZED        | 1                              | 0                   | 0                 | 0              | 0                      | 0       | 2     |
| C_CACHE_BYTE_SIZE       | 4096                           | 32768               | 4096              | 16384          | 8192                   | 8192    | 16384 |
| C_DCACHE_BYTE_SIZE      | 4096                           | 32768               | 4096              | 16384          | 8192                   | 8192    | 16384 |
| C_DCACHE_LINE_LEN       | 4                              | 8                   | 4                 | 4              | 4                      | 4       | 4     |
| C_DCACHE_USE_WRITEBACK  | 0                              | 1                   | 0                 | 0              | 0                      | 0       | 1     |
| C_DEBUG_ENABLED         | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1     |
| C_DIV_ZERO_EXCEPTION    | 0                              | 0                   | 0                 | 1              | 0                      | 0       | 1     |
| C_M_AXI_D_BUS_EXCEPTION | 0                              | 0                   | 0                 | 1              | 1                      | 1       | 1     |
| C_FPU_EXCEPTION         | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 1     |
| C_FSL_EXCEPTION         | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0     |
| C_FSL_LINKS             | 0                              | 0                   | 1                 | 0              | 0                      | 0       | 0     |
| C_ICACHE_LINE_LEN       | 4                              | 8                   | 4                 | 8              | 4                      | 8       | 8     |
| C_ILL_OPCODE_EXCEPTION  | 0                              | 0                   | 0                 | 1              | 1                      | 0       | 1     |
| C_M_AXI_I_BUS_EXCEPTION | 0                              | 0                   | 0                 | 1              | 1                      | 0       | 1     |
| C_MMU_DTLB_SIZE         | 2                              | 4                   | 2                 | 4              | 4                      | 4       | 4     |

Table A-10: Parameter Configurations (Cont'd)

| Parameter                  | Configuration Parameter Values |                     |                   |                |                        |         | Frequency Optimized |
|----------------------------|--------------------------------|---------------------|-------------------|----------------|------------------------|---------|---------------------|
|                            | Minimum Area                   | Maximum Performance | Maximum Frequency | Linux with MMU | Low-end Linux with MMU | Typical |                     |
| C_MMU_ITLB_SIZE            | 1                              | 2                   | 1                 | 2              | 2                      | 2       | 2                   |
| C_MMU_TLB_ACCESS           | 3                              | 3                   | 3                 | 3              | 3                      | 3       | 3                   |
| C_MMU_ZONES                | 2                              | 2                   | 2                 | 2              | 2                      | 2       | 2                   |
| C_NUMBER_OF_PC_BRK         | 0                              | 1                   | 1                 | 1              | 1                      | 2       | 1                   |
| C_NUMBER_OF_RD_ADDR_BRK    | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_NUMBER_OF_WR_ADDR_BRK    | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_OPCODE_0x0_ILLEGAL       | 0                              | 0                   | 0                 | 1              | 1                      | 0       | 1                   |
| C_PVR                      | 0                              | 0                   | 0                 | 2              | 0                      | 0       | 2                   |
| C_UNALIGNED_EXCEPTIONS     | 0                              | 0                   | 0                 | 1              | 1                      | 0       | 1                   |
| C_USE_BARREL               | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1                   |
| C_USE_DCACHE               | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1                   |
| C_USE_DIV                  | 0                              | 1                   | 0                 | 1              | 0                      | 0       | 1                   |
| C_USE_EXTENDED_FSL_INSTR   | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_USE_FPU                  | 0                              | 2                   | 0                 | 0              | 0                      | 0       | 2                   |
| C_USE_HW_MUL               | 0                              | 2                   | 0                 | 2              | 1                      | 1       | 2                   |
| C_USE_ICACHE               | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1                   |
| C_USE_MMU                  | 0                              | 0                   | 0                 | 3              | 3                      | 0       | 3                   |
| C_USE_MSR_INSTR            | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1                   |
| C_USE_PCMP_INSTR           | 0                              | 1                   | 0                 | 1              | 1                      | 1       | 1                   |
| C_USE_REORDER_INSTR        | 0                              | 1                   | 1                 | 1              | 1                      | 1       | 1                   |
| C_USE_BRANCH_TARGET_CACHE  | 0                              | 1                   | 0                 | 0              | 0                      | 0       | 1                   |
| C_BRANCH_TARGET_CACHE_SIZE | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_ICACHE_STREAMS           | 0                              | 1                   | 0                 | 1              | 0                      | 0       | 0                   |
| C_ICACHE_VICTIMS           | 0                              | 8                   | 0                 | 8              | 0                      | 0       | 0                   |
| C_DCACHE_VICTIMS           | 0                              | 8                   | 0                 | 8              | 0                      | 0       | 0                   |
| C_ICACHE_FORCE_TAG_LUTRAM  | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_DCACHE_FORCE_TAG_LUTRAM  | 0                              | 0                   | 0                 | 0              | 0                      | 0       | 0                   |
| C_ICACHE_ALWAYS_USED       | 0                              | 1                   | 0                 | 1              | 1                      | 0       | 1                   |
| C_DCACHE_ALWAYS_USED       | 0                              | 1                   | 0                 | 1              | 1                      | 0       | 1                   |
| C_D_AXI                    | 0                              | 1                   | 0                 | 1              | 1                      | 0       | 1                   |
| C_USE_INTERRUPT            | 0                              | 0                   | 0                 | 1              | 1                      | 0       | 1                   |

## IP Characterization and $f_{MAX}$ Margin System Methodology

### Introduction

This section describes the methods to determine the maximum frequency ( $F_{MAX}$ ) of IP operation within a system design. The method enables realistic performance reporting for any Xilinx FPGA architecture. The maximum frequency of a design is the maximum frequency at which the overall system can be implemented without encountering timing issues.

### The $F_{MAX}$ Margin System Methodology

It is important to determine the IP performance in the context of a user system. In the case of the MicroBlaze characterization, the system includes the following items:

- The IP under test (MicroBlaze Processor)
- Local Memory (LMB)
- One level of Interconnect (AXI4, AXI4-Lite, AXI4-Stream)
- Memory controller (EMC)
- On-chip BRAM controller
- Peripherals (UART, Timer, Interrupt Controller, MDM)

Determining the  $F_{MAX}$  of an Embedded IP with these components provides a more realistic performance target.

The system above has three types of AXI Interconnect. AXI4-Lite used for peripheral command and control, AXI4 used for memory accesses, and AXI4-Stream used for MicroBlaze streams.

For  $F_{MAX}$  Margin System Analysis, the clock frequency of the system is incremented up to the maximum frequency where the system breaks with timing violations (worst case negative slack). The reported frequency is the failing frequency subtracted with this worst case negative slack.

### Tool Options and Other Factors

Xilinx tools offer a number of options and settings that provide a trade-off between design performance, resource usage, implementation run time, and memory footprint. The settings that produce the best results for one design might not necessarily work for another design.

For the purpose of the  $F_{MAX}$  Margin System Analysis, the IP design is characterized with default settings without specific constraints (other than the clocking constraint). This analysis is done with all different FPGA architectures and the maximum speed grade.

# Additional Resources and Legal Notices

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## Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see [Xilinx Support](#).

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## Solution Centers

See the [Xilinx Solution Centers](#) for support on devices, software tools, and intellectual property at all stages of the design cycle. Topics include design assistance, advisories, and troubleshooting tips.

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## References

The following documents are available via your Vivado® installation.

Relevant individual documents are linked below.

1. *Vivado Design Suite User Guide: Designing With IP* ([UG896](#))
2. *Vivado Design Suite User Guide: Designing IP Subsystems Using IP Integrator* ([UG994](#))
3. *Vivado Design Suite User Guide: Embedded Processor Hardware Design* ([UG898](#))
4. *Xilinx Software Development Kit Help* ([UG782](#))
5. *Embedded System Tools Reference Manual* ([UG1043](#))
6. *PowerPC Processor Reference Guide* ([UG011](#))
7. *AMBA 4 AXI4-Stream Protocol Specification, Version 1.0* ([ARM IHI 0051A](#))
8. *AMBA AXI and ACE Protocol Specification* ([ARM IHI 0022E](#))
9. *MicroBlaze Debug Module (MDM) Product Guide* ([PG115](#))

10. *LogiCore IP Soft Error Mitigation Controller* ([PG036](#))
11. *LogiCore IP UltraScale Architecture Soft Error Mitigation Controller* ([PG187](#))
12. *Device Reliability Report* ([UG116](#))
13. *LogiCore IP Processor LMB BRAM Interface Controller* ([PG112](#))
14. *Hierarchical Design Methodology Guide* ([UG748](#))
15. *LogiCore IP System Cache* ([PG118](#))
16. *Triple Modular Redundancy (TMR) Subsystem* ([PG268](#))

The following lists additional resources you can access directly using the provided URLs.

17. The entire set of GNU manuals:  
<http://www.gnu.org/manual>
18. IEEE 754-1985 standard  
[http://en.wikipedia.org/wiki/IEEE\\_754-1985](http://en.wikipedia.org/wiki/IEEE_754-1985)

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## Training Resources

Xilinx provides a variety of QuickTake videos and training courses to help you learn more about the concepts presented in this document. Use these links to explore related training resources:

1. [Vivado Design Suite QuickTake Video: Creating IP Subsystems with Vivado IP Integrator](#)
2. [Vivado Design Suite QuickTake Video: Creating a Simple MicroBlaze Design in IP Integrator](#)
3. [Vivado Design Suite QuickTake Video: IP Integrator Advanced User Tips](#)
4. [Vivado Design Suite QuickTake Video Tutorials](#)
5. [Essentials of FPGA Design Training Course](#)
6. [Vivado Design Suite Tool Flow Training Course](#)
7. [Vivado Design Suite Embedded Systems Design](#)
8. [Vivado Design Suite Advanced Embedded Systems Design](#)
9. [Embedded Systems Software Design](#)

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