IDT™ Interprise™ 79RC32438 Integrated Communications Processor

User Reference Manual

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2. A critical component is any components of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

About This Manual

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Introduction

This user reference manual includes hardware and software information on the RC32438, a high performance integrated processor that combines a high performance 32-bit CPU core with system logic to provide direct connection to boot memory, main memory, I/O, and PCI. It also includes on-chip peripherals such as DMA channels, reset circuitry, interrupts, timers, and UARTs. Each chapter is designed to cover the following topics:

- *High level feature summary of the specific module*
- *Summary of the register set associates with a specific module*
- *Outline of the operation of the module*
- *Detailed register description.*

Finding Additional Information

Information not included in this manual such as mechanicals, package pin-outs, and electrical characteristics can be found in the data sheet for this device, which is available from the IDT website **(www.idt.com)** as well as through your local IDT sales representative.

Content Summary

Chapter 1, "RC32438 Device Overview," provides a complete introduction to the performance capabilities of the RC32438. Included in this chapter is a summary of features for the device as well as a system block diagram and internal register maps.

Chapter 2, "MIPS32 4Kc Processor Core," provides basic information on the architecture and operation of the 4Kc™ processor core from MIPS® Technologies as it applies to the RC32438.

Chapter 3, "Clocking and Initialization," discusses the reset initialization sequence required by the RC32438 and provides information on boot vector settings and clock signals.

Chapter 4, "System Integrity Functions," discusses system integrity functions, including the registers that log system activity and that can be used to indicate the source of hardware or software errors.

Chapter 5, "Bus Arbitration," describes the internal arbitration mechanism used among the various on-chip modules. The chapter also describes the bus protocol used by an external bus master to gain ownership of the memory and peripheral bus.

Chapter 6, "Device Controller," describes the operation of the device controller, including registers and device transactions, which provides a glueless interface to SRAMs, ROMs/PROMs/EEPROMs, dual port memories, and other devices.

Chapter 7, "Double Data Rate (DDR) Controller," describes the features, functions, and operation of the DDR Controller, including a description of the registers.

Chapter 8, "Interrupt Controller," provides information about the interrupt controller and interrupt source descriptions.

Chapter 9, "DMA Controller," describes the DMA controller, channels, descriptors, registers, transactions, and operations.

Chapter 10, "PCI Bus Interface," describes the features, functions, and operations of the PCI bus interface on the RC32438.

Chapter 11, "Ethernet Interfaces," discusses the two Ethernet interfaces on the RC32438 which can be used in applications such as SOHO routers or high speed modems for PCs.

Notes

Chapter 12, "General Purpose I/O Controller," describes this controller and how it is configured to operate as a general purpose I/O or as an alternate function.

Chapter 13, "UART Controller," provides information about the two separate UARTs within the RC32438, including the UART registers.

Chapter 14, "Counter Timers," describes the three general purpose 32-bit counter/timers on the RC32438.

Chapter 15, "I^2C Bus Interface," describes the standard I^2C bus interface, supporting both master and slave operations, that is implemented on the RC32438.

Chapter 16, "Serial Peripheral Interface," describes the SPI master interface which uses three signals to connect to low-cost SPI peripherals and memory.

Chapter 17, "On-Chip Memory," describes the operation and support provided by on-chip memory for memory read and write operations on the RC32438.

Chapter 18, "Debugging and Performance Monitoring," discusses the three different debugging features available on the RC32438: IPBus Monitor, Event Monitor, and Debug Pins.

Chapter 19, "JTAG Boundary Scan," discusses an enhanced JTAG interface, including a system logic TAP controller, signal definitions, a test data register, an instruction register, and usage considerations.

Chapter 20, "EJTAG System," describes the EJTAG's features, its Debug Control Register, TAP registers, EJTAG Probe, hardware breakpoints, and other related topics.

Appendix A, "4Kc Processor Core Instructions," contains additional information about the 4Kc processor core instruction set.

Documentation Conventions and Definitions

Throughout this manual the following conventions and terms are used:

- *To avoid confusion when dealing with a mixture of "active-low" and "active-high" signals, the terms assertion and negation are used. The term assert or assertion is used to indicate that a signal is active or true, independent of whether that level is represented by a high or low voltage. The term negate or negation is used to indicate that a signal is inactive or false.*
- *To define the active polarity of a signal, a suffix will be used. Signals ending with an 'N' should be interpreted as being active, or asserted, when at a logic zero (low) level. All other signals (including clocks, buses and select lines) will be interpreted as being active, or asserted, when at a logic one (high) level.*
- *To define buses, the most significant bit (MSB) will be on the left and least significant bit (LSB) will be on the right. No leading zeros will be included.*
- *To represent numerical values, either decimal, binary, or hexadecimal formats will be used. The binary format is as follows: 0bDDD, where "D" represents either 0 or 1; the hexadecimal format is as follows: 0xDD, where "D" represents the hexadecimal digit(s); otherwise, it is decimal.*
- *Unless otherwise denoted, a byte will refer to an 8-bit quantity. A halfword will refer to a 16-bit quantity. A triple-byte will refer to a 24-bit quantity. A word will refer to a 32-bit quantity, and a double or double word will refer to a 64-bit quantity.*
- *A bit is set when its value is 0b1. A bit is cleared when its value is 0b0.*
- *The compressed notation ABC[x|y|z]D refers to ABCxD, ABCyD, and ABCzD.*
- *The compressed notation ABC[x..y]D refers to ABCxD, ABC(x+1)D, ABC(x+2)D, ... ABCyD.*
- *In words, bit 31 is always the most significant bit and bit 0 is the least significant bit. In halfwords, bit 15 is always the most significant bit and bit 0 is the least significant bit. In bytes, bit 7 is always the most significant bit and bit 0 is the least significant bit.*
- *The ordering of bytes within words is referred to as either "big endian" or "little endian." Big endian systems label byte zero as the most significant (leftmost) byte of a word. Little endian systems label byte zero as the least significant (rightmost) byte of a word.*

Notes

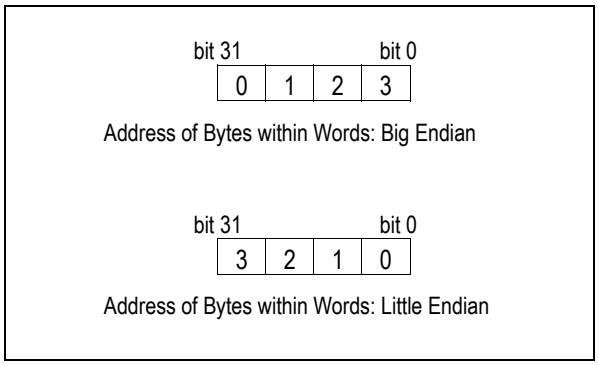

Figure 1 Example of Byte Ordering for "Big Endian" or "Little Endian" System Definition

- *A read-only: register, bit, or field is one which can be read but not modified*
- *A sticky bit is a bit that remains set after being set by hardware until a zero is written to it. Writing a one to a sticky has no effect on its value.*
- *A zero field in a register, denoted as "0" in register figures, must be written with a value of zero and returns a value of zero when read.*

Signal Terminology

Throughout this manual, when describing signal transitions, the following terminology is used:

- *Rising edge indicates a low-to-high (0 to 1) transition.*
- *Falling edge indicates a high-to-low (1 to 0) transition.*

These terms are illustrated in Figure 2.

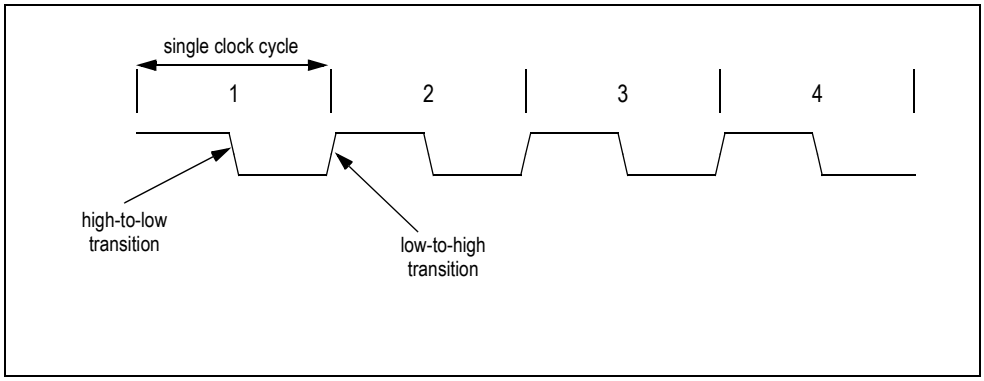

Figure 2 Signal Transitions

Revision History

November 4, 2002: Initial publication.

January 16, 2003: SCL pin under I^2C in Table 1.1 was changed from pull-down to pull-up.

February 5, 2003: Changed DDRDM[7:0] pins from input/output to output only in Chapter 1. Revised description for EJTAG/JTAG pins in Table 1.2. Revised Chapter 20, EJTAG System.

March 7, 2003: Added Table 3.4, Pin State During Reset, in Chapter 3.

April 11, 2003: In Chapter 1, Table 1.2, the description for PCIREQN[3:0] should read that [3:1] in both host and satellite modes are unused and driven high, instead of low. Also in Chapter 1, added the address for DDRRDC register to Table 1.4. In Chapter 7, added the same DDRRDC address to Table 7.1 and revised the DDR Initialization program example.

Notes

May 5, 2003: In Chapter 10, PCI Serial EEPROM Interface section, revised 1st paragraph as follows: changed register addresses from 0x80 to 0x40, added sentence “The interface only supports 93C46-compatible serial EEPROMs,” and added sentence “Only EEPROMs which are 2048 bits in size should be used.” In the second paragraph, the following sentence was deleted, “EEPROM addresses which are greater than or equal to 0x40 in EEPROMs whose size is greater than 1024 bits may be used to store application specific information.” Also in Chapter 10, Disabled Mode section, second paragraph, revised 1st sentence as follows: “When the PCI bus interface is disabled, all of the PCI pins are tri-stated, except PCIGNTN[3:1], and thus should be held at a valid logic level on the board.” Also added that PCIGNTN[3:1] signals are driven high. In Chapter 16, Function Overview, added clarification on PCI serial EEPROM mode of operation.

May 21, 2003: In Chapter 11, Address Recognition Logic section, the 2nd through the 4th paragraphs on page 11-8 were revised.

July 11, 2003: Removed references to IPBus Monitor feature. In Chapter 5, deleted Enable Eager Prefetching bit from IPBus Arbiter Control Register in the IPBus Registers section. In Chapter 10, revised description for EN bit in PCI Control Register, Changed Byte Swapping bit in PCI Local Address Control register to Force Endianess, added “byte and halfword target IO transactions are not supported” to Target I/O Read and Target I/O Write sections, and changed DMA limitations to “32KB minus 8 bytes” for channels 8 and 9. In Chapter 11, removed table associated with MII Management Command Register. In Chapter 16, added information in the Functional Overview section. In Chapter 17, revised first 4 paragraphs of Theory of Operation section.

July 28, 2003: In Chapter 11, changed the First Descriptor bit in Figure 11.10 to Reserved and deleted information about FD in 2 sections: Ethernet Input DMA Operations and Ethernet Output DMA Operations.

November 21, 2003: In Chapter 10, changed the description of the IGM bit on page 10-6, the CWE bit on page 10-8, and the CLS bit on page 10-52.

March 10, 2004: In Chapter 2, references to the RP bit were deleted. In the Target I/O Read and Target I/O Write sections of Chapter 10, the following sentences were removed “The RC32438 PCI I/O interface is a 32-bit interface. Byte and halfword Target I/O transactions are not supported.” In fact, the RC32438 does support PCI Target I/O transactions of byte and half word size. In Chapter 11, changed the description of the PEN bit on page 11-15.

May 11, 2005: In Table 10.6: switched Chapter 8 and Chapter 9 headings only - not the values in the columns; also, switched Yes and No for these two headings in the Memory Read Multiple row.

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RC32438 Device Overview

Notes

Introduction

The objective of this chapter is to provide an overview of the capabilities of the RC32438 device. In addition, it is a centralized resource for three standard items:

- *Summary of the address map for all the registers included in this device. The functionality of each register bit is covered in the relevant chapter within this manual.*
- *Default address memory map.*
- *Pin description list, pin types, drive strengths, and alternate functions.*

The RC32438 is a member of the IDT™ Interprise™ family of PCI integrated communications processors. It is a general-purpose integrated processor that incorporates a high performance CPU core and a number of on-chip peripherals. The integrated processor is designed to transfer information from IO modules to main memory with minimal CPU intervention, using a highly sophisticated direct memory access (DMA) engine. All data transfers through the RC32438 are achieved by writing data from an on-chip IO peripheral to main memory and then out to another IO module.

Key Features

The key features of this part include the following:

- *A 32-bit CPU core 100% compatible with the MIPS32 instruction set architecture (ISA). Specifically, this core features the 4kc developed by MIPS Technologies Inc. (www.mips.com). This core issues a single instruction per cycle, includes a five stage pipeline and is optimized for applications that require integer arithmetic. The version in the RC32438 includes 16 KB instruction and 16 KB data caches. Both caches are 4-way set associative and can be locked on a per line basis, which allows the programmer control over this precious on-chip memory resource. The core also features a memory management unit (MMU). The CPU core also incorporates an enhanced joint test access group (EJTAG) interface that is used to interface to in-circuit emulator tools, providing access to internal registers and enabling the part to be controlled externally, simplifying the system debug process. The use of this core allows IDT's customers to leverage the broad range of software and development tools available for the MIPS architecture, including operating systems, compilers and in-circuit emulators.*
- *High performance double data rate (DDR) memory controller. This supports both x16 and x32 memory configurations up to 2GB. The module provides all of the signals required to interface to both memory modules and discrete devices, including two chip selects, differential clocking outputs, and data strobes.*
- *A dedicated local memory/IO controller including a de-multiplexed 16-bit data and 26-bit address bus. This device includes all of the signals required to interface directly to up to six Intel or Motorola-style external peripherals. This interface can be configured to support both 8-bit and 16-bit peripherals.*
- *Two Ethernet Channels supporting 10Mbps and 100Mbps speeds, and providing a standard media independent interface (MII) off-chip, to enable a wide range of external devices to be connected up efficiently.*
- *A PCI interface compatible with version 2.2 of the PCI specification. An on-chip arbiter supports up to six external bus masters, supporting both fixed priority and rotating priority arbitration schemes. The part can support both satellite and host PCI configurations, enabling the RC32438 to act as a slave controller for a PCI add-in card application, or as the primary PCI controller in the system. The PCI interface can be operated synchronously or asynchronously to the other IO interfaces on the RC32438 device*
- *Two standard 16550-compatible serial ports, with both channels including hardware flow control signals*

Notes

- *An I2C interface*
- *A serial peripheral interface (SPI)*
- *4 KB of on-chip memory (configured as 1kx32 bits) for use as scratch pad memory that can be accessed by the CPU core and other IO modules*
- *Three general-purpose 32-bit counter/timers*
- *An interrupt controller that multiplexes all of the interrupt signals coming from on-chip modules and general purpose IO (GPIO) pins onto one of five available interrupt sources to the CPU core.*

System Block Diagram

An internal block diagram is shown in Figure 1.1.

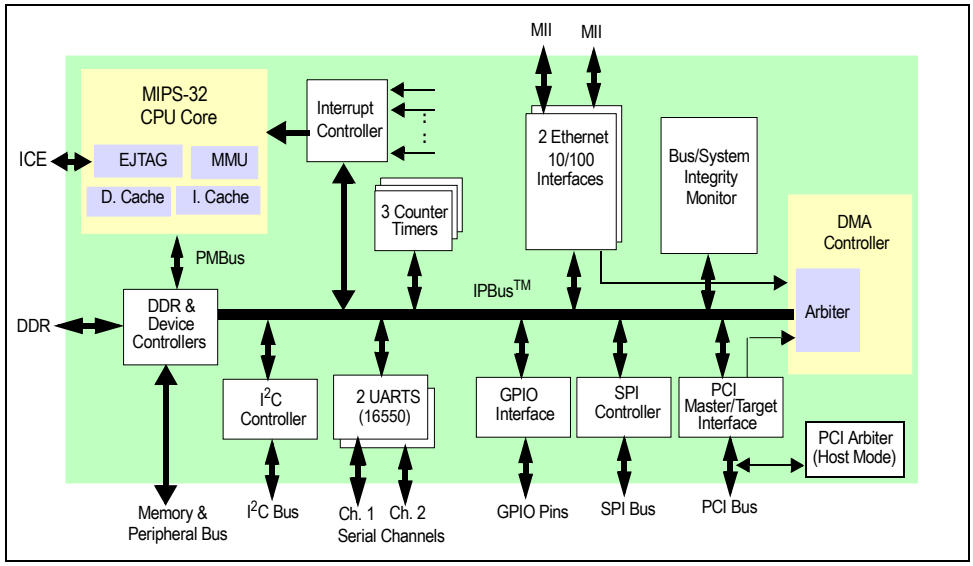


Figure 1.1 RC32438 Block Diagram

Additional Resources

This device provides a performance upgrade for existing users of the RC32332, RC32333, and RC32334 (referred to as the RC3233x series) integrated communications processors. IDT has developed an application note that addresses the migration of software from the RC3233x to the RC32438. This document, AN-368—Migrating RC32332/RC32334 Software to the RC32438 Device, can be found on the company's web site at www.idt.com.

Feature List Summary

32-bit Processor

- *MIPS32 architecture*
- *Single-cycle 32x16 multiply accumulate instructions*
- *16 KB Instruction and Data Caches*
- *Memory Management Unit*
- *8 -word write buffer that supports byte merging*
- *Power-down modes*

Notes

- *Debugging through Enhanced JTAG (EJTAG) interface*
  - *Version 2.5 compatible*
  - *Non-intrusive real-time debugging*
  - *Single stepping*
  - *Instruction and data breakpoints*

DDR Memory Controller

- *Supports up to 2GB of DDR SDRAM (using data bus multiplexing and two chip selects)*
- *2 chip selects (each chip select supports 4 internal DDR banks)*
- *Supports 16-bit or 32-bit data bus width using 8, 16, or 32-bit devices*
- *Supports 64 Mb, 128 Mb, 256 Mb, 512 Mb, and 1Gb DDR SDRAM devices*
- *Data bus multiplexing support allows interfacing to standard DDR DIMMs and SODIMMs*
- *Automatic refresh generation*

Memory and Peripheral Device Controller

- *Provides "glueless" interface to standard SRAM, Flash, ROM, dual-port memory, and peripheral devices*
- *Demultiplexed address and data buses*
  - *16-bit data bus*
  - *26-bit address bus*
  - *6 chip selects*
  - *Supports alternate bus masters*
  - *Control for external data bus buffers*
- *Supports 8-bit and 16-bit width devices*
  - *Automatic byte gathering and scattering*
- *Flexible protocol configuration parameters*
  - *Programmable number of wait states (0 to 63)*
  - *Programmable postread/postwrite delay (0 to 31)*
  - *Supports external wait state generation*
  - *Supports Intel and Motorola style peripherals*
- *Write protect capability per chip select*
- *Programmable bus transaction timer generates warm reset when counter expires*
- *Supports up to 64 MB of memory per chip select*

Counter/Timers

- *Three general purpose 32-bit counter timers*

Interrupt Controller

- *Allows status of all interrupt sources to be read*
- *Each interrupt source may be masked*
- *Provides interrupt test capability*

System Integrity Functions

- *Programmable watchdog timer generates NMI when counter expires*
- *Address space monitor reports error in response to accesses to undecoded address regions*

Notes

DMA Controller

- *10 DMA channels*
  - *Two channels for PCI (PCI to Memory and Memory to PCI)*
  - *Four Ethernet channels — two for each Ethernet interface (transmit/receive)*
  - *Two DMA channels for memory to memory DMA operations*
  - *Two DMA channel for external DMA operations*
- *Provides flexible descriptor based operation*
- *Supports external peripheral DMA operations*
- *Supports unaligned transfers (i.e., source or destination address may be on any byte boundary) with arbitrary byte length.*

Two Ethernet Interfaces

- *10 and 100 Mb/s ISO/IEC 8802-3:1996 compliant*
- *Two IEEE 802.3u compatible Media Independent Interfaces (MII) with serial management interface*
- *MII supports IEEE 802.3u auto-negotiation speed selection*
- *Supports 64 entry hash table based multicast address filtering*
- *512 byte transmit and receive FIFOs*
- *Supports flow control functions outlined in IEEE Std. 802.3x-1997*

PCI Interface

- *32-bit PCI revision 2.2 compliant*
- *Supports host or satellite operation in both master and target modes*
- *PCI clock*
  - *Supports PCI clock frequencies from 16 MHz to 66 MHz*
  - *PCI clock may be asynchronous to master clock (CLK)*
- *PCI arbiter in Host mode*
  - *Supports 6 external masters*
  - *Fixed priority or round robin arbitration*
- *I_2O "like" PCI Messaging Unit*

Universal Asynchronous Receiver Transmitter (UART)

- *Compatible with the 16550 and 16450 UARTs*
- *Two completely separate serial channels*
- *Modem control functions (CTS, RTS, DSR, DTR, RI, DCD)*
- *16-byte transmit and receive buffers*
- *Programmable baud rate generator derived from the system clock*
- *Fully programmable serial characteristics:*
  - *5, 6, 7, or 8 bit characters*
  - *Even, odd or no parity bit generation and detection*
  - *1, 1 1/2, or 2 stop bit generation*
- *Line break generation and detection*
- *False start bit detection*
- *Internal loopback mode*

I^2C-Bus

- *Supports standard 100 Kbps mode as well as 400 Kbps fast mode*
- *Supports 7-bit and 10-bit addressing*

Notes

- *Supports four modes:*
  - *Master transmitter*
  - *Master receiver*
  - *Slave transmitter*
  - *Slave receiver*

Serial Peripheral Interface (SPI)

- *Supports master mode*

General Purpose I/O Controller

- *32 general purpose input/output pins*
- *Each pin may be used as an active high or active low level interrupt or non-maskable interrupt input*
- *Each signal may be used as bit input or output port*

On-chip Memory

- *4 KB of high speed SRAM organized as 1K x 32 bits*
- *Supports burst and non-burst word, half-word, and byte CPU, PCI, and DMA accesses*

Debug Support

- *Rev. 2.6 compliant EJTAG Interface*

Enhanced JTAG and ICE Interface

- *Compatible with IEEE Std. 1149.1-1990*

System Identification

In addition to the MIPS processor revision identification (PRId) register located in CP0 of the CPU, the RC32438 contains a system identification register (SYSID). The SYSID register, which is always located at address 0x1800_0018, may be used by software to determine the vendor, implementation, and revision of an integrated processor. The format for this register is shown in Figure 1.2.

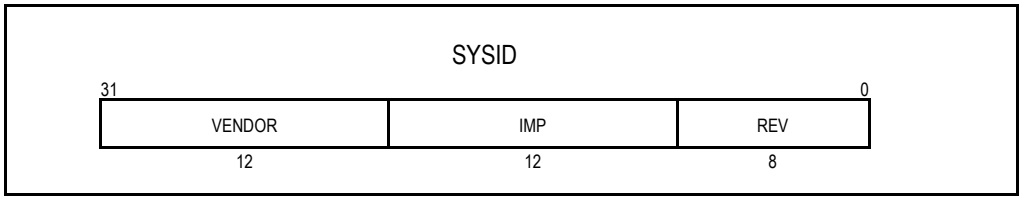


Figure 1.2 System Identification Register (SYSID)

REV

Description: **Revision.** This field contains the revision of the integrated processor. It may be used by software to identify the revision of a particular implementation.

Initial Value: 0x0

Read Value: Revision Number

Write Effect: Read-only

IMP

Description: **Implementation.** This field contains the implementation ID of the integrated processor. RC32438 — 6

Initial Value: 0x6

Read Value: Implementation

Notes

Write Effect: Read-only

VENDOR

Description: **Vendor.** This field contains the vendor of the integrated processor. The currently defined vendor is:
0 Integrated Device Technology

Initial Value: 0x0

Read Value: Vendor

Write Effect: Read-only

Notes

Logic Diagram — RC32438

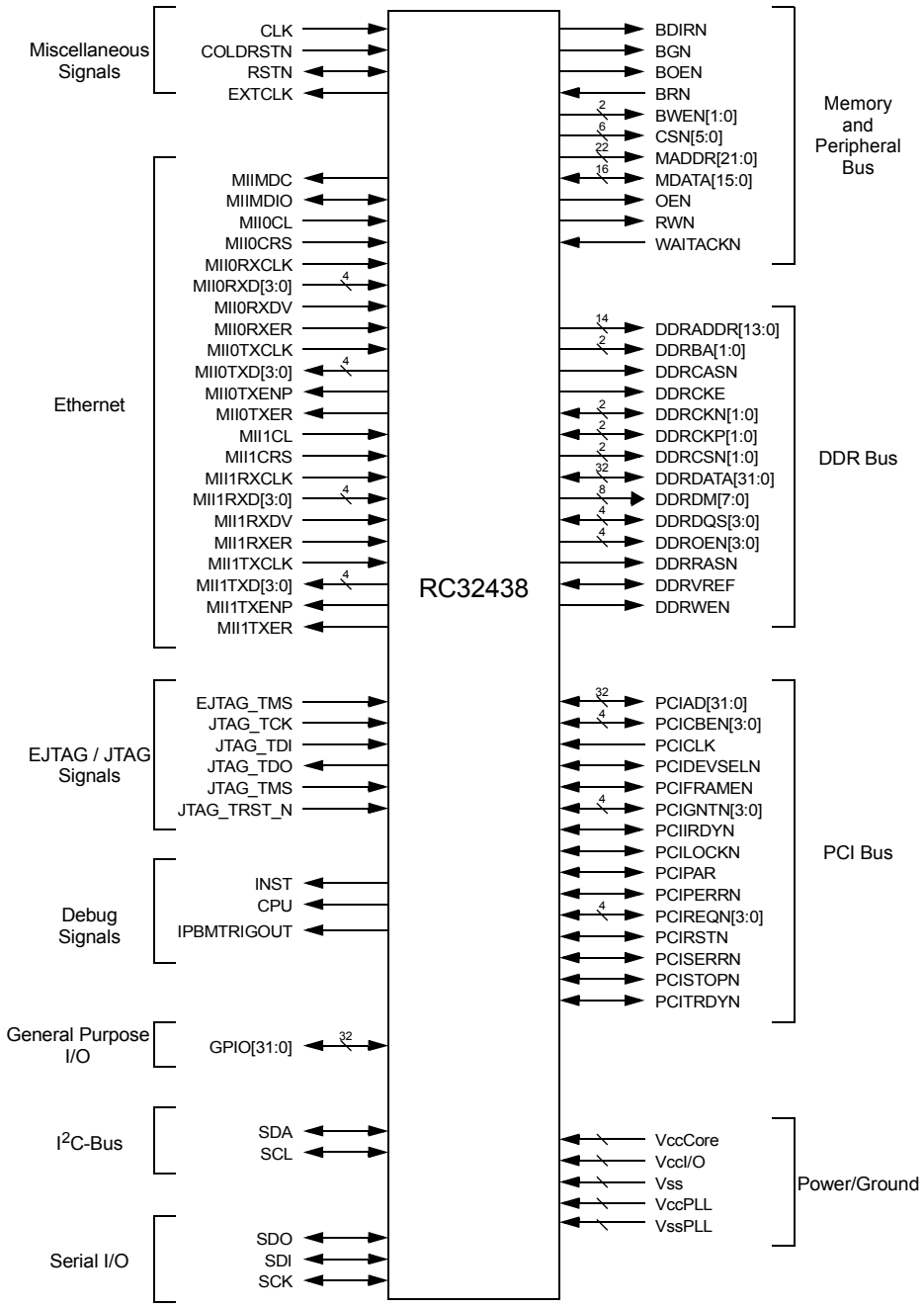


Figure 1.3 Logic Diagram for the RC32438

Notes

Pin Characteristics

Function	Pin Name	Type	Buffer	I/O Type	Internal Resistor	Notes[1]
Memory and Peripheral Bus	BDIRN	O	LVTTL	High Drive		
	BGN	O	LVTTL	Low Drive		
	BOEN	O	LVTTL	High Drive		
	BRN	I	LVTTL	STI[2]	pull-up	
	BWEN[1:0]	O	LVTTL	High Drive		
	CSN[5:0]	O	LVTTL	High Drive		
	MADDR[21:0]	O	LVTTL	High Drive		
	MDATA[15:0]	I/O	LVTTL	High Drive		
	OEN	O	LVTTL	High Drive		
	RWN	O	LVTTL	High Drive		
	WAITACKN	I	LVTTL	STI	pull-up	
DDR Bus	DDRADDR[13:0]	O	SSTL_2	SSTL_2		
	DDRBA[1:0]	O	SSTL_2	SSTL_2		
	DDRCASN	O	SSTL_2	SSTL_2		
	DDRCKE	O	SSTL_2 / LVCMOS	SSTL_2		
	DDRCKN[1:0]	O	SSTL_2	SSTL_2		
	DDRCKP[1:0]	O	SSTL_2	SSTL_2		
	DDRCSN[1:0]	O	SSTL_2	SSTL_2		
	DDRDATA[31:0]	I/O	SSTL_2	SSTL_2		
	DDRDM[7:0]	O	SSTL_2	SSTL_2		
	DDRDQS[3:0]	I/O	SSTL_2	SSTL_2		
	DDROEN[3:0]	O	SSTL_2	SSTL_2		
	DDRRASN	O	SSTL_2	SSTL_2		
	DDRVREF	I	Analog	SSTL_2		
	DDRWEN	O	SSTL_2	SSTL_2		

Table 1.1 Pin Characteristics (Part 1 of 4)

Notes

Function	Pin Name	Type	Buffer	I/O Type	Internal Resistor	Notes[1]
PCI Bus Interface[3]	PCIAD[31:0]	I/O	PCI	PCI		
	PCICBEN[3:0]	I/O	PCI	PCI		
	PCICLK	I	PCI	PCI		
	PCIDEVSELN	I/O	PCI	PCI		pull-up on board
	PCIFRAMEN	I/O	PCI	PCI		pull-up on board
	PCIGNTN[3:0]	I/O	PCI	PCI		pull-up on board
	PCIIRDYN	I/O	PCI	PCI		pull-up on board
	PCILOCKN	I/O	PCI	PCI		
	PCIPAR	I/O	PCI	PCI		
	PCIPERRN	I/O	PCI	PCI		
	PCIREQN[3:0]	I/O	PCI	PCI		pull-up on board
	PCIRSTN	I/O	PCI	PCI		pull-down on board
	PCISERRN	I/O	PCI	Open Collector; PCI		pull-up on board
	PCISTOPN	I/O	PCI	PCI		pull-up on board
	PCITRDYN	I/O	PCI	PCI		pull-up on board
General Purpose I/O	GPIO[23:0]	I/O	LVTTL	Low Drive	pull-up	
	GPIO[24]	I/O	PCI			pull-up on board
	GPIO[25]	I/O	LVTTL		pull-up	
	GPIO[30:26][4]	I/O	PCI			pull-up on board
	GPIO[31]	I/O	LVTTL	Low Drive	pull-up	
Serial Interface	SCK	I/O	LVTTL	Low Drive	pull-up	pull-up on board
	SDI	I/O	LVTTL	Low Drive	pull-up	pull-up on board
	SDO	I/O	LVTTL	Low Drive	pull-up	pull-up on board
I^2C Bus Interface	SCL	I/O	LVTTL	Low Drive / STI		pull-up on board
	SDA	I/O	LVTTL	Low Drive / STI		pull-up on board

Table 1.1 Pin Characteristics (Part 2 of 4)

Notes

Function	Pin Name	Type	Buffer	I/O Type	Internal Resistor	Notes[1]
Ethernet Interfaces	MII0CL	I	LVTTL	STI	pull-down	
	MII0CRS	I	LVTTL	STI	pull-down	
	MII0RXCLK	I	LVTTL	STI	pull-up	
	MII0RXD[3:0]	I	LVTTL	STI	pull-up	
	MII0RXDV	I	LVTTL	STI	pull-down	
	MII0RXER	I	LVTTL	STI	pull-down	
	MII0TXCLK	I	LVTTL	STI	pull-up	
	MII0TXD[3:0]	O	LVTTL	Low Drive		
	MII0TXENP	O	LVTTL	Low Drive		
	MII0TXER	O	LVTTL	Low Drive		
	MII1CL	I	LVTTL	STI	pull-down	
	MII1CRS	I	LVTTL	STI	pull-down	
	MII1RXCLK	I	LVTTL	STI	pull-up	
	MII1RXD[3:0]	I	LVTTL	STI	pull-up	
	MII1RXDV	I	LVTTL	STI	pull-down	
	MII1RXER	I	LVTTL	STI	pull-down	
	MII1TXCLK	I	LVTTL	STI	pull-up	
	MII1TXD[3:0]	O	LVTTL	Low Drive		
	MII1TXENP	O	LVTTL	Low Drive		
	MII1TXER	O	LVTTL	Low Drive		
	MIIMDC	O	LVTTL	Low Drive		
	MIIMDIO	I/O	LVTTL	Low Drive	pull-up	
JTAG / EJTAG	JTAG_TRST_N	I	LVTTL	STI	pull-up	
	JTAG_TCK	I	LVTTL	STI	pull-up	
	JTAG_TDI	I	LVTTL	STI	pull-up	
	JTAG_TDO	O	LVTTL	Low Drive		
	JTAG_TMS	I	LVTTL	STI	pull-up	
	EJTAG_TMS	I	LVTTL	STI	pull-up	
Debug	CPU	O	LVTTL	Low Drive		
	INST	O	LVTTL	Low Drive		
	IPBMTRIGOUT	O	LVTTL	Low Drive		

Table 1.1 Pin Characteristics (Part 3 of 4)

Notes

Function	Pin Name	Type	Buffer	I/O Type	Internal Resistor	Notes[1]
Miscellaneous	CLK	I	LVTTL	STI		
	EXTCLK	O	LVTTL	High Drive		
	COLDRSTN	I	LVTTL	STI		
	RSTN	I/O	LVTTL	Low Drive / STI	pull-up	pull-up on board

Table 1.1 Pin Characteristics (Part 4 of 4)

1. External pull-up required in most system applications. Some applications may require additional pull-ups not identified in this table.

2. Schmidt Trigger Input (STI)

3. The PCI pins have internal pull-ups but they are too weak to guarantee system validity. Therefore, board pull-ups are mandatory where indicated. GPIO alternate function pins for PCI must also have board pull-ups.

4. PCIMUINTN is an alternate function of GPIO[30]. When configured as an alternate function, this pin is tri-stated when not asserted (i.e., it acts as an open collector output).

Pin Description

The following table lists the function of the pins provided on the RC32438. Some of the functions listed may be multiplexed onto the same pin.

Signal	Type	Name/Description
System		
CLK	I	**Master Clock.** This is the master clock input. The processor frequency is a multiple of this clock frequency. This clock is used as the system clock for all memory and peripheral bus operations.
EXTCLK	O	**External Clock.** This clock is used for all memory and peripheral bus operations.
COLDRSTN	I	**Cold Reset.** The assertion of this signal initiates a cold reset. This causes the processor state to be initialized, boot configuration to be loaded, and the internal PLL to lock onto the master clock (CLK).
RSTN	I/O	**Reset.** The assertion of this bidirectional signal initiates a warm reset. This signal is asserted by the RC32438 during a warm reset.
Memory and Peripheral Bus		
BDIRN	O	**External Buffer Direction.** Memory and peripheral bus external data bus buffer direction control. If the RC32438 memory and peripheral bus is connected to the A side of a transceiver such as an IDT74FCT245, then this pin may be directly connected to the direction control (e.g., BDIR) pin of the transceiver.
BGN	O	**Bus Grant.** This signal is asserted by the RC32438 to indicate that the RC32438 has relinquished ownership of the memory and peripheral bus.
BOEN	O	**External Buffer Enable.** This signal provides an output enable control for an external buffer on the memory and peripheral data bus.
BRN	I	**Bus Request.** This signal is asserted by an external device to request ownership of the memory and peripheral bus.

Table 1.2 Pin Description (Part 1 of 9)

Notes

Signal	Type	Name/Description
BWEN[1:0]	O	**Byte Write Enables.** These signals are memory and peripheral bus by write enable signals. BWEN[0] corresponds to byte lane MDATA[7:0] BWEN[1] corresponds to byte lane MDATA[15:8]
CSN[5:0]	O	**Chip Selects.** These signals are used to select an external device on the memory and peripheral bus.
MADDR[21:0]	O	**Address Bus.** 22-bit memory and peripheral bus address bus. MADDRP[25:22] are available as GPIO alternate functions
MDATA[15:0]	I/O	**Data Bus.** 16-bit memory and peripheral data bus. During a cold reset, these pins function as inputs that are used to load the boot configuration vector.
OEN	O	**Output Enable.** This signal is asserted when data should be driven on by an external device on the memory and peripheral bus.
RWN	O	**Read Write.** This signal indicates if the transaction on the memory and peripheral bus is a read transaction or a write transaction. A high level indicates a read from an external device. A low level indicates a write to an external device.
WAITACKN	I	**Wait or Transfer Acknowledge.** When configured as wait, this signal is asserted during a memory and peripheral bus transaction to extend the bus cycle. When configured as a transfer acknowledge, this signal is asserted during a transaction to signal the completion of the transaction.
DDR Bus		
DDRADDR[13:0]	O	**DDR Address Bus.** 14-bit multiplexed DDR bus address bus. This bus is used to transfer the addresses to the DDRs.
DDRBA[1:0]	O	**DDR Bank Address.** These signals are used to transfer the bank address to the DDRs.
DDRCASN	O	**DDR Column Address Strobe.** DDR column address strobe which is asserted during DDR transactions.
DDRCKE	O	**DDR Clock Enable.** DDR clock enable which is asserted during normal DDR operation. This signal is negated during following a cold reset or during a power down operation.
DDRCKN[1:0]	I/O	**DDR Negative DDR clock.** These signals are the negative clock of the differential DDR clock pair. Two copies of this output are provided to reduce signal loading.
DDRCKP[1:0]	I/O	**DDR Positive DDR clock.** These signals are the positive clock of the differential DDR clock pair. Two copies of this output are provided to reduce signal loading.
DDRCSN[1:0]	O	**DDR Chip Selects.** These active low signals are used to select DDR device(s) on the DDR bus.
DDRDATA[31:0]	I/O	**DDR Data Bus.** 32-bit DDR data bus used to transfer data between the RC32438 and the DDR devices. Data is transferred on both edges of the clock.

Table 1.2 Pin Description (Part 2 of 9)

Notes

Signal	Type	Name/Description
DDRDM[7:0]	O	**DDR Data Write Enables.** Byte data write enables are used to enable specific byte lanes during DDR writes. DDRDM[0] corresponds to DDRDATA[7:0] DDRDM[1] corresponds to DDRDATA[15:8] DDRDM[2] corresponds to DDRDATA[23:16] DDRDM[3] corresponds to DDRDATA[31:24] DDRDM[4] corresponds to DDRDATA[39:32] DDRDM[5] corresponds to DDRDATA[47:40] DDRDM[6] corresponds to DDRDATA[55:48] DDRDM[7] corresponds to DDRDATA[54:56] (Refer to the DDR Data Bus Multiplexing section in Chapter 7 of this manual.)
DDRDQS[3:0]	I/O	**DDR Data Strobes.** DDR byte data strobes are used to clock data between DDR devices and the RC32438. These strobes are inputs during DDR reads and outputs during DDR writes. DDRDQS[0] corresponds to DDRDATA[7:0]. DDRDQS[1] corresponds to DDRDATA[15:8]. DDRDQS[2] corresponds to DDRDATA[23:16]. DDRDQS[3] corresponds to DDRDATA[31:24].
DDROEN[3:0]	O	**DDR Bus Switch Output Enables.** In systems that support data bus multiplexing, these pins are used to enable external data bus switches.
DDRRASN	O	**DDR Row Address Strobe.** DDR row address strobe is asserted during DDR transactions.
DDRVREF	I	**DDR Voltage Reference.** SSTL_2 DDR voltage reference generated by an external source.
DDRWEN	O	**DDR Write Enable.** DDR write enable which is asserted during DDR write transactions.
PCI Bus		
PCIAD[31:0]	I/O	**PCI Multiplexed Address/Data Bus**. Address is driven by a bus master during initial PCIFRAMEN assertion. Data is then driven by the bus master during writes or by the bus target during reads.
PCICBEN[3:0]	I/O	**PCI Multiplexed Command/Byte Enable Bus**. PCI command is driven by the bus master during the initial PCIFRAMEN assertion. Byte enables are driven by the bus master during subsequent data phase(s).
PCICLK	I	**PCI Clock**. Clock used for all PCI bus transactions.
PCIDEVSELN	I/O	**PCI Device Select**. This signal is driven by a bus target to indicate that the target has decoded the address as one of its own address spaces.
PCIFRAMEN	I/O	**PCI Frame**. Driven by a bus master. Assertion indicates the beginning of a bus transaction. Negation indicates the last datum.

Table 1.2 Pin Description (Part 3 of 9)

Notes

Signal	Type	Name/Description
PCIGNTN[3:0]	I/O	**PCI Bus Grant**. **In PCI host mode with internal arbiter:** The assertion of these signals indicates to the agent that the internal RC32438 arbiter has granted the agent access to the PCI bus. **In PCI host mode with external arbiter:** PCIGNTN[0]: asserted by an external arbiter to indicate to the RC32438 that access to the PCI bus has been granted. PCIGNTN[3:1]: unused and driven high. **In PCI satellite mode:** PCIGNTN[0]: this signal is asserted by an external arbiter to indicate to the RC32438 that access to the PCI bus has been granted. PCIGNTN[1]: this signal takes on the alternate function of PCIEECS and is used as a PCI Serial EEPROM chip select. PCIGNTN[3:2]: unused and driven high. **Note**: When the GPIO register is programmed in the alternate function mode for bits GPIO [26] and [28], these bits become PCIGNTN [4] and [5] respectively.
PCIIRDYN	I/O	**PCI Initiator Ready**. Driven by the bus master to indicate that the current datum can complete.
PCILOCKN	I/O	**PCI Lock**. This signal is asserted by an external bus master to indicate that an exclusive operation is occurring.
PCIPAR	I/O	**PCI Parity**. Even parity of the PCIAD[31:0] bus. Driven by the bus master during address and write Data phases. Driven by the bus target during the read data phase.
PCIPERRN	I/O	**PCI Parity Error**. If a parity error is detected, this signal is asserted by the receiving bus agent 2 clocks after the data is received.
PCIREQN[3:0]	I/O	**PCI Bus Request.** **In PCI host mode with internal arbiter:** These signals are inputs whose assertion indicates to the internal RC32438 arbiter that an agent desires ownership of the PCI bus. **In PCI host mode with external arbiter:** PCIREQN[0]: asserted by the RC32438 to request ownership of the PCI bus. PCIREQN[3:1]: unused and driven high. **In PCI satellite mode:** PCIREQN[0]: this signal is asserted by the RC32438 to request use of the PCI bus. PCIREQN[1]: PCIIDSELP and is used as a chip select during configuration read and write transactions. PCIREQN[3:2]: unused and driven high. **Note**: When the GPIO register is programmed in the alternate function mode for bits GPIO [24] and [27], these bits become PCIREQN [4] and [5] respectively.
PCIRSTN	I/O	**PCI Reset**. In host mode this signal is asserted by the RC32438 to generate a PCI reset. In satellite mode, assertion of this signal initiates a warm reset.

Table 1.2 Pin Description (Part 4 of 9)

Notes

Signal	Type	Name/Description
PCISERRN	I/O	**PCI System Error**. This signal is driven by an agent to indicate an address parity error, data parity error during a special cycle command, or any other system error. Requires an external pull-up.
PCISTOPN	I/O	**PCI Stop**. Driven by the bus target to terminate the current bus transaction for example to indicate a retry.
PCITRDYN	I/O	**PCI Target Ready**. Driven by the bus target to indicate that the current datum can complete.
General Purpose Input/Output		
GPIO[0]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0SOUT Alternate function: UART channel 0 serial output
GPIO[1]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0SINP Alternate function: UART channel 0 serial input
GPIO[2]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0RIN Alternate function: UART channel 0 ring indicator
GPIO[3]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0DCDN Alternate function: UART channel 0 data carrier detect
GPIO[4]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0DTRN Alternate function: UART channel 0 data terminal ready
GPIO[5]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0DSRN Alternate function: UART channel 0 data set ready
GPIO[6]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0RTSN Alternate function: UART channel 0 request to send
GPIO[7]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U0CTSN Alternate function: UART channel 0 clear to send
GPIO[8]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1SOUT Alternate function: UART channel 1 serial output
GPIO[9]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1SINP Alternate function: UART channel 1 serial input

Table 1.2 Pin Description (Part 5 of 9)

Notes

Signal	Type	Name/Description
GPIO[10]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1DTRN Alternate function: UART channel 1 data terminal ready
GPIO[11]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1DSRN Alternate function: UART channel 1 data set ready
GPIO[12]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1RTSN Alternate function: UART channel 1 request to send
GPIO[13]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: U1CTSN Alternate function: UART channel 1 clear to send
GPIO[14]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMAREQN0 Alternate function: External DMA channel 0 request
GPIO[15]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMAREQN1 Alternate function: External DMA channel 1 request
GPIO[16]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMADONEN0 Alternate function: External DMA channel 0 done
GPIO[17]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMADONEN1 Alternate function: External DMA channel 1 done
GPIO[18]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMAFINN0 Alternate function: External DMA channel 0 finished
GPIO[19]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: DMAFINN1 Alternate function: External DMA channel 1 finished
GPIO[20]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: MADDR[22] Alternate function: Memory and peripheral bus address
GPIO[21]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: MADDR[23] Alternate function: Memory and peripheral bus address

Table 1.2 Pin Description (Part 6 of 9)

Notes

Signal	Type	Name/Description
GPIO[22]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: MADDR[24] Alternate function: Memory and peripheral bus address
GPIO[23]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: MADDR[25] Alternate function: Memory and peripheral bus address
GPIO[24]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: PCIREQN[4] Alternate function: PCI Request 4
GPIO[25]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: AFSPARE1 Alternate function: *reserved*
GPIO[26]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: PCIGNTN[4] Alternate function: PCI Grant 4
GPIO[27]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: PCIREQN[5] Alternate function: PCI Request 5
GPIO[28]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: PCIGNTN[5] Alternate function: PCI Grant 5
GPIO[29]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: Reserved Alternate function: Reserved.
GPIO[30]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin. Alternate function pin name: PCIMUINTN Alternate function: PCI Messaging unit interrupt output
GPIO[31]	I/O	**General Purpose I/O.** This pin can be configured as a general purpose I/O pin.
SPI Interface		
SCK	I/O	**Serial Clock**. This signal is used as the serial clock output in SPI mode and in PCI satellite mode with suspended CPU execution during PCI serial EEPROM loading. This pin may be configured as a GPIO pin.
SDI	I/O	**Serial Data Input**. This signal is used to shift in serial data in SPI mode and in PCI satellite mode with suspended CPU execution during PCI serial EEPROM loading. This pin may be configured as a GPIO pin.
SDO	I/O	**Serial Data Output**. This signal is used shift out serial data in SPI mode and in PCI satellite mode with suspended CPU execution during PCI serial EEPROM loading. This pin may be configured as a GPIO pin.

Table 1.2 Pin Description (Part 7 of 9)

Notes

Signal	Type	Name/Description
I²C Bus Interface		
SCL	I/O	**I²C Clock.** I²C-bus clock.
SDA	I/O	**I²C Data Bus.** I²C-bus data bus.
Ethernet Interfaces		
MII0CL	I	**Ethernet 0 MII Collision Detected.** This signal is asserted by the ethernet PHY when a collision is detected.
MII0CRS	I	**Ethernet 0 MII Carrier Sense.** This signal is asserted by the ethernet PHY when either the transmit or receive medium is not idle.
MII0RXCLK	I	**Ethernet 0 MII Receive Clock.** This clock is a continuous clock that provides a timing reference for the reception of data.
MII0RXD[3:0]	I	**Ethernet 0 MII Receive Data.** This nibble wide data bus contains the data received by the ethernet PHY.
MII0RXDV	I	**Ethernet 0 MII Receive Data Valid.** The assertion of this signal indicates that valid receive data is in the MII receive data bus.
MII0RXER	I	**Ethernet 0 MII Receive Error.** The assertion of this signal indicates that an error was detected somewhere in the ethernet frame currently being sent in the MII receive data bus.
MII0TXCLK	I	**Ethernet 0 MII Transmit Clock.** This clock is a continuous clock that provides a timing reference for the transfer of transmit data.
MII0TXD[3:0]	O	**Ethernet 0 MII Transmit Data.** This nibble wide data bus contains the data to be transmitted.
MII0TXENP	O	**Ethernet 0 MII Transmit Enable.** The assertion of this signal indicates that data is present on the MII for transmission.
MII0TXER	O	**Ethernet 0 MII Transmit Coding Error.** When this signal is asserted together with MIITXENP, the ethernet PHY will transmit symbols which are not valid data or delimiters.
MII1CL	I	**Ethernet 1 MII Collision Detected.** This signal is asserted by the ethernet PHY when a collision is detected.
MII1CRS	I	**Ethernet 1 MII Carrier Sense.** This signal is asserted by the ethernet PHY when either the transmit or receive medium is not idle.
MII1RXCLK	I	**Ethernet 1 MII Receive Clock.** This clock is a continuous clock that provides a timing reference for the reception of data.
MII1RXD[3:0]	I	**Ethernet 1 MII Receive Data.** This nibble wide data bus contains the data received by the ethernet PHY.
MII1RXDV	I	**Ethernet 1 MII Receive Data Valid.** The assertion of this signal indicates that valid receive data is in the MII receive data bus.
MII1RXER	I	**Ethernet 1 MII Receive Error.** The assertion of this signal indicates that an error was detected somewhere in the ethernet frame currently being sent in the MII receive data bus.
MII1TXCLK	I	**Ethernet 1 MII Transmit Clock.** This clock is a continuous clock that provides a timing reference for the transfer of transmit data.
MII1TXD[3:0]	O	**Ethernet 1 MII Transmit Data.** This nibble wide data bus contains the data to be transmitted.

Table 1.2 Pin Description (Part 8 of 9)

Notes

Signal	Type	Name/Description
MII1TXENP	O	**Ethernet 1 MII Transmit Enable.** The assertion of this signal indicates that data is present on the MII for transmission.
MII1TXER	O	**Ethernet 1 MII Transmit Coding Error.** When this signal is asserted together with MIITXENP, the ethernet PHY will transmit symbols which are not valid data or delimiters.
MIIMDC	O	**MII Management Data Clock.** This signal is used as a timing reference for transmission of data on the management interface.
MIIMDIO	I/O	**MII Management Data.** This bidirectional signal is used to transfer data between the station management entity and the ethernet PHY.
JTAG / EJTAG		
EJTAG_TMS	I	**EJTAG Mode**. The value on this signal controls the test mode select of the EJTAG Controller. When using the JTAG boundary scan, this pin should be left disconnected (since there is an internal pull-up) or driven high.
JTAG_TCK	I	**JTAG Clock**. This is an input test clock used to clock the shifting of data into or out of the boundary scan logic, JTAG Controller, or the EJTAG Controller. JTAG_TCK is independent of the system and the processor clock with a nominal 50% duty cycle.
JTAG_TDI	I	**JTAG Data Input**. This is the serial data input to the boundary scan logic, JTAG Controller, or the EJTAG Controller.
JTAG_TDO	O	**JTAG Data Output**. This is the serial data shifted out from the boundary scan logic, JTAG Controller, or the EJTAG Controller. When no data is being shifted out, this signal is tri-stated.
JTAG_TMS	I	**JTAG Mode**. The value on this signal controls the test mode select of the boundary scan logic or JTAG Controller. When using the EJTAG debug interface, this pin should be left disconnected (since there is an internal pull-up) or driven high.
JTAG_TRST_N	I	**JTAG Reset**. This active low signal asynchronously resets the boundary scan logic, JTAG TAP Controller, and the EJTAG Debug TAP Controller. An external pull-up on the board is recommended to meet the JTAG specification in cases where the tester can access this signal. However, for systems running in functional mode, one of the following should occur: 1) actively drive this signal low with control logic 2) statically drive this signal low with an external pull-down on the board 3) clock JTAG_TCK while holding EJTAG_TMS and/or JTAG_TMS high.
Debug		
CPU	O	**CPU Transaction.** This signal is asserted during all CPU instruction fetches and data transfers to/from the DDR and devices on the memory and peripheral bus. The signal is negated during PCI and DMA transactions to/from the DDR and devices on the memory and peripheral bus.
INST	O	**Instruction or Data.** This signal is driven high during CPU instruction fetches on the memory and peripheral bus memory or DDR bus.

Table 1.2 Pin Description (Part 9 of 9)

Notes

Default Memory Map

The RC32438 contains 2 initially-enabled physical address regions. They are: Boot device region (i.e., Device 0) and an internal register region. Associated with each memory region (i.e., device, DDR, or on-chip memory) is a base and mask register pair. When a bit in the mask register is set, then the corresponding physical address bit generated by the CPU participates in address comparisons for the region. If a bit in the mask register is cleared, then the corresponding physical address bit does not participate in address comparisons for the region. When the CPU, PCI, or DMA controller generates a physical address, the address is compared with all non-masked bits in each base register. If all non-masked physical address bits match a base register, then the corresponding address region is selected. If no base register matches or if multiple base registers match, then no region is selected and the address space monitor reports an error (see Chapter 4, System Integrity).[1]

The initial default memory map following a cold reset is shown in Table 1.3. Software may alter this default configuration by modifying the base and mask registers. Base and mask registers should not be modified for the region(s) from which the CPU is executing.

Physical Address Range	Size	RC32438 Memory Region	Reset Initialization	
0x0000_0000 to 0x17FF_FFFF	384 MB	Unused		
0x1800_0000 to 0x181F_FFFF	2 MB	RC32438 internal registers		
0x1820_0000 to 0x1BFF_FFFF	62 MB	Unused		
0x1C00_0000 to 0x1FFF_FFFF	64 MB	Device 0 (CSN[0])	DEV0BASE	0x1C00
			DEV0MASK	0xFC00
0x2000_0000 to 0xFFFF_FFFF	Approx. 3 GB	Unused		

Table 1.3 RC32438 Default Memory Map Following a Cold Reset

1. If a device or SDRAM is mapped such that it overlaps the internal system address space (0x1800_000 through 0x181F_FFFF), the internal system controller address space will take precedence. Any subsequent CPU or PCI access to this redundantly mapped space will result in the system controller being accessed.

Notes

RC32438 Internal Register Map

The physical address of a RC32438 internal register is equal to the register offset, shown in Table 1.4, added to the base value 0x1800_0000. The RC32438 internal register region is not fully decoded.[1] Unless otherwise noted, all registers should be accessed as aligned 32-bit quantities. Also, all internal registers should be accessed through non-cacheable addresses.

Function	Register Offset	Register Name	Register Function
System Identification	0x00_0000 through 0x00_0017	Reserved	
	0x00_0018	SYSID	System Identification
	0x00_001C	Reserved	
	0x00_0020 through 0x00_7FFF	Reserved	
Reset and Initialization	0x00_8000	RESET	Reset
	0x00_8004	BCV	Boot configuration
	0x00_8008[1]	CEA	CPU error address **Note**: This register can only be accessed by the CPU. It cannot be accessed by IPBus masters.
	0x00_800C through 0x00_FFFF	Reserved	
Device Controller	0x01_0000	DEV0BASE	Device 0 Base
	0x01_0004	DEV0MASK	Device 0 Mask
	0x01_0008	DEV0C	Device 0 Control
	0x01_000C	DEV0TC	Device 0 Timing control
	0x01_0010	DEV1BASE	Device 1 Base
	0x01_0014	DEV1MASK	Device 1 Mask
	0x01_0018	DEV1C	Device 1 Control
	0x01_001C	DEV1TC	Device 1 Timing control
	0x01_0020	DEV2BASE	Device 2 Base
	0x01_0024	DEV2MASK	Device 20 Mask
	0x01_0028	DEV2C	Device 2 Control
	0x01_002C	DEV2TC	Device 2 Timing control
	0x01_0030	DEV3BASE	Device 3 Base
	0x01_0034	DEV3MASK	Device 3 Mask

Table 1.4 Internal Register Map (Part 1 of 11)

1. Addresses for each function may be partitioned into two regions. Region one includes addresses from the start of the function's address range to one less than the lowest address that modulo 256 is zero and which is greater than or equal to the highest defined register for that function. Region two consists of those function addresses not in region one. For the system identification function, region one would consist of 0x00_0000 through 0x00_00FF and region two could consist of 0x00_0100 through 0x00_7FFF. Reads from a region one reserved address return zero. Writes to a region one reserved address are ignored. Reads and writes to region two result in an undecoded address error. For more information, see the Address Space Monitor section in Chapter 4.

Notes

Function	Register Offset	Register Name	Register Function
Device Controller (Cont.)	0x01_0038	DEV3C	Device 3 Control
	0x01_003C	DEV3TC	Device 3 Timing control
	0x01_0040	DEV4BASE	Device 4 Base
	0x01_0044	DEV4MASK	Device 40 Mask
	0x01_0048	DEV4C	Device 4 Control
	0x01_004C	DEV4TC	Device 4 Timing control
	0x01_0050	DEV5BASE	Device 5 Base
	0x01_0054	DEV5MASK	Device 5 Mask
	0x01_0058	DEV5C	Device 5 Control
	0x01_005C	DEV5TC	Device 5 Timing control
	0x01_0060	BTCS	Bus Timer Control and Status
	0x01_0064	BTCOMPARE	Bus Transaction Timer Compare
	0x01_0068	BTADDR	Bus Transaction Timer Address
	0x01_006C	DEVDACS	Device Decoupled Access Control and Status
	0x01_0070	DEVDAA	Device Decoupled Access Address
	0x01_0074	DEVDAD	Device Decoupled Access Data
	0x01_0078 through 0x01_7FFF	Reserved	
DDR Controller	0x01_8000	DDR0BASE	DDR 0 base
	0x01_8004	DDR0MASK	DDR 0 mask
	0x01_8008	DDR1BASE	DDR 1 base
	0x01_800C	DDR1MASK	DDR 1 mask
	0x01_8010	DDRC	DDR control
	0x01_8014	DDR0ABASE	DDR 0 alternate base
	0x01_8018	DDR0AMASK	DDR 0 alternate mask
	0x01_801C	DDR0AMAP	DDR 0 alternate mapping
	0x01_8020	DDRCUST	DDR Custom transaction
	0x01_8024	DDRRDC	DDR Read Data Capture
	0x01_8028 through 0x01_BFFF	Reserved	
PMBus Arbiter	0x02_0000	PMAPP	PMBus arbiter processor priority
	0x02_0004	PMASAC	PMBus arbiter sneak access control
	0x02_0008 through 0x02_7FFF	Reserved	
Counter/Timers	0x02_8000	COUNT0	Counter timer 0 count
	0x02_8004	COMPARE0	Counter timer 0 compare
	0x02_8008	CTC0	Counter timer 0 control
	0x02_800C	COUNT1	Counter timer 1 count

Table 1.4 Internal Register Map (Part 2 of 11)

Notes

Function	Register Offset	Register Name	Register Function
	0x02_8010	COMPARE1	Counter timer 1 compare
	0x02_8014	CTC1	Counter timer 1 control
	0x02_8018	COUNT2	Counter timer 2 count
	0x02_801C	COMPARE2	Counter timer 2 compare
	0x02_8020	CTC2	Counter timer 2 control
	0x02_8024	RCOUNT	Refresh timer count
	0x02_8028	RCOMPARE	Refresh timer compare
	0x02_802C	RTC	Refresh timer control
	0x02_8030 through 0x02_FFFF	Reserved	
System Integrity Functions	0x03_0000 through 0x03_002C	Reserved	
	0x03_0030	ERRCS	Error control and status
	0x03_0034	WTCOUNT	Watchdog timer count
	0x03_0038	WTCOMPARE	Watchdog timer compare
	0x03_003C	WTC	Watchdog timer control
	0x03_0040 through 0x03_7FFF	Reserved	
Interrupt Controller	0x03_8000	IPEND2	Interrupt pending 2
	0x03_8004	ITEST2	Interrupt test 2
	0x03_8008	IMASK2	Interrupt mask 2
	0x03_800C	IPEND3	Interrupt pending 3
	0x03_8010	ITEST3	Interrupt test 3
	0x03_8014	IMASK3	Interrupt mask 3
	0x03_8018	IPEND4	Interrupt pending 4
	0x03_801C	ITEST4	Interrupt test 4
	0x03_8020	IMASK4	Interrupt mask 4
	0x03_8024	IPEND5	Interrupt pending 5
	0x03_8028	ITEST5	Interrupt test 5
	0x03_802C	IMASK5	Interrupt mask 5
	0x03_8030	IPEND6	Interrupt pending 6
	0x03_8034	ITEST6	Interrupt test 6
	0x03_8038	IMASK6	Interrupt mask 6
	0x03_803C	NMIPS	Non-maskable interrupt pin status
	0x03_8040 through 0x03_FFFF	Reserved	
DMA Controller	0x04_0000	DMA0C	DMA 0 control
	0x04_0004	DMA0S	DMA 0 status
	0x04_0008	DMA0SM	DMA 0 status mask

Table 1.4 Internal Register Map (Part 3 of 11)

Notes

Function	Register Offset	Register Name	Register Function
DMA Controller (Cont.)	0x04_000C	DMA0DPTR	DMA 0 descriptor pointer
	0x04_0010	DMA0NDPTR	DMA 0 next descriptor pointer
	0x04_0014	DMA1C	DMA 1 control
	0x04_0018	DMA1S	DMA 1 status
	0x04_001C	DMA1SM	DMA 1 status mask
	0x04_0020	DMA1DPTR	DMA 1 descriptor pointer
	0x04_0024	DMA1NDPTR	DMA 1 next descriptor pointer
	0x04_0028	DMA2C	DMA 2 control
	0x04_002C	DMA2S	DMA 2 status
	0x04_0030	DMA2SM	DMA 2 status mask
	0x04_0034	DMA2DPTR	DMA 2 descriptor pointer
	0x04_0038	DMA2NDPTR	DMA 2 next descriptor pointer
	0x04_003C	DMA3C	DMA 3 control
	0x04_0040	DMA3S	DMA 3 status
	0x04_0044	DMA3SM	DMA 3 status mask
	0x04_0048	DMA3DPTR	DMA 3 descriptor pointer
	0x04_004C	DMA3NDPTR	DMA 3 next descriptor pointer
	0x04_0050	DMA4C	DMA 4 control
	0x04_0054	DMA4S	DMA 4 status
	0x04_0058	DMA4SM	DMA 4 status mask
	0x04_005C	DMA4DPTR	DMA 4 descriptor pointer
	0x04_0060	DMA4NDPTR	DMA 4 next descriptor pointer
	0x04_0064	DMA5C	DMA 5 control
	0x04_0068	DMA5S	DMA 5 status
	0x04_006C	DMA5SM	DMA 5 status mask
	0x04_0070	DMA5DPTR	DMA 5 descriptor pointer
	0x04_0074	DMA5NDPTR	DMA 5 next descriptor pointer
	0x04_0078	DMA6C	DMA 6 control
	0x04_007C	DMA6S	DMA 6 status
	0x04_0080	DMA6SM	DMA 6 status mask
	0x04_0084	DMA6DPTR	DMA 6 descriptor pointer
	0x04_0088	DMA6NDPTR	DMA 6 next descriptor pointer
	0x04_008C	DMA7C	DMA 7 control
	0x04_0090	DMA7S	DMA 7 status
	0x04_0094	DMA7SM	DMA 7 status mask
	0x04_0098	DMA7DPTR	DMA 7 descriptor pointer

Table 1.4 Internal Register Map (Part 4 of 11)

Notes

Function	Register Offset	Register Name	Register Function
DMA Controller (Cont.)	0x04_009C	DMA7NDPTR	DMA 7 next descriptor pointer
	0x04_00A0	DMA8C	DMA 8 control
	0x04_00A4	DMA8S	DMA 8 status
	0x04_00A8	DMA8SM	DMA 8 status mask
	0x04_00AC	DMA8DPTR	DMA 8 descriptor pointer
	0x04_00B0	DMA8NDPTR	DMA 8 next descriptor pointer
	0x04_00B4	DMA9C	DMA 9 control
	0x04_00B8	DMA9S	DMA 9 status
	0x04_00BC	DMA9SM	DMA 9 status mask
	0x04_00C0	DMA9DPTR	DMA 9 descriptor pointer
	0x04_00C4	DMA9NDPTR	DMA 9 next descriptor pointer
	0x04_00C8	DMA10C	DMA 10 control
	0x04_00CC	DMA10S	DMA 10 status
	0x04_00D0	DMA10SM	DMA 10 status mask
	0x04_00D4	DMA10DPTR	DMA 10 descriptor pointer
	0x04_00D8	DMA10NDPTR	DMA 10 next descriptor pointer
	0x04_00DC	DMA11C	DMA 11 control
	0x04_00E0	DMA11S	DMA 11 status
	0x04_00E4	DMA11SM	DMA 11 status mask
	0x04_00E8	DMA11DPTR	DMA 11 descriptor pointer
	0x04_00EC	DMA11NDPTR	DMA 11 next descriptor pointer
	0x04_00F0	DMA12C	DMA 12 control
	0x04_00F4	DMA12S	DMA 12 status
	0x04_00F8	DMA12SM	DMA 12 status mask
	0x04_00FC	DMA12DPTR	DMA 12 descriptor pointer
	0x04_0100	DMA12NDPTR	DMA 12 next descriptor pointer
	0x04_0104 through 0x04_3FFF	Reserved	
IPBus Arbiter	0x04_4000	IPAP0C	IPBus arbiter priority 0 configuration
	0x04_4004	IPAP1C	IPBus arbiter priority 1 configuration
	0x04_4008	IPAP2C	IPBus arbiter priority 2 configuration
	0x04_400C	IPAP3C	IPBus arbiter priority 3 configuration
	0x04_4010	IPABM0C	IPBus arbiter bus master 0 configuration

Table 1.4 Internal Register Map (Part 5 of 11)

Notes

Function	Register Offset	Register Name	Register Function
IPBus Arbiter (Cont.)	0x04_4014	IPABM1C	IPBus arbiter bus master 1 configuration
	0x04_4018	IPABM2C	IPBus arbiter bus master 2 configuration
	0x04_401C	IPABM3C	IPBus arbiter bus master 3 configuration
	0x04_4020	IPABM4C	IPBus arbiter bus master 4 configuration
	0x04_4024	IPABM5C	IPBus arbiter bus master 5 configuration
	0x04_4028	IPABM6C	IPBus arbiter bus master 6 configuration
	0x04_402C	IPABM7C	IPBus arbiter bus master 7 configuration
	0x04_4030	IPABM8C	IPBus arbiter bus master 8 configuration
	0x04_4034	IPABM9C	IPBus arbiter bus master 9 configuration
	0x04_4038 through 0x04_4040	Reserved	
	0x04_4044	IPABM13C	IPBus arbiter bus master 13 configuration
	0x04_4048	IPABM14C	IPBus arbiter bus master 14 configuration
	0x04_404C	IPABM15C	IPBus arbiter bus master 15 configuration
	0x04_4050	IPABM16C	IPBus arbiter bus master 16 configuration
	0x04_4054	IPAC	IPBus arbiter control
	0x04_4058	IPAITCC	IPBus arbiter idle transaction cycle count
	0x04_405C through 0x04_7FFF	Reserved	
GPIO Controller	0x04_8000	GPIOFUNC	GPIO function
	0x04_8004	GPIOCFG	GPIO configuration
	0x04_8008	GPIOD	GPIO data
	0x04_800C	GPIOILEVEL	GPIO interrupt level
	0x04_8010	GPIOISTAT	GPIO interrupt status
	0x04_8014	GPIONMIEN	GPIO nonmaskable interrupt enable
	0x04_8018 through 0x04_FFFF	Reserved	

Table 1.4 Internal Register Map (Part 6 of 11)

Notes

Function	Register Offset	Register Name	Register Function
UART	0x05_0000	UART0RB / UART0TH / UART0DLL	UART 0 receive buffer / UART 0 transmit holding / UART 0 divisor latch low
	0x05_0004	UART0IE / UART0DLH	UART 0 interrupt enable / UART 0 divisor latch high
	0x05_0008	UART0II / UART0FC	UART 0 interrupt identification / UART 0 FIFO control
	0x05_000C	UART0LC	UART 0 line control
	0x05_0010	UART0MC	UART 0 modem control
	0x05_0014	UART0LS	UART 0 line status
	0x05_0018	UART0MS	UART 0 modem status
	0x05_001C	UART0S	UART 0 scratch
	0x05_0020	UART1RB / UART1TH / UART1DLL	UART 1 receive buffer / UART 1 transmit holding / UART 1 divisor latch low
	0x05_0024	UART1IE / UART1DLH	UART 1 interrupt enable / UART 1 divisor latch high
	0x05_0028	UART1II / UART1FC	UART 1 interrupt identification / UART 1 FIFO control
	0x05_002C	UART1LC	UART 1 line control
	0x05_0030	UART1MC	UART 1 modem control
	0x05_0034	UART1LS	UART 1 line status
	0x05_0038	UART1MS	UART 1 modem status
	0x05_003C	UART1S	UART 1 scratch
	0x05_0040	UART0RR	UART 0 Reset
	0x05_0044	UART1RR	UART 1 Reset
	0x05_0048 through 0x05_7FFF	Reserved	
Ethernet Interface 0	0x05_8000	ETH0INTFC	Ethernet 0 interface control
	0x05_8004	ETH0FIFOTT	Ethernet 0 FIFO transmit threshold
	0x05_8008	ETH0ARC	Ethernet 0 address recognition control
	0x05_800C	ETH0HASH0	Ethernet 0 hash table 0
	0x05_8010	ETH0HASH1	Ethernet 0 hash table 1
	0x05_8014 through 0x05_8020	Reserved	
	0x05_8024	ETH0PFS	Ethernet 0 pause frame status
Management Clock	0x05_8028	ETHMCP	Ethernet management clock pre-scalar
	0x05_802C through 0x05_80FF	Reserved	
	0x05_8100	ETH0SAL0	Ethernet 0 station address 0 low

Table 1.4 Internal Register Map (Part 7 of 11)

Notes

Function	Register Offset	Register Name	Register Function
	0x05_8104	ETH0SAH0	Ethernet 0 station address 0 high
	0x05_8108	ETH0SAL1	Ethernet 0 station address 1 low
	0x05_810C	ETH0SAH1	Ethernet 0 station address 1 high
	0x05_8110	ETH0SAL2	Ethernet 0 station address 2 low
	0x05_8114	ETH0SAH2	Ethernet 0 station address 2 high
	0x05_8118	ETH0SAL3	Ethernet 0 station address 3 low
	0x05_811C	ETH0SAH3	Ethernet 0 station address 3 high
	0x05_8120	ETH0RBC	Ethernet 0 receive byte count
	0x05_8124	ETH0RPC	Ethernet 0 receive packet count
	0x05_8128	ETH0RUPC	Ethernet 0 receive undersized packet count
	0x05_812C	ETH0RFC	Ethernet 0 receive fragment count
	0x05_8130	ETH0TBC	Ethernet 0 transmit byte count
	0x05_8134	ETH0GPF	Ethernet 0 generate pause frame
	0x05_8138 through 0x05_81FF	Reserved	
	0x05_8200	ETH0MAC1	Ethernet 0 MAC configuration 1
	0x05_8204	ETH0MAC2	Ethernet 0 MAC configuration 2
	0x05_8208	ETH0IPGT	Ethernet 0 back-to-back inter-packet gap
	0x05_820C	ETH0IPGR	Ethernet 0 non back-to-back inter-packet gap
	0x05_8210	ETH0CLRT	Ethernet 0 collision window retry
	0x05_8214	ETH0MAXF	Ethernet 0 maximum frame length
	0x05_8218	Reserved	
	0x05_821C	ETH0MTEST	Ethernet 0 MAC test
MII Management	0x05_8220	MIIMCFG	MII management configuration
MII Management	0x05_8224	MIIMCMD	MII management command
MII Management	0x05_8228	MIIMADDR	MII management address
MII Management	0x05_822C	MIIMWTD	MII management write data
MII Management	0x05_8230	MIIMRDD	MII management read data
MII Management	0x05_8234	MIIMIND	MII management indicators
	0x05_8238 through 0x05_823C	Reserved	
	0x05_8240	ETH0CFSA0	Ethernet 0 control frame station address 0
	0x05_8244	ETH0CFSA1	Ethernet 0 control frame station address 1
	0x05_8248	ETH0CFSA2	Ethernet 0 control frame station address 2

Table 1.4 Internal Register Map (Part 8 of 11)

Notes

Function	Register Offset	Register Name	Register Function
	0x05_824C through 0x5_FFFF	Reserved	
Ethernet Interface 1	0x06_0000	ETH1INTFC	Ethernet 1 interface control
	0x06_0004	ETH1FIFOTT	Ethernet 1 FIFO transmit threshold
	0x06_0008	ETH1ARC	Ethernet 1 address recognition control
	0x06_000C	ETH1HASH0	Ethernet 1 hash table 0
	0x06_0010	ETH1HASH1	Ethernet 1 hash table 1
	0x06_0014 through 0x06_0020	Reserved	
	0x06_0024	ETH1PFS	Ethernet 1 pause frame status
	0x06_0028 through 0x06_00FF	Reserved	
	0x06_0100	ETH1SAL0	Ethernet 1 station address 0 low
	0x06_0104	ETH1SAH0	Ethernet 1 station address 0 high
	0x06_0108	ETH1SAL1	Ethernet 1 station address 1 low
	0x06_010C	ETH1SAH1	Ethernet 1 station address 1 high
	0x06_0110	ETH1SAL2	Ethernet 1 station address 2 low
	0x06_0114	ETH1SAH2	Ethernet 1 station address 2 high
	0x06_0118	ETH1SAL3	Ethernet 1 station address 3 low
	0x06_011C	ETH1SAH3	Ethernet 1 station address 3 high
	0x06_0120	ETH1RBC	Ethernet 1 receive byte count
	0x06_0124	ETH1RPC	Ethernet 1 receive packet count
	0x06_0128	ETH1RUPC	Ethernet 1 receive undersized packet count
	0x06_012C	ETH1RFC	Ethernet 1 receive fragment count
	0x06_0130	ETH1TBC	Ethernet 1 transmit byte count
	0x06_0134	ETH1GPF	Ethernet 1 generate pause frame
	0x06_0138 through 0x06_01FF	Reserved	
	0x06_0200	ETH1MAC1	Ethernet 1 MAC configuration 1
	0x06_0204	ETH1MAC2	Ethernet 1 MAC configuration 2
	0x06_0208	ETH1IPGT	Ethernet 1 back-to-back inter-packet gap
	0x06_020C	ETH1IPGR	Ethernet 1 non back-to-back inter-packet gap
	0x06_0210	ETH1CLRT	Ethernet 1 collision window retry
	0x06_0214	ETH1MAXF	Ethernet 1 maximum frame length
	0x06_0218	Reserved	
	0x06_021C	ETH1MTEST	Ethernet 1 MAC test
	0x06_0220 through 0x06_023C	Reserved	

Table 1.4 Internal Register Map (Part 9 of 11)

Notes

Function	Register Offset	Register Name	Register Function
	0x06_0240	ETH1CFSA0	Ethernet 1 control frame station address 0
	0x06_0244	ETH1CFSA1	Ethernet 1 control frame station address 1
	0x06_0248	ETH1CFSA2	Ethernet 1 control frame station address 2
	0x06_024C through 0x6_FFFF	Reserved	
I2C Bus	0x07_0000	I2CC	I^2C bus control
	0x07_0004	I2CDI	I^2C bus data input
	0x07_0008	I2CDO	I^2C bus data output
	0x07_000C	I2CCP	I^2C bus clock prescalar
	0x07_0010	I2CMCMD	I^2C bus master command
	0x07_0014	I2CMS	I^2C bus master status
	0x07_0018	I2CMSM	I^2C bus master status mask
	0x07_001C	I2CSS	I^2C bus slave status
	0x07_0020	I2CSSM	I^2C bus slave status mask
	0x07_0024	I2CSADDR	I^2C bus slave address
	0x07_0028	I2CSACK	I^2C bus slave acknowledge
	0x07_002C through 0x7_7FFF	Reserved	
Serial Peripheral Interface	0x07_8000	SPCP	SPI clock prescalar
	0x07_8004	SPC	SPI control
	0x07_8008	SPS	SPI status
	0x07_800C	SPD	SPI data
	0x07_8010	SIOFUNC	Serial I/O function
	0x07_8014	SIOCFG	Serial I/O configuration
	0x07_8018	SIOD	Serial I/O data
	0x07_801C through 0x7_FFFF	Reserved	
PCI Bus Interface	0x08_0000	PCIC	PCI control
	0x08_0004	PCIS	PCI status
	0x08_0008	PCISM	PCI status mask
	0x08_000C	PCICFGA	PCI configuration address
	0x08_0010	PCICFGD	PCI configuration data
	0x08_0014	PCILBA0	PCI local base address 0
	0x08_0018	PCILBA0C	PCI local base address 0 control
	0x08_001C	PCILBA0M	PCI local base address 0 mapping
	0x08_0020	PCILBA1	PCI local base address 1

Table 1.4 Internal Register Map (Part 10 of 11)

Notes

Function	Register Offset	Register Name	Register Function
PCI Bus Interface (Cont.)	0x08_0024	PCILBA1C	PCI local base address 1 control
	0x08_0028	PCILBA1M	PCI local base address 1 mapping
	0x08_002C	PCILBA2	PCI local base address 2
	0x08_0030	PCILBA2C	PCI local base address 2 control
	0x08_0034	PCILBA2M	PCI local base address 2 mapping
	0x08_0038	PCILBA3	PCI local base address 3
	0x08_003C	PCILBA3C	PCI local base address 3 control
	0x08_0040	PCILBA3M	PCI local base address 3 mapping
	0x08_0044	PCIDAC	PCI decoupled access control
	0x08_0048	PCIDAS	PCI decoupled access status
	0x08_004C	PCIDASM	PCI decoupled access status mask
	0x08_0050	PCIDAD	PCI decoupled access data
	0x08_0054	PCIDMA8C	PCI DMA channel 8 configuration
	0x08_0058	PCIDMA9C	PCI DMA channel 9 configuration
	0x08_005C	PCITC	PCI target control
	0x08_0060 through 0x8_7FFF	Reserved	
PCI Messaging Unit	0x08_8000 through 0x8_800C	Reserved	
	0x08_8010	PCIIM0	PCI Inbound Message 0
	0x08_8014	PCIIM1	PCI Inbound Message 1
	0x08_8018	PCIOM0	PCI Outbound Message 0
	0x08_801C	PCIOM1	PCI Outbound Message 1
	0x08_8020	PCIID	PCI Inbound Doorbell
	0x08_8024	PCIIIC	PCI Inbound Interrupt Cause
	0x08_8028	PCIIIM	PCI Inbound Interrupt Mask
	0x08_802C	PCIOD	PCI Outbound Doorbell
	0x08_8030	PCIOIC	PCI Outbound Interrupt Cause
	0x08_8034	PCIOIM	PCI Outbound Interrupt Mask
	0x08_8038 through 0x8_FFFF	Reserved	
Reserve	0x09_0000 through 0x09_7FFF	Reserved	
On-Chip Memory	0x09_8000	OCMBASE	On-chip memory base
	0x09_8004	OCMMASK	On-chip memory mask
	0x09_8008 through 0x09_FFFF	Reserved	

Table 1.4 Internal Register Map (Part 11 of 11)

[1] Addresses for each function may be partitioned into two regions. Region one includes addresses from the start of the function's address range to one less than the lowest address that modulo 256 is zero and which is greater than or equal to the highest defined register for that function. Region two consists of those function addresses not in region one. For the system identification function, region one would consist of 0x00_0000 through 0x00_00FF and region two could consist of 0x00_0100 through 0x00_7FFF. Reads from a region one reserved address return zero. Writes to a region one reserved address are ignored. Reads and writes to region two result in an undecoded address error. For more information, refer to the Address Space Monitor section in Chapter 4.

Notes

MIPS32 4Kc Processor Core

Notes

Introduction

The MIPS32™ 4Kc™ processor core from MIPS® Technologies is a high performance, low power, 32 bit MIPS RISC core intended for custom system-on-silicon applications. The 4Kc processor incorporates aspects of both the MIPS Technologies R3000® and R4000® processors. This chapter provides basic information on the architecture and operation of the 4Kc processor core as it applies to the RC32438. Additional information about the 4Kc core can be obtained by contacting MIPS Technologies or visiting their 4Kc web page at: http://www.mips.com/products/s2p4.html.

Functional Overview

The 4Kc core contains a fully-associative translation lookaside buffer (TLB) based MMU (Memory Management Unit) and a pipelined MDU (Multiply/Divide Unit). The instruction and data caches are both 16 Kbytes in size and organized as 4-way set associative. On a cache miss, loads are blocked only until the first critical word becomes available. The pipeline resumes execution while the remaining words are being written to the cache. Both caches are virtually indexed and physically tagged. Virtual indexing allows the cache to be indexed in the same clock in which the address is generated rather than waiting for the virtual-to-physical address translation in the Memory Management Unit (MMU).

The 4Kc core executes the MIPS32 instruction set architecture (ISA). The MIPS32 ISA contains all MIPS II instructions as well as special multiply-accumulate, conditional move, prefetch, wait, and zero/one detect instructions. The R4000-style memory management unit of the 4Kc core contains a 3-entry instruction TLB (ITLB), a 3-entry data TLB (DTLB), and a 16 dual-entry joint TLB (JTLB) with variable page sizes.

The 4Kc MDU supports a maximum issue rate of one 32x16 multiply (MUL/MULT/MULTU), multiply-add (MADD/MADDU), or multiply-subtract (MSUB/MSUBU) operation per clock, or one 32x32 MUL, MADD, or MSUB every other clock. The basic Enhanced JTAG (EJTAG) features provide CPU run control with stop, single stepping and re-start, and with software breakpoints through the SDBBP instruction. In addition, optional instruction and data virtual address hardware breakpoints, and optional connection to an external EJTAG probe through the Test Access Port (TAP) may be included.

Features

- *32-bit Address and Data Paths*
- *MIPS32 compatible instruction set*
  - *All MIPSII™ instructions*
  - *Multiply-add and multiply-subtract instructions (MADD, MADDU, MSUB, MSUBU)*
  - *Targeted multiply instruction (MUL)*
  - *Zero and one detect instructions (CLZ, CLO)*
  - *Wait instruction (WAIT)*
  - *Conditional move instructions (MOVZ, MOVN)*
  - *Prefetch instruction (PREF)*

Notes

- *Cache Sizes*
  - *16KB instruction and data caches*
  - *4-Way set associative*
  - *Loads that miss in the cache are blocked only until critical word is available*
  - *Write-through, no write-allocate*
  - *128 bit (16-byte) cache line size, word sectored - suitable for standard 32-bit wide single-port SRAM*
  - *Virtually indexed, physically tagged*
  - *Cache line locking support*
- *R4000 Style Privileged Resource Architecture*
  - *Count/compare registers for real-time timer interrupts*
  - *Instruction and data watch registers for software breakpoints*
  - *Separate interrupt exception vector*
- *Programmable Memory Management Unit*
  - *16 dual-entry R4000 style JTLB with variable page sizes*
  - *3-entry instruction TLB*
  - *3-entry data TLB*
- *Multiply-Divide Unit*
  - *Max issue rate of one 32x16 multiply per clock*
  - *Max issue rate of one 32x32 multiply every other clock*
  - *Early in divide control. Minimum 11, maximum 34 clock latency on divide*
- *Power Control*
  - *No minimum frequency*
  - *Power-down mode (triggered by WAIT instruction)*
  - *Support for software-controlled clock divider*
- *EJTAG Debug Support*
  - *CPU control with start, stop, and single stepping*
  - *Software breakpoints via the SDBBP instruction*
  - *Optional hardware breakpoints on virtual addresses; 4 instruction and 2 data breakpoints, 2 instruction and 1 data breakpoint, or no breakpoints*
  - *Test Access Port (TAP) facilitates high speed download of application code*

Notes

Functional Overview

Figure 2.1 shows a block diagram of the 4Kc CPU core.

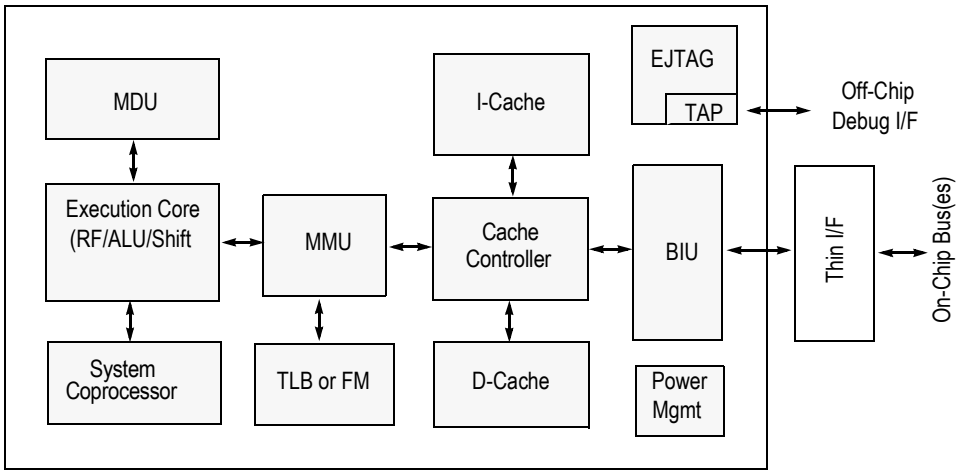


Figure 2.1 RC32438 Block Diagram

Blocks

The following sections describe the various blocks in the 4Kc processor core.

Execution Unit

The execution unit includes:

32-bit adder used for calculating the data address

Address unit for calculating the next instruction address

Logic for branch determination and branch target address calculation

Load aligner

Bypass multiplexers used to avoid stalls when executing instruction streams where data-producing instructions are followed closely by consumers of their results

Zero/One detect unit for implementing the CLZ and CLO instructions

ALU for performing bitwise logical operations

Shifter and Store aligner

The core execution unit implements a load-store architecture with single-cycle Arithmetic Logic Unit (ALU) operations (logical, shift, add, subtract) and an autonomous multiply-divide unit. The core contains thirty-two 32-bit general-purpose registers used for scalar integer operations and address calculation. The register file consists of two read ports and one write port and is fully bypassed to minimize operation latency in the pipeline.

Multiply/Divide Unit (MDU)

The Multiply/Divide unit performs multiply and divide operations. In the 4Kc processor, the MDU consists of a 32x16 booth-encoded multiplier, result-accumulation registers (HI and LO), a divide state machine, and all multiplexers and control logic required to perform these functions. This pipelined MDU supports execution of a 16x16 or 32x16 multiply operation every clock cycle; 32x32 multiply operations can be issued every other clock cycle. Appropriate interlocks are implemented to stall the issue of back-to-back 32x32 multiply operations. Divide operations are implemented with a simple 1 bit per clock iterative algorithm and may require up to 35 clock cycles (worst case scenario) to complete. In the early stages of executions, the algorithm detects a sign extension of the dividend and, if its actual size is 24, 16, or 8 bits. Based on this

Notes

information, the divider will skip 7, 15, or 23 iterations respectively (out of a total of 32 iterations). An attempt to issue a subsequent MDU instruction while a divide is still in progress causes a pipeline stall until the divide operation is completed.

An additional multiply instruction, MUL, is implemented. This instruction specifies that the lower 32 bits of the multiply result be placed in the register file instead of the HI/LO register pair. By avoiding the explicit move from the LO (MFLO) instruction (required when using the LO register) and by supporting multiple destination registers, the throughput of multiply-intensive operations is increased.

Two instructions, multiply-add (MADD/MADDU) and multiply-subtract (MSUB/MSUBU), are used to perform the multiply-add and multiply-subtract operations. The MADD instruction multiplies two numbers and then adds the product to the current contents of the HI and LO registers. Similarly, the MSUB instruction multiplies two operands and then subtracts the product from the HI and LO registers. The MADD/MADDU and MSUB/MSUBU operations are commonly used in Digital Signal Processor (DSP) algorithms.

System Control Coprocessor (CP0)

In the MIPS architecture, CP0 is responsible for the virtual-to-physical address translation, cache protocols, the exception control system, the processor's diagnostics capability, operating mode selection (kernel vs. user mode), and the enabling/disabling of interrupts. Configuration information, such as cache size, set associativity, and EJTAG debug features, is available by accessing the CP0 registers. Additional information on CP0 registers can be found in the CP0 Registers section. Additional information on EJTAG can be found in Chapter 20.

Memory Management Unit (MMU)

Each core contains an MMU that interfaces between the execution unit and the cache controller, shown in Figure 2.1. Although the 4Kc core implements a 32-bit architecture, the Memory Management Unit (MMU) is modeled after the MMU found in the 64-bit R4000 family, as defined by the MIPS32 architecture.

The 4Kc core implements an MMU based on a Translation Lookaside Buffer (TLB). The TLB actually consists of three translation buffers: a 16 dual-entry fully associative Joint TLB (JTLB), a 3-entry fully associative Instruction TLB (ITLB), and a 3-entry fully associative data TLB(DTLB). The ITLB and DTLB, also referred to as the micro TLBs, are managed by the hardware and are not software visible. The micro TLBs contain subsets of the JTLB. When translating addresses, the corresponding micro TLB (I or D) is accessed first. If there is no matching entry, the JTLB is used to translate the address and refill the micro TLB. If the entry is not found in the JTLB, an exception is taken. To minimize the micro TLB miss penalty, the JTLB is looked-up in parallel with the DTLB for data references. This results in a 1 cycle stall for a DTLB miss and a 2 cycle stall for an ITLB miss.

Figure 2.2 shows how the ITLB, DTLB, and JTLB are used in the 4Kc core.

Notes

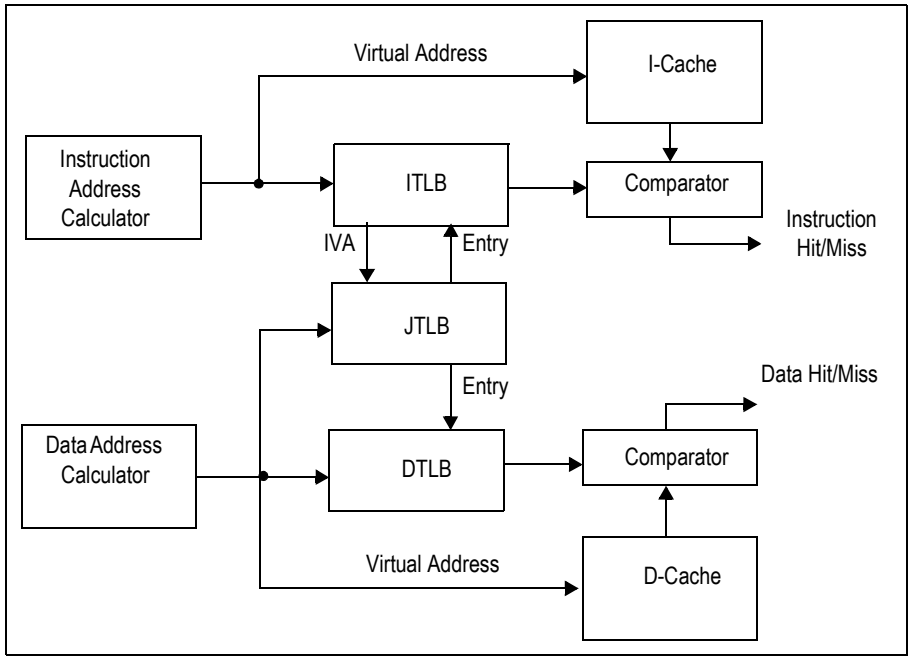


Figure 2.2 Address Translation During a Cache Access in the 4Kc Core

Cache Controller

The data and instruction cache controllers support 16KB 4-way set associative caches. There are separate cache controllers for the I-Cache and D-Cache.

Each cache controller contains and manages a one-line fill buffer. Besides accumulating data to be written to the cache, the fill buffer is accessed in parallel with the cache and data can be bypassed back to the core.

Bus Interface Unit (BIU)

The Bus Interface Unit (BIU) controls the external interface signals. It also contains the implementation of a 32-byte collapsing write-buffer. The purpose of this buffer is to hold and combine write transactions before issuing them to the external interface. Since the data caches for all cores follow a write-through cache policy, the write-buffer significantly reduces the number of write transactions on the external interface, as well as reducing the amount of stalling in the core due to issuance of multiple writes in a short period of time.

The write-buffer is organized as two 16-byte buffers. Each buffer contains data from a single 16-byte aligned block of memory. One buffer contains the data currently being transferred on the external interface, while the other buffer contains accumulating data from the core.

Power Management

The 4Kc processor core offers a number of power management features, including low-power design, active power management, and power-down modes of operation. This core is a static design that supports a WAIT instruction designed to signal the rest of the device that execution and clocking should be halted, thereby reducing system power consumption during idle periods.

The 4Kc core provides two mechanisms for system-level, low-power support:

Register-controlled power management

Instruction-controlled power management

Notes

In register-controlled power management mode, the 4Kc core provides three bits in the CP0 Status register for software control of the power management function and allows interrupts to be serviced even when the core is in power-down mode. In instruction-controlled power-down mode, execution of the WAIT instruction is used to invoke low-power mode.

For additional information on power management, refer to the Power Management section.

Instruction Cache

The instruction cache is 16 Kbytes in size. The cache is virtually indexed and physically tagged, allowing the virtual-to-physical address translation to occur in parallel with the cache access rather than having to wait for the physical address translation. The tag holds 22 bits of the physical address, 4 valid bits, a lock bit, and the LRF (Least Recently Filled) replacement bit.

All cores support instruction cache locking. Cache locking allows critical code to be locked into the cache on a per-line basis, enabling the system designer to maximize the efficiency of the system cache. Cache locking is always available on all instruction cache entries. Entries can be marked as locked or unlocked (by setting or clearing the lock-bit) on a per-entry basis using the CACHE instruction.

Data Cache

The data cache is 16-Kbytes in size. The cache is virtually indexed and physically tagged, allowing the virtual-to-physical address translation to occur in parallel with the cache access. The tag holds 22 bits of the physical address, 4 valid bits, a lock bit, and the LRF replacement bit.

In addition to instruction cache locking, all cores also support a data cache locking mechanism identical to the instruction cache, with critical data segments to be locked into the cache on a per-line basis. The locked contents cannot be selected for replacement on a cache miss, but can be updated on a store hit.

Cache locking is always available on all data cache entries. Entries can be marked as locked or unlocked on a per-entry basis using the CACHE instruction.

The physical data cache memory must be byte-writable to support non-word store operations.

EJTAG Controller

All cores provide basic EJTAG support with debug mode, run control, single step and software breakpoint instruction (SDBBP) as part of the core. These features allow for the basic software debug of user and kernel code.

Optional EJTAG features include hardware breakpoints. A 4K core may have four instruction breakpoints and two data breakpoints, two instruction breakpoints and one data breakpoint, or no breakpoints. The hardware instruction breakpoints can be configured to generate a debug exception when an instruction is executed anywhere in the virtual address space. Bit mask and address space identifier (ASID) values may apply in the address compare. These breakpoints are not limited to code in RAM like the software instruction breakpoint (SDBBP). The data breakpoints can be configured to generate a debug exception on a data transaction. The data transaction may be qualified with both virtual address, data value, size, and load/store transaction type. Bit mask and ASID values may apply in the address compare, and byte mask may apply in the value compare.

An optional Test Access Port (TAP), which provides for the communication from an EJTAG probe to the CPU through a dedicated port, may also be applied to the core. This provides the possibility for debugging without debug code in the application and for download of application code to the system.

For additional information on the EJTAG controller, refer to Chapter 20, EJTAG System.

Pipeline Description

The MIPS32 4Kc processor core implements a 5-stage pipeline similar to the original R3000 pipeline. The five stages are:

Instruction (I stage)

Execution (E stage)

Notes

Memory (M stage)

Align/Accumulate (A stage)

Writeback (W stage)

This pipeline allows the processor to achieve high frequency while minimizing device complexity, reducing both cost and power consumption. The 4Kc core implements a “Bypass” mechanism that allows the result of an operation to be sent directly to the instruction that needs it without having to write the result to the register and then read it back.

Figure 2.3 shows the operations performed in each pipeline stage of the 4Kc processor.

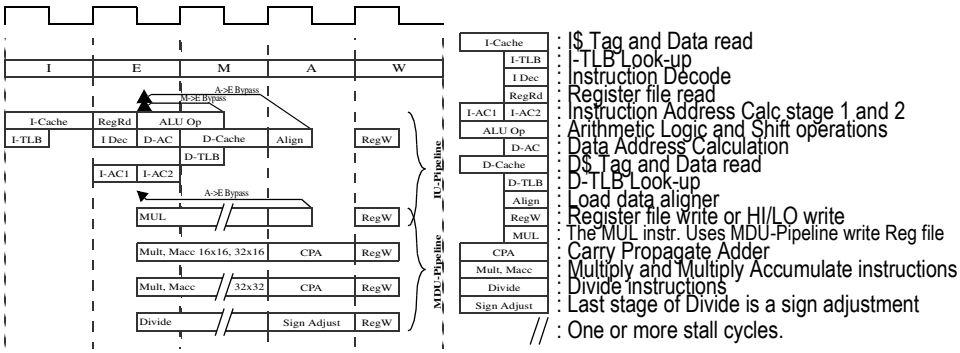


Figure 2.3 4Kc Core Pipeline Stages

During the Instruction fetch stage:

An instruction is fetched from the instruction cache

The ITLB performs a virtual-to-physical address translation.

During the Execution stage:

Operands are fetched from the register file

Operands from M and A stage are bypassed to this stage

The Arithmetic Logic Unit (ALU) begins the arithmetic or logical operation for register-to-register instructions

The ALU calculates the data virtual address for load and store instructions

The ALU determines whether the branch condition is true and calculates the virtual branch target address for branch instructions

Instruction logic selects an instruction address

All multiply and divide operations begin in this stage.

During the Memory Fetch stage:

The arithmetic or logic ALU operation completes

The data cache fetch and the data virtual-to-physical address translation are performed for load and store instructions

Data TLB and data cache lookup are performed and a hit/miss determination is made

A 16x16 or 32x16 MUL operation completes in the array and stalls for one clock in the M stage to complete the carry-propagate-add in the M stage

A 32x32 MUL operation stalls for two clocks in the M stage to complete second cycle of the array and the carry-propagate-add in the M stage

A 16x16 or 32x16 MULT/MADD/MSUB operation completes in the array

A 32x32 MULT/MADD/MSUB operation stalls for one clock in the MMDU stage of the MDU pipeline to complete second cycle in the array

Notes

A divide operation stalls for a maximum of 32 clocks in the MMDU stage of the MDU pipeline.

During the Align/Accumulate stage:

A separate aligner aligns loaded data with its word boundary

A MUL operation makes the result available for writeback. The actual register writeback is performed in the W stage

A MULT/MADD/MSUB operation performs the carry-propagate-add. This includes the accumulate step for the MADD/MSUB operations. The actual register writeback to HI and LO is performed in the W stage.

A divide operation perform the final Sign-Adjust. The actual register writeback to HI and LO is performed in the W stage.

During the Writeback stage:

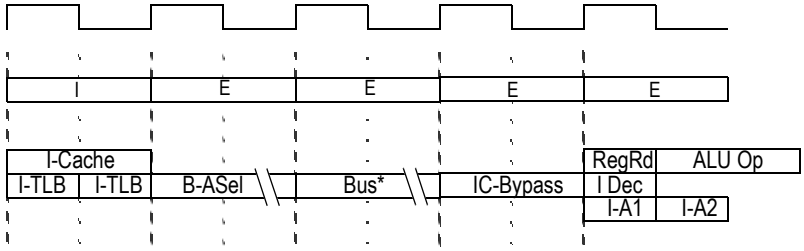
For register-to-register or load instructions, the result is written back to the register file during the W stage.

Instruction Cache Miss

When the instruction cache is indexed, the instruction address is translated to determine if the required instruction resides in the cache. An instruction cache miss occurs when the requested instruction address does not reside in the instruction cache. When a cache miss is detected in the I stage, the core transitions to the E stage. The pipeline stalls in the E stage until the miss is resolved. The bus interface unit must select the address from multiple sources. If the address bus is busy, the request will remain in this arbitration stage (B-ASel in Figure 2.4) until the bus is available. The core drives the selected address onto the bus. The number of clocks required to access the bus is determined by the access time of the array that contains the data. The number of clocks required to return the data once the bus is accessed is also determined by the access time of the array.

Once the data is returned to the core, the critical word is written to the instruction register for immediate use. The bypass mechanism allows the core to use the data once it becomes available, as opposed to having the entire cache line written to the instruction cache, then reading out the required word.

Figure 2.4 shows a timing diagram of an instruction cache miss for the 4Kc core.



* Contains all of the cycles that address and data are utilizing the bus.

Figure 2.4 4Kc Instruction Cache Miss Timing

When the data cache is indexed, the data address is translated to determine if the required data resides in the cache. A data cache miss occurs when the requested data address does not reside in the data cache.

When a data cache miss is detected in the M stage (D-TLB), the core transitions to the A stage. The pipeline stalls in the A stage until the miss is resolved (requested data is returned). The bus interface unit arbitrates between multiple requests and selects the correct address to be driven onto the bus (B-ASel in Figure 2.5). The core drives the selected address onto the bus. The number of clocks required to access the bus is determined by the access time of the array containing the data. The number of clocks required to return the data once the bus is accessed is also determined by the access time of the array.

Notes

Once the data is returned to the core, the critical word of data passes through the aligner before being forwarded to the execution unit and register file. The bypass mechanism allows the core to use the data once it becomes available, as opposed to having the entire cache line written to the data cache, then reading out the required word.

Figure 2.5 shows a timing diagram of a data cache miss for the 4Kc core.

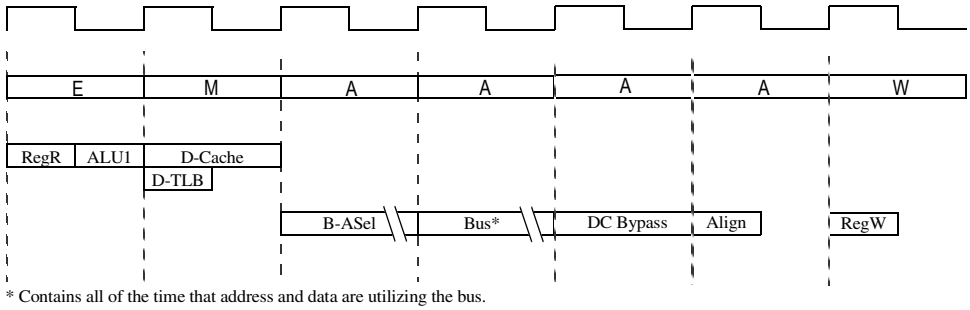


Figure 2.5 Load/Store Cache Miss Timing

Multiply/Divide Operations

The 4Kc core implements the standard MIPS II™ multiply and divide instructions. In addition, several new instructions have been added that enhance the core's performance.

The targeted multiply instruction, MUL, specifies that multiply results are placed in the general purpose register file instead of the HI/LO register pair. By avoiding the explicit MFLO instruction, required when using the LO register, and by supporting multiple destination registers, the throughput of multiply-intensive operations is increased.

Four instructions — multiply-add (MADD), multiply-add-unsigned (MADDU), multiply-subtract (MSUB), and multiply-subtract-unsigned (MSUBU) — are used to perform the multiply-accumulate and multiply-subtract operations. The MADD/MADDU instruction multiplies two numbers and then adds the product to the current contents of the HI and LO registers. Similarly, the MSUB/MSUBU instruction multiplies two operands and then subtracts the product from the HI and LO registers. The MADD/MADDU and MSUB/MSUBU operations are commonly used in DSP algorithms.

All multiply operations (except the MUL instruction) write to the HI/LO register pair. All integer operations write to the general purpose registers (GPR). Because MDU operations write to different registers than integer operations, integer instructions that follow MDU operations can execute before the MDU operation has finished. The MFLO and MFHI instructions are used to move data from the HI/LO register pair to the GPR file. If a MFLO or MFHI instruction is issued before the MDU operation finishes, the instruction will stall to wait for the data.

MDU Pipeline

The 4Kc processor core contains an autonomous multiply/divide unit (MDU) with a separate pipeline for multiply and divide operations. This pipeline operates in parallel with the integer unit (IU) pipeline and does not stall when the IU pipeline stalls. This allows long-running MDU operations, such as a divide, to be partially masked by system stalls and/or other integer unit instructions.

The MDU consists of a 32x16 booth encoded multiplier, result/accumulation registers (HI and LO), a divide state machine, and all necessary multiplexers and control logic. The first number shown ('32' of 32x16) represents the rs operand. The second number ('16' of 32x16) represents the rt operand. The core only checks the latter (rt) operand value to determine how many times the operation must pass through the multiplier. The 16x16 and 32x16 operations pass through the multiplier once. A 32x32 operation passes through the multiplier twice.

Notes

The MDU supports execution of a 16x16 or 32x16 multiply operation every clock cycle; 32x32 multiply operations can be issued every other clock cycle. Appropriate interlocks are implemented to stall the issue of back-to-back 32x32 multiply operations. Multiply operand size is automatically determined by logic built into the MDU. Divide operations are implemented with a simple 1 bit per clock iterative algorithm with an early in detection of sign extension on the dividend (rs). Any attempt to issue a subsequent MDU instruction while a divide is still active causes an IU pipeline stall until the divide operation is completed.

Table 2.1 lists the latencies (number of cycles until a result is available) for multiply and divide instructions. The latencies are listed in terms of pipeline clocks. In this table "latency" refers to the number of cycles necessary for the first instruction to produce the result needed by the second instruction.

Operand Size of 1st Instruction[1]	Instruction Sequence		Latency Clocks
	1st Instruction	2nd Instruction	
16 bit	MULT/MULTU, MADD/ MADDU, or MSUB/ MSUBU	MADD/MADDU, MSUB/ MSUBU, or MFHI/MFLO	1
32 bit	MULT/MULTU, MADD/ MADDU, or MSUB/ MSUBU	MADD/MADDU, MSUB/ MSUBU, or MFHI/MFLO	2
16 bit	MUL	Integer operation[2]	2[3]
32 bit	MUL	Integer operation[2]	2[3]
8 bit	DIVU	MFHI/MFLO	9
16 bit	DIVU	MFHI/MFLO	17
24 bit	DIVU	MFHI/MFLO	25
32 bit	DIVU	MFHI/MFLO	33
8 bit	DIV	MFHI/MFLO	10[4]
16 bit	DIV	MFHI/MFLO	18[4]
24 bit	DIV	MFHI/MFLO	26[4]
32 bit	DIV	MFHI/MFLO	34[4]
any	MFHI/MFLO	Integer operation[2]	2
any	MTHI/MTLO	MADD/MADDU or MSUB/MSUBU	1

Table 2.1 4Kc Core Instruction Latencies

1. For multiply operations, this is the rt operand. For divide operations, this is the rs operand.
2. Integer operation refers to any integer instruction that uses the result of a previous MDU operation.
3. This does not include the 1 or 2 IU pipeline stalls (16 bit or 32 bit) that MUL operation causes regardless of the following instruction. These stalls do not add to the latency of 2.
4. If both operands are positive, the Sign Adjust stage is bypassed. Latency is then the same as for DIVU.

In Table 2.1, a latency of one means that the first and second instruction can be issued back to back in the code without the MDU causing any stalls in the IU pipeline. A latency of two means that if the instructions are issued back to back, the IU pipeline will be stalled for one cycle. An MUL operation is special because it needs to stall the IU pipeline in order to maintain its register file write slot. Consequently, the MUL 16x16 or 32x16 operation will always force a one cycle stall of the IU pipeline, and the MUL 32x32 will force a two cycle stall. If the integer instruction immediately following the MUL operation uses its (MUL operation) result, an additional stall is forced on the IU pipeline.

Notes

Table 2.2 lists the repeat rates (peak issue rate of cycles until the operation can be reissued) for multiply accumulate/subtract instructions. The repeat rates are listed in terms of pipeline clocks. In this table "repeat rate" refers to the case where the first MDU instruction is back to back with the second instruction.

Operand Size of 1st Instruction	Instruction Sequence		Repeat Rate
	1st Instruction	2nd Instruction	
16 bit	MULT/MULTU, MADD/MADDU, MSUB/MSUBU	MADD/MADDU, MSUB/MSUBU	1
32 bit	MULT/MULTU, MADD/MADDU, MSUB/MSUBU	MADD/MADDU, MSUB/MSUBU	2

Table 2.2 4Kc Core Instruction Repeat Rates

The 32x16 multiply operation requires one clock of each pipeline stage to complete. The 32x32 requires two clocks in the MMDU pipe-stage. The MDU pipeline is shown as the shaded areas of Figure 2.6 and always starts a computation in the final phase of the E stage. As shown in Figure 2.6, the MMDU pipe-stage of the MDU pipeline occurs in parallel with the M stage of the IU pipeline, the AMDU stage occurs in parallel with the A stage, and the WMDU stage occurs in parallel with the W stage. However, in case the instruction in the MDU pipeline needs multiple passes through the same MDU stage, this parallel behavior will be skewed by one or more clocks. This is not a problem because results in the MDU pipeline are written to HI and LO registers, while the integer pipeline results are written to the register file.

Figure 2.6 shows the pipeline flow for the following sequence:

32x16 multiply (Mult1)

Add

32x32 multiply (Mult2)

Sub

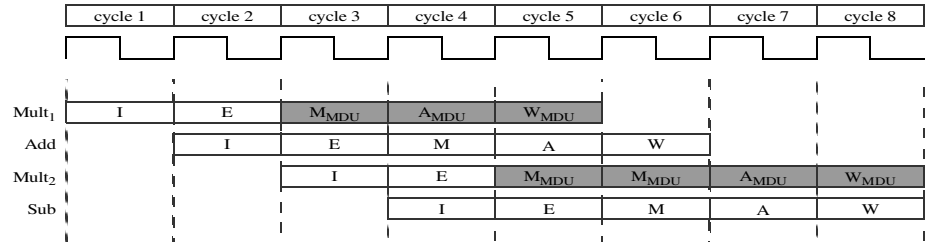


Figure 2.6 MDU Pipeline Behavior During Multiply Operations

Notes

The following is a cycle-by-cycle analysis of Figure 2.6.

1. The first 32x16 multiply operation (Mult1) enters the I stage and is fetched from the instruction cache.
2. An Add operation enters the I stage. The Mult1 operation enters the E stage. The integer and MDU pipelines share the I and E pipeline stages. At the end of the E stage in cycle 2, the multiply operation (Mult1) is passed to the MDU pipeline.
3. In cycle 3 a 32x32 multiply operation (Mult2) enters the I stage and is fetched from the instruction cache. Since the Add operation has not yet reached the M stage by cycle 3, there is no activity in the M stage of the integer pipeline at this time.
4. In cycle 4 the Sub instruction enters I stage. The second multiply operation (Mult2) enters the E stage. And the Add operation enters M stage of the integer pipe. Since the Mult1 multiply is a 32x16 operation, only one clock is required for the MMDU stage, hence the Mult1 operation passes to the AMDU stage of the MDU pipeline.
5. In cycle 5 the Sub instruction enters E stage. The Mult2 multiply enters the MMDU stage. The Add operation enters the A stage of the integer pipeline. The Mult1 operation completes and is written back in to the HI/LO register pair in the WMDU stage.
6. Since a 32x32 multiply requires two passes through the multiplier, with each pass requiring one clock, the 32x32 Mult2 remains in the MMDU stage in cycle 6. The Sub instruction enters M stage in the integer pipeline. The Add operation completes and is written to the register file in the W stage of the integer pipeline.
7. The Mult2 multiply operation progresses to the AMDU stage, and the Sub instruction progress to A stage.
8. The Mult2 operation completes and is written to the HI/LO registers pair the WMDU stage, while the Sub instruction write to the register file in W stage.

32x16 Multiply

The 32x16 multiply operation begins in the last phase of the E stage, which is shared between the integer and MDU pipelines. In the latter phase of the E stage, the rs and rt operands arrive and the booth recoding function occurs at this time. The multiply calculation requires one clock and occurs in the MMDU stage. In the AMDU stage, the carry-propagate-add function occurs and the operation is completed. The result is written back to the HI/LO register pair in the first half of the WMDU stage.

Figure 2.7 shows a diagram of a 32x16 multiply operation.

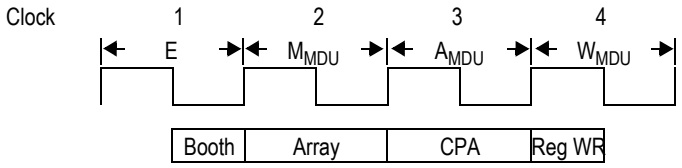


Figure 2.7 MDU Pipeline Flow During a 32x16 Multiply Operation

32x32 Multiply

The 32x32 multiply operation begins in the last phase of the E stage, which is shared between the integer and MDU pipelines. In the latter phase or the E stage, the rs and rt operands arrive and the booth recoding function occurs at this time. The multiply calculation requires two clocks and occurs in the MMDU stage. In the AMDU stage, the carry-propagate-add (CPA) function occurs and the operation is completed. The result is written back to the HI/LO register pair in the first half of the WMDU stage.

Figure 2.8 shows a diagram of a 32x32 multiply operation.

Notes

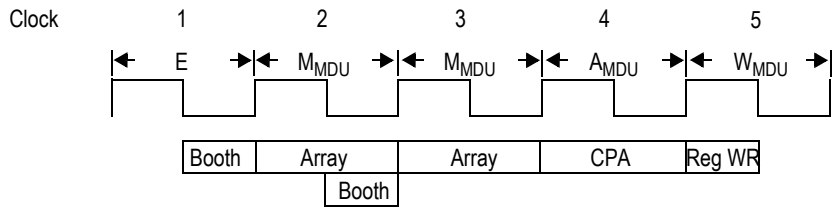


Figure 2.8 MDU Pipeline Flow During a 32x32 Multiply Operation

Divide Operations

Divide operations are implemented using a simple non-restoring division algorithm. This algorithm works only for positive operands, thus the first cycle of the MMDU stage is used to negate the rs operand (RS Adjust) if needed. Note that this cycle is executed even if the adjustment is not necessary. At maximum, the next 32 clocks (3-34) execute an iterative add/subtract function. In cycle 3, an early in detection is performed in parallel with the add/subtract. The adjusted rs operand is detected to be zero extended on the upper most 8, 16, or 24 bits. If this is the case the following 7, 15, or 23 cycles of the add/subtract iterations are skipped.

The remainder adjust (Rem Adjust) cycle is required if the remainder was negative. Note that this cycle is taken even if the remainder was positive. A sign adjust is performed on the quotient and/or remainder if necessary. Note that the sign adjust cycle is skipped if both operands are positive. In this case the Rem Adjust is moved to the AMDU stage.

Figures 2.9 through 2.12 show the latency for 8, 16, 24, and 32-bit divide operations, respectively. The repeat rate is either 11, 19, 27, or 35 cycles (one less if the Sign Adjust stage is skipped) since a second divide can be in the RS Adjust stage when the first divide is in the Reg WR stage.

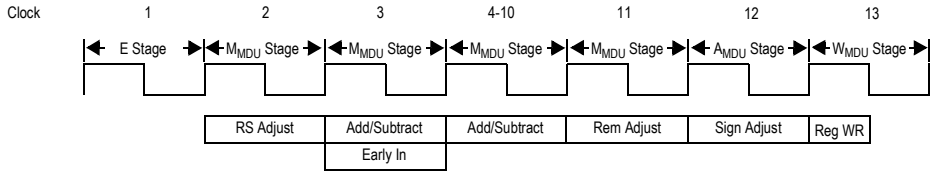


Figure 2.9 MDU Pipeline Flow During an 8-bit Divide (DIV) Operation

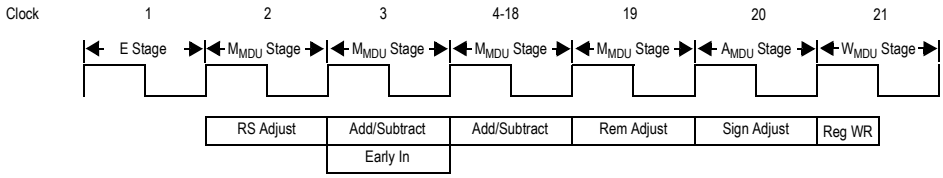


Figure 2.10 MDU Pipeline Flow During a 16-bit Divide (DIV) Operation

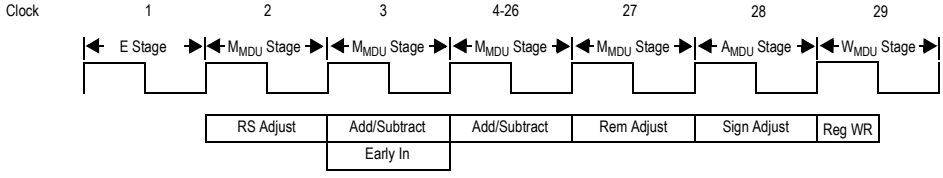


Figure 2.11 MDU Pipeline Flow During a 24-bit Divide (DIV) Operation

Notes

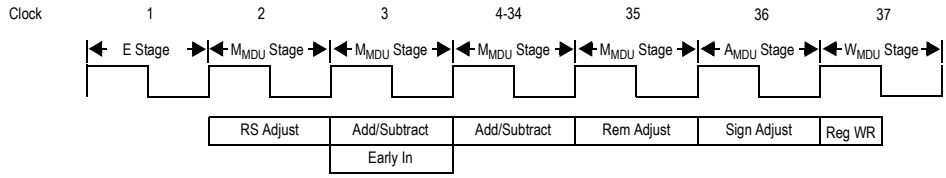


Figure 2.12 MDU Pipeline Flow During a 32-bit Divide (DIV) Operation

Branch Delay

The pipeline has a branch delay of one cycle. The one-cycle branch delay is a result of the branch decision logic operating during the E pipeline stage. This allows the branch target address calculated in the previous stage to be used for the instruction access in the following E stage. The branch delay slot means that no bubbles are injected into the pipeline on branch instructions. The address calculation and branch condition check are both performed in the E stage. The target PC is used for the next instruction in the I stage (2nd instruction after the branch).

The pipeline begins the fetch of either the branch path or the fall-through path in the cycle following the delay slot. After the branch decision is made, the processor continues with the fetch of either the branch path (for a taken branch) or the fall-through path (for the non-taken branch).

The branch delay means that the instruction immediately following a branch is always executed, regardless of the branch direction. If no useful instruction can be placed after the branch, then the compiler or assembler must insert a NOP instruction in the delay slot.

Figure 2.13 illustrates the branch delay.

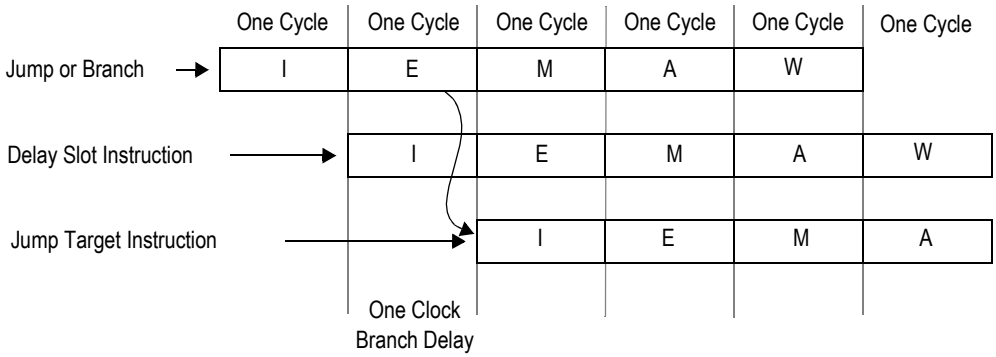


Figure 2.13 IU Pipeline Branch Delay

Data Bypassing

Most MIPS32 instructions use one or two register values as source operands for the execution. These operands are fetched from the register file in the first part of E stage. The ALU straddles the E to M boundary, and can present the result early in M stage. However, the result is not written in the register file until W stage. This leaves following instructions unable to use the result for 3 cycles. To overcome this problem, Data bypassing is used.

Between the register file and the ALU, a data bypass multiplexer is placed on both operands (see Figure 2.14). This enables the 4K core to forward data from preceding instructions which have the target register of the first instruction as one of the source operands. An M to E bypass and an A to E bypass feed the bypass multiplexers. A W to E bypass is not needed, as the register file is capable of making an internal bypass of Rd write data directly to the Rs and Rt read ports.

Notes

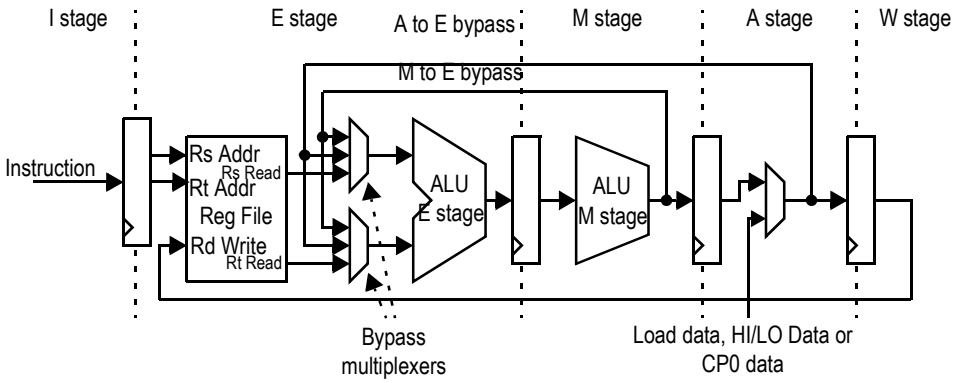


Figure 2.14 IU Pipeline Data Bypass

Figure 2.15 shows the Data bypass for an Add1 instruction followed by a Sub2 and another Add3 instruction. The Sub2 instruction uses the output from the Add1 instruction as one of the operands, and thus the M to E bypass is used. The following Add3 uses the result from both the first Add1 instruction and the Sub2 instruction. Since the Add1 data is now in A stage, the A to E bypass is used, and the M to E bypass is used to bypass the Sub2 data to the Add2 instruction.

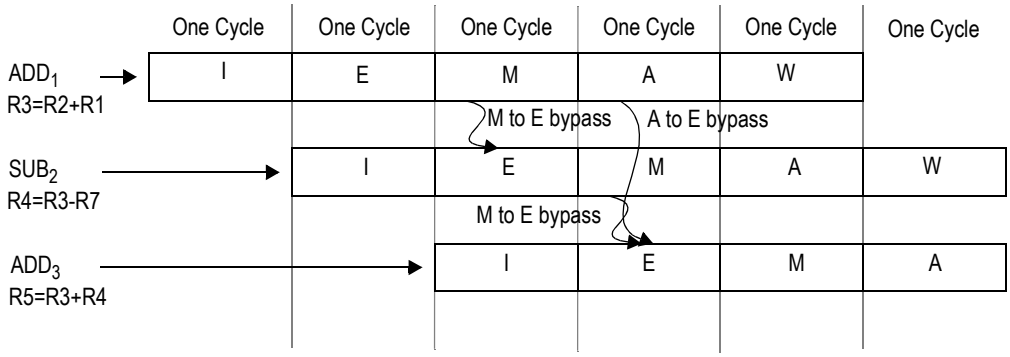


Figure 2.15 IU Pipeline M to E Bypass

Load Delay

Load delay means that data fetched by a load instruction is not available in the integer pipeline until after the load aligner is in A stage. All instructions need the source operands available in E stage. An instruction immediately following a load instruction will, if it has the same source register as the target of the load, cause an instruction interlock pipeline slip in E stage (see the Instruction Interlocks section). If the second instruction after the load (not the first instruction), uses the data from the load, the A to E bypass exists to provide for stall free operation (refer to Figure 2.14). An instruction flow of this is shown in Figure 2.16.

Notes

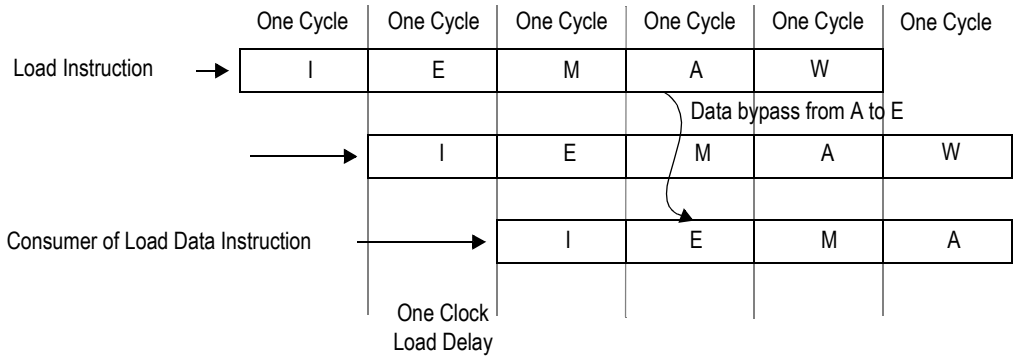


Figure 2.16 IU Pipeline A to E Data Bypass

Move from HI/LO and CP0 Delay

As indicated in Figure 2.14, not only load data but also data from a move from the HI or LO register instruction (MFHI/MFLO) or a move from CP0 (MFC0) can enter the IU-Pipeline in A stage. That is, data is not available in the integer pipeline until early in the A stage. The A to E bypass is available for this data. But as for Loads, the instruction immediately following one of these instructions can not use this data right away. If it does, it will cause an instruction interlock slip in E stage (refer to the Instruction Interlocks section). An interlock slip after an MFHI is illustrated in Figure 2.17.

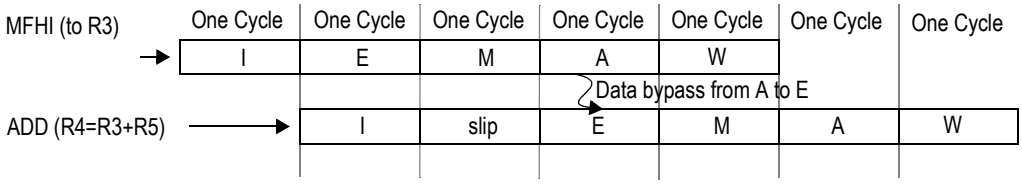


Figure 2.17 IU Pipeline Slip after MFHI

Interlock Handling

Smooth pipeline flow is interrupted when cache misses occur or when data dependencies are detected. Interruptions handled using hardware, such as cache misses, are referred to as interlocks. At each cycle, interlock conditions are checked for all active instructions.

Table 2.3 lists the types of pipeline interlocks for the 4Kc processor core.

Interlock Type	Source	Slip Stage
ITLB Miss	Instruction TLB	I Stage
ICache Miss	Instruction cache	E Stage
Instructions	Producer-consumer hazards	E/M Stage
	Hardware Dependencies (MDU/TLB)	E Stage
DTLB Miss	Data TLB	M Stage

Table 2.3 Pipeline Interlocks (Part 1 of 2)

Notes

Interlock Type	Source	Slip Stage
Data Cache Miss	Load that misses in data cache	W Stage
	Multi-cycle cache Op	
	Sync	
	Store when write through buffer full	
	EJTAG breakpoint on store	
	VA match needing data value comparison	
	Store hitting in fill buffer	

Table 2.3 Pipeline Interlocks (Part 2 of 2)

In general, MIPS processors support two types of hardware interlocks:

Stalls, which are resolved by halting the pipeline

Slips, which allow one part of the pipeline to advance while another part of the pipeline is held static.

The 4Kc processor core handles all interlocks as slips.

Slip Conditions

On every clock, internal logic determines whether each pipe stage is allowed to advance. These slip conditions propagate backwards down the pipe. For example, if the M stage does not advance, neither will the E or I stages. Slipped instructions are retried on subsequent cycles until they issue. The back end of the pipeline advances normally during slips in an attempt to resolve the conflict. NOPS are inserted into the bubble in the pipeline.

Figure 2.18 shows a diagram of a two-cycle slip. In the first clock cycle, the pipeline is full and the cache miss is detected. Instruction I0 is in the A stage, instruction I1 is in the M stage, instruction I2 is in the E stage, and instruction I3 is in the I stage. The cache miss occurs in clock 2 when the I4 instruction fetch is attempted. I4 advances to the E-stage and waits for the instruction to be fetched from main memory. In this example it takes two clocks (3 and 4) to fetch the I4 instruction from memory. Once the cache miss is resolved in clock 4 and the instruction is bypassed to the cache, the pipeline is restarted, causing the I4 instruction to finally execute it's E-stage operations.

Notes

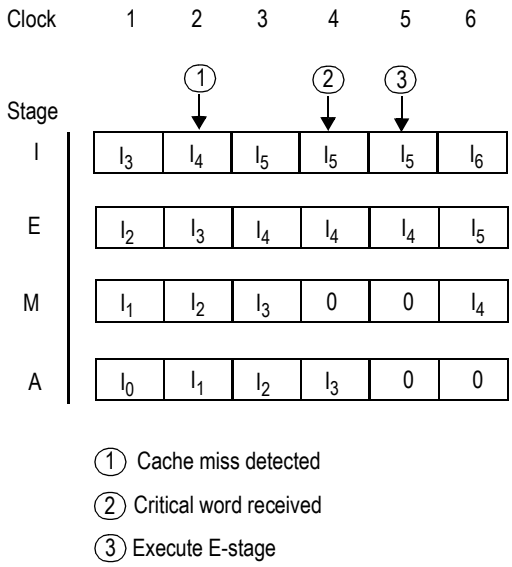


Figure 2.18 Instruction Cache Miss Slip

Instruction Interlocks

Most instructions can be issued at a rate of one per clock cycle. In some cases, in order to ensure a sequential programming model, the issue of an instruction is delayed to ensure that the results of a prior instruction will be available. Table 2.4 details the instruction interactions that delay the issuance of an instruction into the processor pipeline.

1st Instruction		2nd Instruction	Issue Delay (in Clock Cycles)	Slip Stage
LB/LBU/LH/LHU/LL/LW/LWL/LWR		Consumer of load data	1	E stage
MFC0		Consumer of destination register	1	E stage
MULT/MADD/ MSUB	16x32b	MFLO/MFHI	0	M stage
	32x32b		1	M stage
MUL	16x32b	Consumer of target data	2	E stage
	32x32b		3	E stage
MUL	16x32b	Non-Consumer of target data	1	E stage
	32x32b		2	E stage
MFHI and MFLO		Consumer of target data	1	E stage
MULT/MADD/ MSUB	16x32b	MULT/MUL/MADD/ MSUB/MTHI/MTLO/DIV	0	E stage
	32x32b		1	E stage
DIV		MULT/MUL/MADD/ MSUB/MTHI/MTLO/ MFHI/MFLO/DIV	Until DIV completes	E stage

Table 2.4 Instruction Interlocks (Part 1 of 2)

Notes

1st Instruction	2nd Instruction	Issue Delay (in Clock Cycles)	Slip Stage
MFC0	Consumer of target data	1	E stage
TLBWR/TLBWI	Load/Store/PREF/ CACHE/Cop0 op	2	E stage
TLBR		1	E stage

Table 2.4 Instruction Interlocks (Part 2 of 2)

Instruction Hazards

In general, the core ensures that instructions are executed following a fully sequential program model. Each instruction in the program sees the results of the previous instruction. There are some exceptions to this model. These exceptions are referred to as instruction hazards.

Table 2.5 shows the instruction hazards that exist in the core. The first and second instruction fields indicate the combination of instructions that do not ensure a sequential programming model. The Spacing field indicates the number of unrelated instructions (such as NOPs or SSNOPs) that should be placed between the first and second instructions of the hazard in order to ensure that the effects of the first instruction are seen by the second instruction. Entries in the table that are listed as 0 are traditional MIPS hazards which are not hazards on the 4Kc core. (MT Compare to Timer Interrupt cleared is system dependent since Timer Interrupt is an output of the core that can be returned to the core on one of the SI_Int pins. This number is the minimum time due its passage through the core's I/O registers. Typical implementations will not add any latency to this).

1st Instruction	2nd Instruction	Spacing (Instructions)
Watch Register Write	Instruction Fetch Matching Watch Register	2
	Load/Store Reference Matching Watch Register	0
TLBWI/TLBWR	Instruction fetch affected by new page mapping	3
	Load/Store affected by new page mapping	0
	TLBP/TLBR	0
TLBR	Move from Coprocessor Zero Register	0
Move to EntryHi	TLBWR/TLBWI/TLBP	1
Move to EntryLow0 or EntryLo1	TLBWR/TLBWI	0
Move to EntryHi	Load/Store affected by new ASID	1
Move to EntryHi	Instruction fetch affected by new ASID	3
TLBP	Move from Coprocessor Zero Register	0
Move to Index Register	TLBR/TLBWI	1

Table 2.5 Instruction Hazards (Part 1 of 2)

Notes

1st Instruction	2nd Instruction	Spacing (Instructions)
Change to CU Bits in Status Register	Coprocessor Instruction	1
Move to EPC, ErrorPC, or DEPC	ERET	1
Move to Status Register	ERET	0
Set of IP in Cause Register	Interrupted Instruction	3
Any Other Move to Coprocessor 0 Registers	Instruction Affected by Change	2
CACHE instruction operating on I$	Instruction fetch seeing new cache state	3
LL	Move From LLAddr	1
Move to Compare	Instruction not seeing Timer Interrupt	4[1]

Table 2.5 Instruction Hazards (Part 2 of 2)

1. This is the minimum value. Actual value is system-dependent since it is a function of the sequential logic between the SI-TimerInt output and the external logic which feeds SI-TimerInt back into one of the SI_Int inputs.

Memory Management

The MMU in a 4Kc processor core will translate any virtual address to a physical address before a request is sent to the cache controllers for tag comparison or to the bus interface unit for an external memory reference. This translation is a very useful feature for operating systems when trying to manage physical memory to accommodate multiple tasks active in the same memory, possibly on the same virtual address but of course in different locations in physical memory. Other features handled by the MMU are protection of memory areas and defining the cache protocol.

In the 4Kc processor core, the MMU is TLB based. The TLB consists of three address translation buffers: a 16 dual-entry fully associative Joint TLB (JTLB), a 3-entry instruction micro TLB (ITLB), and a 3-entry data micro TLB (DTLB). When an address is translated, the appropriate micro TLB (ITLB or DTLB) is accessed first. If the translation is not found in the micro TLB, the JTLB is accessed. If there is a miss in the JTLB, an exception is taken.

Figure 2.19 shows how the memory management unit interacts with cache accesses in the 4Kc core.

Notes

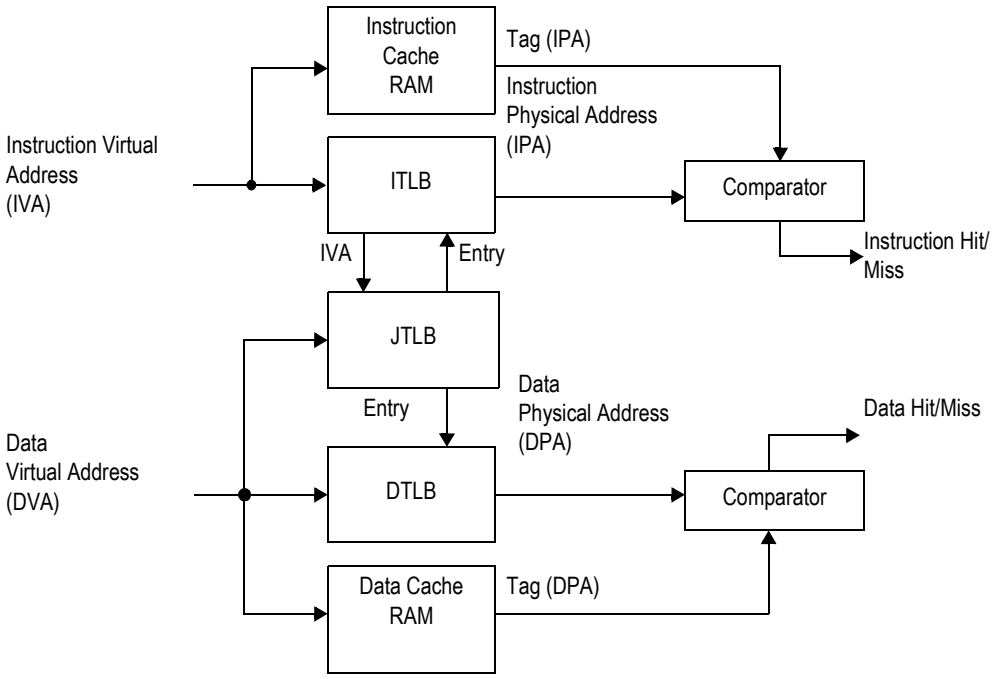


Figure 2.19 Address Translation During a Cache Access

Modes of Operation

The 4Kc processor core supports three modes of operation:

User mode

Kernel mode

Debug mode

User mode is most often used for application programs. Kernel mode is typically used for handling exceptions and privileged operating system functions, including CP0 management and I/O device accesses. Debug mode is used for software debugging and most likely occurs within a software development tool. The address translation performed by the MMU depends on the mode in which the processor is operating.

Virtual Memory Segments

The Virtual memory segments are different depending on the mode of operation. Figure 2.20 shows the segmentation for the 4 GByte (2^{32} bytes) virtual memory space addressed by a 32-bit virtual address, for the three modes of operation.

The core enters Kernel mode both at reset and when an exception is recognized. While in Kernel mode, software has access to the entire address space, as well as all CP0 registers. User mode accesses are limited to a subset of the virtual address space (0x0000_0000 to 0x7FFF_FFFF) and can be inhibited from accessing CP0 functions. In User mode, virtual addresses 0x8000_0000 to 0xFFFF_FFFF are invalid and cause an exception if accessed.

Debug mode is entered on a debug exception. While in Debug mode, the debug software has access to the same address space and CP0 registers as for Kernel mode. In addition, while in Debug mode the core has access to the debug segment dseg. This area overlays part of the kernel segment kseg3. dseg access in Debug mode can be turned on or off, allowing full access to the entire kseg3 in Debug mode, if so desired.

Notes

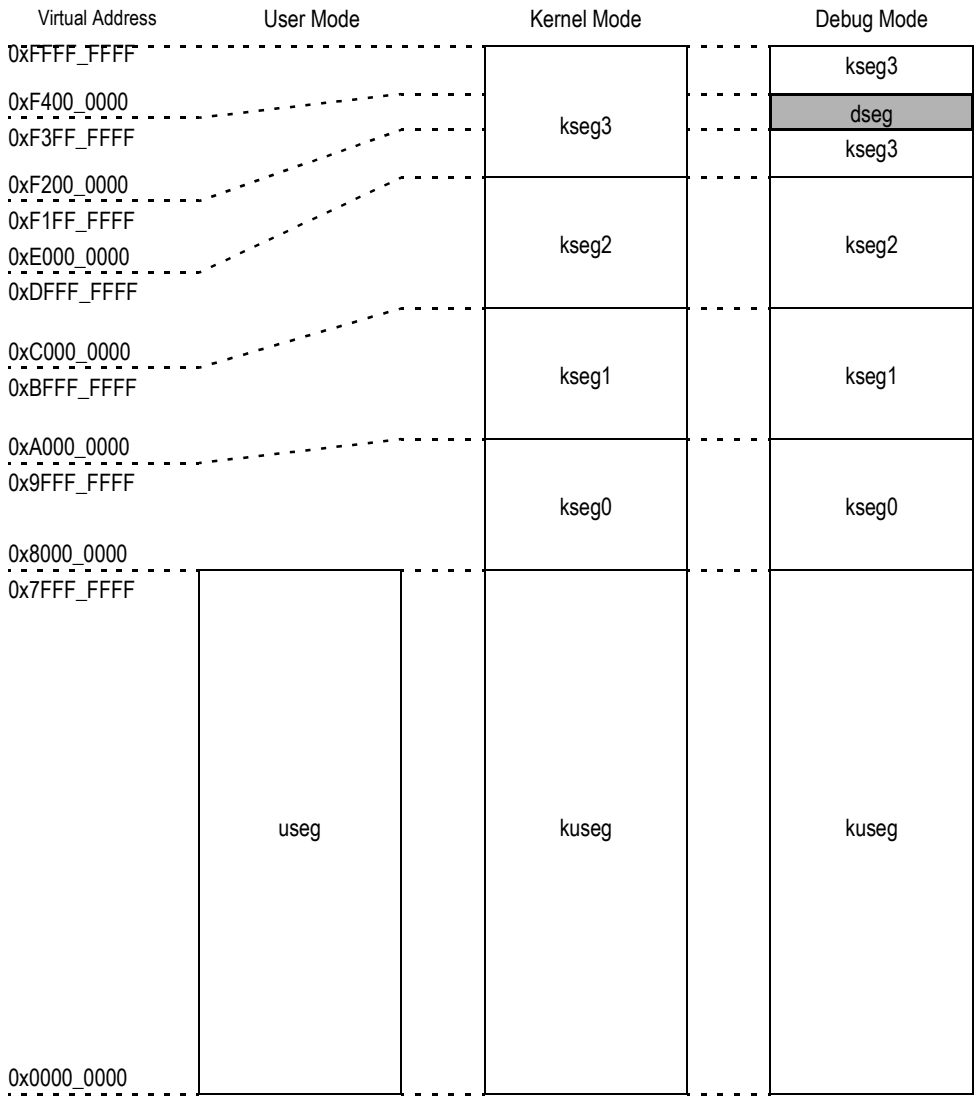


Figure 2.20 4K Processor Core Virtual Memory Map

Each of the segments shown in Figure 2.20 is either mapped or unmapped. The following two subsections, Unmapped Segments and Mapped Segments, explain the distinction. Following this, the User Mode, Kernel Mode, and Debug Mode sections specify which segments are actually mapped and unmapped.

Unmapped Segments

An unmapped segment in the 4Kc core does not use the TLB to translate from virtual to physical address. Especially after reset, it is important to have unmapped memory segments because the TLB is not yet programmed to perform the translation.

Unmapped segments have a fixed simple translation from virtual to physical address. Except for kseg0, unmapped segments are always uncached. The cacheability of kseg0 is set in the K0 field of the CP0 Register Config (see the Config Register (CP0 Register 16, Select 0) section later in this chapter.

Mapped Segments

A mapped segment in the 4Kc core does use the TLB. The translation of mapped segments is handled on a per-page basis. Included in this translation is information defining whether the page is cacheable or not, and the protection attributes that apply to the page.

Notes

User Mode

In user mode, a single 2 GByte (2^{31} bytes) uniform virtual address space called the user segment (useg) is available. Figure 2.21 shows the location of user mode virtual address space.

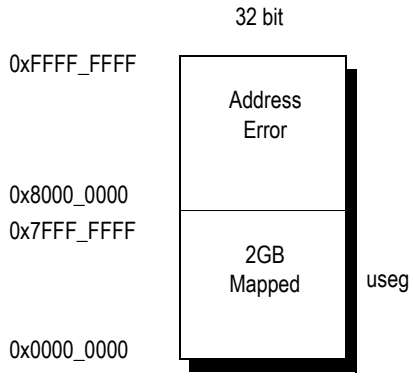


Figure 2.21 User Mode Virtual Address Space

The user segment starts at address 0x0000_0000 and ends at address 0x7FFF_FFFF. Accesses to all other addresses cause an address error exception.

The processor operates in User mode when the Status register contains the following bit values:

UM = 1

EXL = 0

ERL = 0

In addition to the above values, the DM bit in the Debug register must be 0. Table 2.6 lists the characteristics of the useg User mode segments.

Address Bit Value	Status Register Bit Value			Segment Name	Address Range	Segment Size
	EXL	ERL	UM			
32-bit A(31)=0	0	0	1	useg	0x0000_0000 0x7FFF_FFFF	2 GByte 2^{31} bytes)

Table 2.6 User Mode Segments

All valid user mode virtual addresses have their most-significant bit cleared to 0, indicating that user mode can only access the lower half of the virtual memory map. Any attempt to reference an address with the most-significant bit set while in user mode causes an address error exception.

The system maps all references to useg through the TLB. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address before translation. Bit settings within the TLB entry for the page determine the cacheability of a reference.

Kernel Mode

The processor operates in Kernel mode when the DM bit in the Debug register is 0 and the Status register contains one or more of the following values:

UM = 0

ERL = 1

EXL = 1

Notes

When a non-debug exception is detected, EXL or ERL will be set and the processor will enter Kernel mode. At the end of the exception handler routine, an Exception Return (ERET) instruction is generally executed. The ERET instruction jumps to the Exception PC, clears ERL, and clears EXL if ERL=0. This may return the processor to User mode.

Kernel mode virtual address space is divided into regions differentiated by the high-order bits of the virtual address, as shown in Figure 2.22. Also, Table 2.7 lists the characteristics of the Kernel mode segments.

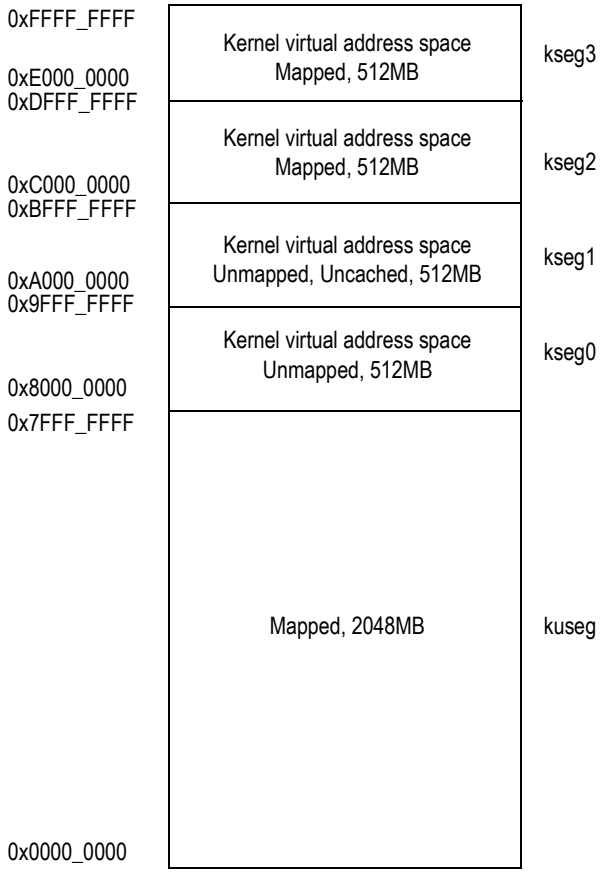


Figure 2.22 Kernel Mode Virtual Address Space

Notes

Address Bit Values	Status Register Is One Of These Values			Segment Name	Address Range	Segment Size
	UM	EXL	ERL			
A(31)=0	(UM = 0 or EXL = 1 or ERL = 1) and DM = 0			kuseg	0x0000_0000 ▶ 0x7FFF_FFFF	2 GBytes (2^{31} bytes)
A(31:29)=100_2				kseg0	0x8000_0000 ▶ 0x9FFF_FFFF	512 MBytes (2^{29} bytes)
A(31:29)=101_2				kseg1	0xA000_0000 ▶ 0xBFFF_FFFF	512 MBytes (2^{29} bytes)
A(31:29)=110_2				kseg2	0xC000_0000 ▶ 0xDFFF_FFFF	512 MBytes (2^{29} bytes)
A(31:29)=111_2				kseg3	0xE000_0000 ▶ 0xFFFF_FFFF	512 MBytes (2^{29} bytes)

Table 2.7 Kernel Mode Segments

Kernel Mode, User Space (kuseg)

In Kernel mode, when the most-significant bit of the virtual address (A31) is cleared, the 32-bit kuseg virtual address space is selected and covers the full 2^{31} bytes (2 GByte) of the current user address space mapped to addresses 0x0000_0000 - 0x7FFF_FFFF. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

When ERL = 1 in the Status register, the user address region becomes a 2^{31}-byte unmapped and uncached address space. While in this setting, the kuseg virtual address maps directly to the same physical address, and does not include the ASID field.

Kernel Mode, Kernel Space 0 (kseg0)

In Kernel mode, when the most-significant three bits of the virtual address are 100_2, 32-bit kseg0 virtual address space is selected; it is the 2^{29}-byte (512-MByte) kernel virtual space located at addresses 0x8000_0000 - 0x9FFF_FFFF. References to kseg0 are unmapped; the physical address selected is defined by subtracting 0x8000_0000 from the virtual address. The K0 field of the Config register controls cacheability.

Kernel Mode, Kernel Space 1 (kseg1)

In Kernel mode, when the most-significant three bits of the 32-bit virtual address are 101_2, 32-bit kseg1 virtual address space is selected. kseg1 is the 2^{29}-byte (512-MByte) kernel virtual space located at addresses 0xA000_0000 - 0xBFFF_FFFF. References to kseg1 are unmapped; the physical address selected is defined by subtracting 0xA000_0000 from the virtual address. Caches are disabled for accesses to these addresses, and physical memory (or memory-mapped I/O device registers) are accessed directly.

Kernel Mode, Kernel Space 2 (kseg2)

In Kernel mode, when UM = 0, ERL = 1, or EXL = 1 in the Status register, and DM = 0 in the Debug register, and the most-significant three bits of the 32-bit virtual address are 110_2, 32-bit kseg2 virtual address space is selected. This 2^{29}-byte (512-MByte) kernel virtual space is mapped through the TLB in the 4Kc processor core.

Kernel Mode, Kernel Space 3 (kseg3)

In Kernel mode, when the most-significant three bits of the 32-bit virtual address are 111_2, the kseg3 virtual address space is selected. This 2^{29}-byte (512-MByte) kernel virtual space is mapped through the TLB in the 4Kc processor core.

Notes

Debug Mode

Debug mode address space is identical to Kernel mode address space with respect to mapped and unmapped areas, except for kseg3. In kseg3, a debug segment dseg co-exists in the virtual address range 0xFF20_0000 to 0xFF3F_FFFF. The layout is shown in Figure 2.23.

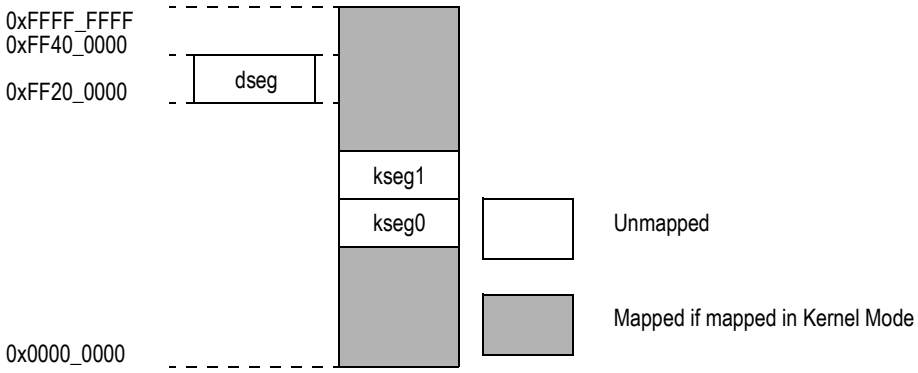


Figure 2.23 Debug Mode Virtual Address Space

The dseg is sub-divided into the dmseg segment at 0xFF20_0000 to 0xFF2F_FFFF which is used when the probe services the memory segment, and the drseg segment at 0xFF30_0000 to 0xFF3F_FFFF which is used when memory mapped debug registers are accessed. The subdivision and attributes for the segments are shown in Table 2.8.

Accesses to memory that would normally cause an exception if tried from kernel mode cause the core to re-enter debug mode via a debug mode exception. This includes accesses usually causing a TLB exception (4Kc core only), with the result that such accesses are not handled by the usual memory management routines. The unmapped kseg0 and kseg1 segments from kernel mode address space are available from debug mode, which allows the debug handler to be executed from uncached and unmapped memory.

Segment Name	Sub-segment Name	Virtual Address	Generates Physical Address	Cache Attribute
dseg	dmseg	0xFF20_0000 through 0xFF2F_FFFF	mseg maps to addresses 0x0_0000 - 0xF_FFFF in EJTAG probe memory space.	Uncached
	drseg	0xFF30_0000 through 0xFF3F_FFFF	drseg maps to the breakpoint registers 0x0_0000 - 0xF_FFFF	

Table 2.8 Physical Address and Cache Attributes for dseg, dmseg, and drseg Address Spaces

Conditions and Behavior for Access to drseg and EJTAG Registers

The behavior of CPU access to the drseg address range at 0xFF30_0000 to 0xFF3F_FFFF is determined as shown in Table 2.9.

Notes

Transaction	LSNM bit in Debug Register	Access
Load / Store	1	Kernel mode address space (kseg3)
Fetch	Don't care	drseg, see comments below
Load / Store	0	

Table 2.9 CPU Access to drseg Address Range

Debug software is expected to read the debug control register (DCR) to determine which other memory mapped registers exist in drseg. The value returned in response to a read of any unimplemented memory mapped register is unpredictable, and writes are ignored to any unimplemented register in the drseg.

The allowed access size is limited for the drseg. Only word size transactions are allowed. Operation of the processor is undefined for other transaction sizes.

Conditions and Behavior for Access to dmseg, EJTAG Memory

The behavior of CPU access to the dmseg address range at 0xFF20_0000 to 0xFF2F_FFFF is determined by Table 2.10.

Transaction	ProbEn bit in DCR Register	LSNM bit in Debug Register	Access
Load / Store	Don't care	1	Kernel mode address space (kseg3)
Fetch	1	Don't care	dmseg
Load / Store	1	0	
Fetch	0	Don't care	See comments below
Load / Store	0	0	

Table 2.10 CPU Access to dmseg Address Range

The case with access to the dmseg when the ProbEn bit in the DCR register is 0 is not expected to happen. Debug software is expected to check the state of the ProbEn bit in DCR register before attempting to reference dmseg. If such a reference does happen, the reference hangs until it is satisfied by the probe. The probe can not assume that there will never be a reference to dmseg if the ProbEn bit in the DCR register is 0 because there is an inherent race between the debug software sampling the ProbEn bit as 1 and the probe clearing it to 0.

Translation Lookaside Buffer

The following subsections discuss the TLB memory management scheme used in the 4Kc processor core. The TLB consists of one joint and two micro address translation buffers:

16 dual-entry fully associative Joint TLB (JTLB)

3-entry fully associative Instruction micro TLB (ITLB)

3-entry fully associative Data micro TLB (DTLB).

Notes

Joint TLB

The 4Kc core implements a 16 dual-entry, fully associative Joint TLB that maps 32 virtual pages to their corresponding physical addresses. The JTLB is organized as 16 pairs of even and odd entries containing pages that range in size from 4-KBytes to 16-MBytes into the 4-GByte physical address space. The purpose of the TLB is to translate virtual addresses and their corresponding Address Space Identifier (ASID) into a physical memory address. The translation is performed by comparing the upper bits of the virtual address (along with the ASID bits) against each of the entries in the tag portion of the JTLB structure. Because this structure is used to translate both instruction and data virtual addresses, it is referred to as a "joint" TLB.

The JTLB is organized in page pairs to minimize its overall size. Each virtual tag entry corresponds to two physical data entries, an even page entry and an odd page entry. The highest order virtual address bit not participating in the tag comparison is used to determine which of the two data entries is used. Since page size can vary on a page-pair basis, the determination of which address bits participate in the comparison and which bit is used to make the even-odd determination must be determined dynamically during the TLB lookup.

Figure 2.24 shows the contents of one of the 16 dual-entries in the JTLB.

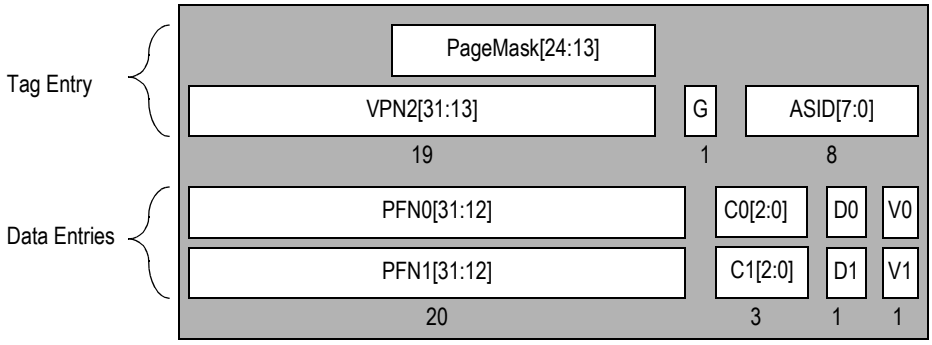


Figure 2.24 JTLB Entry (Tag and Data)

Notes

Table 2.11 and Table 2.12 explain each of the fields in a JTLB entry.

Field Name	Description
PageMask[24:13]	Page Mask Value. The Page Mask defines the page size by masking the appropriate VPN2 bits from being involved in a comparison. It is also used to determine which address bit is used to make the even-odd page (PFN0-PFN1) determination. See the table below. **PageMask[11:0] / Page Size / Even/Odd Bank Select Bit** 0000_0000_0000 / 4KB / VAddr[12] 0000_0000_0011 / 16KB / VAddr[14] 0000_0000_1111 / 64KB / VAddr[16] 0000_0011_1111 / 256KB / VAddr[18] 0000_1111_1111 / 1MB / VAddr[20] 0011_1111_1111 / 4MB / VAddr[22] 1111_1111_1111 / 16MB / VAddr[24] The PageMask column above show all the legal values for PageMask. Because each pair of bits can only have the same value, the physical entry in the JTLB will only save a compressed version of the PageMask using only 6 bits. However, this is transparent to software, which will always work with a 12 bit field.
VPN2[31:13]	Virtual Page Number divided by 2. This field contains the upper bits of the virtual page number. Because it represents a pair of TLB pages, it is divided by 2. Bits 31:25 are always included in the TLB lookup comparison. Bits 24:13 are included depending on the page size, defined by PageMask.
G	Global Bit. When set, indicates that this entry is global to all processes and/or threads and thus disables inclusion of the ASID in the comparison.
ASID[7:0]	Address Space Identifier. Identifies which process or thread this TLB entry is associated with.

Table 2.11 TLB Tag Entry Fields

Notes

<table>
<tr><th>Field Name</th><th>Description</th></tr>
<tr><td>PFN0[31:12],
PFN1[31:12]</td><td>Physical Frame Number. Defines the upper bits of the physical address. For page sizes larger than 4 KBytes, only a subset of these bits is actually used.</td></tr>
<tr><td>C0[2:0],
C1[2:0]</td><td>Cacheability. Contains an encoded value of the cacheability attributes and determines whether the page should be placed in the cache or not. The field is encoded as follows:
<table>
<tr><th>C[2:0]</th><th>Coherency Attribute</th></tr>
<tr><td>000</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>001</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>010</td><td>Uncached</td></tr>
<tr><td>011</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>100</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>101</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>110</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
<tr><td>111</td><td>Cacheable, noncoherent, write-through, no write allocated</td></tr>
</table></td></tr>
<tr><td>D0, D1</td><td>“Dirty” or Write-enable Bit. Indicates that the page has been written, and/or is writable. If this bit is set, stores to the page are permitted. If the bit is cleared, stores to the page cause a TLB Modified exception.</td></tr>
<tr><td>V0, V1</td><td>Valid Bit. Indicates that the TLB entry and, thus, the virtual page mapping are valid. If this bit is set, accesses to the page are permitted. If the bit is cleared, accesses to the page cause a TLB Invalid exception.</td></tr>
</table>

Table 2.12 TLB Data Entry Fields

In order to fill an entry in the JTLB, software executes a TLBWI or TLBWR instruction (see the TLB Instructions section). Prior to invoking one of these instructions, several CP0 registers must be updated with the information to be written to a TLB entry:

PageMask is set in the CP0 PageMask register

VPN2 and ASID are set in the CP0 EntryHi register

PFN0, C0, D0, V0 and G bit are set in the CP0 EntryLo0 register

PFN1, C1, D1, V1 and G bit are set in the CP0 EntryLo1 register.

Note that the global bit “G” is part of both EntryLo0 and EntryLo1. The resulting “G” bit in the JTLB entry is the logical AND between the two fields in EntryLo0 and EntryLo1. For additional information, refer to section “CP0 Registers” on page 2-56.

The address space identifier (ASID) helps to reduce the frequency of TLB flushing on a context switch. The existence of the ASID allows multiple processes to exist in both the TLB and instruction caches. The ASID value is stored in the EntryHi register and is compared to the ASID value of each entry.

Notes

Instruction TLB

The ITLB is a small 3-entry, fully associative TLB dedicated to performing translations for the instruction stream. The ITLB only maps 4-Kbyte pages/sub-pages.

The ITLB is managed by hardware and is transparent to software. If a fetch address cannot be translated by the ITLB, the JTLB is accessed to attempt to translate it in the following clock cycle. If successful, the translation information is copied into the ITLB. The ITLB is then re-accessed and the address will be successfully translated. This results in an ITLB miss penalty of at least 2 cycles (if the JTLB is busy with other operations, it may take additional cycles).

Data TLB

The DTLB is a small 3-entry, fully associative TLB which provides a faster translation for Load/Store addresses than is possible with the JTLB. The DTLB only maps 4-Kbyte pages/sub-pages.

Like the ITLB, the DTLB is managed by hardware and is transparent to software. Unlike the ITLB, when translating Load/Store addresses, the JTLB is accessed in parallel with the DTLB. If there is a DTLB miss and a JTLB hit, the DTLB can be reloaded that cycle. The DTLB is then re-accessed and the translation will be successful. This parallel access reduces the DTLB miss penalty to 1 cycle.

Virtual to Physical Address Translation

Converting a virtual address to a physical address begins by comparing the virtual address from the processor with the virtual addresses in the TLB. There is a match when the virtual page number (VPN) of the address is the same as the VPN field of the entry, and either:

The Global (G) bit of both the even and odd pages of the TLB entry are set, or

The ASID field of the virtual address is the same as the ASID field of the TLB entry.

This match is referred to as a TLB hit. If there is no match, a TLB miss exception is taken by the processor and software is allowed to refill the TLB from a page table of virtual/physical addresses in memory.

Figure 2.25 shows the logical translation of a virtual address into a physical address. In this figure, the virtual address is extended with an 8-bit address-space identifier (ASID), which reduces the frequency of TLB flushing during a context switch. This 8-bit ASID contains the number assigned to that process and is stored in the CP0 EntryHi register.

Notes

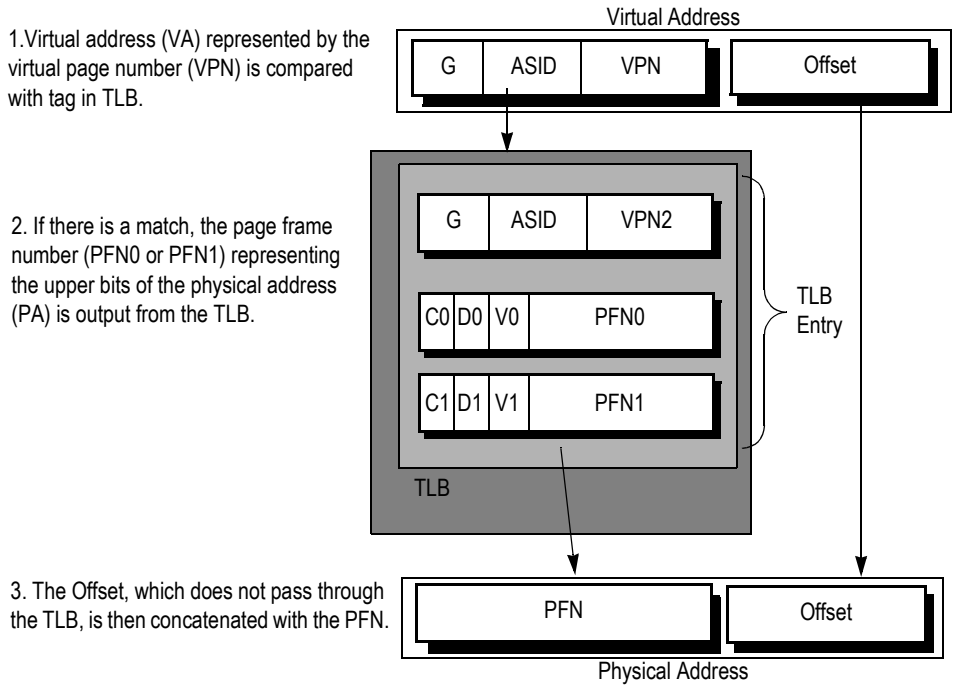


Figure 2.25 Overview of a Virtual-to-Physical Address Translation

If there is a virtual address match in the TLB, the physical frame number (PFN) is output from the TLB and concatenated with the Offset, to form the physical address. The Offset represents an address within the page frame space. As shown in Figure 2.25, the Offset does not pass through the TLB.

Figure 2.26 shows a flow diagram of the 4Kc core address translation process. The top portion of the figure shows a virtual address for a 4-KByte page size. The width of the Offset is defined by the page size. The remaining 20 bits of the address represent the virtual page number (VPN) that indexes the 1M-entry page table.

The bottom portion of Figure 2.26 shows the virtual address for a 16-MByte page size. The remaining 8 bits of the address represent the VPN that indexes the 256-entry page table.

Notes

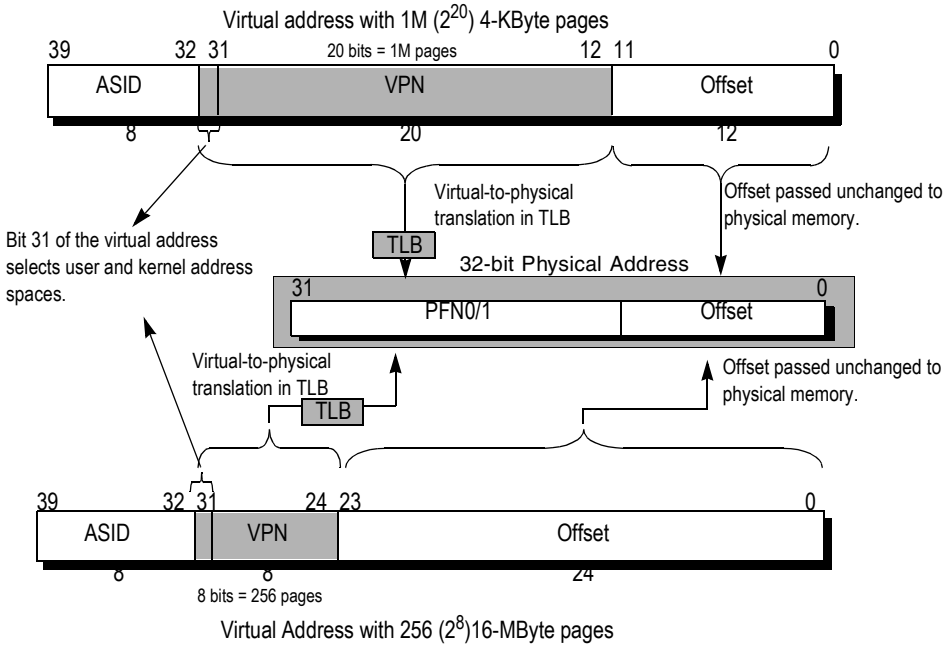


Figure 2.26 32-bit Virtual Address Translation

Hits, Misses, and Multiple Matches

Each JTLB entry contains a tag and two data fields. If a match is found, the upper bits of the virtual address are replaced with the page frame number (PFN) stored in the corresponding entry in the data array of the JTLB. The granularity of JTLB mappings is defined in terms of TLB pages. The 4Kc core JTLB supports pages of different sizes ranging from 4 KB to 16 MB in powers of 4. If a match is found, but the entry is invalid (i.e., the V bit in the data field is 0), a TLB Invalid exception is taken.

If no match occurs (TLB miss), an exception is taken and software refills the TLB from the page table resident in memory. Figure 2.27 shows the translation and exception flow of the TLB.

Software can write over a selected TLB entry or use a hardware mechanism to write into a random entry. The Random register selects which TLB entry to use on a TLBWR. This register decrements almost every cycle, wrapping to the maximum once it's value is equal to the Wired register. Thus, TLB entries below the Wired value cannot be replaced by a TLBWR allowing important mappings to be preserved. In order to reduce the possibility for a livelock situation, the Random register includes a 10b LFSR that introduces a pseudo-random perturbation into the decrementing.

The 4Kc core implements a TLB write-compare mechanism to ensure that multiple TLB matches do not occur. On the TLB write operation, the VPN2 field to be written is compared with all other entries in the TLB. If a match occurs, the 4Kc core takes a machine-check exception, sets the TS bit in the CP0 Status register, and aborts the write operation. For additional information on exceptions, see "Exceptions" on page 2-35. There is a hidden bit in each TLB entry that is cleared on a ColdReset. This bit is set once the TLB entry is written and is included in the match detection. Therefore, uninitialized TLB entries will not cause a TLB shutdown.

> **Note:** This hidden initialization bit leaves the entire JTLB invalid after a ColdReset, eliminating the need to flush the TLB. But, to be compatible with other MIPS processors, it is recommended that software initialize all TLB entries with unique tag values and V bits cleared before the first access to a mapped location.

Notes

Page Sizes and Replacement Algorithm

To assist in controlling both the amount of mapped space and the replacement characteristics of various memory regions, the 4Kc core provides two mechanisms. First, the page size can be configured, on a per entry basis, to map page sizes ranging from 4 KByte to 16 MByte (in multiples of 4). The CP0 PageMask register is loaded with the desired page size, which is then entered into the TLB when a new entry is written. Thus, operating systems can provide special-purpose maps. For example, a typical frame buffer can be memory mapped with only one TLB entry.

The second mechanism controls the replacement algorithm when a TLB miss occurs. To select a TLB entry to be written with a new mapping, the 4Kc core provides a random replacement algorithm. However, the processor also provides a mechanism whereby a programmable number of mappings can be locked into the TLB via the CP0 Wired register, thus avoiding random replacement. For additional information, see “Wired Register (CP0 Register 6, Select 0)” on page 2-60.

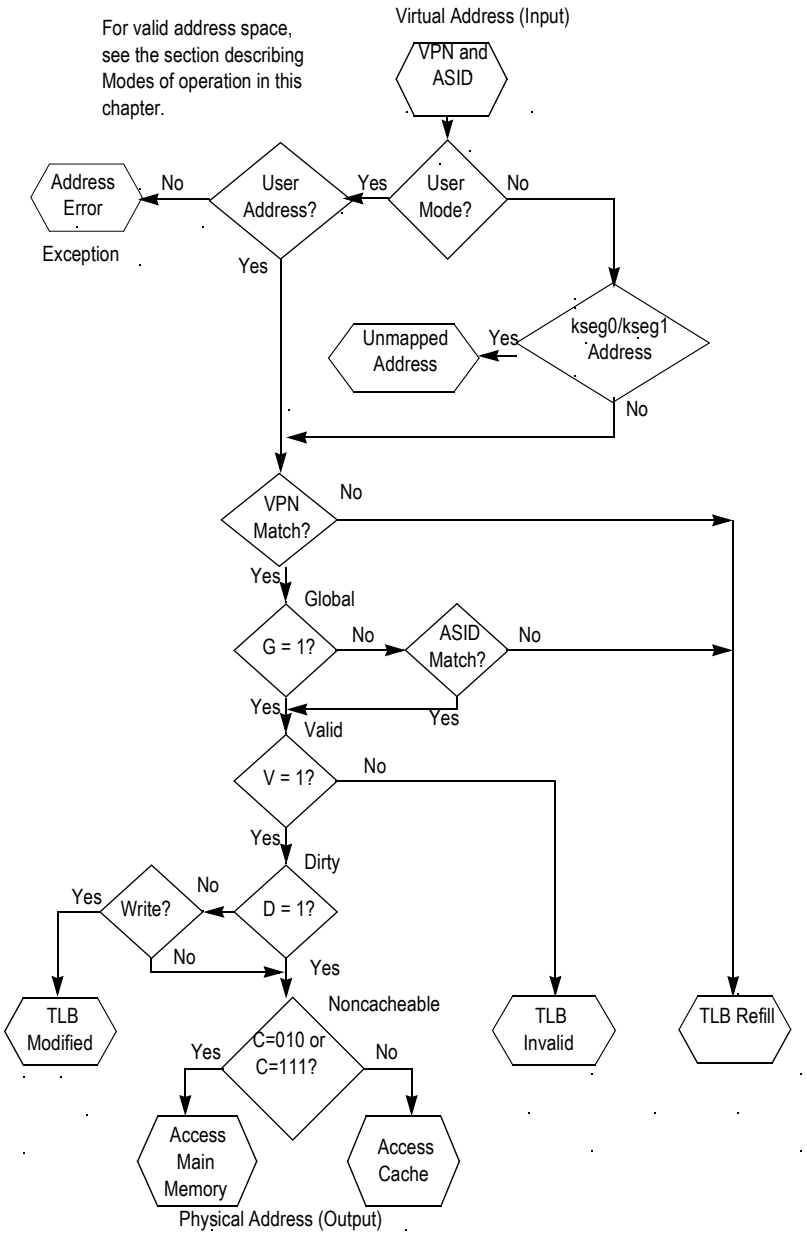


Figure 2.27 TLB Address Translation Flow in the 4Kc Processor Core

Notes

TLB Instructions

Table 2.13 lists the 4Kc core's TLB-related instructions. For additional information on these instructions, see Appendix A, 4Kc Processor Core Instructions.

Op Code	Description of Instructions
TLBP	Translation Lookaside Buffer Probe
TLBR	Translation Lookaside Buffer Read
TLBWI	Translation Lookaside Buffer Write Index
TLBWR	Translation Lookaside Buffer Write Random

Table 2.13 TLB Instructions

System Control Coprocessor

The System Control Coprocessor (CP0) is implemented as an integral part of the 4Kc processor core and supports memory management, address translation, exception handling, and other privileged operations. Certain CP0 registers are used to support memory management. For additional information on the CP0 register set, see the CP0 Registers section later in this chapter.

Exceptions

The 4Kc processor core receives exceptions from a number of sources, including translation lookaside buffer (TLB) misses, arithmetic overflows, I/O interrupts, and system calls. When the CPU detects one of these exceptions, the normal sequence of instruction execution is suspended and the processor enters kernel mode.

In kernel mode, the core disables interrupts and forces execution of a software exception processor (called a handler) located at a fixed address. The handler saves the context of the processor, including the contents of the program counter, the current operating mode, and the status of the interrupts (enabled or disabled). This context is saved so it can be restored when the exception has been serviced.

When an exception occurs, the core loads the Exception Program Counter (EPC) register with a location where execution can restart after the exception has been serviced. The restart location in the EPC register is the address of the instruction that caused the exception or, if the instruction was executing in a branch delay slot, the address of the branch instruction immediately preceding the delay slot. To distinguish between the two, software must read the BD bit in the CP0 Cause register.

Exception Conditions

When an exception condition occurs, the relevant instruction and all those that follow it in the pipeline are cancelled. Accordingly, all stall conditions and all later exception conditions that may have referenced this instruction are inhibited; there is no benefit in servicing stalls for a cancelled instruction.

When an exception condition is detected on an instruction fetch, the core aborts that instruction and all instructions that follow. When this instruction reaches the W stage, the exception flag causes it to write various CP0 registers with the exception state, change the current program counter (PC) to the appropriate exception vector address, and clear the exception bits of earlier pipeline stages.

This implementation allows all preceding instructions to complete execution and prevents all subsequent instructions from completing. Thus, the value in the EPC (ErrorEPC for errors or DEPC for debug exceptions) is sufficient to restart execution. It also ensures that exceptions are taken in the order of execution; an instruction taking an exception may itself be killed by an instruction further down the pipeline that takes an exception in a later cycle.

Notes

Exception Priority

Table 2.14 lists all possible exceptions and the relative priority of each, highest to lowest. Several of these exceptions can happen simultaneously. If that happens, the exception with the highest priority is the one taken.

Exception	Condition
Reset	Assertion of SI_ColdReset signal.
Soft Reset	Assertion of SI_Reset signal.
DSS	EJTAG Debug Single Step.
DINT	EJTAG Debug Interrupt. Caused by the assertion of the external EJ_DINT input, or by setting the EjtagBrk bit in the *ECR* register.
NMI	Asserting edge of SI_NMI signal.
Machine Check	TLB write that conflicts with an existing entry.
Interrupt	Assertion of unmasked HW or SW interrupt signal.
Deferred Watch	Deferred Watch (unmasked by K|DM->!(K|DM) transition).
DIB	EJTAG debug hardware instruction break matched.
WATCH	A reference to an address in one of the watch registers (fetch).
AdEL	Fetch address alignment error. User mode fetch reference to kernel address.
TLBL	Fetch TLB miss. Fetch TLB hit to page with V=0.
IBE	Instruction fetch bus error.
DBp	EJTAG Breakpoint (execution of SDBBP instruction).
Sys	Execution of SYSCALL instruction.
Bp	Execution of BREAK instruction.
CpU	Execution of a coprocessor instruction for a coprocessor that is not enabled.
RI	Execution of a Reserved Instruction.
Ov	Execution of an arithmetic instruction that overflowed.
Tr	Execution of a trap (when trap condition is true).
DDBL / DDBS	EJTAG Data Address Break (address only) or EJTAG Data Value Break on Store (address and value).
WATCH	A reference to an address in one of the watch registers (data).
AdEL	Load address alignment error. User mode load reference to kernel address.
AdES	Store address alignment error. User mode store to kernel address.
TLBL	Load TLB miss. Load TLB hit to page with V=0.
TLBS	Store TLB miss. Store TLB hit to page with V=0.

Table 2.14 Priority of Exceptions

Notes

Exception Vector Locations

The Reset, Soft Reset, and NMI exceptions are always vectored to location 0xBFC0_0000. Debug exceptions are vectored to location 0xBFC0_0480 or to location 0xFF20_0200 if the ProbTrap bit is 0 or 1, respectively, in the EJTAG Control register (ECR). Addresses for all other exceptions are a combination of a vector offset and a base address. Table 2.15 gives the base address as a function of the exception and whether the BEV bit is set in the Status register. Table 2.16 gives the offsets from the base address as a function of the exception. Table 2.17 combines these two tables into one that contains all possible vector addresses as a function of the state that can affect the vector selection.

Exception	$Status_{BEV}$	
	0	1
Reset, Soft Reset, NMI	0xBFC0_0000	
Debug (with ProbTrap = 0 in the *ECR*)	0xBFC0_0480	
Debug (with ProbTrap = 1 in the *ECR*)	0xFF20_0200 (in dmseg handled by probe, and not system memory)	
Other	0x8000_0000	0xBFC0_0200

Table 2.15 Exception Vector Base Addresses

Exception	Vector Offset
TLB refill, EXL = 0 (4Kc core)	0x000
Reset, Soft Reset, NMI	0x000 (uses reset base address)
General Exception	0x180
Interrupt, $Cause_{IV}$ = 1	0x200

Table 2.16 Exception Vector Offsets

Exception	BEV	EXL	IV	EJTAG ProbTrap	Vector
Reset, Soft Reset, NMI	x	x	x	x	0xBFC0_0000
Debug	x	x	x	0	0xBFC0_0480
Debug	x	x	x	1	0xFF20_0200 (in dmseg)
TLB Refill	0	0	x	x	0x8000_0000
TLB Refill	0	1	x	x	0x8000_0180
TLB Refill	1	0	x	x	0xBFC0_0200
TLB Refill	1	1	x	x	0xBFC0_0380
Interrupt	0	0	0	x	0x8000_0180
Interrupt	0	0	1	x	0x8000_0200
Interrupt	1	0	0	x	0xBFC0_0380

Table 2.17 Exception Vectors

Notes

Exception	BEV	EXL	IV	EJTAG ProbTrap	Vector
Interrupt	1	0	1	x	0xBFC0_0400
All others	0	x	x	x	0x8000_0180
All others	1	x	x	x	0xBFC0_0380

Table 2.17 Exception Vectors

General Exception Processing

With the exception of Reset, Soft Reset, NMI, and Debug exceptions, which have their own special processing as described below, exceptions have the same basic processing flow:

1. If the EXL bit in the Status register is cleared, the EPC register is loaded with the PC at which execution will be restarted and the BD bit is set appropriately in the Cause register. If the instruction is not in the delay slot of a branch, the BD bit in Cause will be cleared and the value loaded into the EPC register is the current PC. If the instruction is in the delay slot of a branch, the BD bit in Cause is set and EPC is loaded with PC-4. If the EXL bit in the Status register is set, the EPC register is not loaded and the BD bit is not changed in the Cause register.
2. The CE and ExcCode fields of the Cause registers are loaded with the values appropriate to the exception. The CE field is loaded, but not defined, for any exception type other than a coprocessor unusable exception.
3. The EXL bit is set in the Status register.
4. The processor is started at the exception vector.

The value loaded into EPC represents the restart address for the exception and need not be modified by exception handler software in the normal case. Software need not look at the BD bit in the Cause register unless is wishes to identify the address of the instruction that actually caused the exception.

Note that individual exception types may load additional information into other registers. This is noted in the description of each exception type below.

Operation:

```
if StatusEXL = 0 then
    if InstructionInBranchDelaySlot then
        EPC << PC - 4
        CauseBD << 1
    else
        EPC << PC
        CauseBD << 0
    endif
    if ExceptionType = TLBRefill then
        vectorOffset << 0x000
    elseif (ExceptionType = Interrupt) and
    (CauseIV = 1) then
        vectorOffset << 0x200
    else
        vectorOffset << 0x180
    endif
else
    vectorOffset << 0x180
endif
CauseCE << FaultingCoprocessorNumber
CauseExcCode << ExceptionType
StatusEXL << 1
if StatusBEV = 1 then
    PC << 0xBFC0_0200 + vectorOffset
else
```

Notes

```
        PC << 0x8000_0000 + vectorOffset
    endif
```

Debug Exception Processing

All debug exceptions have the same basic processing flow:

1. The DEPC register is loaded with the program counter (PC) value at which execution will be restarted and the DBD bit is set appropriately in the Debug register. The value loaded into the DEPC register is the current PC if the instruction is not in the delay slot of a branch, or the PC-4 of the branch if the instruction is in the delay slot of a branch.
2. The DSS, DBp, DDBL, DDBS, DIB and DINT bits (D* bits at [5:0]) in the Debug register are updated appropriately depending on the debug exception type.
3. Halt and Doze bits in the Debug register are updated appropriately.
4. DM bit in the Debug register is set to 1.
5. The processor is started at the debug exception vector.

The value loaded into DEPC represents the restart address for the debug exception and need not be modified by the debug exception handler software in the usual case. Debug software need not look at the DBD bit in the Debug register unless it wishes to identify the address of the instruction that actually caused the debug exception.

A unique debug exception is indicated through the DSS, DBp, DDBL, DDBS, DIB and DINT bits (D* bits at [5:0]) in the Debug register.

No other CP0 registers or fields are changed due to the debug exception, thus no additional state is saved.

Operation:

```
    if InstructionInBranchDelaySlot then
        DEPC << PC-4
        DebugDBD << 1
    else
        DEPC << PC
        DebugDBD << 0
    endif
    DebugD* bits at at [5:0] <- DebugExceptionType
    DebugHalt << HaltStatusAtDebugException
    DebugDoze << DozeStatusAtDebugException
    DebugDM << 1
    if EJTAGControlRegisterProbTrap = 1 then
        PC << 0xFF20_0200
    else
        PC << 0xBFC0_0480
    endif
```

The same debug exception vector location is used for all debug exceptions. The location is determined by the ProbTrap bit in the EJTAG Control register (ECR), as shown in Table 2.18.

ProbTrap bit in ECR Register	Debug Exception Vector Address
0	0xBFC0_0480
1	0xFF20_0200 in dmseg

Table 2.18 Debug Exception Vector Addresses

Exceptions

The following subsections describe each of the exceptions listed in the same sequence as shown in Table 2.14.

Notes

Reset Exception

A reset exception occurs when the SI_ColdReset signal is asserted to the processor. This exception is not maskable. When a Reset exception occurs, the processor performs a full reset initialization, including aborting state machines, establishing critical state, and generally placing the processor in a state in which it can execute instructions from uncached, unmapped address space. On a Reset exception, the state of the processor in not defined, with the following exceptions:

The Random register is initialized to the number of TLB entries - 1 (4Kc core.

The Wired register is initialized to zero (4Kc core)

The Config register is initialized with its boot state

The BEV, TS, SR, NMI, and ERL fields of the Status register are initialized to a specified state

The I, R, and W fields of the WatchLo register are initialized to 0

The ErrorEPC register is loaded with PC-4 if the state of the processor indicates that it was executing an instruction in the delay slot of a branch. Otherwise, the ErrorEPC register is loaded with PC. Note that this value may or may not be predictable.

PC is loaded with 0xBFC0_0000.

Cause Register ExcCode Value:

None

Additional State Saved:

None

Entry Vector Used:

Reset (0xBFC0_0000)

Operation:

```
Random << TLBEntries - 1
Wired << 0
Config << ConfigurationState
StatusBEV << 1
StatusTS << 0
StatusSR << 0
StatusNMI << 0
StatusERL << 1
WatchLoI << 0
WatchLoR << 0
WatchLoW << 0
if InstructionInBranchDelaySlot then
    ErrorEPC << PC - 4
else
    ErrorEPC << PC
endif
PC << 0xBFC0_0000
```

Soft Reset Exception

A soft reset exception occurs when the *SI_Reset* signal is asserted to the processor. This exception is not maskable. When a soft reset exception occurs, the processor performs a subset of the full reset initialization. Although a soft reset exception does not unnecessarily change the state of the processor, it may be forced to do so in order to place the processor in a state in which it can execute instructions from uncached, unmapped address space. Since bus, cache, or other operations may be interrupted, portions of the cache, memory, or other processor state may be inconsistent. In addition to any hardware initialization required, the following state is established on a soft reset exception:

The BEV, TS, SR, NMI, and ERL fields of the Status register are initialized to a specified state.

Notes

The ErrorEPC register is loaded with PC-4 if the state of the processor indicates that it was executing an instruction in the delay slot of a branch. Otherwise, the ErrorEPC register is loaded with PC. Note that this value may or may not be predictable.

PC is loaded with 0xBFC0_0000.

Cause Register ExcCode Value:

None

Additional State Saved:

None

Entry Vector Used:

Reset (0xBFC0_0000)

Operation:

```
StatusBEV << 1
StatusTS << 0
StatusSR << 1
StatusNMI << 0
StatusERL << 1
if InstructionInBranchDelaySlot then
    ErrorEPC << PC - 4
else
    ErrorEPC << PC
endif
PC << 0xBFC0_0000
```

Debug Single Step Exception

A debug single step exception occurs after the CPU has executed one/two instructions in non-debug mode, when returning to non-debug mode after debug mode. One instruction is allowed to execute when returning to a non jump/branch instruction, otherwise two instructions are allowed to execute since the jump/branch and the instruction in the delay slot are executed as one step. Debug single step exceptions are enabled by the SSt bit in the Debug register, and are always disabled for the first one/two instructions after a DERET.

The DEPC register points to the instruction on which the debug single step exception occurred, which is also the next instruction to single step or execute when returning from debug mode. So the DEPC will not point to the instruction which has just been single stepped, but rather the following instruction. The DBD bit in the Debug register is never set for a debug single step exception, since the jump/branch and the instruction in the delay slot is executed in one step.

Exceptions occurring on the instruction(s) executed with debug single step exception enabled are taken even though debug single step was enabled. For a normal exception (other than reset), a debug single step exception is then taken on the first instruction in the normal exception handler. Debug exceptions are unaffected by single step mode, e.g. returning to a SDBBP instruction with debug single step exceptions enabled causes a debug software breakpoint exception, and the DEPC will point to the SDBBP instruction. However, returning to an instruction (not jump/branch) just before the SDBBP instruction, causes a debug single step exception with the DEPC pointing to the SDBBP instruction.

To ensure proper functionality of single step, the debug single step exception has priority over all other exceptions, except reset and soft reset.

Debug Register Debug Status Bit Set

DSS

Additional State Saved

None

Entry Vector Used

Notes

Debug exception vector

Debug Interrupt Exception

A debug interrupt exception is either caused by the EjtagBrk bit in the EJTAG Control register (controlled through the TAP) or caused by the debug interrupt request signal to the CPU.

The debug interrupt exception is an asynchronous debug exception which is taken as soon as possible, but with no specific relation to the executed instructions. The DEPC register is set to the instruction where execution should continue after the debug handler is through. The DBD bit is set based on whether the interrupted instruction was executing in the delay slot of a branch.

Debug Register Debug Status Bit Set

DINT

Additional State Saved

None

Entry Vector Used

Debug exception vector

Non-Maskable Interrupt (NMI) Exception

A non-maskable interrupt exception occurs when the SI_NMI signal is asserted to the processor. SI_NMI is an edge sensitive signal - only one NMI exception will be taken each time it is asserted. An NMI exception occurs only at instruction boundaries, so it does not cause any reset or other hardware initialization. The state of the cache, memory, and other processor states are consistent and all registers are preserved, with the following exceptions:

The BEV, TS, SR, NMI, and ERL fields of the Status register are initialized to a specified state.

The ErrorEPC register is loaded with PC-4 if the state of the processor indicates that it was executing an instruction in the delay slot of a branch. Otherwise, the ErrorEPC register is loaded with PC.

PC is loaded with 0xBFC0_0000.

Cause Register ExcCode Value:

None

Additional State Saved:

None

Entry Vector Used:

Reset (0xBFC0_0000)

Operation:

```
StatusBEV << 1
StatusTS << 0
StatusSR << 0
StatusNMI << 1
StatusERL << 1
if InstructionInBranchDelaySlot then
    ErrorEPC << PC - 4
else
    ErrorEPC << PC
endif
PC << 0xBFC0_0000
```

Machine Check Exception

A machine check exception occurs when the processor detects an internal inconsistency. The following condition causes a machine check exception:

Notes

The detection of multiple matching entries in the TLB in a TLB-based MMU. The core detects this condition on a TLB write and prevents the write from being completed. The TS bit in the Status register is set to indicate this condition. This bit is only a status flag and does not affect the operation of the device. Software clears this bit at the appropriate time. This condition is resolved by flushing the conflicting TLB entries. The TLB write can then be completed.

Cause Register ExcCode Value:

MCheck

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Interrupt Exception

The interrupt exception occurs when one or more of the eight interrupt requests is enabled by the Status register and the interrupt input is asserted. The delay from assertion of an unmasked interrupt to fetch of the first instructions at the exception vector is a minimum of 5 clock cycles. More may be needed if a committed instruction has to complete before the exception can be taken. A SYNC instruction which has already started flushing the cache and write buffers must wait until this is completed before the interrupt exception can be taken.

Register ExcCode Value:

Int

Additional State Saved:

Register State	Value
$Cause_{IP}$	Indicates the interrupts that are pending.

Table 2.19 Register States an Interrupt Exception

Entry Vector Used:

General exception vector (offset 0x180) if the IV bit in the Cause register is 0;

interrupt vector (offset 0x200) if the IV bit in the Cause register is 1.

Debug Instruction Break Exception

A debug instruction break exception occurs when an instruction hardware breakpoint matches an executed instruction. The DEPC register and DBD bit in the Debug register indicates the instruction that caused the instruction hardware breakpoint to match. This exception can only occur if instruction hardware breakpoints are implemented.

Debug Register Debug Status Bit Set:

DIB

Additional State Saved:

None

Entry Vector Used:

Debug exception vector

Notes

Watch Exception — Instruction Fetch or Data Access

The Watch facility provides a software debugging vehicle by initiating a watch exception when an instruction or data reference matches the address information stored in the WatchHi and WatchLo registers. A Watch exception is taken immediately if the EXL and ERL bits of the Status register are both zero and the DM bit of the Debug is also zero. If any of those bits is a one at the time that a watch exception would normally be taken, the WP bit in the Cause register is set, and the exception is deferred until both all three bits are zero. Software may use the WP bit in the Cause register to determine if the EPC register points to the instruction that caused the watch exception or if the exception actually occurred while in kernel mode.

The Watch exception can occur on either an instruction fetch or a data access. Watch exceptions that occur on an instruction fetch have a higher priority than watch exceptions that occur on a data access.

Register ExcCode Value:

WATCH

Additional State Saved:

Register State	Value
$Cause_{WP}$	Indicates that the watch exception was deferred until after $Status_{EXL}$, $Status_{ERL}$, and $Debug_{DM}$ were zero. This bit directly causes a watch exception, so software must clear this bit as part of the exception handler to prevent a watch exception loop at the end of the current handler execution.

Table 2.20 Register States on a Watch Exception

Entry Vector Used:

General exception vector (offset 0x180)

Address Error Exception — Instruction Fetch/Data Access

An address error exception occurs on an instruction or data access when an attempt is made to execute one of the following:

Fetch an instruction, load a word, or store a word that is not aligned on a word boundary

Load or store a halfword that is not aligned on a halfword boundary

Reference the kernel address space from user mode.

Note that in the case of an instruction fetch that is not aligned on a word boundary, PC is updated before the condition is detected. Therefore, both EPC and BadVAddr point to the unaligned instruction address. In the case of a data access, the exception is taken if either an unaligned address or an address that was inaccessible in the current processor mode was referenced by a load or store instruction.

Cause Register ExcCode Value:

ADEL: Reference was a load or an instruction fetch

ADES: Reference was a store

Additional State Saved:

Register State	Value
BadVAddr	Failing address
$Context_{VPN2}$	UNPREDICTABLE

Table 2.21 CP0 Register States on an Address Exception Error (Part 1 of 2)

Notes

Register State	Value
$EntryHi_{VPN2}$	UNPREDICTABLE
EntryLo0	UNPREDICTABLE
EntryLo1	UNPREDICTABLE

Table 2.21 CP0 Register States on an Address Exception Error (Part 2 of 2)

Entry Vector Used:

General exception vector (offset 0x180)

TLB Refill Exception — Instruction Fetch or Data Access

During an instruction fetch or data access, a TLB refill exception occurs when no TLB entry in a TLB-based MMU matches a reference to a mapped address space and the EXL bit is 0 in the Status register. Note that this is distinct from the case in which an entry matches but has the valid bit off. In that case, a TLB Invalid exception occurs.

Cause Register ExcCode Value:

TLBL: Reference was a load or an instruction fetch

TLBS: Reference was a store

Additional State Saved:

Register State	Value
BadVAddr	Failing address
Context	The BadVPN2 fields contains $VA_{31:13}$ of the failing address.
EntryHi	The VPN2 field contains $VA_{31:13}$ of the failing address; the ASID field contains the ASID of the reference that missed.
EntryLo0	UNPREDICTABLE
EntryLo1	UNPREDICTABLE

Table 2.22 CP0 Register States on a TLB Refill Exception

Entry Vector Used:

TLB refill vector (offset 0x000) if StatusEXL = 0 at the time of exception;

general exception vector (offset 0x180) if StatusEXL = 1 at the time of exception.

TLB Invalid Exception — Instruction Fetch or Data Access (4Kc core)

During an instruction fetch or data access, a TLB invalid exception occurs in one of the following cases:

No TLB entry in a TLB-based MMU matches a reference to a mapped address space; and the EXL bit is 1 in the Status register

A TLB entry in a TLB-based MMU matches a reference to a mapped address space, but the matched entry has the valid bit off

The virtual address is greater than or equal to the bounds address in a FM-based MMU.

Cause Register ExcCode Value:

TLBL: Reference was a load or an instruction fetch

TLBS: Reference was a store

Additional State Saved:

Notes

Register State	Value
BadVAddr	Failing address
Context	The BadVPN2 field contains $VA_{31:13}$ of the failing address.
EntryHi	The VPN2 field contains $VA_{31:13}$ of the failing address; the ASID field contains the ASID of the reference that missed.
EntryLo0	UNPREDICTABLE
EntryLo1	UNPREDICTABLE

Table 2.23 CP0 Register States on a TLB Invalid Exception

Entry Vector Used:

General exception vector (offset 0x180)

Bus Error Exception — Instruction Fetch or Data Access

A bus error exception occurs when an instruction or data access makes a bus request (due to a cache miss or an uncacheable reference) and that request terminates in an error. The bus error exception can occur on either an instruction fetch or a data access. Bus error exceptions that occur on an instruction fetch have a higher priority than bus error exceptions that occur on a data access.

Bus errors taken on the requested (critical) word of an instruction fetch or data load are precise. Other bus errors, such as stores or non-critical words of a burst read, can be imprecise. These errors are taken when the EB_RBErr or EB_WBErr signals are asserted and may occur on an instruction that was not the source of the offending bus cycle.

Cause Register ExcCode Value:

IBE:Error on an instruction reference

DBE:Error on a data reference

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Debug Software Breakpoint Exception

A debug software breakpoint exception occurs when an SDBBP instruction is executed. The DEPC register and DBD bit in the Debug register will indicate the SDBBP instruction that caused the debug exception.

Debug Register Debug Status Bit Set:

DBp

Additional State Saved:

None

Entry Vector Used:

Debug exception vector

Execution Exception — System Call

The system call exception is one of the six execution exceptions. All of these exceptions have the same priority. A system call exception occurs when a SYSCALL instruction is executed.

Notes

Cause Register ExcCode Value:

Sys

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Execution Exception — Breakpoint

The breakpoint exception is one of the six execution exceptions. All of these exceptions have the same priority. A breakpoint exception occurs when a BREAK instruction is executed.

Cause Register ExcCode Value:

Bp

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Execution Exception — Reserved Instruction

The reserved instruction exception is one of the six execution exceptions. All of these exceptions have the same priority. A reserved instruction exception occurs when a reserved or undefined major opcode or function field is executed.

Cause Register ExcCode Value:

RI

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Execution Exception — Coprocessor Unusable

The coprocessor unusable exception is one of the six execution exceptions. All of these exceptions have the same priority. A coprocessor unusable exception occurs when an attempt is made to execute a coprocessor instruction for one of the following:

A corresponding coprocessor unit that has not been marked usable by setting its CU bit in the Status register

CP0 instructions, when the unit has not been marked usable, and the processor is executing in user mode.

Cause Register ExcCode Value:

CpU

Additional State Saved:

Register State	Value
$Cause_{CE}$	Unit number of the coprocessor being referenced

Figure 2.28 Register States on a Coprocessor Unusable Exception

Notes

Entry Vector Used:

General exception vector (offset 0x180)

Execution Exception — Integer Overflow

The integer overflow exception is one of the six execution exceptions. All of these exceptions have the same priority. An integer overflow exception occurs when selected integer instructions result in a 2's complement overflow.

Cause Register ExcCode Value:

Ov

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Execution Exception — Trap

The trap exception is one of the six execution exceptions. All of these exceptions have the same priority. A trap exception occurs when a trap instruction results in a TRUE value.

Cause Register ExcCode Value:

Tr

Additional State Saved:

None

Entry Vector Used:

General exception vector (offset 0x180)

Debug Data Break Exception

A debug data break exception occurs when a data hardware breakpoint matches the load/store transaction of an executed load/store instruction. The DEPC register and DBD bit in the Debug register will indicate the load/store instruction that caused the data hardware breakpoint to match. The load/store instruction that caused the debug exception has not completed, e.g. not updated the register file, and the instruction can be re-executed after returning from the debug handler.

Debug Register Debug Status Bit Set:

DDBL for a load instruction or DDBS for a store instruction

Additional State Saved:

None

Entry Vector Used:

Debug exception vector

TLB Modified Exception — Data Access

During a data access, a TLB modified exception occurs on a store reference to a mapped address if the following condition is true:

The matching TLB entry in a TLB-based MMU is valid, but not dirty.

Cause Register ExcCode Value:

Mod

Additional State Saved:

Notes

Register State	Value
BadVAddr	Failing address
Context	The BadVPN2 field contains $VA_{31:13}$ of the failing address.
EntryHi	The VPN2 field contains $VA_{31:13}$ of the failing address; the ASID field contains the ASID of the reference that missed.
EntryLo0	UNPREDICTABLE
EntryLo1	UNPREDICTABLE

Table 2.24 Register States on a TLB Modified Exception

Entry Vector Used:

General exception vector (offset 0x180)

Exception Handling and Servicing Flowcharts

The remainder of this chapter contains flowcharts for the following exceptions and guidelines for their handlers:

General exceptions and their exception handler

TLB miss exceptions and their exception handler (4Kc core)

Reset, soft reset and NMI exceptions, and a guideline to their handler

Debug exceptions.

Generally speaking, the exceptions are handled by hardware (HW); the exceptions are then serviced by software (SW). Note that unexpected debug exceptions to the debug exception vector at 0xBFC0_0200 may be viewed as a reserved instruction since uncontrolled execution of a SDBBP instruction caused the exception. The DERET instruction must be used at return from the debug exception handler, in order to leave debug mode and return to non-debug mode. The DERET instruction returns to the address in the DEPC register.

Notes

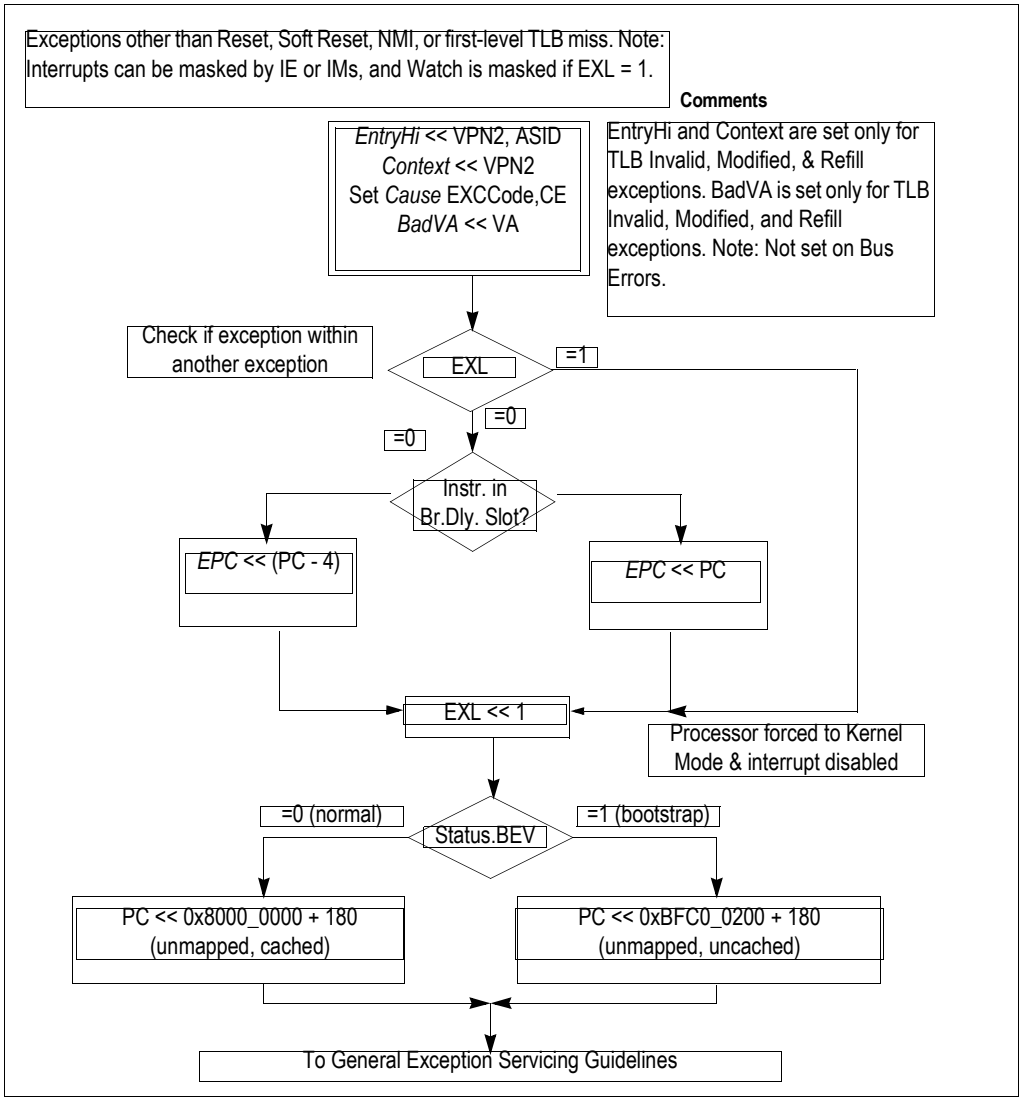


Figure 2.29 General Exception Handler (HW)

Notes

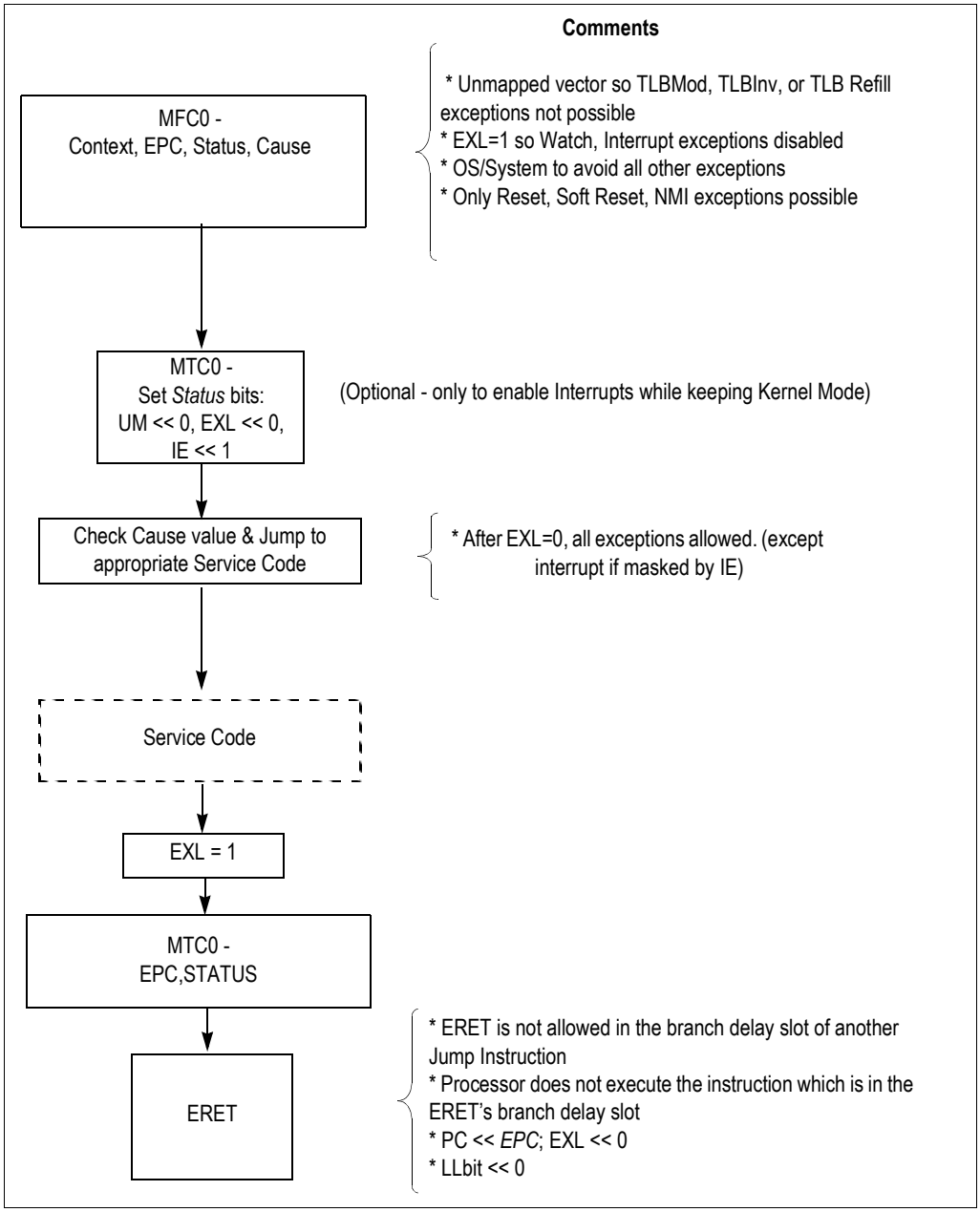


Figure 2.30 General Exception Servicing Guidelines (SW)

Notes

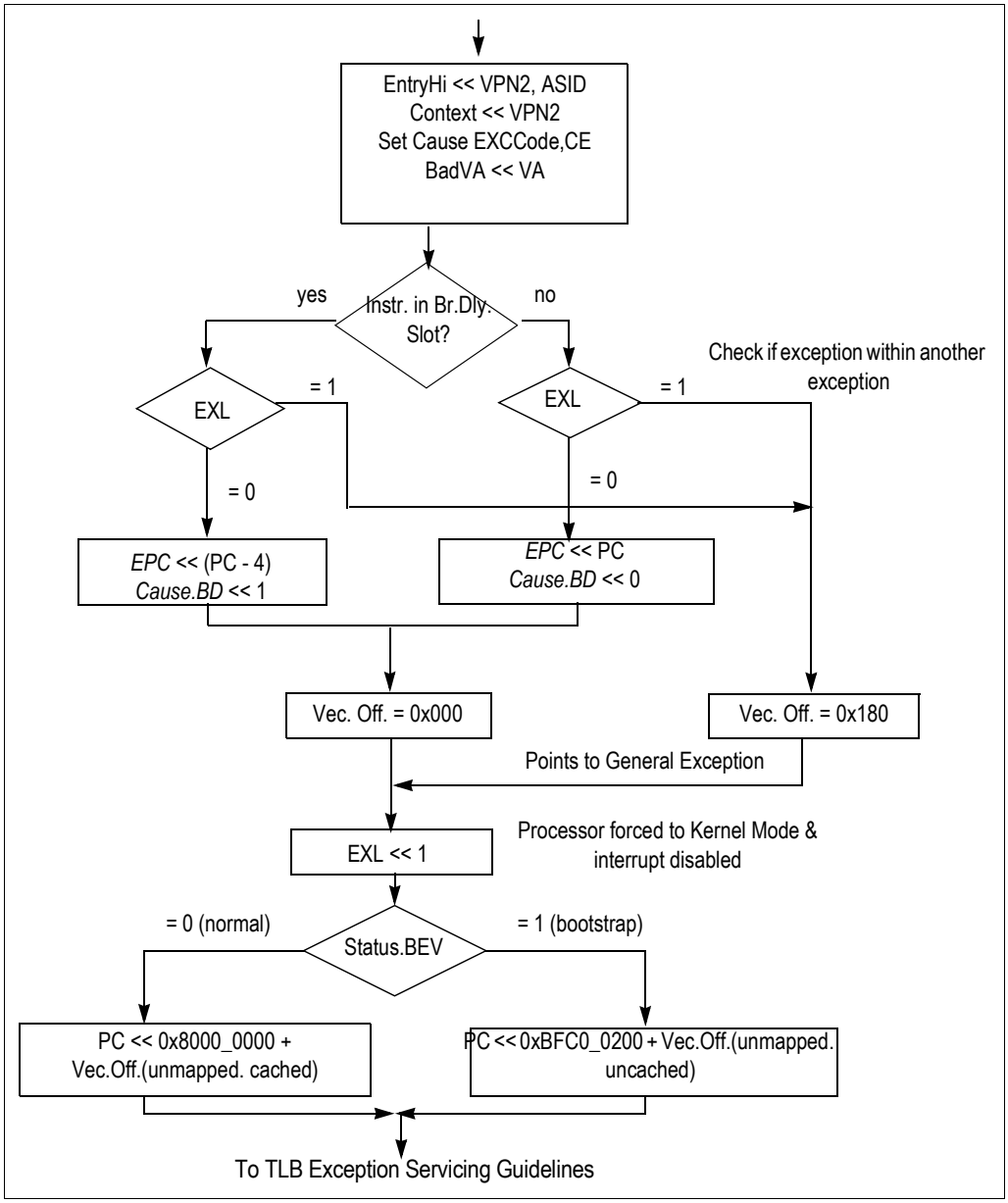


Figure 2.31 TLB Miss Exception Handler (HW)

Notes

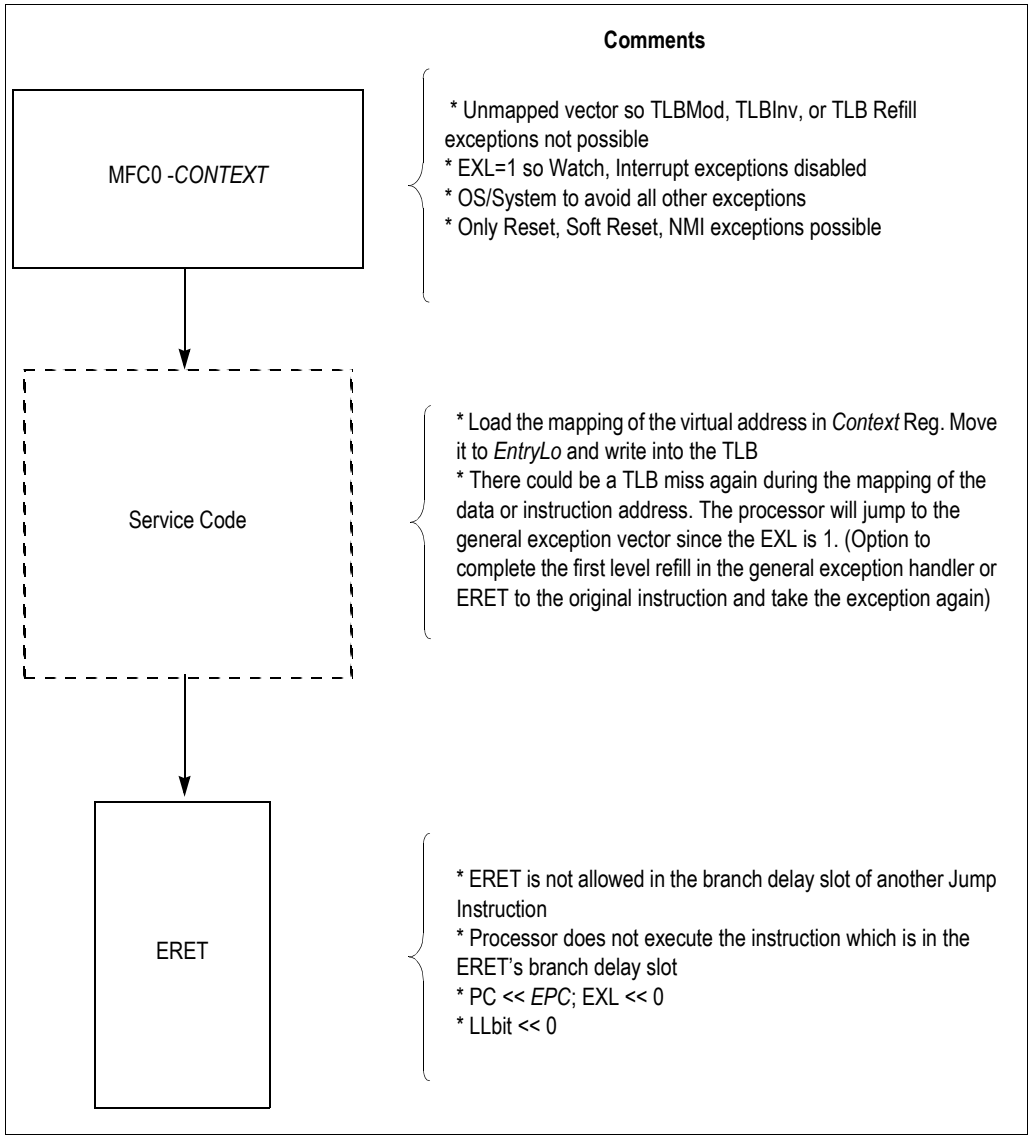


Figure 2.32 TLB Exception Servicing Guidelines (SW)

Notes

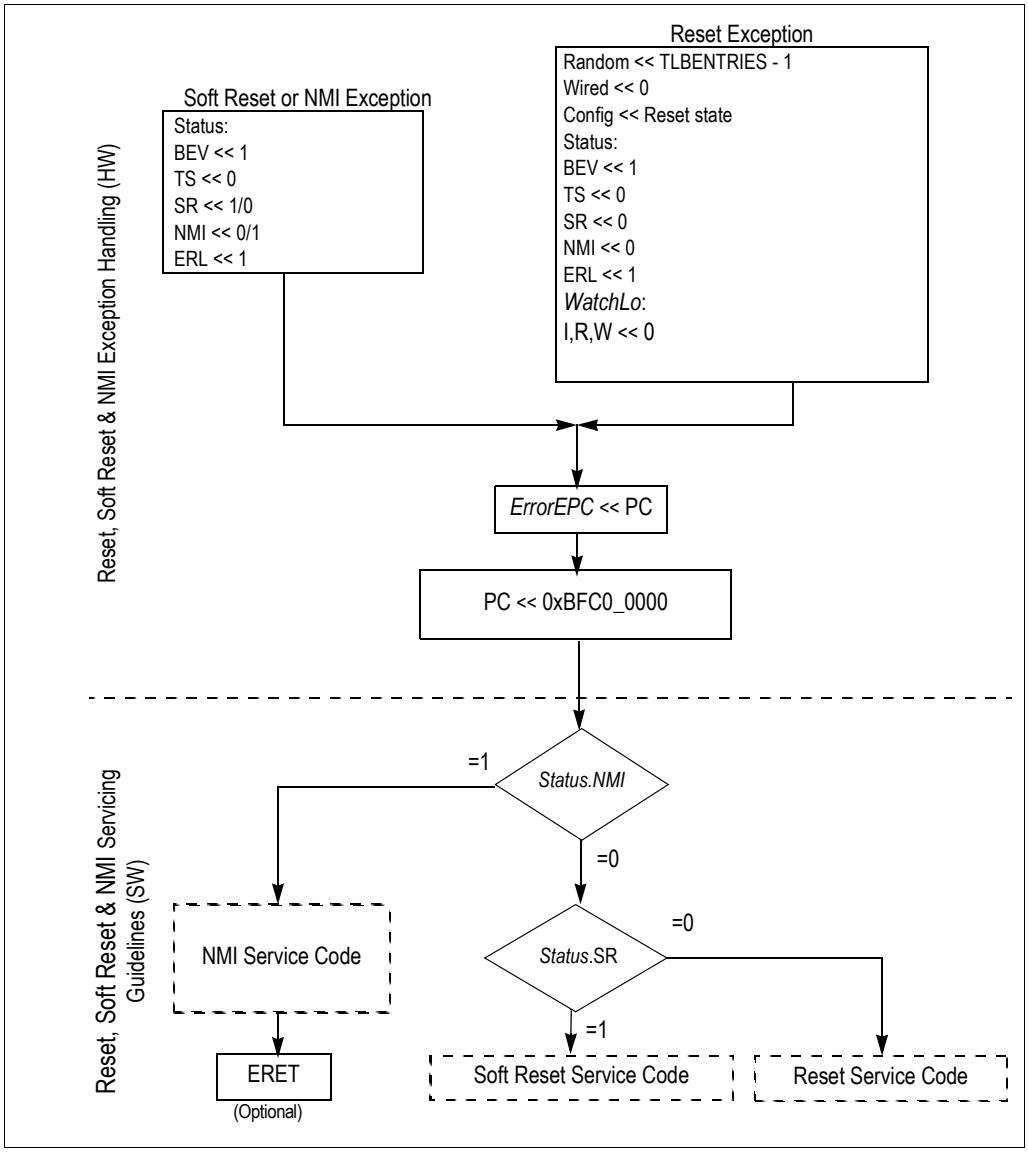


Figure 2.33 Reset, Soft Reset, and NMI Exception Handling and Servicing Guidelines

CP0 Registers

The System Control Coprocessor (CP0) provides the register interface to the MIPS32 4Kc processor core and supports memory management, address translation, exception handling, and other privileged operations. Each CP0 register has a unique number (register number) that identifies it. For example, the PageMask register is register number 5. For more information on the EJTAG registers, refer to Chapter 20, EJTAG System.

After updating a CP0 register, there is a hazard period of zero or more instructions from the update instruction (MTC0) and until the effect of the update has taken place in the core.

CP0 Register Summary

Table 5-1 lists the CP0 registers in numerical order.

Notes

Register Number	Register Name	Function
0	Index[1]	Index into the TLB array
1	Random[1]	Randomly generated index into the TLB array
2	EntryLo0[1]	Low-order portion of the TLB entry for even-numbered virtual pages
3	EntryLo1[1]	Low-order portion of the TLB entry for odd-numbered virtual pages
4	Context[2]	Pointer to page table entry in memory
5	PageMask[1]	Controls the variable page sizes in TLB entries
6	Wired[1]	Controls the number of fixed (“wired”) TLB entries
7	Reserved	Reserved
8	BadVAddr[2]	Reports the address for the most recent address-related exception
9	Count[2]	Processor cycle count
10	EntryHi[1]	High-order portion of the TLB entry.
11	Compare[2]	Timer interrupt control
12	Status[2]	Processor status and control
13	Cause[2]	Cause of last exception
14	EPC[2]	Program counter at last exception
15	PRId	Processor identification and revision
16	Config/Config1	Configuration register
17	LLAddr	Load linked address
18	WatchLo[2]	Watchpoint address (low order)
19	WatchHi[2]	Watchpoint address (high order) and mask
20 - 22	Reserved	Reserved
23	Debug[3]	Debug control and exception status
24	DEPC[3]	Program counter at last debug exception
25	Reserved	Reserved
26	ErrCtl	Controls access to data and SPRAM arrays for CACHE instruction
27	Reserved	Reserved
28	TagLo/DataLo	Low-order portion of cache tag interface
29	Reserved	Reserved
30	ErrorEPC[2]	Program counter at last error
31	DESAVE[3]	Debug handler scratchpad register

Table 2.25 CP0 Registers

1. Registers used in memory management.
2. Registers used in exception processing.
3. Registers used in debug.

Notes

CP0 Registers

The CP0 registers provide the interface between the ISA and the architecture. Each register is discussed below, with the registers presented in numerical order, first by register number, then by select field number. For each register described below, field descriptions include the read/write properties of the field and the reset state of the field. Table 2.26 summarizes the read/write properties of the field.

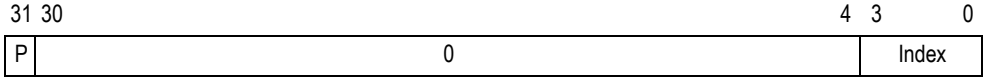
Read/Write Notation	Hardware Interpretation	Software Interpretation
R/W	A field in which all bits are readable and writable by software and, potentially, by hardware. Hardware updates of this field are visible by software read. Software updates of this field are visible by hardware read. If the reset state of this field is "Undefined," either software or hardware must initialize the value before the first read will return a predictable value. This should not be confused with the formal definition of UNDEFINED behavior.	
R	A field that is either static or is updated only by hardware. If the Reset State of this field is either "0" or "Preset", hardware initializes this field to zero or to the appropriate state, respectively, on powerup. If the Reset State of this field is "Undefined", hardware updates this field only under those conditions specified in the description of the field.	A field to which the value written by software is ignored by hardware. Software may write any value to this field without affecting hardware behavior. Software reads of this field return the last value updated by hardware. If the Reset State of this field is "Undefined," software reads of this field result in an UNPREDICTABLE value except after a hardware update done under the conditions specified in the description of the field.
0	A field that hardware does not update, and for which hardware can assume a zero value.	A field to which the value written by software must be zero. Software writes of non-zero values to this field may result in UNDEFINED behavior of the hardware. Software reads of this field return zero as long as all previous software writes are zero. If the Reset State of this field is "Undefined," software must write this field with zero before it is guaranteed to read as zero.

Table 2.26 CP0 Register Field Types

Index Register (CP0 Register 0, Select 0)

The Index register is a 32-bit read/write register that contains the index used to access the TLB for TLBP, TLBR, and TLBWI instructions. The width of the index field is 4-bits wide in order to address the 16 entries in the TLB. The operation of the processor is UNDEFINED if a value greater than or equal to the number of TLB entries is written to the Index register. This register is only valid with the TLB.

IIndex Register Format



Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
P	31	Probe Failure. Set to 1 when the previous TLBProbe (TLBP) instruction failed to find a match in the TLB.	R	Undefined
0	30:4	Must be written as zero; returns zero on read.	0	0
Index	3:0	Index to the TLB entry affected by the TLBRead and TLBWrite instructions.	R/W	Undefined

Table 2.27 Index Register Field Descriptions

Random Register (CP0 Register 1, Select 0)

The Random register is a read-only register whose value is used to index the TLB during a TLBWR instruction. The width of the Random field is calculated in the same manner as that described for the Index register above.

The value of the register varies between an upper and lower bound as follow:

A lower bound is set by the number of TLB entries reserved for exclusive use by the operating system (the contents of the Wired register). The entry indexed by the Wired register is the first entry available to be written by a TLB Write Random operation.

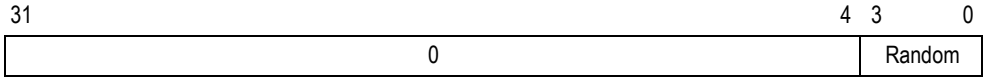
An upper bound is set by the total number of TLB entries minus 1.

The Random register is decremented by one almost every clock wrapping after the value in the Wired register is reached. To enhance the level of randomness and reduce the possibility of a live lock condition, an LFSR register is used that prevents the decrement pseudo-randomly.

The processor initializes the Random register to the upper bound on a Reset exception and when the Wired register is written.

This register is only valid with the TLB.

Random Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	31:4	Must be written as zero; returns zero on read.	0	0
Random	3:0	TLB Random Index	R	TLB Entries - 1

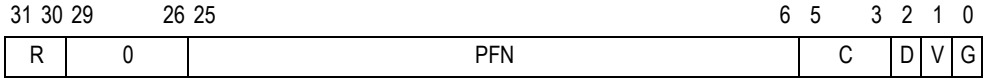
Table 2.28 Random Register Field Descriptions

EntryLo0, EntryLo1 (CP0 Registers 2 and 3, Select 0)

The pair of EntryLo registers act as the interface between the TLB and the TLBR, TLBWI, and TLBWR instructions. For a TLB-based MMU, EntryLo0 holds the entries for even pages and EntryLo1 holds the entries for odd pages. The contents of the EntryLo0 and EntryLo1 registers are undefined after an address error, TLB invalid, TLB modified, or TLB refill exceptions. These registers are only valid with the TLB.

Notes

EntryLo0, EntryLo1 Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
R	31:30	Reserved. Should be ignored on writes; returns zero on read.	R	0
0	29:26	These 4 bits are normally part of the PFN. However, since the core supports only 32-bits of physical address, the PFN is only 20-bits wide. Therefore, bits 29:26 of this register must be written with zeros.	R/W	0
PFN	25:6	Page Frame Number. Corresponds to bits 31:12 of the physical address.	R/W	Undefined
C	5:3	Coherency attribute of the page. See Table 2.30.	R/W	Undefined
D	2	"Dirty" or write-enable bit, indicating that the page has been written, and/or is writable. If this bit is a one, stores to the page are permitted. If this bit is a zero, stores to the page cause a TLB Modified exception.	R/W	Undefined
V	1	Valid bit, indicating that the TLB entry, and thus the virtual page mapping are valid. If this bit is a one, accesses to the page are permitted. If this bit is a zero, accesses to the page cause a TLB Invalid exception.	R/W	Undefined
G	0	Global bit. On a TLB write, the logical AND of the G bits in both the EntryLo0 and EntryLo1 registers become the G bit in the TLB entry. If the TLB entry G bit is a one, ASID comparisons are ignored during TLB matches. On a read from a TLB entry, the G bits of both EntryLo0 and EntryLo1 reflect the state of the TLB G bit.	R/W	Undefined

Table 2.29 EntryLo0, EntryLo1 Register Field Descriptions

Table 2.30 lists the encoding of the C field of the EntryLo0 and EntryLo1 registers and the K0 field of the Config register.

C(5:3) Value	Cache Coherency Attributes
0, 1, 3[1], 4, 5, 6	Cacheable, noncoherent, write through, no write allocate
2[1], 7	Uncached

Table 2.30 Cache Coherency Attributes

1. These two values are required by the MIPS32 architecture. No other values are used. For example, values 0, 1, 4, 5 and 6 are not used and are mapped to 3. The value 7 is not used and is mapped to 2. Note that these values do have meaning in other MIPS Technologies processor implementations. Refer to the MIPS32 specification for more information.

Notes

Context Register (CP0 Register 4, Select 0)

The Context register is a read/write register containing a pointer to an entry in the page table entry (PTE) array. This array is an operating system data structure that stores virtual-to-physical translations. During a TLB miss, the operating system loads the TLB with the missing translation from the PTE array. The Context register duplicates some of the information provided in the BadVAddr register but is organized in such a way that the operating system can directly reference an 8-byte page table entry (PTE) in memory.

A TLB exception (TLB Refill, TLB Invalid, or TLB Modified) causes bits VA31:13 of the virtual address to be written into the BadVPN2 field of the Context register. The PTEBase field is written and used by the operating system. Refer to Table 2.31. The BadVPN2 field of the Context register is not defined after an address error exception. This register is only valid with the TLB.

Context Register Format

31 23	22 4	3 0
PTEBase	BadVPN2	0

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
PTEBase	31:23	This field is for use by the operating system and is normally written with a value that allows the operating system to use the *Context* Register as a pointer into the current PTE array in memory.	R/W	Undefined
BadVPN2	22:4	This field is written by hardware on a TLB miss for the 4Kc core. It contains bits $VA_{31:13}$ of the virtual address that missed.	R	Undefined
0	3:0	Must be written as zero; returns zero on read.	0	0

Table 2.31 Context Register Field Descriptions

PageMask Register (CP0 Register 5, Select 0)

The PageMask register is a read/write register used for reading from and writing to the TLB. It holds a comparison mask that sets the variable page size for each TLB entry, as shown in Table 2.33. Behavior is UNDEFINED if a value other than those listed is used. This register is only valid with the TLB.

PageMask Register Format

31 25	24 13	12 0
0	Mask	0

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
Mask	24:13	The Mask field is a bit mask in which a “1” indicates that the corresponding bit of the virtual address should not participate in the TLB match.	R/W	Undefined
0	31:25 and 12:0	Must be written as zero; returns zero on read.	0	0

Table 2.32 PageMask Register Field Descriptions

Notes

Page Size	Bit											
	24	23	22	21	20	19	18	17	16	15	14	13
4 KBytes	0	0	0	0	0	0	0	0	0	0	0	0
16 KBytes	0	0	0	0	0	0	0	0	0	0	1	1
64 KBytes	0	0	0	0	0	0	0	0	1	1	1	1
256 KBytes	0	0	0	0	0	0	1	1	1	1	1	1
1 MByte	0	0	0	0	1	1	1	1	1	1	1	1
4 MByte	0	0	1	1	1	1	1	1	1	1	1	1
16 Mbyte	1	1	1	1	1	1	1	1	1	1	1	1

Table 2.33 Values for the Mask Field of the PageMask Register

Wired Register (CP0 Register 6, Select 0)

The Wired register is a read/write register that specifies the boundary between the wired and random entries in the TLB as shown in Figure 2.34. The width of the Wired field is calculated in the same manner as that described for the Index register above. Wired entries are fixed, non-replaceable entries that are not overwritten by a TLBWR instruction. Wired entries can be overwritten by a TLBWI instruction. The Wired register is set to zero by a Reset exception. Writing the Wired register causes the Random register to reset to its upper bound. The operation of the processor is undefined if a value greater than or equal to the number of TLB entries is written to the Wired register. This register is only valid with a TLB.

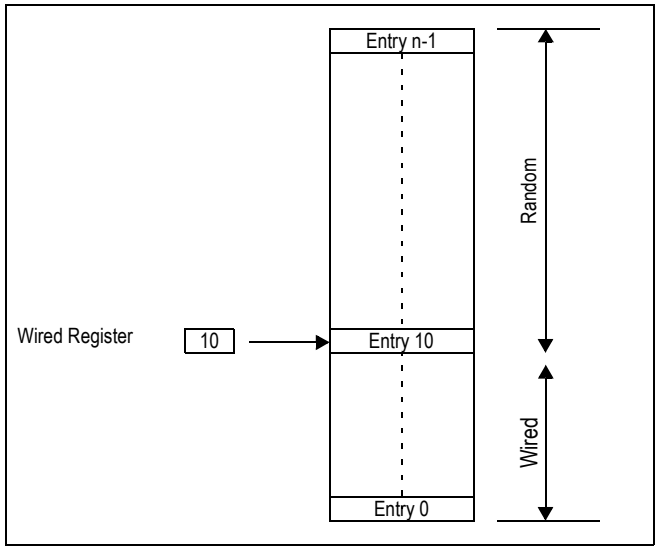
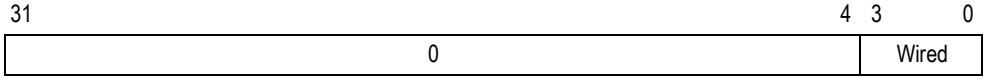


Figure 2.34 Wired and Random Entries in the TLB

Wired Register Format



Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	31:4	Must be written as zero; returns zero on read.	0	0
Wired	3:0	TLB wired boundary.	R/W	0

Table 2.34 Wired Register Field Descriptions

BadVAddr Register (CP0 Register 8, Select 0)

The BadVAddr register is a read-only register that captures the most recent virtual address that caused one of the following exceptions:

Address error (AdEL or AdES)

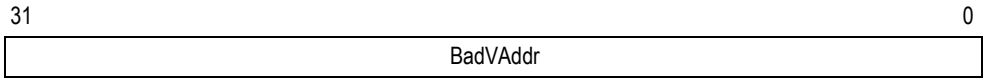
TLB Refill

TLB Invalid

TLB Modified

The BadVAddr register does not capture address information for cache or bus errors, since neither is an addressing error.

BadVAddr Register Format



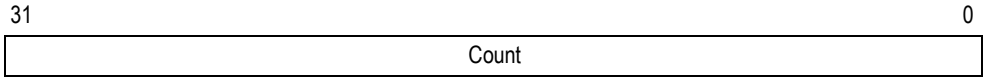
Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
BadVAddr	31:0	Bad virtual address	R	Undefined

Table 2.35 BadVAddr Register Field Descriptions

Count Register (CP0 Register 9, Select 0)

The Count register acts as a timer, incrementing at a constant rate, whether or not an instruction is executed, retired, or any forward progress is made through the pipeline. The counter increments every other clock. The Count register can be written for functional or diagnostic purposes, including at reset or to synchronize processors. Whether the Count register continues incrementing while the processor is in debug mode is determined by the CountDM bit in the Debug register. Refer to section “Debug Register (CP0 Register 23)” on page 2-73.

Count Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
Count	31:0	Interval counter.	R/W	Undefined

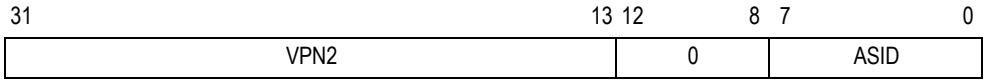
Table 2.36 Count Register Field Descriptions

Notes

EntryHi Register (CP0 Register 10, Select 0)

The EntryHi register contains the virtual address match information used for TLB read, write, and access operations. A TLB exception (TLB Refill, TLB Invalid, or TLB Modified) causes bits VA31:13 of the virtual address to be written into the VPN2 field of the EntryHi register. The ASID field is written by software with the current address space identifier value and is used during the TLB comparison process to determine TLB match. The VPN2 field of the EntryHi register is not defined after an address error exception. This register is only valid with the TLB.

EntryHi Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
VPN2	31:13	$VA_{31:13}$ of the virtual address (virtual page number / 2). This field is written by hardware on a TLB exception or on a TLB read, and is written by software before a TLB write.	R/W	Undefined
0	12:8	Must be written as zero; returns zero on read.	0	0
ASID	7:0	Address space identifier. This field is written by hardware on a TLB read and by software to establish the current ASID value for TLB write and against which TLB references match each entry's TLB ASID field.	R/W	Undefined

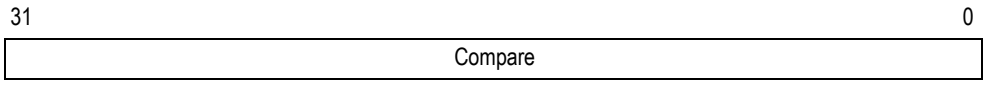
Table 2.37 EntryHi Register Field Descriptions

Compare Register (CP0 Register 11, Select 0)

The Compare register acts in conjunction with the Count register to implement a timer and timer interrupt function. The timer interrupt is an output of the cores. The Compare register maintains a stable value and does not change on its own. When the value of the Count register equals the value of the Compare register, the SI_TimerInt pin is asserted. This pin will remain asserted until the Compare register is written. The SI_TimerInt pin can be fed back into the core on one of the interrupt pins to generate an interrupt. Traditionally, this has been done by connecting it with hardware interrupt 5 to set interrupt bit IP(7) in the Cause register.

For diagnostic purposes, the Compare register is a read/write register. In normal use, however, the Compare register is write-only. Writing a value to the Compare register, as a side effect, clears the timer interrupt.

Compare Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
Compare	31:0	Interval count compare value	R/W	Undefined

Table 2.38 Compare Register Field Description

Notes

Status Register (CP0 Register 12, Select 0)

The Status register (SR) is a read/write register that contains the operating mode, interrupt enabling, and the diagnostic states of the processor. Fields of this register combine to create operating modes for the processor, as follows:

Interrupt Enable: Interrupts are enabled when all of the following conditions are true:

IE = 1

EXL = 0

ERL = 0

DM = 0

If these conditions are met, the settings of the IM and IE bits enable the interrupt.

Operating Modes: If the DM bit in the Debug register is 1, the processor is in debug mode. Otherwise the processor is in either kernel or user mode. The following CPU Status register bit settings determine user or kernel mode.

User mode: UM = 1, EXL = 0, and ERL = 0

Kernel mode: UM = 0, or EXL = 1, or ERL = 1

Coprocessor Accessibility: The Status register CU bits control coprocessor accessibility. If any coprocessor is unusable, an instruction that accesses it generates an exception.

Coprocessor 0 is always enabled in kernel mode, regardless of the setting of the CU0 bit.

Status Register Format

31	28	27	26	25	24	23	22	21	20	19	18	17	16	15	8	7	5	4	3	2	1	0
CU3-CU0		0	R	RE	0		BEV	TS	SR	NMI	0	0		IM7-IM0		R		UM	R	ERL	EXL	IE

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
CU3-CU0	31:28	Controls access to coprocessors 3, 2, 1, and 0, respectively: 0: access not allowed 1: access allowed Coprocessor 0 is always usable when the processor is running in kernel mode, independent of the state of the CU0 bit. The core does not support coprocessors 1-3, but CU3:1 can still be set. However, processor behavior is unpredictable if a coprocessor instruction to coprocessors 1-3 is attempted with the corresponding CU3:1 bit set.	R/W	Undefined
0	27	This bit must be written as zero; returns zero on read.	R/W	0
R	26	This bit must be ignored on writes and read as zero.	R	0
RE	25	Used to enable reverse-endian memory references while the processor is running in user mode: 0: User mode uses configured endianness 1: User mode uses reversed endianness Kernel or debug mode references are not affected by the state of this bit.	R/W	Undefined

Table 2.39 Status Register Field Description (Part 1 of 3)

Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	24:23	This bit must be written as zero; returns zero on read.	R	0
BEV	22	Controls the location of exception vectors: 0: Normal 1: Bootstrap	R/W	1
TS	21	TLB shutdown. This bit is set if a TLBWI or TLBWR instruction is issued that would cause a TLB shut-down condition if allowed to complete. Software can only write a 0 to this bit to clear it and cannot force a 0-1 transition.	R/W	0
SR	20	Indicates that the entry through the reset exception vector was due to a Soft Reset: 0: Not Soft Reset (NMI or hard reset) 1: Soft Reset Software can only write a 0 to this bit to clear it and cannot force a 0-1 transition.	R/W	1 for Soft Reset; 0 otherwise
NMI	19	Indicates that the entry through the reset exception vector was due to an NMI. 0: Not NMI (soft or hard reset) 1: NMI Software can only write a 0 to this bit to clear it and cannot force a 0-1 transition.	R/W	1 for NMI; 0 other-wise
0	18	Must be written as zero; returns zero on read.	R	0
R	17:16	Reserved. Must be ignored on write and read as zero.	R	0
IM[7:0]	15:8	Interrupt Mask: Controls the enabling of each of the external, internal, and software interrupts. An inter-rupt is taken if interrupts are enabled and the corre-sponding bits are set in both the Interrupt Mask field of the Status register and the Interrupt Pending field of the Cause register and the IE bit is set in the Sta-tus register. 0: Interrupt request disabled 1: Interrupt request enabled	R/W	Undefined
R	7:5	Reserved. Must be ignored on write and read as zero.	R	0
UM	4	Indicates that the processor is operating in user mode: 0: processor is operating in kernel mode 1: processor is operating in user mode Note that the processor can also be in kernel mode if EXR or ERL are set. This condition does not affect the state of the UM bit.	R/W	Undefined
R	3	Reserved. Must be ignored on write and read as zero.	R	0

Table 2.39 Status Register Field Description (Part 2 of 3)

Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
ERL	2	Error Level. Set by the processor when a Reset, Soft Reset, or NMI exception is taken. 0: normal level 1: error level When ERL is set: The processor is running in kernel mode. Interrupts are disabled. The ERET instruction uses the return address held in ErrorEPC instead of EPC. kuseg is treated as an unmapped and uncached region. This allows main memory to be accessed in the presence of cache errors. Behavior is **UNDEFINED** if ERL is set while executing code in useg/kuseg.	R/W	1
EXL	1	Exception Level. Set by the processor when any exception other than a Reset, Soft Reset, or NMI exception is taken. 0: normal level 1: exception level When EXL is set: The processor is running in kernel mode. Interrupts are disabled. In the 4Kc core, TLB refill exceptions use the general exception vector instead of the TLB refill vector. EPC is not updated if another exception is taken.	R/W	Undefined
IE	0	Interrupt Enable. Acts as the master enable for software and hardware interrupts: 0: disables interrupts 1: enables interrupts	R/W	Undefined

Table 2.39 Status Register Field Description (Part 3 of 3)

Cause Register (CP0 Register 13, Select 0)

The Cause register primarily describes the cause of the most recent exception. In addition, fields also control software interrupt requests and the vector through which interrupts are dispatched. With the exception of the IP[1:0], IV, and WP fields, all fields in the Cause register are read-only.

Cause Register Format

31	30	29 28 27	24	23	22	21 16	15 10	9 8	7	6 2	1 0
BD	0	CE	0	IV	WP	0	IP[7:2]	IP[1:0]	0	Exc Code	0

Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
BD	31	Indicates whether the last exception taken occurred in a branch delay slot: 0: Not in delay slot 1: In delay slot Note that the BD bit is not updated on a new exception if the EXL bit is set.	R	Undefined
CE	29:28	Coprocessor unit number referenced when a Coprocessor Unusable exception is taken. This field is loaded by hardware on every exception but is unpredictable for all exceptions except for Coprocessor Unusable.	R	Undefined
IV	23	Indicates whether an interrupt exception uses the general exception vector or a special interrupt vector: 0: Use the general exception vector (0x180) 1: Use the special interrupt vector (0x200)	R/W	Undefined
WP	22	Indicates that a watch exception was deferred because $Status_{EXL}$ or $Status_{ERL}$ were a one at the time the watch exception was detected. This bit both indicates that the watch exception was deferred and causes the exception to be initiated once $Status_{EXL}$ and $Status_{ERL}$ are both zero. As such, software must clear this bit as part of the watch exception handler to prevent a watch exception loop. Software can only write a 0 to this bit to clear it and cannot force a 0-1 transition.	R/W	Undefined
IP[7:2]	15:10	Indicates an external interrupt is pending: 15: Hardware interrupt 5 or timer interrupt 14: Hardware interrupt 4 13: Hardware interrupt 3 12: Hardware interrupt 2 11: Hardware interrupt 1 10: Hardware interrupt 0	R	Undefined
IP[1:0]	9:8	Controls the request for software interrupts: 9: Request software interrupt 1 8: Request software interrupt 0	R/W	Undefined
Exc Code	6:2	Exception code — see Table 2.41.	R	Undefined
0	30, 27:24, 21:16, 7, 1:0	Must be written as zero; returns zero on read.	R	0

Table 2.40 Cause Register Field Descriptions

Notes

Exception Code Value	Mnemonic	Description
0	Int	Interrupt
1	Mod	TLB modification exception
2	TLBL	TLB exception (load or instruction fetch)
3	TLBS	TLB exception (store)
4	AdEL	Address error exception (load or instruction fetch)
5	AdES	Address error exception (store)
6	IBE	Bus error exception (instruction fetch)
7	DBE	Bus error exception (data reference: load or store)
8	Sys	Syscall exception
9	Bp	Breakpoint exception
10	RI	Reserved instruction exception
11	CpU	Coprocessor Unusable exception
12	Ov	Integer Overflow exception
13	Tr	Trap exception
14-22	—	Reserved
23	WATCH	Reference to WatchHi/WatchLo address
24	MCheck	Machine check
25-31	—	Reserved

Table 2.41 Cause Register ExcCode Field Descriptions

Exception Program Counter (CP0 Register 14, Select 0)

The Exception Program Counter (EPC) is a read/write register that contains the address at which processing resumes after an exception has been serviced. All bits of the EPC register are significant and must be writable.

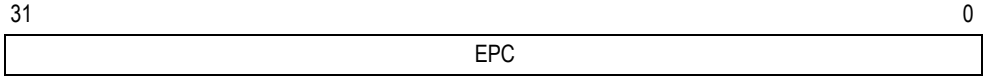
For synchronous (precise) exceptions, the EPC contains one of the following:

The virtual address of the instruction that was the direct cause of the exception

The virtual address of the immediately preceding branch or jump instruction, when the exception causing instruction is in a branch delay slot and the Branch Delay bit in the Cause register is set.

On new exceptions, the processor does not write to the EPC register when the EXL bit in the Status register is set. However, the register can still be written via the MTC0 instruction.

EPC Register Format



Notes

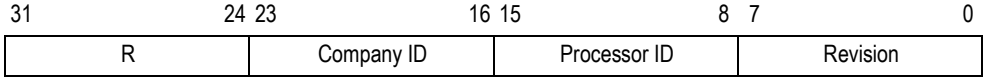
Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
EPC	31:0	Exception Program Counter	R/W	Undefined

Table 2.42 EPC Register Field Description

Processor Identification (CP0 Register 15, Select 0)

The Processor Identification (PRId) register is a 32-bit read-only register that contains information identifying the manufacturer, manufacturer options, processor identification, and revision level of the processor.

PRId Register Format



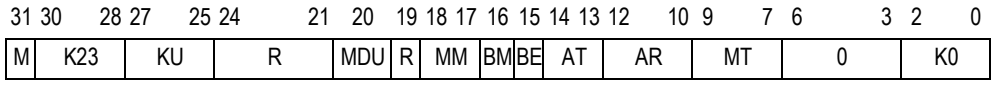
Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
R	31:24	Reserved. Must be ignored on write and read as zero.	R	0
Company ID	23:16	Identifies the company that designed or manufactured the processor. In all three cores this field contains a value of 1 to indicate MIPS Technologies, Inc.	R	1
Processor ID	15:8	Identifies the type of processor. This field allows software to distinguish between the various types of MIPS Technologies processors. This field contains a value of 0x80 for the 4Kc processor.	R	0x80
Revision	7:0	Specifies the revision number of the processor. This field allows software to distinguish between one revision and another of the same processor type. Current values are: 0x1: 1.1-2.2 0x2: 2.3-2.4 0x3: 2.5-2.6 0x4: 3.0 0x5: 3.1 0x6: 3.2 0x7: 3.3 0x8: 3.4 0x9: 3.5	R	0x09

Table 2.43 PRId Register Field Descriptions

Config Register (CP0 Register 16, Select 0)

The Config register specifies various configuration and capabilities information. Most of the fields in the Config register are initialized by hardware during the Reset exception process, or are constant. One field, K0, must be initialized by software in the Reset exception handler.

Register Format — Select 0



Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
M	31	This bit is hardwired to '1' to indicate the presence of the Config1 register.	R	1
K23	30:28	This field is reserved (must be written as 0; returns 0 on read).	FM: R/W TLB: 0	FM: 010 TLB: 000
KU	27:25	This field is reserved (must be written as 0; returns 0 on read).	FM: R/W TLB: 0	FM: 010 TLB: 000
0	24:21	Must be written as 0. Returns 0 on read.	0	0
MDU	20	This bit indicates the MDU type. 0 = Fast Multiplier Array 1 = Reserved	R	Preset
0	19	Must be written as 0. Returns 0 on read.	0	0
MM	18:17	This field contains the merge mode for the 32-byte collapsing write buffer: 00 = No Merging 01 = SysAD Valid merging 10 = Full merging 11 = Reserved	R	Externally Set
BM	16	Burst order. 0: Sequential 1: SubBlock	R	Externally Set
BE	15	Indicates the endian mode in which the processor is running: 0: Little endian 1: Big endian	R	Externally Set
AT	14:13	Architecture type implemented by the processor. This field is always 00 to indicate MIPS32.	R	00
AR	12:10	Architecture revision level. This field is always 000 to indicate revision 1. 0: Revision 1 1-7: Reserved	R	000
MT	9:7	MMU Type: 1: Standard TLB All other values: Reserved	R	Preset
0	6:3	Must be written as zero; returns zero on read.	0	0
K0	2:0	Kseg0 coherency algorithm. Refer to Table 2.45 for the field encoding.	R/W	010

Table 2.44 Config Register Field Descriptions

Notes

C(2:0) Value	Cache Coherency Attribute
0, 1, 3[1], 4, 5, 6	Cacheable, noncoherent, write-through, no write allocate
2[1], 7	Uncached

Table 2.45 Cache Coherency Attributes

1. These two values are required by the MIPS32 architecture. No other values are used. For example, values 0, 1, 4, 5 and 6 are not used and are mapped to 3. The value 7 is not used and is mapped to 2. Note that these values do have meaning in other MIPS Technologies processor implementations. Refer to the MIPS32 specification for more information.

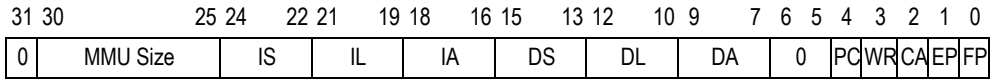
Config1 Register (CP0 Register 16, Select 1)

The Config1 register is an adjunct to the Config register and encodes additional capabilities information. All fields in the Config1 register are read-only. The instruction and data cache configuration parameters include encodings for the number of sets per way, the line size, and the associativity. The total cache size for a cache is therefore:

*Associativity * Line Size * Sets Per Way*

If the line size is zero, there is no cache implemented.

Config1 Register Format — Select 1



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	31	This bit is reserved to and must be read or written as zero.	R	0
MMU Size	30:25	This field contains the number of entries in the TLB minus one. The field is read as 15 decimal.	R	Preset
IS	24:22	This field contains the number of instruction cache sets per way. Three options are available. All others values are reserved: 0x0: 64 0x1: 128 0x2: 256 0x3 - 0x7: Reserved	R	Preset
IL	21:19	This field contains the instruction cache line size. If an instruction cache is present, it must contain a fixed line size of 16 bytes. 0x0: No Icache present 0x3: 16 bytes 0x1, 0x2, 0x4 - 0x7: Reserved	R	Preset
IA	18:16	This field contains the level of instruction cache associativity. 0x0: Direct mapped 0x1: 2-way 0x2: 3-way 0x3: 4-way 0x4 - 0x7: Reserved	R	Preset

Table 2.46 Config1 Register Field Descriptions — Select 1 (Part 1 of 2)

Notes

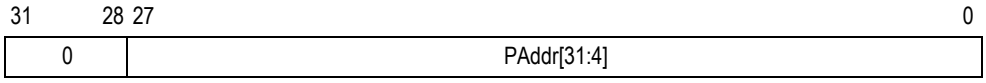
Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
DS	15:13	This field contains the number of data cache sets per way: 0x0: 64 0x1: 128 0x2: 256 0x3 - 0x7: Reserved	R	Preset
DL	12:10	This field contains the data cache line size. If a data cache is present, it must contain a line size of 16 bytes. 0x0: No Dcache present 0x3: 16 bytes 0x1, 0x2, 0x4 - 0x7: Reserved	R	Preset
DA	9:7	This field contains the type of set associativity for the data cache: 0x0: Direct mapped 0x1: 2-way 0x2: 3-way 0x3: 4-way 0x4 - 0x7: Reserved	R	Preset
0	6:5	Must be written as zero; returns zero on read.	0	0
PC	4	Performance Counter registers implemented. Always a 0 since the cores do not implement any.	R	0
WR	3	Watch registers implemented. This bit always reads as 1 since the cores each contain one pair of Watch registers.	R	1
CA	2	Code compression (MIPS16™) implemented. This bit always reads as 0 because MIPS16 is not supported.	R	0
EP	1	EJTAG present: This bit is always set to indicate that the core implements EJTAG.	R	1
FP	0	FPU implemented. This bit is always zero since the core does not contain a floating-point unit.	R	0

Table 2.46 Config1 Register Field Descriptions — Select 1 (Part 2 of 2)

Load Linked Address (CP0 Register 17, Select 0)

The LLAddr register contains the physical address read by the most recent Load Linked (LL) instruction. This register is for diagnostic purposes only, and serves no function during normal operation.

LLAddr Register Format



Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	31:28	Must be written as zero; returns zero on read.	0	0
PAddr[31:4]	27:0	This field encodes the physical address read by the most recent Load Linked instruction.	R	Undefined

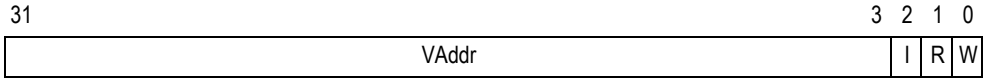
Table 2.47 LLAddr Register Field Descriptions

WatchLo Register (CP0 Register 18)

The WatchLo and WatchHi registers together provide the interface to a watchpoint debug facility that initiates a watch exception if an instruction or data access matches the address specified in the registers. As such, they duplicate some functions of the EJTAG debug solution. Watch exceptions are taken only if the EXL and ERL bits are zero in the Status register. If either bit is a one, the WP bit is set in the Cause register, and the watch exception is deferred until both the EXL and ERL bits are zero.

The WatchLo register specifies the base virtual address and the type of reference (instruction fetch, load, store) to match.

WatchLo Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
VAddr	31:3	This field specifies the virtual address to match. Note that this is a doubleword address, since bits [2:0] are used to control the type of match.	R/W	Undefined
I	2	If this bit is set, watch exceptions are enabled for instruction fetches that match the address.	R/W	0 for Cold Reset only.
R	1	If this bit is set, watch exceptions are enabled for loads that match the address.	R/W	0 for Cold Reset only.
W	0	If this bit is set, watch exceptions are enabled for stores that match the address.	R/W	0 for Cold Reset only.

Table 2.48 WatchLo Register Field Descriptions

WatchHi Register (CP0 Register 19)

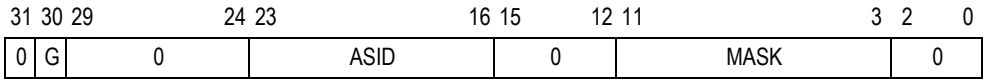
The WatchLo and WatchHi registers together provide the interface to a watchpoint debug facility that initiates a watch exception if an instruction or data access matches the address specified in the registers. As such, they duplicate some functions of the EJTAG debug solution. Watch exceptions are taken only if the EXL and ERL bits are zero in the Status register. If either bit is a one, the WP bit is set in the Cause register, and the watch exception is deferred until both the EXL and ERL bits are zero.

The WatchHi register contains information that qualifies the virtual address specified in the WatchLo register: an ASID, a Global (G) bit, and an optional address mask. If the G bit is 1, any virtual address reference that matches the specified address will cause a watch exception. If the G bit is a 0, only those virtual

Notes

address references for which the ASID value in the WatchHi register matches the ASID value in the EntryHi register cause a watch exception. The optional mask field provides address masking to qualify the address specified in WatchLo.

WatchHi Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
0	31	Must be written as zero; returns zero on read.	0	0
G	30	If this bit is one, any address that matches that specified in the *WatchLo* register causes a watch exception. If this bit is zero, the ASID field of the *WatchHi* register must match the ASID field of the *EntryHi* register to cause a watch exception.	R/W	Undefined
0	29:24	Must be written as zero; returns zero on read.	0	0
ASID	23:16	ASID value which is required to match that in the *EntryHi* register if the G bit is zero in the *WatchHi* register.	R/W	Undefined

Table 2.49 WatchHi Register Field Descriptions

Debug Register (CP0 Register 23)

The Debug register is used to control the debug exception and provide information about the cause of the debug exception and when re-entering at the debug exception vector due to a normal exception in debug mode. The read-only information bits are updated every time the debug exception is taken or when a normal exception is taken when already in debug mode.

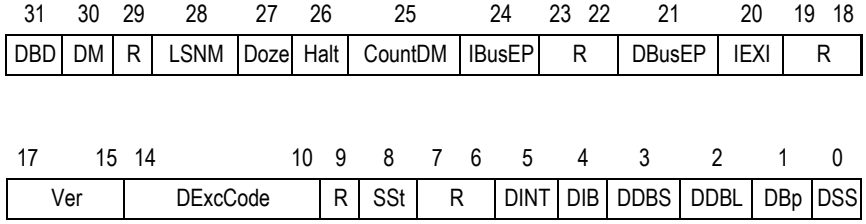
Only the DM bit and the EJTAGver field are valid when read from non-debug mode; the value of all other bits and fields is UNPREDICTABLE. Operation of the processor is UNDEFINED if the Debug register is written from non-debug mode.

Some of the bits and fields are only updated on debug exceptions and/or exceptions in debug mode, as shown below:

- *DSS, DBp, DDBL, DDBS, DIB, DINT are updated on both debug exceptions and on exceptions in debug modes*
- *DExcCode is updated on exceptions in debug mode, and is undefined after a debug exception*
- *Halt and Doze are updated on a debug exception, and is undefined after an exception in debug mode*
- *DBD is updated on both debug and on exceptions in debug modes.*

All bits and fields are undefined when read from normal mode, except those explicitly described to be defined, such as EJTAGver and DM.

Debug Register Format



Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
DBD	31	Indicates whether the last debug exception or exception in debug mode, occurred in a branch delay slot: 0: Not in delay slot 1: In delay slot	R	Undefined
DM	30	Indicates that the processor is operating in debug mode: 0: Processor is operating in non-debug mode 1: Processor is operating in debug mode	R	0
R	29	Reserved. Must be written as zero; returns zero on read.	R	0
LSNM	28	Controls access of load/store between dseg and main memory: 0: Load/stores in dseg address range goes to dseg. 1: Load/stores in dseg address range goes to main memory.	R/W	0
Doze	27	Indicates that the processor was in any kind of low power mode when a debug exception occurred: 0: Processor not in low power mode when debug exception occurred 1: Processor in low power mode when debug exception occurred	R	Undefined
Halt	26	Indicates that the internal system bus clock was stopped when the debug exception occurred: 0: Internal system bus clock stopped 1: Internal system bus clock running	R	Undefined
CountDM	25	Indicates the Count register behavior in debug mode. Encoding of the bit is: 0: Count register stopped in debug mode 1: Count register increments in debug mode	R/W	1
IBusEP	24	Instruction fetch Bus Error exception Pending. Set when an instruction fetch bus error event occurs or if a 1 is written to the bit by software. Cleared when a Bus Error Exception on Instruction Fetch is taken by the processor, and by reset. If IBusEP is set when IEXI is cleared, a Bus Error exception on instruction fetch is taken by the processor, and IBusEP is cleared.	R/W1	0
R	23:22	Reserved. Must be written as zero; returns zero on read.	R	0
DBusEP	21	Data access Bus Error exception Pending. Covers imprecise bus errors on data access, similar to behavior of IBusEP for imprecise bus errors on an instruction fetch.	R/W1	0

Table 2.50 Debug Register Field Descriptions (Part 1 of 2)

Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
IEXI	20	Imprecise Error eXception Inhibit controls exceptions taken due to imprecise error indications. Set when the processor takes a debug exception or exception in debug mode. Cleared by execution of the DERET instruction. Otherwise modifiable by debug mode software. When IEXI is set then the imprecise error exceptions from bus error on instruction fetch or data access, cache error or machine check are inhibited and deferred until the bit is cleared.	R/W	0
R	19:18	Reserved. Must be written as zero; returns zero on read.	R	0
Ver	17:15	EJTAG version	R	1
DExcCode	14:10	Indicates the cause of the latest exception in debug mode. The field is encoded as the ExcCode field in the Cause register for those normal exceptions that may occur in debug mode. Value is undefined after a debug exception.	R	Undefined
R	9	Reserved. Must be written as zero; returns zero on read.	R	0
SSt	8	Controls if debug single step exception is enabled: 0: No debug single step exception enabled 1: Debug single step exception enabled	R/W	0
R	7:6	Reserved. Must be written as zero; returns zero on read.	R	0
DINT	5	Indicates that a debug interrupt exception occurred. Cleared on exception in debug mode. 0: No debug interrupt exception 1: Debug interrupt exception	R/W	Undefined
DIB	4	Indicates that a debug instruction break exception occurred. Cleared on exception in debug mode. 0: No debug instruction exception 1: Debug instruction exception	R	Undefined
DDBS	3	Indicates that a debug data break exception occurred on a store. Cleared on exception in debug mode. 0: No debug data exception on a store 1: Debug instruction exception on a store	R	Undefined
DDBL	2	Indicates that a debug data break exception occurred on a load. Cleared on exception in debug mode. 0: No debug data exception on a load 1: Debug instruction exception on a load	R	Undefined
DBp	1	Indicates that a debug software breakpoint exception occurred. Cleared on exception in debug mode. 0: No debug software breakpoint exception 1: Debug software breakpoint exception	R	Undefined
DSS	0	Indicates that a debug single step exception occurred. Cleared on exception in debug mode. 0: No debug single step exception 1: Debug single step exception	R	Undefined

Table 2.50 Debug Register Field Descriptions (Part 2 of 2)

Notes

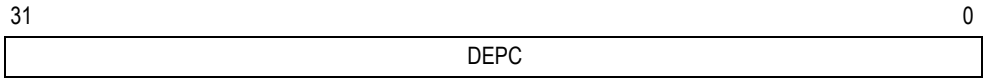
Debug Exception Program Counter Register (CP0 Register 24)

The Debug Exception Program Counter (DEPC) register is a read/write register that contains the address at which processing resumes after a debug exception or debug mode exception has been serviced. For synchronous (precise) debug and debug mode exceptions, the DEPC contains either:

- *The virtual address of the instruction that was the direct cause of the debug exception, or*
- *The virtual address of the immediately preceding branch or jump instruction, when the debug exception causing instruction is in a branch delay slot, and the Debug Branch Delay (BDB) bit in the Debug register is set.*

For asynchronous debug exceptions (debug interrupt), the DEPC contains the virtual address of the instruction where execution should resume after the debug handler code is executed.

DEPC Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
DEPC	31:0	The DEPC register is updated with the virtual address of the instruction that caused the debug exception. If the instruction is in the branch delay slot, the virtual address of the immediately preceding branch or jump instruction is placed in this register. Execution of the DERET instruction causes a jump to the address in the DEPC.	R/W	Undefined

Table 2.51 DEPC Register Field Description

ErrCtl Register (CP0 Register 26, Select 0)

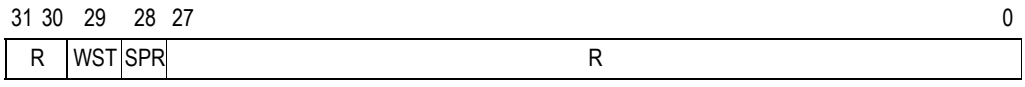
Note: This register was added to version 3.5 of the core. It is reserved in earlier versions.

The ErrCtl register provides a mechanism for enabling software testing of the way-select and data RAM arrays for both the ICache and DCache. The way-selection RAM test mode is enabled by setting the WST bit. It modifies the functionality of the CACHE Index Load Tag and Index Store Tag operations so that they modify the way-selection RAM and leave the Tag RAMs untouched. When this bit is set, the lower 6 bits of the PA field in the TagLo register are used as the source and destination for Index Load Tag and Index Store Tag CACHE operations.

The WST bit also enables the data RAM test mode. When this bit is set, the Index Store Data CACHE instruction is enabled. This CACHE operation writes the contents of the DataLo register to the word in the data array that is indicated by the index and byte address.

The SPR bit enables CACHE accesses to the optional Scratchpad RAMs. When this bit is set, Index Load Tag, Index Store Tag, and Index Store Data CACHE instructions will send reads or writes to the Scratchpad RAM port. The effects of these operations are dependent on the particular Scratchpad implementation.

ErrCtl Register Format



Notes

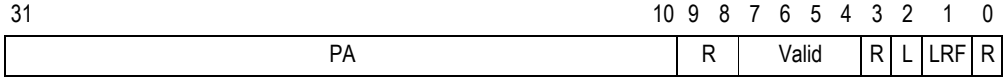
Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
WST	29	Indicates whether the tag array or the way-select array should be read/written on Index Load/Store Tag CACHE instructions. Also enables the Index Store Data CACHE instruction which writes the contents of DataLo to the data array.	R/W	0
SPR	28	Forces indexed CACHE instructions to operate on the ScratchPad RAM instead of the cache	R/W	0
R	31:30, 27:0	Must be written as zero; returns zero on reads.	0	0

Table 2.52 ErrCtl Register Field Descriptions

TagLo Register (CP0 Register 28, Select 0)

The TagLo register acts as the interface to the cache tag array. The Index Store Tag and Index Load Tag operations of the CACHE instruction use the TagLo register as the source of tag information, respectively.

TagLo Register Format



Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
PA	31:10	This field contains the physical address of the cache line being stored.	R/W	Undefined
R	9:8	Must be written as zero; returns zero on read.	0	0
Valid	7:4	This field indicates whether the corresponding word in the cache line is valid in the cache.	R/W	Undefined
R	3	Must be written as zero; returns zero on read.	0	0
L	2	Specifies the lock bit for the cache tag. When this bit is set, the corresponding cache line should not be replaced by the cache replacement algorithm.	R/W	Undefined
LRF	1	LRF. One bit of the LRF bits for the set this cache line is a part of. This bit is inverted every time a new cache line is filled in the cache entry.	R/W	Undefined
R	0	Must be written as zero; returns zero on read.	0	0

Table 2.53 TagLo Register Field Descriptions

Notes

DataLo Register (CP0 Register 28, Select 1)

The DataLo register acts as the interface to the cache data array. The Index Load Tag operation of the CACHE instruction reads the corresponding data values into the DataLo register. This register was made writeable on revision 3.5 and the Index Store Data operation of the CACHE instruction was added. This operation will write the cache data array with the value of this register.

DataLo Register Format

31	0
DATA	

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
DATA	31:0	Low-order data read from the cache data array.	R/W	Undefined

Table 2.54 DataLo Register Field Descriptions

ErrorEPC (CP0 Register 30, Select 0)

The ErrorEPC register is a read-write register, similar to the EPC register, except that ErrorEPC is used on error exceptions. All bits of the ErrorEPC register are significant and must be writable. It is also used to store the program counter on Reset, Soft Reset, and non-maskable interrupt (NMI) exceptions.

The ErrorEPC register contains the virtual address at which instruction processing can resume after servicing an error. This address can be:

- *The virtual address of the instruction that caused the exception*
- *The virtual address of the immediately preceding branch or jump instruction when the error causing instruction is in a branch delay slot.*

Unlike the EPC register, there is no corresponding branch delay slot indication for the ErrorEPC register.

ErrorEPC Register Format

31	0
ErrorEPC	

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
ErrorEPC	31:0	Error Exception Program Counter	R/W	Undefined

Table 2.55 ErrorEPC Register Field Descriptions

DeSave Register (CP0 Register 31)

The Debug Exception Save (DeSave) register is a read/write register that functions as a simple memory location. This register is used by the debug exception handler to save one of the GPRs that is then used to save the rest of the context to a pre-determined memory area (such as in the EJTAG Probe). This register allows the safe debugging of exception handlers and other types of code where the existence of a valid stack for context saving cannot be assumed.

DeSave Register Format

31	0
DESAVE	

Notes

Fields		Description	Read/ Write	Reset State
Name	Bit(s)			
DESAVE	31:0	Debug exception save contents.	R/W	Undefined

Table 2.56 DeSave Register Field Descriptions

Hardware and Software Initialization

The 4Kc processor core is not fully initialized by reset. Only a minimal subset of the processor state is cleared. This is enough to bring the core up while running in unmapped and uncached code space. All other processor states can then be initialized by software. SI_ColdReset is asserted after power-up to bring the device into a known state. Soft reset can be forced by asserting the SI_Reset pin. This can be used when the device is already up and running and does not need as much initialization.

Hardware Initialized Processor State

Coprocessor Zero State

Much of the hardware initialization occurs in Coprocessor Zero.

- *Random - set to maximum value on Reset*
- *Wired - set to 0 on Reset*
- *$Status_{BEV}$ - set to 1 on Reset/SoftReset*
- *$Status_{TS}$ - cleared to 0 on Reset/SoftReset*
- *$Status_{SR}$ - cleared to 0 on Reset, set to 1 on SoftReset*
- *$Status_{NMI}$ - cleared to 0 on Reset/SoftReset*
- *$Status_{ERL}$ - set to 1 on Reset/SoftReset*
- *$WatchLo_{I,R,W}$ - cleared to 0 on Reset*
- *Config fields related to static inputs - set to input value by Reset*
- *$Config_{K0}$ - set to 010 (uncached) on Reset*
- *DebugDM - cleared to 0 on Reset/SoftReset (unless EJTAGBOOT option is used to boot into DebugMode (see the EJTAG Debug Support section for more information)*
- *$Debug_{LSNM}$ - cleared to 0 on Reset/SoftReset*
- *$Debug_{IBusEP}$ - cleared to 0 on Reset/SoftReset*
- *$Debug_{DBusEP}$ - cleared to 0 on Reset/SoftReset*
- *$Debug_{IEXI}$ - cleared to 0 on Reset/SoftReset*
- *$Debug_{SSt}$ - cleared to 0 on Reset/SoftReset.*

TLB Initialization

Each TLB entry has a “hidden” state bit which is set by Reset/SoftReset and is cleared when the TLB entry is written. This bit disables matches and prevents “TLB Shutdown” conditions from being generated by the power-up values in the TLB array (when two or more TLB entries match on a single address). This bit is not visible to software.

Bus State Machines

All pending bus transactions are aborted and the state machines in the bus interface unit are reset when a Reset or SoftReset exception is taken.

Static Configuration Inputs

All static configuration inputs (defining the bus mode and cache size for example) should only be changed during Reset.

Notes

Fetch Address

Upon Reset/SoftReset, unless the EJTAGBOOT option is used, the fetch is directed to VA 0xBFC00000 (PA 0x1FC00000). This address is in kseg1, which is unmapped and uncached, so that the TLB and caches do not require hardware unitization.

Software Initialized Processor State

Software is required to initialize the following parts of the device.

Register File

The register file powers up in an unknown state with the exception of r0 which is always 0. Initializing the rest of the register file is not required for proper operation. Good code will generally not read a register before writing to it, but the boot code can initialize the register file for added safety.

TLB

Because of the hidden bit indicating initialization, the 4Kc processor core does not require TLB initialization upon ColdReset. This is a feature of the 4Kc core.

> **Note:** When initializing the TLB, care must be taken to avoid creating a “TLB Shutdown” condition where two TLB entries could match on a single address. Unique virtual addresses should be written to each TLB entry to avoid this.

Caches

The cache tag and data arrays power up to an unknown state and are not affected by reset. Every tag in the cache arrays should be initialized to an invalid state using the CACHE instruction (typically the Index Invalidate function). This can be a long process, especially since the instruction cache initialization needs to be run in an uncached address region.

Coprocessor Zero State

Miscellaneous Cop0 states need to be initialized prior to leaving the boot code. There are various exceptions that are blocked by ERL=1 or EXL=1 and that are not cleared by Reset. These can be cleared to avoid taking spurious exceptions when leaving the boot code.

Cause: WP (Watch Pending), SW0/1 (Software Interrupts) should be cleared.

Config: K0 should be set to the desired Cache Coherency Algorithm (CCA) prior to accessing kseg0.

Count: Should be set to a known value if Timer Interrupts are used.

Compare: Should be set to a known value if Timer Interrupts are used. The write to compare will also clear any pending Timer Interrupts (Thus, Count should be set before Compare to avoid any unexpected interrupts).

Status: Desired state of the device should be set.

Other Cop0 state: Other registers should be written before they are read. Some registers are not explicitly writable, and are only updated as a by-product of instruction execution or a taken exception. Uninitialized bits should be masked off after reading these registers.

Caches

The 4Kc processor core supports separate instruction and data caches which may be flexibly configured at build time for various sizes, organizations, and set-associativities. The use of separate caches allows instruction and data references to proceed simultaneously. Both caches are virtually indexed and physically tagged, allowing cache access to occur in parallel with virtual-to-physical address translation. The instruction and data caches are independently configured. Each cache is accessed in a single processor cycle.

Notes

Cache refills are performed using a 4-word fill buffer, which holds data returned from memory during a 4-beat burst transaction. The critical miss word is always returned first. The caches are blocking until the critical word is returned, but the pipeline may proceed while the other 3 beats of the burst are still active on the bus. Table 2.57 lists the instruction and data cache attributes for the RC32438.

Parameter	Instruction	Data
Size	16 KBytes	16 KBytes
Number of Cache Sets	256	256
Lines Per Set (Associativity)	4 way set associative	4 way set associative
Line Size	16 Bytes	16 Bytes
Read Unit	32-bits	32-bits
Write Policy	N/A	write-through without write-allocate
Miss restart after transfer of	miss word	miss word
Cache Locking	per line	per line

Table 2.57 Instruction and Data Cache Attributes

Software can identify the instruction or data cache configuration by reading the appropriate bits of the Config1 register (see section Config1 Register (CP0 Register 16, Select 1) earlier in this chapter.

Cache Protocols

Cache Organization

The instruction and data caches each consist of two arrays: a tag array and a data array. The caches are virtually indexed, since a virtual address is used to select the appropriate line within both the tag and data arrays. The caches are physically tagged, as the tag array contains a physical, not virtual, address.

The tag and data arrays hold “n” ways of information per line, corresponding to the n-way set associativity of the cache, where “n” can be between 1 and 4 for a cache. Figure 2.35 shows the format of each line of the tag and data arrays for each way. A tag entry consists of the upper 22 bits of the physical address (bits [31:10]), 4 valid bits (one for each data word in the line), a lock bit and a LRF bit. A data entry contains the four 32-bit words in the line, for a total of 16 bytes. Not every word need be present in the data array, hence the per-word validity information stored with the tag. A word is the minimum valid quanta, so it is not possible to hold a partially valid subword. Once a valid word is resident in the cache, then a byte, halfword, or tri-byte stores can update a portion of the word.

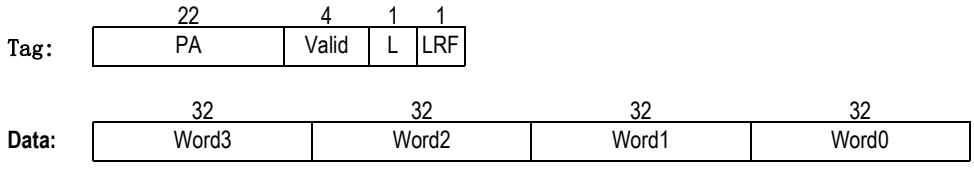


Figure 2.35 Cache Array Formats

Notes

Cacheability Attributes

The 4Kc processor core supports the following cacheability attributes:

- *Uncached: Addresses in a memory area indicated as uncached are not read from the cache. Stores to such addresses are written directly to main memory, without changing cache contents.*
- *Write-through: Loads and instruction fetches first search the cache, reading main memory only if the desired data does not reside in the cache. On data store operations, the cache is first searched to see if the target address is cache resident. If it is resident, the cache contents are updated, and main memory is also written. If the cache lookup misses on a store, only main memory is written. Hence, the allocation policy on a cache miss is read-allocate only.*

Some segments of memory employ a fixed caching policy; for example the kseg1 is always uncacheable. Other segments of memory allow the caching policy to be selected by software. Generally, the cache policy for these programmable regions is defined by a cacheability attribute field associated with that region of memory. For additional information, see “Memory Management” on page 2-20.

Replacement Policy

The replacement policy refers to how a way is chosen to hold an incoming cache line on a miss which will result in a cache fill, when a cache is at least two-way set associative. In a direct mapped cache (one-way set associative), the replacement policy is irrelevant since there is only one way available. The replacement policy is least recently filled (LRF), first considering invalid ways and excluding any locked ways. On a cache miss, the valid, lock and LRF bits for each tag entry of the selected line may be used to determine the way which will be chosen. The number of tag entries which are looked at depends on the set associativity of the cache.

First the valid bits are inspected. If an invalid way is available, as determined by all 4 of the valid bits in a tag being zero, then that way will be selected. If more than one invalid way is available, then the first one found starting from way0 will be selected.

If all ways are valid, then any locked ways will be excluded from consideration for replacement. If all ways are locked, then no replacement can occur to that line. For the unlocked ways, the LRF bits from each tag are used to identify the way which has been filled least recently, and that way is selected for replacement. When the new tag is written during the line fill, its LRF bit is modified to indicate that way is no longer the least recently filled.

Instruction Cache

The instruction cache is a memory block of 16 KBytes. The virtually indexed, physically tagged cache allows the virtual-to-physical address translation to occur in parallel with the cache access rather than having to wait for the physical address translation.

The 4Kc core supports instruction cache-locking. Cache locking allows critical code or data segments to be locked into the cache on a “per-line” basis, enabling the system programmer to maximize the efficiency of the system cache. The cache locking function is always enabled on all instruction cache entries. Entries can then be marked as locked or unlocked on a per entry basis using the CACHE instruction.

Data Cache

The data cache is a memory block of 16 KBytes. The virtually indexed, physically tagged cache allows the virtual-to-physical address translation to occur in parallel with the cache access rather than having to wait for the physical address translation.

The core also supports a data cache locking mechanism identical to the instruction cache. Critical data segments to be locked into the cache on a “per-line” basis. The locked contents can be updated on a store hit, but cannot be selected for replacement on a miss.

The cache locking function is always enabled on all data cache entries. Entries can then be marked as locked or unlocked on a per entry basis using the CACHE instruction.

Notes

Memory Coherence Issues

A cache presents coherency issues within the memory hierarchy which must be considered in the system design. Since a cache holds a copy of memory data, it is possible for another memory master to modify a memory location, thus making other copies of that location stale if those copies are still in use. A detailed discussion of memory coherence is beyond the scope of this document, but following are a few related comments.

The 4Kc processor core contains no direct hardware support for managing coherency with respect to its caches, so it must be handled via system design or software. The 4Kc caches are write-through, so all data writes will eventually be sent to memory. Due to write buffers, however, there could be a delay in how long it takes for the write to memory to actually occur. If another memory master updates cacheable memory which could also be in the 4Kc caches, then those locations may need to be flushed from the cache. The only way to accomplish this invalidation is by use of the CACHE instruction.

The SYNC instruction may also be useful to software enforcing memory coherence, as it flushes the 4Kc processor core's write buffers.

Power Management

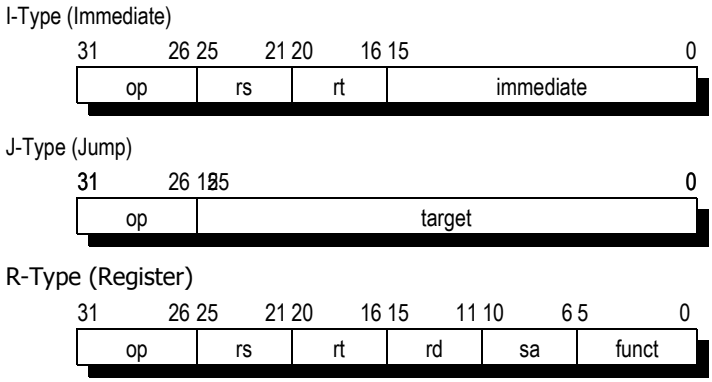
Instruction-Controlled Power Management

The mechanism for invoking power down mode is through execution of the WAIT instruction. If the bus is idle at the time the WAIT instruction reaches the M stage of the pipeline, the internal clocks are suspended and the pipeline is frozen. However, the internal timer and some of the input pins (SI_Int[5:0], SI_NMI, SI_Reset, SI_ColdReset, and EJ_DINT) continue to run. If the bus is not idle at the time the WAIT instruction reaches the M stage, the pipeline stalls until the bus becomes idle, at which time the clocks are stopped. Once the CPU is in instruction controlled power management mode, any enabled interrupt, NMI, debug interrupt, or reset condition causes the CPU to exit this mode and resume normal operation. While the part is in this low-power mode, the SI_SLEEP signal is asserted to indicate to external agents what the state of the chip is.

Instruction Set

The 4Kc core processor has 3 instruction set formats — immediate, jump, and register — as shown in Figure 2.36. Each CPU instruction consists of a single 32-bit word, aligned on a word boundary.

Notes



op	6-bit operation code
rs	5-bit source register specifier
rt	5-bit target (source/destination) register or branch condition
immediate	16-bit immediate value, branch displacement or address displacement
target	26-bit jump target address
rd	5-bit destination register specifier
sa	5-bit shift amount
funct	6-bit function field

Figure 2.36 Instruction Set Formats

Load and Store Instructions

Load and store are immediate (I-type) instructions that move data between memory and the general registers. The only addressing mode that load and store instructions directly support is base register plus 16-bit signed immediate offset.

Scheduling a Load Delay Slot

A load instruction that does not allow its result to be used by the instruction immediately following is called a delayed load instruction. The instruction slot immediately following this delayed load instruction is referred to as the load delay slot. The instruction immediately following a load instruction can use the contents of the loaded register. However, in such cases, hardware interlocks insert additional real cycles. Although not required, the scheduling of load delay slots can be desirable for performance.

Defining Access Types

Access type indicates the size of a core data item to be loaded or stored, set by the load or store instruction opcode. Regardless of access type or byte ordering (endianness), the address given specifies the low-order byte in the addressed field. For a big-endian configuration, the low-order byte is the most-significant byte; for a little-endian configuration, the low-order byte is the least-significant byte.

The access type and the three low-order bits of the address define the bytes accessed within the addressed word as shown in Table 2.58. Only the combinations shown in Table 2.58 are permissible; other combinations cause address error exceptions.

Notes

Access Type	Low Order Address Bits			Bytes Accessed							
				Big Endian 31.....0				Little Endian 31.....0			
	2	1	0	Byte				Byte			
Word	0	0	0	0	1	2	3	3	2	1	0
Triple byte	0	0	0	0	1	2			2	1	0
	0	0	1		1	2	3	3	2	1	
Half word	0	0	0	0	1					1	0
	0	1	0			2	3	3	2		
Byte	0	0	0	0							0
	0	0	1		1					1	
	0	1	0			2			2		
	0	1	1				3	3			

Table 2.58 Byte Access within a Word

Computational Instructions

Computational instructions can be either in register (R-type) format, in which both operands are registers, or in immediate (I-type) format, in which one operand is a 16-bit immediate.

Computational instructions perform the following operations on register values:

Arithmetic

Logical

Shift

Multiply

Divide

These operations fit in the following four categories of computational instructions:

- *ALU Immediate instructions*
- *Three-operand Register-type Instructions*
- *Shift Instructions*
- *Multiply And Divide Instructions*

Cycle Timing for Multiply and Divide Instructions

Any multiply instruction in the integer pipeline is transferred to the multiplier as remaining instructions continue through the pipeline; the product of the multiply instruction is saved in the HI and LO registers. If the multiply instruction is followed by an MFHI or MFLO before the product is available, the pipeline interlocks until this product does become available. For more information on instruction latency and repeat rates, see the Pipeline Description section earlier in this chapter.

Jump and Branch Instructions

Jump and branch instructions change the control flow of a program. All jump and branch instructions occur with a delay of one instruction: that is, the instruction immediately following the jump or branch (this is known as the instruction in the delay slot) always executes while the target instruction is being fetched from storage.

Notes

Overview of Jump Instructions

Subroutine calls in high-level languages are usually implemented with Jump or Jump and Link instructions, both of which are J-type instructions. In J-type format, the 26-bit target address shifts left 2 bits and combines with the high-order 4 bits of the current program counter to form an absolute address. Returns, dispatches, and large cross-page jumps are usually implemented with the Jump Register or Jump and Link Register instructions. Both are R-type instructions that take the 32-bit byte address contained in one of the general purpose registers. For more information about jump instructions, see the Instruction Set section earlier in this chapter.

Overview of Branch Instructions

All branch instruction target addresses are computed by adding the address of the instruction in the delay slot to the 16-bit offset (shifted left 2 bits and sign-extended to 32 bits). All branches occur with a delay of one instruction. If a conditional branch likely is not taken, the instruction in the delay slot is nullified. Branches, jumps, ERET, and DERET instructions should not be placed in the delay slot of a branch or jump.

Control Instructions

Control instructions allow the software to initiate traps; they are always R-type.

Coprocessor Instructions

CP0 instructions perform operations on the System Control Coprocessor registers to manipulate the memory management and exception handling facilities of the processor. For a listing of CP0 instructions, refer to Appendix A, 4Kc Processor Core Instructions, in this manual.

Enhancements to the MIPS Architecture

The core execution unit implements the MIPS32 architecture, which includes the following instructions:

- *CLO – Count Leading Ones*
- *CLZ – Count Leading Zeros*
- *MADD – Multiply and Add Word*
- *MADDU – Multiply and Add Unsigned Word*
- *MSUB – Multiply and Subtract Word*
- *MSUBU – Multiply and Subtract Unsigned Word*
- *MUL – Multiply Word to Register*
- *SSNOP – Superscalar Inhibit NOP.*

CLO - Count Leading Ones

The CLO instruction counts the number of leading ones in a word. The 32-bit word in the GPR rs is scanned from most-significant to least-significant bit. The number of leading ones is counted and the result is written to the GPR rd. If all 32 bits are set in the GPR rs, the result written to the GPR rd is 32.

CLZ - Count Leading Zeros

The CLZ instruction counts the number of leading zeros in a word. The 32-bit word in the GPR rs is scanned from most-significant to least-significant bit. The number of leading zeros is counted and the result is written to the GPR rd. If all 32 bits are cleared in the GPR rs, the result written to the GPR rd is 32.

MADD - Multiply and Add Word

The MADD instruction multiplies two words and adds the result to the HI/LO register pair. The 32-bit word value in the GPR rs is multiplied by the 32-bit value in the GPR rt, treating both operands as signed values, to produce a 64-bit result. The product is added to the 64-bit concatenated values in the HI and LO register pair. The resulting value is then written back to the HI and LO registers. No arithmetic exception occurs under any circumstances.

Notes

MADDU - Multiply and Add Unsigned Word

The MADDU instruction multiplies two unsigned words and adds the result to the HI/LO register pair. The 32-bit word value in the GPR rs is multiplied by the 32-bit value in the GPR rt, treating both operands as unsigned values, to produce a 64-bit result. The product is added to the 64-bit concatenated values in the HI and LO register pair. The resulting value is then written back to the HI and LO registers. No arithmetic exception occurs under any conditions.

MSUB - Multiply and Subtract Word

The MSUB instruction multiplies two words and subtracts the result from the HI/LO register pair. The 32-bit word value in the GPR rs is multiplied by the 32-bit value in the GPR rt, treating both operands as signed values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values in the HI and LO register pair. The resulting value is then written back to the HI and LO registers. No arithmetic exception occurs under any circumstances.

MSUBU - Multiply and Subtract Unsigned Word

The MSUBU instruction multiplies two unsigned words and subtracts the result from the HI/LO register pair. The 32-bit word value in the GPR rs is multiplied by the 32-bit value in the GPR rt, treating both operands as unsigned values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values in the HI and LO register pair. The resulting value is then written back to the HI and LO registers. No arithmetic exception occurs under any circumstances.

MUL - Multiply Word

The MUL instruction multiplies two words and writes the result to a GPR. The 32-bit word value in the GPR rs is multiplied by the 32-bit value in the GPR rt, treating both operands as signed values, to produce a 64-bit result. The least-significant 32 bits of the product are written to the GPR rd. The contents of the HI and LO register pair are not defined after the operation. No arithmetic exception occurs under any circumstances.

SSNOP- Superscalar Inhibit NOP

The 4Kc processor core treats this instruction as a regular NOP.

Processor Core Instructions

The 4Kc Processor Core Instructions are discussed in Appendix A of this user manual.

Notes

Clocking and Initialization

Notes

Introduction

This chapter discusses the reset initialization sequence that is required by the RC32438 device and includes information on the boot vector settings. These settings are used to configure the processor for the remainder of the power-up sequence. This chapter also provides a description of the clock signals that are used on the RC32438.

Block Diagram

Figure 3.1 illustrates how the boot configuration vector and reset signals may be generated in a system.

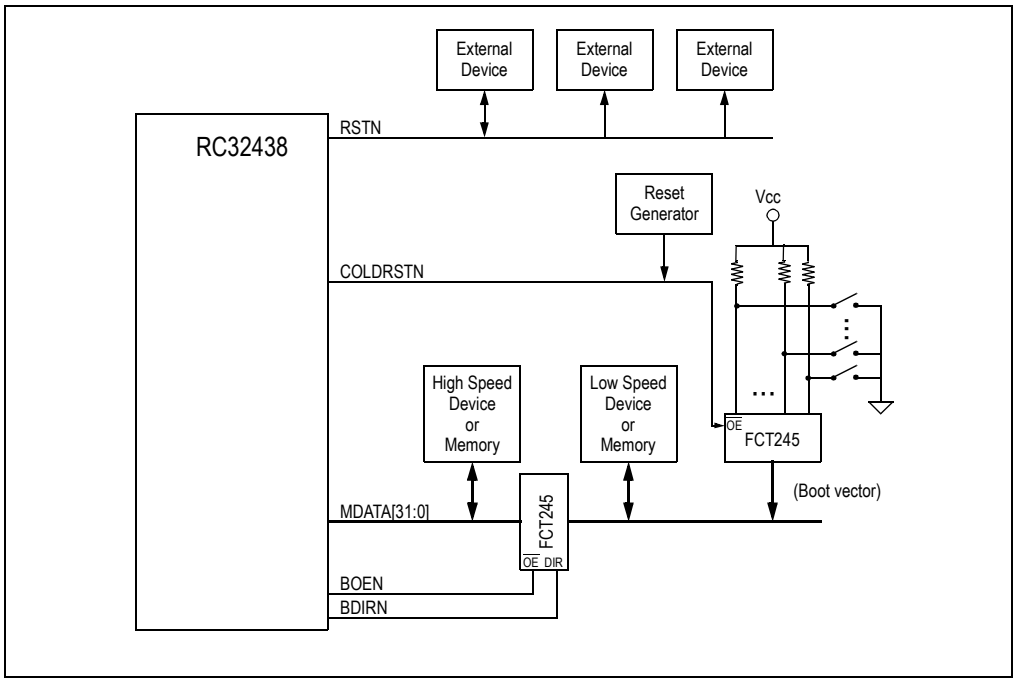


Figure 3.1 System Block Diagram of Reset and Boot Configuration Vector Generation

Clocking Overview

The RC32438 is designed to simplify the external clocking requirements for an embedded system. The device requires one input clock and from this generates the processor clock (PCLK) from which the CPU pipeline operates, the clock for the DDR memory subsystem and the clock for the local address/data bus. If the PCI interface is desired to be operated synchronously to the other RC32438 interfaces, the PCI clock can be tied externally to the clock for the local address/data bus.

Internally, the device supports a range of clock multipliers and divisors to allow system designers to select a combination that best meets their needs. Additionally, this device has been designed to operate from a relatively low external clock frequency without compromising the CPU or memory performance. For example, the use of a 33MHz clock can support a 266MHz CPU pipeline frequency and standard DDR 266 memories. In this case, the local memory bus can be operated at either 66MHz or 33MHz, enabling the PCI interface to be operated from the same clock signal if synchronous operation is desired. The use of low external clock frequencies simplifies board design and reduces noise emissions. Refer to Table 3.1 for more information on the clock ratios that are supported.

Notes

A PLL multiplies the master clock input and generates an internal CPU pipeline clock (PCLK) and an IPBus clock (ICLK). The CPU pipeline clock (PCLK) is divided by two to form the IPBus clock (ICLK). All of the logic that interfaces to the IPBus use this clock. In addition, the IPBus clock is used to generate the clock signals for the external DDR Memory subsystem. The IPBus clock is further divided by the value selected in the External Clock Divider field in the boot configuration vector to generate an external clock output on the EXTCLK pin. The external clock output (EXTCLK) is used by the memory and peripheral bus. The relationship between CLK, PCLK, ICLK, and the EXTCLK pin are shown in Figure 3.2.

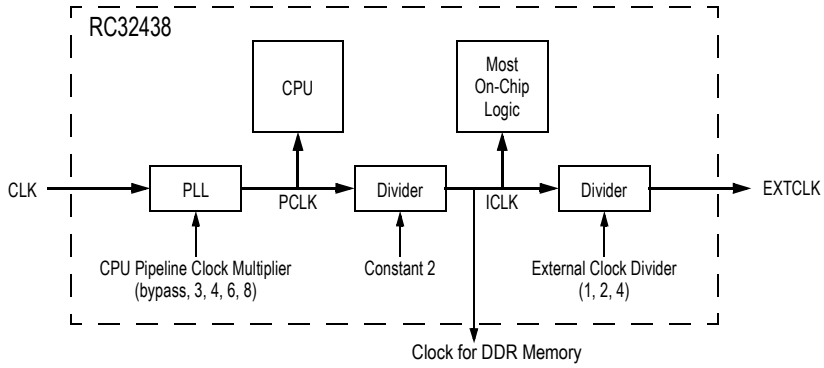


Figure 3.2 RC32438 Clocking Architecture

The CPU pipeline clock is equal to the master clock input multiplied by the value selected by the CPU Pipeline Clock Multiplier field in the boot configuration vector during a cold reset. Table 3.1 shows the supported CPU Pipeline Clock Multiplier field modes. Care must be exercised to ensure that the master clock input frequency falls within the range supported by a selected mode. For example, when multiply by 3 is selected, the master clock input frequency must be between 66.6 MHz and 88.6 MHz.

CPU Pipeline Clock Multiplier	CLK		PCLK	
	Min[1]	Max[1]	Min[1]	Max[1]
PLL Bypass	-	-	-	-
Multiply by 3	66.6	88.6	200	266
Multiply by 4	50	66.6	200	266
Multiply by 6	33.3	44.3	200	266
Multiply by 8	25	33.25	200	266

Table 3.1 Processor Clock PLL Multiplier Modes

1. Frequency in MHz.

Notes

Reset Register Description

Register Offset[1]	Register Name	Register Function	Size
0x00_8000	RESET	Reset	32-bit
0x00_8004	BVC	Boot configuration vector	32-bit
0x00_8008	CEA[2]	CPU error address	32-bit
0x00_800C through 0x00_FFFF	Reserved		

Table 3.2 Reset Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

2. Note that the CEA register is discussed in Chapter 4, System Integrity Functions.

Reset and Initialization

The RC32438 may be reset with either a warm reset or a cold reset.

Cold Reset

A cold reset is initiated through the assertion of the cold reset (COLDRSTN) pin. The COLDRSTN pin is typically asserted by an external voltage monitor or reset switch at power-up. A cold reset causes the RC32438 to initialize its internal state, assert the reset (RSTN) bidirectional pin, assert the BOEN pin, and assert the BDIRN pin. No state information of any kind is preserved. Figure 3.3 shows a cold reset.

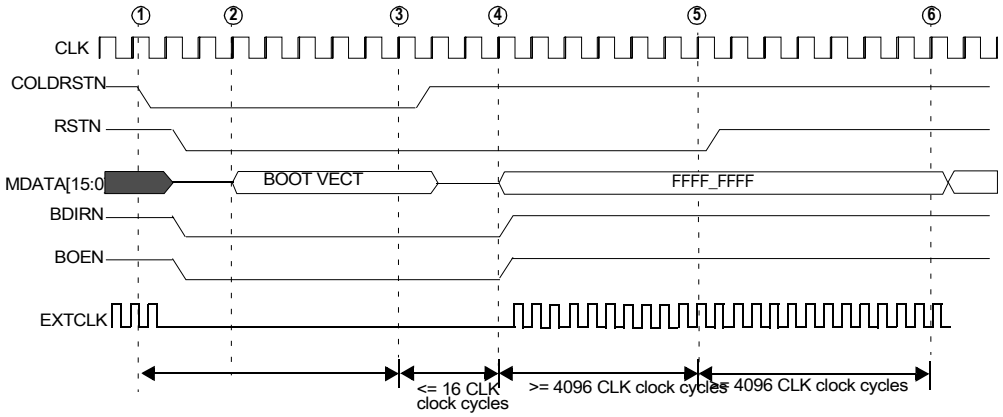
Using the boot configuration vector the internal phase lock loop locks onto the master clock input (CLK) and generates the CPU pipeline clock (PCLK) and the IPBus clock (ICLK). When the COLDRSTN signal is negated, the boot configuration vector is obtained from the bottom 16-bits of the data bus (MDATA[15:0] clocked in on the previous rising edge of CLK).[1]

Once the processor clock stabilizes, the RSTN pin is tri-stated. Then, the RC32438 waits an additional 4096 master clock cycles to allow the RSTN pin to be pulled up by an external resistor and samples the state of the RSTN pin. In addition, the RC32438 examines the state of the PCIRSTN pin if the PCI interface is selected to operate in satellite mode by the boot configuration vector. If RSTN is negated and if the PCI interface is selected to operate in satellite mode, the de-glitched PCIRSTN signal is also negated, and the CPU begins execution by taking a MIPS soft reset exception. If RSTN is still asserted, the RC32438 waits an additional 4096 master clock cycles, then repeats the above process. If the PCI interface is selected to operate in satellite mode and the de-glitched PCIRSTN signal is asserted, the RC32438 remains in a reset state until it is negated (or until COLDRSTN or RSTN is asserted, at which point a cold or warm reset process begins).

Before the boot configuration vector has been read during a cold reset, the external clock (EXTCLK) pin output is held low. Within 16 CLK clock cycles of reading the boot configuration vector, the RC32438 will begin generating EXTCLK. EXTCLK is guaranteed to be glitch free and maintain a 60/40 duty cycle.

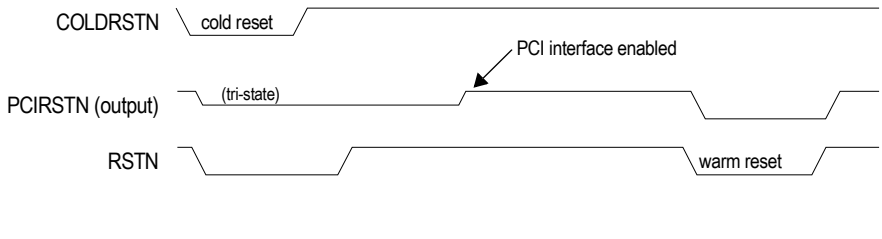
1. The CPU pipeline clock multiplier field (i.e., MDATA[3:0]) should be driven to a valid value as soon as possible after power stabilizes. This field is use by the PLL before COLDRSTN is negated. All other fields of the boot configuration vector are sampled only when COLDRSTN is negated.

Notes



1. COLDRSTN asserted by external logic. The RC32438 asserts RSTN, asserts BOEN low, drives BDIRN low, disables EXTCLK, and tri-states the data bus and all output pins in response.
2. External logic begins driving valid boot configuration vector on the data bus, and the RC32438 starts sampling it.
3. External logic negates COLDRSTN and tri-states the boot configuration vector on MDATA[15:0]. The boot configuration vector must not be tri-stated before COLDRSTN is negated. The RC32438 stops sampling the boot configuration vector.
4. The RC32438 starts driving the data bus, MDATA[15:0], negates BOEN, drives BDIRN high, and starts driving EXTCLK.
5. RSTN negated by the RC32438.
6. CPU begins executing by taking MIPS reset exception, and the RC32438 starts sampling RSTN as a warm reset input.

Figure 3.3 Cold Reset



Note: During and after cold reset, PCIRSTN is tri-stated and requires a pull-down to reach a low state. After the PCI interface is enabled in host mode, PCIRSTN will be driven high and low depending on the reset state of the 79RC32438.

Figure 3.4 PCI Reset in Host Mode

Boot Configuration Vector

The boot configuration vector is read by the RC32438 during a cold reset. The vector defines essential RC32438 parameters that are required once the cold reset completes.

The encoding of boot configuration vector is described in Table 3.3, and the vector input is illustrated in Figure 3.5. The value of the boot configuration vector read in by the RC32438 during a cold reset may be determined by reading the Boot Configuration Vector (BCV) Register.

Notes

Signal	Name/Description
MDATA[3:0]	**CPU Pipeline Clock Multiplier**. This field specifies the value by which the PLL multiplies the master clock input (CLK) to obtain the processor clock frequency (PCLK). See Table 3.1 for master clock input frequency constraints. 0x0 - PLL Bypass 0x1 - Multiply by 3 0x2 - Multiply by 4 0x3 - Multiply by 6 0x4 - Multiply by 8 0x5 to 0xF - reserved
MDATA[5:4]	**External Clock Divider**. This field specifies the value by which the IPBus clock (ICLK) is divided in order to generate the external clock output on the EXTCLK pin. 0x0 - Divide by 1 0x1 - Divide by 2 0x2 - Divide by 4 0x3 - reserved
MDATA[6]	**Endian.** This bit specifies the endianness. 0x0 - little endian 0x1 - big endian
MDATA[7]	**Boot Device Width**. This field specifies the width of the boot device (i.e., Device 0). 0x0 - 8-bit boot device width 0x1 - 16-bit boot device width
MDATA[8]	**Reset Mode**. This bit specifies the length of time the RSTN signal is driven. 0x0 - Normal reset: RSTN driven for minimum of 4096 clock cycles 0x1 - reserved
MDATA[11:9]	**PCI Mode**. This bit controls the operating mode of the PCI bus interface. The initial value of the EN bit in the PCIC register is determined by the PCI mode. 0x0 - Disabled (EN initial value is zero) 0x1 - PCI satellite mode with PCI target not ready (EN initial value is one) 0x2 - PCI satellite mode with suspended CPU execution (EN initial value is one) 0x3 - PCI host mode with external arbiter (EN initial value is zero) 0x4 - PCI host mode with internal arbiter using fixed priority arbitration algorithm (EN initial value is zero) 0x5 - PCI host mode with internal arbiter using round robin arbitration algorithm (EN initial value is zero) 0x6 - *reserved* 0x7 - *reserved*
MDATA[12]	**Disable Watchdog Timer**. When this bit is set, the watchdog timer is disabled following a cold reset. 0x0 - Watchdog timer enabled 0x1 - Watchdog timer disabled
MDATA[15:13]	**Reserved**. These pins must be driven low during boot configuration.

Table 3.3 Boot Configuration Encoding

Notes

Reset/Initialization Registers

Boot Configuration Vector Register

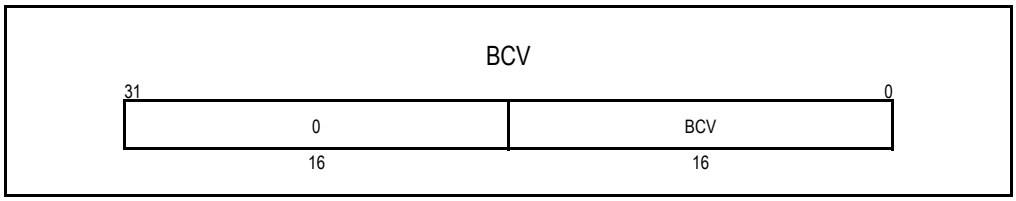


Figure 3.5 Boot Configuration Vector Register (BCV)

BCV

Description: **Boot Configuration Vector.** This field contains the boot configuration vector read in by the RC32438 during a cold reset. See Table 3.3 for a description of the encoding of this vector.

Initial Value: Boot configuration vector

Read Value: Boot configuration vector

Write Effect: Read-only

Warm Reset

A warm reset may be initiated by one of seven conditions:

- *Assertion of the reset pin (RSTN) by an external agent*
- *A CPU write of 0x8000_0001 to the Reset (RESET) register*
- *An IPBus transaction timer time-out*
- *A watchdog timer time-out with the WRE bit set in the ERRCS register*
- *A CPU or PCI master write setting the Warm Reset (WR) bit in the PCI Management (PCIMGT) register in PCI configuration space*
- *Assertion of the PCI reset signal (PCIRSTN) when operating in PCI satellite mode*
- *Generation of a processor reset by EJTAG debug software by setting of the PrRst bit in the EJTAG control register (i.e., assertion of the EJ_PrRst output signal by the CPU core).*

When one of these conditions occurs, the RC32438 asserts the RSTN pin for a minimum of 4096 CLK clock cycles. Then, the RC32438 tri-states RSTN, waits an additional 4096 CLK clock cycles, and examines the state of the RSTN pin. In addition, the RC32438 will examine the state of the PCIRSTN pin if the PCI interface is selected to operate in satellite mode by the boot configuration vector. If RSTN is negated and if the PCI interface is selected to operate in satellite mode, the de-glitched PCIRSTN signal is also negated, and the CPU begins execution by taking a MIPS soft reset exception.[1] If RSTN is still asserted, the warm reset procedure above is repeated. If the PCI interface is selected to operate in satellite mode and the de-glitched PCIRSTN signal is asserted, then the RC32438 remains in a warm reset until it is negated (or until RSTN is asserted again, at which point the warm reset process repeats).

The delay between tri-stating the RSTN pin and then sampling whether it is asserted allows the signal to be pulled up with a resistor. During a warm reset, all memory and peripheral bus transactions are inhibited. The DDR Controller continues operation across warm resets and may generate a refresh transaction during a warm reset.

A warm reset causes the following:

- *All blocks within the RC32438 are reset with the exception of the CPU, CPU BIU, and IPBus monitor*
- *The CPU to take a MIPS soft reset exception*

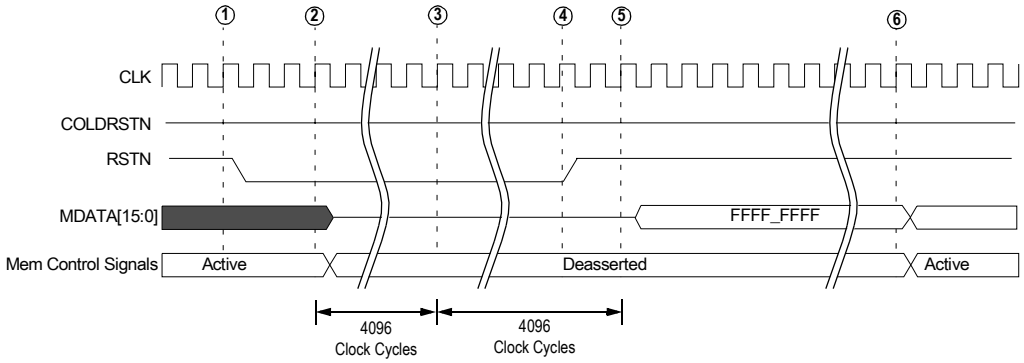
[1] The assertion of CSN[0] will occur no sooner than 16 clock cycles after the RC32438 samples RSTN negated.

Notes

- *All registers are reset to their initial value, except the following:*
  - *BTCOMPARE[1], BTADDR, and BTCS registers in the Device Controller*
  - *All bits in the PCIC register (except the TNR and IGM bits which are, in fact, reset)*
  - *TO bit in the WTC register*
  - *EN bit in the WTC register if the warm reset was not caused by the expiration of the watchdog timer*
  - *WTO bit in the ERRCS register*
  - *WR bit in the PCIS register*
  - *Registers in PCI configuration space*
  - *DDR controller registers*
  - *Event monitor registers*
  - *Contents of on-chip memory.*

Note: All PCI registers are reset to their initial value if the warm reset was the result of an assertion of the PCI reset signal when operating in PCI satellite mode. Also, the external clock, EXTCLK, is always driven during any warm reset.

An externally initiated warm reset caused by assertion of RSTN by an external agent is shown in Figure 3.6, while an internally initiated warm reset, for example, caused by a write of 0x8000_0001 to the RESET register is shown in Figure 3.7.

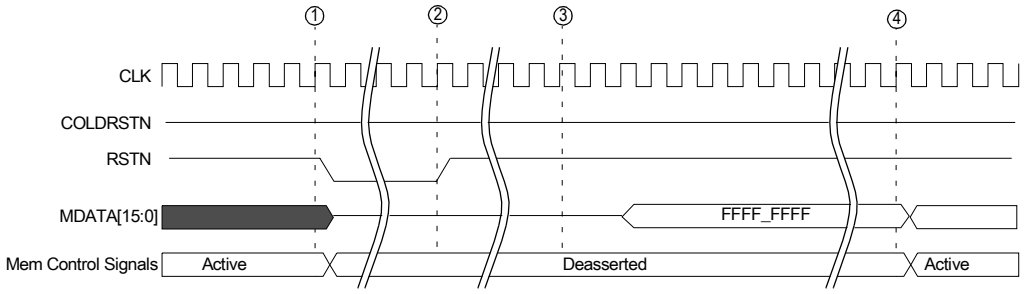


1. Warm reset condition caused by assertion of RSTN by an external agent.
2. RC32438 tri-states the data bus, MDATA[15:0], negates all memory control signals, and itself asserts RSTN.
3. RC32438 negates RSTN after 4096 master clock (CLK) cycles.
4. External agent negates RSTN.
5. RC32438 samples RSTN negated 4096 master clock (CLK) cycles after step 3 and starts driving the data bus, MDATA[15:0].
6. CPU begins executing by taking a MIPS soft reset exception. The assertion of CSN[0] will occur no sooner than 16 clock cycles after the RC32438 samples RSTN negated (i.e., step 5).

Figure 3.6 Externally Initiated Warm Reset

[1] If the warm reset is the result of a bus transaction time-out, the BTCOMPARE field is initialized to 0xFFFF.

Notes



1. Warm reset condition caused by a CPU write of 0x8000_0001 to the RESET register. The RC32438 tri-states the data bus, MDATA[15:0], negates all memory control signals, and asserts RSTN.
2. RC32438 negates RSTN after 4096 master clock (CLK) cycles.
3. RC32438 samples RSTN negated after waiting 4096 or 64 master clock (CLK) clock cycles depending on the boot configuration mode and starts driving the data bus, MDATA[15:0].
4. CPU begins executing by taking a MIPS soft reset exception. The assertion of CSN[0] will occur no sooner than 16 clock cycles after the RC32438 samples RSTN negated (i.e., step 5).

Figure 3.7 Internally Initiated Warm Reset

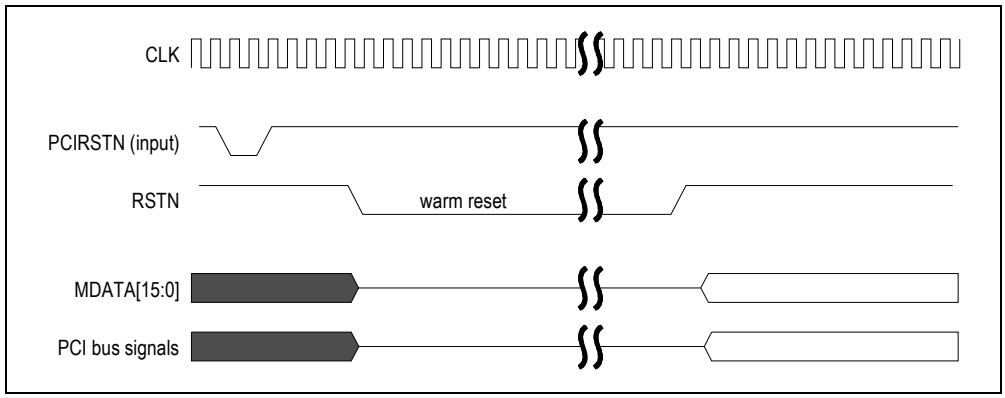


Figure 3.8 PCI Reset in Satellite Mode

Reset Register

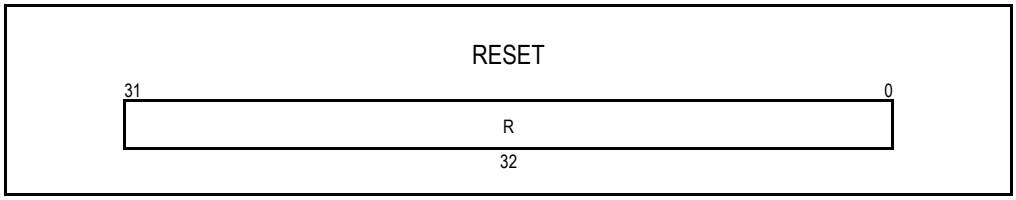


Figure 3.9 Reset Register (RESET)

R

Description: **Reset.** A write of the value 0x8000_0001 to this register causes the RC32438 to generate a warm reset. A write of any other value has no effect.

Initial Value: Undefined

Read Value: Undefined

Write Effect: Write value of 0x8000_0001 generates a warm reset

Notes

Pin State During Reset

Table 3.4 shows the state of each pin during cold reset (COLDRSTN pin asserted low) and warm reset (RSTN pin asserted low). Because input-only pins are never driven, they are not included in this table.

Function	Pin Name	Type	Cold Reset	Warm Reset
Memory and Peripheral Bus	BDIRN	O	low	low
	BGN	O	high	high
	BOEN	O	low	low
	BWEN[1:0]	O	high	high
	CSN[5:0]	O	high	high
	MADDR[21:0]	O	low	low
	MDATA[15:0]	I/O	Z	Z
	OEN	O	high	high
	RWN	O	high	high
DDR Bus	DDRADDR[13:0]	O	low	low
	DDRBA[1:0]	O	low	low
	DDRCASN	O	high	high
	DDRCKE	O	low	low
	DDRCKN[1:0]	O	high	toggle
	DDRCKP[1:0]	O	low	toggle
	DDRCSN[1:0]	O	high	high
	DDRDATA[31:0]	I/O	Z	Z
	DDRDM[7:0]	I/O	high	high
	DDRDQS[3:0]	I/O	Z	Z
	DDROEN[3:0]	O	high	high
	DDRRASN	O	high	high
	DDRWEN	O	high	high

Table 3.4 Pin State During Reset (Part 1 of 3)

Notes

Function	Pin Name	Type	Cold Reset	Warm Reset
PCI Bus Interface	PCIAD[31:0]	I/O	Z	Z
	PCICBEN[3:0]	I/O	Z	Z
	PCIDEVSELN	I/O	Z	Z
	PCIFRAMEN	I/O	Z	Z
	PCIGNTN[3:0]	I/O	low, high, Z[1]	low, high, Z[1]
	PCIIRDYN	I/O	Z	Z
	PCILOCKN	I/O	Z	Z
	PCIPAR	I/O	Z	Z
	PCIPERRN	I/O	Z	Z
	PCIREQN[3:0]	I/O	low, high, Z[1]	low, high, Z[1]
	PCIRSTN	I/O	Z	low, Z[2]
	PCISERRN	I/O	Z	Z
	PCISTOPN	I/O	Z	Z
	PCITRDYN	I/O	Z	Z
General Purpose I/O	GPIO[31:0]	I/O	Z	Z
Serial Interface	SCK	I/O	Z	Z
	SDI	I/O	Z	Z
	SDO	I/O	Z	Z
I^2C Bus Interface	SCL	I/O	Z	Z
	SDA	I/O	Z	Z
Ethernet Interfaces	MII0TXD[3:0]	O	low	low
	MII0TXENP	O	low	low
	MII0TXER	O	low	low
	MII1TXD[3:0]	O	low	low
	MII1TXENP	O	low	low
	MII1TXER	O	low	low
	MIIMDC	O	low	low
	MIIMDIO	I/O	Z	Z
JTAG / EJTAG	JTAG_TDO	O	Z	Z
Debug	CPU	O	high	high
	INST	O	high	high
	IPBMTRIGOUT	O	high	high

Table 3.4 Pin State During Reset (Part 2 of 3)

Notes

Function	Pin Name	Type	Cold Reset	Warm Reset
Miscellaneous	EXTCLK	O	low	toggle
	RSTN	I/O	low	low

Table 3.4 Pin State During Reset (Part 3 of 3)

1. To determine the actual pin state, refer to Chapter 10, Tables 10.3, 10.4, and 10.5

2. In PCI satellite mode, PCIRSTN is Z. In PCI host mode, PCIRSTN is low.

Notes

System Integrity Functions

Notes

Introduction

This chapter describes the system integrity functions on the RC32438. The system integrity module includes several registers that log system activity. These registers can be used to indicate the source of hardware or software errors.

Features

- *Programmable bus transaction timer generates warm reset when counter expires*
- *Address space monitor*
- *Programmable watchdog timer generates NMI when counter expires*

Functional Overview

The RC32438 supports three functions to monitor activity within the system and report potential hardware or software error conditions.

The first function is the bus transaction timer. The bus transaction timer times memory and peripheral bus transactions, generating a warm reset if a transaction does not complete within a specified number of clock cycles. The bus transaction timer is part of the device controller. For more information on the bus transaction timer, see the Memory and Peripheral Bus Transaction Timer section in Chapter 6.

A second function is the address space monitor. The address space monitor generates an error in response to bus transactions with invalid RC32438 local address space addresses. This applies to transactions generated by the CPU as well as the PCI and DMA controllers.

A third function is the watchdog timer. The watchdog timer is a general purpose timer that, if not periodically reset by software, generates a nonmaskable interrupt (NMI) exception to the CPU or a warm reset. The watchdog timer is independent from the three general purpose timers described in Chapter 14, Counter Timers.

System integrity functions are controlled, and their status is reported in the Error Control and Status (ERRCS) Register. The bus transaction timer, the address space monitor, and the watchdog are all enabled following a cold reset. The bus timer and watchdog timer can be individually disabled by software.

The address of an undecoded CPU read/write operation or IPBus slave acknowledge error is recorded in the CPU Error Address (CEA) register. This register is only accessible by the CPU since it is located in the CPU BIU.

System Integrity Register Description

Register Offset[1]	Register Name	Register Function	Size
0x03_0000 through 0x03_002C	Reserved		
0x03_0030	ERRCS	Error control and status	32-bit
0x03_0034	WTCOUNT	Watchdog timer count	32-bit

Table 4.1 System Integrity Register Map (Part 1 of 2)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x03_0038	WTCOMPARE	Watchdog timer compare	32-bit
0x03_003C	WTC	Watchdog timer control	32-bit
0x03_0040 through 0x03_7FFF	Reserved		

Table 4.1 System Integrity Register Map (Part 2 of 2)

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

System Integrity Registers

Error Control and Status Register

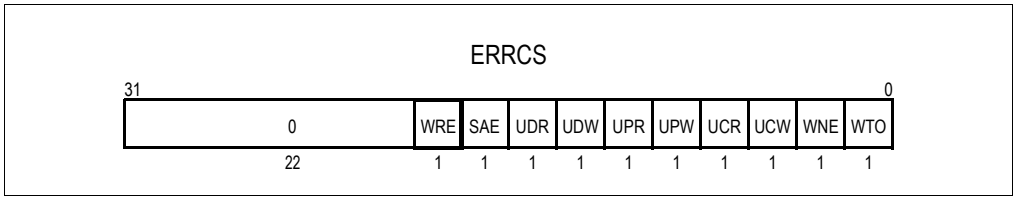


Figure 4.1 Error Control and Status Register (ERRCS)

WTO

Description: **Watchdog Timer Time Out.** When the watchdog timer times-out and either the WNE or WRE bit in this register is set, this bit is set.

Initial Value: 0x0

Read Value: Status (**this field is not modified due to a warm reset**)

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

WNE

Description: **Watchdog Timer NMI Enable.** When this bit is cleared, the watchdog timer is masked from generating an NMI. When the watchdog timer expires, and this bit is set, and the WRE bit is cleared, an NMI is generated.
0 Watchdog timer NMI masked
1 Watchdog timer NMI enabled (unmasked)

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

UCW

Description: **Undecoded CPU Write.** This bit is set when the CPU writes to an undecoded address space. This bit is presented to the interrupt handler as the undecoded CPU write interrupt source.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

UCR

Description: **Undecoded CPU Read.** This bit is set when the CPU reads from an undecoded address space. This bit is presented to the interrupt handler as the undecoded CPU read interrupt source.

Notes

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

UPW

Description: **Undecoded PCI Write.** This bit is set when the PCI interface writes to an undecoded address space. This bit is presented to the interrupt handler as the undecoded PCI write interrupt source.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

UPR

Description: **Undecoded PCI Read.** This bit is set when the PCI interface reads from an undecoded address space. This bit is presented to the interrupt handler as the undecoded PCI read interrupt source.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

UDW

Description: **Undecoded DMA Write.** This bit is set when the DMA writes to an undecoded address space. This bit is presented to the interrupt handler as the undecoded DMA write interrupt source.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

UDR

Description: **Undecoded DMA Read.** This bit is set when the DMA interface reads from an undecoded address space. This bit is presented to the interrupt handler as the undecoded DMA read interrupt source.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

SAE

Description: **IPBus Slave Acknowledge Error.** This bit is set when an IPBus slave signals a slave acknowledge error.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. The interrupt service routine must clear this bit.

Notes

WRE

Description: **Watchdog Timer Warm Reset Enable.** When this bit is set and the watchdog timer times-out, a warm reset is generated. When this bit is cleared, a warm reset is never generated due to a watchdog timer time-out.
0 - No warm reset on watchdog timer time-out
1 - Generate warm reset on watchdog timer time-out

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

CPU Error Address Register

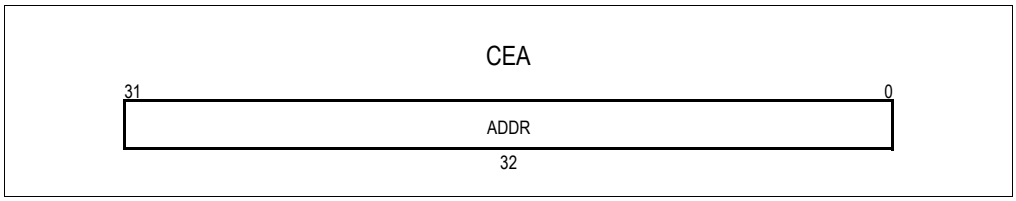


Figure 4.2 CPU Error Address Register (CEA)

ADDR

Description: **Address.** This field contains the physical address of the first CPU transaction which resulted in an undecoded address error or slave acknowledge error. This register is only updated when an undecoded address error or slave acknowledge error occurs if the ADDR field is all ones (i.e., 0xFFFF_FFFF).

Initial Value: 0xFFFF_FFFF

Read Value: Physical address of the last CPU transaction that resulted in undecoded address error or previous value written.

Write Effect: Modify value

Note: The register address for CEA can be found in Chapter 3, Table 3.2.

Address Space Monitor

The address space monitor observes physical addresses in transactions generated by the CPU, PCI, and DMA controller and generates an error if the address does not decode to a valid region within the RC32438 memory map or if an address maps to two regions due to mis-configuration of a region's base and mask registers.[1] Table 4.2 summarizes the methods used to report an undecoded address or redundant mapping errors to the CPU, PCI, and DMA controller. The address space monitor is always enabled.

If an undecoded address error is detected during a single byte, half-word, or word DMA transfer, then the CA field in the DMA descriptor is incremented by one byte, half-word, or word respectively and the COUNT field is decremented accordingly. If an undecoded address error is detected in a burst DMA transfer, then the COUNT and CA fields in the DMA descriptor are unmodified.

1. If a device or SDRAM is mapped such that it overlaps the internal system address space (0x1800_000 through 0x181F_FFFF), the internal system controller address space will take precedence. Any subsequent CPU or PCI access to this redundantly mapped space will result in the system controller being accessed.

Notes

Bus Master	Bus Master Operation	Undecoded Address Error Reporting Mechanism
CPU	CPU read operation	CPU bus error exception and Undecoded CPU Read (UCR) bit set in the ERRCS register. The CPU Error Address (CEA) register contains the address of the undecoded read.
	CPU write operation	CPU core interrupt from UCW bit (Undecoded CPU Write (UCW) bit is set in the ERRCS register. The CPU Error Address (CEA) register contains the address of the undecoded write.
PCI	PCI read operation	PCI transaction terminated with Target Abort and Undecoded PCI Read (UPR) bit set in ERRCS register. For additional information, refer to Chapter 10, section “Target Error Handling” on page 10-38.
	PCI write operation	PCI transaction terminated with Target Abort and Undecoded PCI Write (UPW) bit set in ERRCS register. If the PCI transaction resulted in a posted write, then a PCI system error is signalled on the PCI bus by asserting the SERRN signal of the SEN bit is set in the PCI COMMAND register. For additional information, refer to Chapter 10, section “Target Error Handling” on page 10-38.
DMA	DMA descriptor read	Error (E) bit set in corresponding DMA status (DMAxS) register and Undecoded DMA Read (UDR) bit set in ERRCS register.
	DMA descriptor write	Error (E) bit in set in corresponding DMA status (DMAxS) register and Undecoded DMA Write (UDW) bit set in ERRCS register.
	DMA data read	The terminated (T) bit is set in the descriptor in which the error was detected. The Undecoded DMA Read (UDR) bit is set in ERRCS register.
	DMA data write	The terminated (T) bit is set in the descriptor in which the error was detected. The Undecoded DMA Write (UDW) bit is set in the ERRCS register.

Table 4.2 Address Space Monitor Undecoded Address Error Reporting

Watchdog Timer

When the watchdog timer NMI Enable (WNE) bit is set in the ERRCS register, the watchdog timer will generate an NMI when it times out. In addition, the watchdog timer may be configured to generate a warm reset when it times out by setting the watchdog timer warm reset enable (WRE) bit in the ERRCS register. If both the WNE and WRE bits are cleared, the watchdog timer operates as a general purpose counter timer.

The watchdog timer is enabled by setting the enable (EN) bit in the watchdog timer control (WTC) register. When this occurs, the watchdog timer begins incrementing its current watchdog timer count value with each IPBus clock (ICLK) cycle. The CPU may determine the current watchdog timer count value by reading the Watchdog Timer Count Register (WTCOUNT). Writing to this register modifies the watchdog timer count value. For normal operation, this register should be initialized to zero prior to enabling the watchdog timer. Following a cold reset, the watchdog timer is normally enabled. The watchdog timer may be disabled by setting the Disable Watchdog Timer bit in the boot configuration vector.

When the watchdog timer count value matches the value in the Watchdog Timer Compare Register (WTCOMPARE), the timer expires[1]. When this occurs, the time out (WTO) bit in the Watchdog Timer Control Register (WTC) is set. In addition, if either the Watchdog Timer Warm Reset Enable (WRE) bit or Watchdog Timer NMI Enable (WNE) bit is set in the Error Control and Status Register (ERRCS), the Watchdog Timer Time-Out (WTO) bit is set in the ERRCS register.

1. The counter timer expires at the point when the value in the WTCOUNT register first equals the value in the WTCOMPARE register (i.e., the rising edge of the master clock, that is, CLK (WTCOUNT == WTCOMPARE)).

Notes

If the watchdog timer is enabled to generate an NMI interrupt (i.e., the WNE bit is set) and the timer expires, the watchdog timer time-out (WTO) bit in the ERRCS register is set, the EN bit in the WTC register is cleared, and an NMI is generated.

> **Note:** Until the WTO bit is cleared by software, another watchdog NMI interrupt cannot be generated.

If the watchdog timer is configured to generate a warm reset (i.e., the WRE bit is set) and the timer expires, the TO bit in the WTC register and the WTO bit in the ERRCS register are set, the EN bit in the WTC register is cleared, and a warm reset is generated. The TO and WTO bits are not modified due to a warm reset.

Setting both the WNE and WRE bits results in a warm reset, causing all watchdog timer registers and fields (except the TO and WTO bits) to take on their initial value. If neither the WNE bit nor the WRE bit is set, the watchdog timer behaves simply as a timer. When it expires, it resets its count value to zero and begins incrementing at the master clock frequency. The TO bit is presented as an interrupt source to the interrupt handler.

Watchdog Timer Count Register

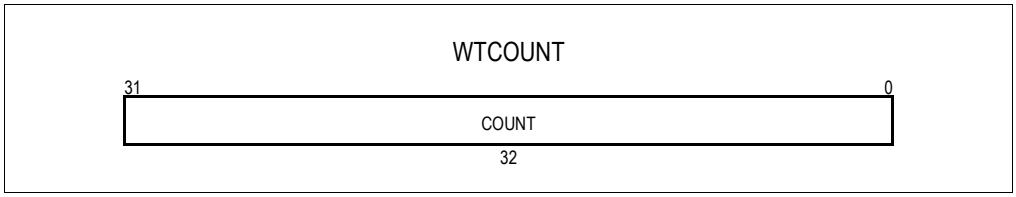


Figure 4.3 Watchdog Timer Count Register (WTCOUNT)

COUNT

Description: **Watchdog Timer Count.** This field contains the current watchdog timer count value.

Initial Value: 0x0000_0000 **(this register is not reset after a warm reset)**

Read Value: Current watchdog timer count

Write Effect: Set watchdog timer count

Watchdog Timer Compare Register

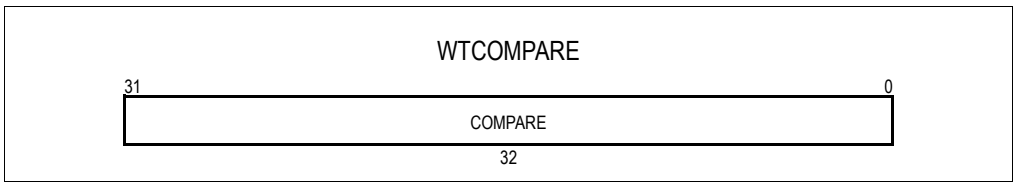


Figure 4.4 Watchdog Timer Compare Register (WTCOMPARE)

COMPARE

Description: **Compare Value.** This field contains the maximum watchdog timer count value. When the value in the WTCOUNT register equals this value, the watchdog timer expires.

Initial Value: 0xFFFF_FFFF

Read Value: Previous value written

Write Effect: Modify value

Notes

Watchdog Timer Control Register

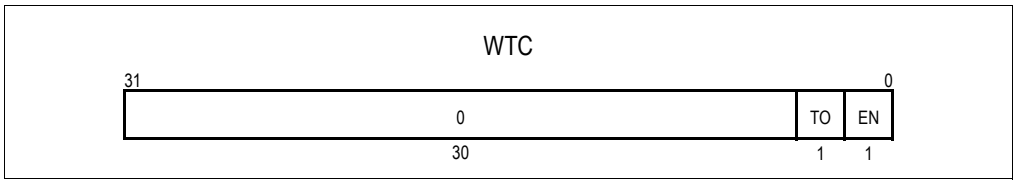


Figure 4.5 Watchdog Timer Control Register (WTC)

EN

Description: **Enable.** When this bit is set, the watchdog timer is enabled. Clearing this bit disables the watchdog timer. Neither enabling nor disabling the timer affects the watchdog timer count value. The EN bit is automatically cleared when the watchdog timer expires and the WNE bit in the ERRCS register is set. The state of the EN bit is preserved across warm resets not caused by the expiration of the watchdog timer.

Initial Value: See boot configuration vector (i.e., disable watchdog timer bit)

Read Value: Previous value written

Write Effect: Modify value

TO

Description: **Time Out.** This bit is set to a one to indicate that the watchdog timer has expired. Once this bit is set, it will remain set until a zero is written into this field.

Initial Value: 0x0

Read Value: Status **(this field is not modified when a warm reset occurs)**

Write Effect: Sticky bit

IPBus Slave Acknowledge Errors

The IPBus provides a general mechanism for slaves to report errors to IPBus masters during a read or write transaction. Each IPBus slave that may generate an IPBus slave acknowledge error has two sticky bits that serve as interrupt sources. One bit is set on the occurrence of a slave acknowledge error during a read transaction while the other is set on the occurrence of a slave acknowledge error during a write transaction.

The only IPBus slave in the RC32438 device that generates slave acknowledge errors is the PCI interface. See Chapter 10, PCI Bus Interface, for conditions that result in a PCI slave acknowledge error. Table 4.3 summarizes the methods used to report IPBus slave acknowledge errors.

The DMA controller does not stop a burst transfer when a slave acknowledge error is detected. It completes the burst transfer and, as a result, the CA field in the descriptor in which the error is detected is set to the last address of the burst transfer. The COUNT is updated accordingly. A slave acknowledge error during a memory to peripheral DMA results in undefined data being written to the peripheral (in order to complete the DMA burst transfer). A slave acknowledge error during a peripheral to memory DMA results in data read from the peripheral being discarded (in order to complete the DMA burst transfer).

Notes

Bus Master	Bus Master Operation	IPBus Slave Acknowledge Error Reporting Mechanism
CPU	CPU read operation	A CPU bus error exception is generated and the Slave Acknowledge Error (SAE) bit is set in the ERRCS register. The CPU Error Address (CEA) register contains the address of the transaction which resulted in an IPBus slave acknowledge error. A sticky bit is set in the IPBus slave that generated the error. The sticky bit may be selected as an interrupt source. For additional information, see Chapter 10, section “Master Error Handling” on page 10-21.
	CPU write operation	A slave acknowledge error is not generated by the PCI interface when a CPU generated PCI master write transaction experiences a fatal error. For additional information, see Chapter 10, section “Master Error Handling” on page 10-21.
PCI	PCI read operation	Since the only interface that supports Slave Acknowledge Errors in the RC32438 is the PCI interface, this condition never occurs.
	PCI write operation	Since the only interface that supports Slave Acknowledge Errors in the RC32438 is the PCI interface, this condition never occurs.
DMA	DMA descriptor read	This condition never occurs in the RC32438.
	DMA descriptor write	This condition never occurs in the RC32438.
	DMA data read	This condition never occurs in the RC32438.
	DMA data write	This condition never occurs in the RC32438.

Table 4.3 IPBus Slave Acknowledge Error Reporting

Bus Arbitration

Notes

Introduction

This chapter describes the internal bus arbitration mechanism used among the various on-chip modules and explains the bus protocol used by an external bus master to gain ownership of the memory and peripheral bus.

Functional Overview

The RC32438 has two internal buses, the IPBus and PMBus. It also has one external bus, the memory and peripheral bus. A bus master may have ownership of one or more buses at any given time, but no two masters can own the same bus at the same time. There are 16 potential IPbus masters. They consist of the 10 DMA channels, an external bus master (on the memory and peripheral bus), the PCI target interface, and the CPU when it is reading or writing devices on the IPBus.

Each potential IPbus master is assigned a bus master index (see Table 5.1). There are seventeen indices. The PCI target interface is allocated two indices. One for the first target read or write transfer and one for subsequent target read transfers. This allows the initial data transfer of a target read or write transaction to be given a higher priority than subsequent reads and writes.

Index	Bus Master
0	External DMA channel 0
1	External DMA channel 1
2	Ethernet Channel 0 Receive
3	Ethernet Channel 0 Transmit
4	Ethernet Channel 1 Receive
5	Ethernet Channel 1 Transmit
6	Memory to Memory (Memory to Holding FIFO)
7	Memory to Memory (Holding FIFO to Memory)
8	PCI (PCI to Memory)
9	PCI (Memory to PCI)
10	Reserved
11	Reserved
12	Reserved
13	External Memory and Peripheral Bus Master
14	PCI Target
15	PCI Target - Read and Write Start
16	CPU (CPU accesses to IPBus)

Table 5.1 Bus Master Index

Notes

IPBus Register Description

Register Offset[1]	Register Name	Register Function	Size
0x04_4000	IPAP0C	IPBus arbiter priority 0 configuration	32-bit
0x04_4004	IPAP1C	IPBus arbiter priority 1 configuration	32-bit
0x04_4008	IPAP2C	IPBus arbiter priority 2 configuration	32-bit
0x04_400C	IPAP3C	IPBus arbiter priority 3 configuration	32-bit
0x04_4010	IPABM0C	IPBus arbiter bus master 0 configuration	32-bit
0x04_4014	IPABM1C	IPBus arbiter bus master 1 configuration	32-bit
0x04_4018	IPABM2C	IPBus arbiter bus master 2 configuration	32-bit
0x04_401C	IPABM3C	IPBus arbiter bus master 3 configuration	32-bit
0x04_4020	IPABM4C	IPBus arbiter bus master 4 configuration	32-bit
0x04_4024	IPABM5C	IPBus arbiter bus master 5 configuration	32-bit
0x04_4028	IPABM6C	IPBus arbiter bus master 6 configuration	32-bit
0x04_402C	IPABM7C	IPBus arbiter bus master 7 configuration	32-bit
0x04_4030	IPABM8C	IPBus arbiter bus master 8 configuration	32-bit
0x04_4034	IPABM9C	IPBus arbiter bus master 9 configuration	32-bit
0x04_4038 through 0x04_4040	Reserved		
0x04_4044	IPABM13C	IPBus arbiter bus master 13 configuration	32-bit
0x04_4048	IPABM14C	IPBus arbiter bus master 14 configuration	32-bit
0x04_404C	IPABM15C	IPBus arbiter bus master 15 configuration	32-bit
0x04_4050	IPABM16C	IPBus arbiter bus master 16 configuration	32-bit
0x04_4054	IPAC	IPBus arbiter control	32-bit
0x04_4058	IPAITCC	IPBus arbiter idle transaction cycle count	32-bit
0x04_405C through 0x04_7FFF	Reserved		

Table 5.2 IPBus Arbitration Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

PMBus Arbitration Register Description

Register Offset[1]	Register Name	Register Function	Size
0x02_0000	PMAPP	PMBus arbiter processor priority	32-bit
0x02_0004	PMASAC	PMBus arbiter sneak access control	32-bit
0x02_0008 through 0x02_7FFF	Reserved		

Table 5.3 PMBus Arbitration Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Notes

Theory of Operation

The IPBus has four priorities. Zero is the lowest and three is the highest.

Each IPBus priority has an associated IPBus Arbiter Priority Configuration (IPAPxC) register. The IPAPxC register contains a Priority Transaction Count (PTC) and Current Priority Transaction Count (CPTC) field. Each bus master index has a corresponding IPBus Arbiter Bus Master Configuration (IPABMxC) register. The CMTC field in IPABMxC indicates the current transaction count for the corresponding bus master, while MTC indicates the transaction count. The MSK field in IPABMxC allows bus ownership requests to be masked from the corresponding bus master index. CPU bus ownership requests cannot be masked. The P field in IPABMxC contains the IPBus priority for the bus master.

The arbiter should be initialized in the following manner. First, the MTC field of all bus masters should be configured. Next, the PTC field of all priorities should be configured. Since the arbiter only looks at the CPTC and CMTC fields, the configuration will take affect in the next epoch (i.e., when CPTC reaches zero). The configuration of the arbiter may be modified when the system is running.

The IPBus arbiter implements an enhanced Weighted Round Robin arbitration scheme that supports priorities and full resource utilization.

Figure 5.1 shows a graphical view of the bus arbitration algorithm. In this example, bus masters with indices 4, 8, and 11 are assigned a priority of three (the highest). Bus masters with indices 3 and 15 are assigned a priority of two. Bus masters with indices 1, 5, and 14 are assigned a priority of one. Finally, bus masters with indices 2, 9, 13, and 16 are assigned a priority of zero (the lowest). Arbitration requests from the other bus masters are masked.

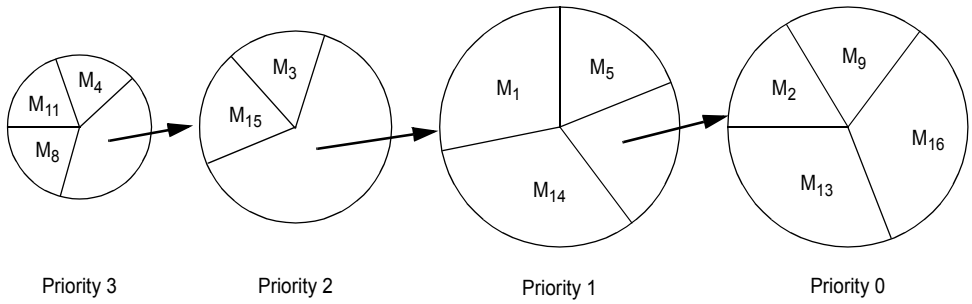


Figure 5.1 Illustration of IPbus Arbitration Algorithm

The circumference of the circles represent the number of IPBus transactions required before the arbitration epoch for that priority restarts. When an arbitration epoch restarts, the CMTC field of all bus masters with that priority is set to the corresponding MTC, and the CPTC field of the priority is set to the PTC field.

The algorithm looks at the highest priority. If there is a bus master requesting service whose CMTC is non-zero, then the bus is granted to that master. If multiple masters exist, then the bus is granted to the master that currently owns the bus. If none of the masters currently own the bus, then the bus is granted to the master with the lowest index. The CMTC for the bus master that was granted the bus and the CPTC of all priorities higher than or equal to the master priority are decremented. If no such bus master was granted the bus, then the algorithm repeats for the next highest priority.

Because priority is given to the master which currently has the bus, the arbiter will tend to cause transactions to the same bus master to be clustered. This feature is desired to allow IPBus transaction merging.

If the CMTC field for a bus master reaches zero, then the bus master is not granted ownership until the CPTC of the corresponding priority reaches zero and the arbitration epoch for the priority restarts. Thus, the MTC field of a bus master can be viewed as limiting the percentage of bus bandwidth allocated to the bus master. The MTC fields of all bus masters with a given priority are normally less than or equal to the PTC field of the priority. If the sum is less than the PTC field, then the remaining transfers for the priority are allocated to lower priorities.

Notes

The minimum percentage of bus bandwidth available for a given priority can be calculated as follows for the above example:

$$\text{BW available to priority 3} = 100\%$$

$$\text{BW available to priority 2} = \left(1 - \frac{MTC_8 + MTC_4 + MTC_{11}}{PTC_3}\right) x 100\%$$

$$\text{BW available to priority 1} = \left(1 - \frac{MTC_8 + MTC_4 + MTC_{11}}{PTC_3}\right) x \left(1 - \frac{MTC_3 + MTC_{15}}{PTC_2}\right) x 100\%$$

$$\text{BW available to priority 0} = \left(1 - \frac{MTC_8 + MTC_4 + MTC_{11}}{PTC_3}\right) x \left(1 - \frac{MTC_3 + MTC_{15}}{PTC_2}\right) \left(1 - \frac{MTC_1 + MTC_5 + MTC_{14}}{PTC_1}\right) x 100\%$$

Where MTCi is the MTC for the bus master with index i and PTCj is the PTC for priority j.

As an example, the percentage of bus bandwidth available to bus masters 3 and 4 may be calculated as follows:

$$\text{BW available to bus master 4} = \frac{MTC_4}{PTC_3} x 100\%$$

$$\text{BW available to bus master 3} = \frac{MTC_3}{PTC_2} x \left(1 - \frac{MTC_8 + MTC_4 + MTC_{11}}{PTC_3}\right) x 100\%$$

It should be apparent that these equations approximate bus bandwidth since the IPBus arbiter deals with transactions and not clock cycles. Despite this fact, the IPBus arbiter provides a mechanism to bound service delays and provide a guaranteed level of service.

When the CMTC field of all bus masters requesting service is zero, then instead of allowing the IPBus to go idle, the bus is granted in a fair manner to one of the bus master(s) with the highest priority.

IPBus supports transaction merging. This allows burst transfers to the Double Data Rate (DDR) controller that are longer than a maximal length DMA burst (16 words). It also allows the system to limit queueing delays and hence minimize the size of buffers.

The DDR controller can supply data at twice the data rate required by the IPBus. The IPBus arbiter passes hints to the DDR controller when IPBus transaction merging may take place. The DDR controller uses this information to speculatively prefetch data potentially required for the next DMA transaction. When the Disable Prefetching (DP) bit is set in the IPBus Arbiter Control (IPAC) register, DDR prefetching hints are disabled (i.e., the DDR controller will never speculatively prefetch data).

Figure 5.2 depicts a flow chart of the IPBus arbitration algorithm.

Notes

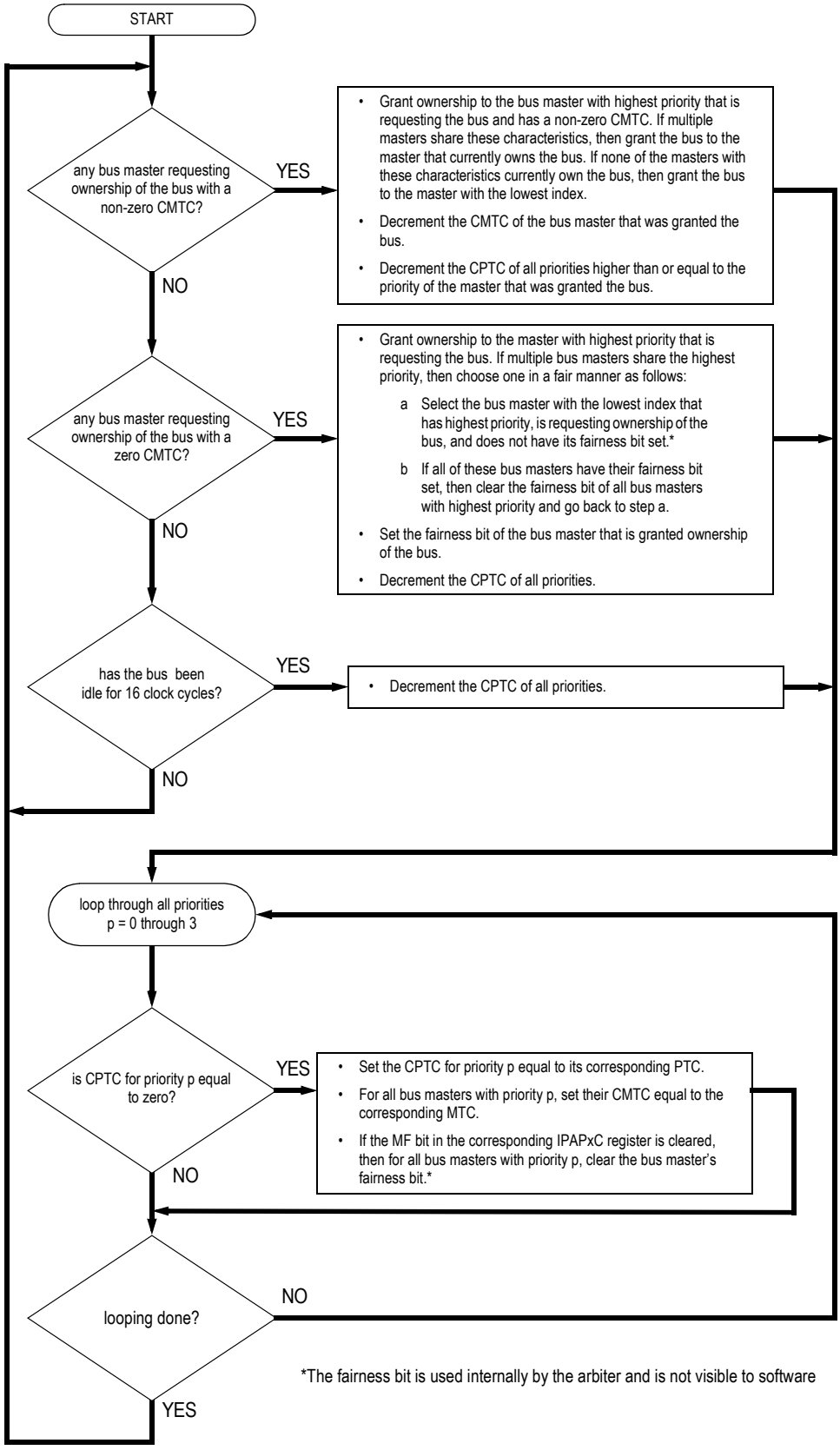


Figure 5.2 IPBus Arbitration Algorithm Flow Chart

Notes

Example IPBus Arbiter Configurations

To illustrate the operation of the IPBus arbiter, this section examines several IPBus arbiter configurations. For simplicity, only three priorities and four bus masters are considered. The examples can be easily extended to all priorities and bus masters.

Strict Priority Arbitration

Figure 5.3 shows an IPBus arbiter configuration that implements strict priority. In this example, masters with priority three are given preference over masters with lower priorities. Priority two is given preference over priority one. Since the PTC and MTC values for priority three are one, a new arbitration epoch begins each time the bus is granted to a priority three master.

Figure 5.4 illustrates the operation of the IPBus arbiter with the configuration in Figure 5.3. Each rectangle represents one transaction or 64 clock cycles. The value in a rectangle shows the current value of CPTC or CMTC. The bottom row shows the current bus master. A rectangle is shaded if the corresponding bus master is requesting ownership of the bus.

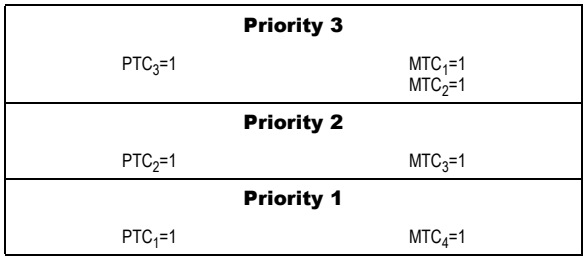


Figure 5.3 IPBus Arbiter Configuration for Strict Priority Arbitration

MF=0												
$CMTC_1$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CMTC_2$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CMTC_3$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CMTC_4$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CPTC_1$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CPTC_2$=1	1	1	1	1	1	1	1	1	1	1	1	1
$CPTC_3$=1	1	1	1	1	1	1	1	1	1	1	1	1
Bus Ownership	Idle	Master 1	Master 2	Master 3	Master 1	Master 4	Idle	Master 1	Master 2	Master 1	Master 2	Master 2

Figure 5.4 Example Operation of IPBus Arbiter with Strict Priority Arbitration

Fair Arbitration

Figure 5.5 shows an IPBus arbiter configuration that implements fair arbitration. In this configuration the MF bit in the IPAP3C register must be set. This maintains fairness across arbitration epochs.[1] Since all masters have the same priority and a zero MTC, access to the bus is granted in a fair manner using the fairness bit method described in Figure 5.2.

1. If the MF bit were not set, then the fairness bit would be cleared each clock cycle since PTC is equal to one. This would result in the bus being granted unfairly to the bus master with the lowest index.

Notes

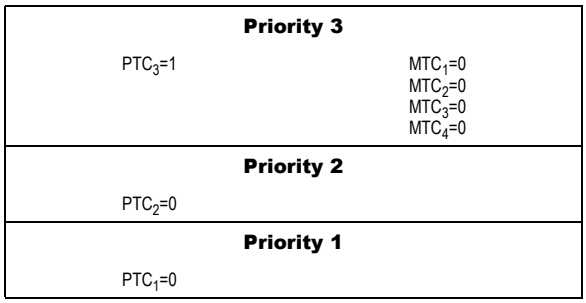


Figure 5.5 IPBus Arbiter Configuration for Fair Arbitration

MF=1												
$CMTC_1$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_2$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_3$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_4$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_1$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_2$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_3$=1	1	1	1	1	1	1	1	1	1	1	1	1
Bus Ownership	Idle	Master 1	Master 2	Master 3	Master 4	Master 1	Idle	Master 2	Master 1	Master 2	Master 1	Master 2

Figure 5.6 Example Operation of IPBus Arbiter with Fair Arbitration

Priority Arbitration with Fairness

A difficulty with strict priority arbitration, presented above, is that it can lead to starvation within a priority. For the example in Figure 5.4, it is possible for master two to starve since it has a higher index than master one. If master one continuously requests the bus, master two will starve. Priority arbitration with fairness within a priority eliminates this starvation. As in the fair arbitration example, the MF bit in the IPAP3C register must be set. This maintains fairness across arbitration epochs.

Figure 5.7 shows an IPBus arbiter configuration that implements priority arbitration with fairness. Ownership is granted to the bus master with the highest priority level which is requesting the bus. If multiple bus masters are requesting ownership and share the same priority level, then ownership is granted in a fair manner within the priority level.

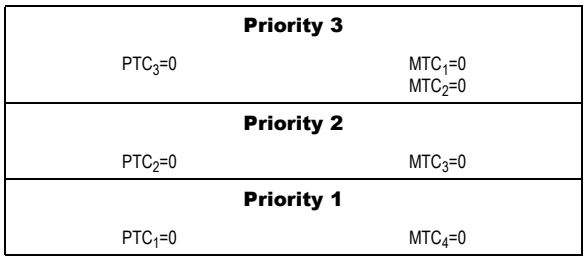


Figure 5.7 IPBus Arbiter Configuration for Priority Arbitration with Fairness

Notes

MF=1												
$CMTC_1$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_2$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_3$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CMTC_4$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_1$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_2$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_3$=0	0	0	0	0	0	0	0	0	0	0	0	0
Bus Ownership	Idle	Master 1	Master 2	Master 3	Master 1	Master 4	Idle	Master 2	Master 1	Master 2	Master 1	Master 2

Figure 5.8 Example Operation of IPBus Arbiter with Priority Arbitration with Fairness

Weighted Round Robin

Figure 5.9 shows an IPBus arbiter configuration that implements weighted round robin. Master one is allocated 33.3% of the transaction, master two is allocated 4.8%, master three is allocated 14.3%, and master four is allocated 47.6%.

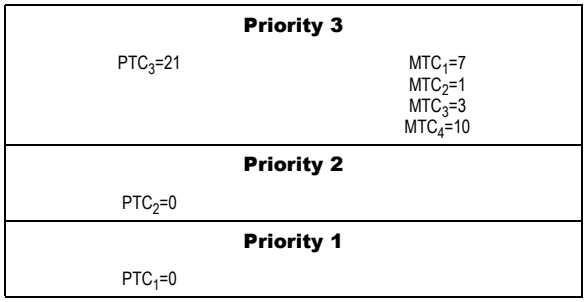


Figure 5.9 IPBus Arbiter Configuration for Weighted Round Robin

MF=0												
$CMTC_1$=7	7	6	6	6	5	5	4	3	2	1	0	0
$CMTC_2$=1	1	1	0	0	0	0	0	0	0	0	0	0
$CMTC_3$=3	3	3	3	2	2	2	2	2	2	2	2	1
$CMTC_4$=10	10	10	10	10	10	10	10	10	10	10	10	10
$CPTC_1$=21	21	20	19	18	17	16	15	14	13	12	11	10
$CPTC_2$=0	0	0	0	0	0	0	0	0	0	0	0	0
$CPTC_3$=0	0	0	0	0	0	0	0	0	0	0	0	0
Bus Ownership	Idle	Master 1	Master 2	Master 3	Master 1	Idle	Master 1	Master 1	Master 1	Master 1	Master 1	Master 2

Figure 5.10 Example Operation of IPBus Arbiter with Weighted Round Robin

Notes

IPBus Registers

IPBus Arbiter Control Register

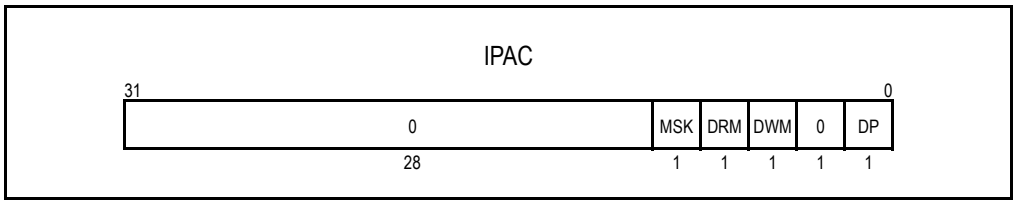


Figure 5.11 IPBus Arbiter Control Register (IPAC)

DP

Description: **Disable Prefetching**. When this bit is set, the IPBus arbiter disables prefetching hints passed to the DDR controller (i.e., the DDR controller will never speculatively prefetch data).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DWM

Description: **Disable Write Transaction Merging**. When this bit is set, write transaction merging is disabled for all IPBus masters.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DRM

Description: **Disable Read Transaction Merging**. When this bit is set, read transaction merging is disabled for all IPBus masters.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MSK

Description: **Mask Bus Ownership Requests**. When this bit is set, all bus ownership requests are masked except those from the CPU.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPBus Arbiter Priority Configuration Register

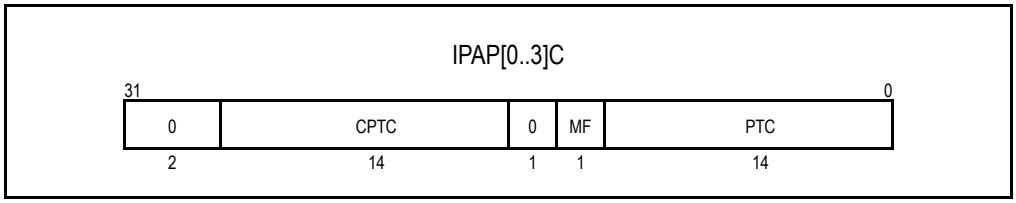


Figure 5.12 IPBus Arbiter Priority Configuration [0..3] Register (IPAP[0..3]C)

PTC

Description: **Priority Transaction Count**. This field contains the transaction count for the corresponding arbitration priority.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

MF

Description: **Maintain Fairness**. When this bit is set, the fairness bit mentioned in Figure 5.2 is not cleared when the CPTC for a priority reaches zero. This allows fairness to be maintained across arbitration epochs.

The MF bit must be set when fair arbitration or priority arbitration with fairness algorithms are desired.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

CPTC

Description: **Current Priority Transaction Count**. This field contains the current arbitration transaction count for the corresponding arbitration priority. This field is provided for status only and cannot be modified by the CPU.

Initial Value: 0x1

Read Value: Status

Write Effect: Read-only

Notes

IPBus Arbiter Bus Master Configuration Register

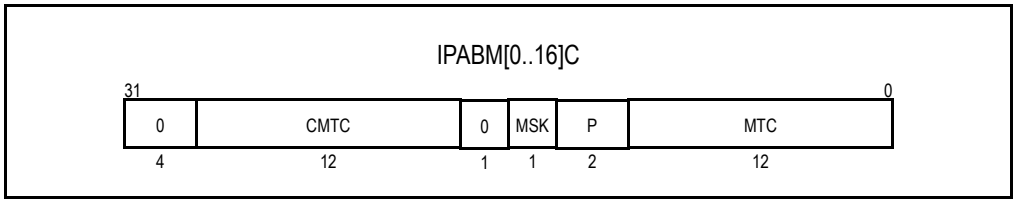


Figure 5.13 IPBus Arbiter Bus Master [0..16] Configuration Register (IPABM[0..16])

Note: Registers 10 through 12 are reserved. Only use registers 0 through 9 and 13 through 16.

MTC

Description: **Master Transaction Count**. This field contains the transaction count for the corresponding bus master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

P

Description: **Priority**. This field contains the arbitration priority for the corresponding bus master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MSK

Description: **Mask Bus Ownership Requests**. When this bit is set, bus ownership requests from the corresponding bus master are masked. CPU bus ownership requests can never be masked.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value (read only for index 16, the CPU)

CMTC

Description: **Current Master Transaction Count**. This field contains the current arbitration transaction count for the corresponding bus master. This field is provided for status only and cannot be modified by the CPU.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Notes

IPBus Idle Transaction Cycle Count Register

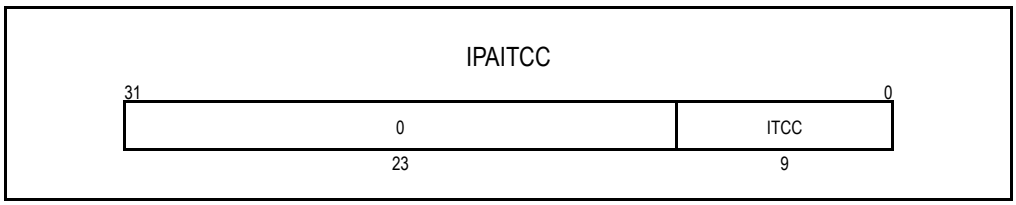


Figure 5.14 IPBus Idle Transaction Cycle Count Register (IPAITCC)

ITCC

Description: **Idle Transaction Cycle Count**. This field contains the number of clock cycles the IPBus must be idle before it is viewed as an idle transaction. See Figure 5.2.

Initial Value: 0x10

Read Value: Previous value written

Write Effect: Modify value

PMBus Arbitration

Since the PMBus and DDR controller operate at twice the IPBus clock rate, they have twice the available bandwidth. The goal of PMBus arbitration is to utilize this spare bus bandwidth for CPU transactions to DDR without adversely affecting IPBus performance. Since there are buffers associated with the IPBus Master Bus Bridge that links the IPBus to the PMBus, it is possible for the IPBus to be active while the PMBus is idle.

IPBus Idle

If the PMBus and IPBus are idle, then the CPU is granted access to memory without delay (i.e., nothing to arbitrate).

IPBus Active

If the IPBus is active and the CPU has higher priority than the current or pending[1] IPBus transaction, then the CPU is granted ownership of the PMBus and the IPBus transaction is delayed. If the IPBus is active and the CPU priority is equal to that of the current or pending IPBus transaction, then access to the PMBus is granted in a fair manner (i.e., access alternates between an IPBus transaction and the CPU). Sneak transactions (see next section) have no effect on fair access (i.e., they are ignored by the arbiter). If the IPBus is active and the CPU priority is less than that of the current or pending IPBus transaction, then access to the PMBus is granted to the IPBus transaction and the CPU is delayed.

Sneak Transactions

Due to buffering between the IPBus and PMBus, it is possible for the PMBus to be idle while a transaction is in progress on the IPBus. Sneak transactions allow the CPU to utilize otherwise idle PMBus cycles to perform accesses to DDR. Sneak transactions are never allowed to devices on the memory and peripheral bus since sneak transactions may delay the completion of an IPBus transaction. Control is provided to allow sneak transactions to be disabled. The PMBus Arbiter Sneak Access Control (PMASAC) register has a sneak transaction enable bit associated with each of the four IPBus priorities.

The IPBus sneak priority is equal to the highest value of any current or pending IPBus transaction. For a sneak transaction to take place, the sneak transaction enable bit associated with the IPBus sneak priority must be set in the PMASAC register. Sneak transactions do not count toward fair access to the PMBus.

1. When an IPBus master requests the IPBus, a transaction is considered to be pending since eventually the IPBus will be granted to the master.

Notes

Bus Parking

When the PMBus is idle, it is normally parked on the CPU in order to minimize CPU memory access latency. When the Park On IPBus (POI) bit is set in the PMBus Arbiter Sneak Access Control (PMASAC) register, then the PMBus is parked on the IPBus when it is idle. This minimizes IPBus master memory access latency rather than CPU latency.

PMBus Registers

PMBus Arbiter Processor Priority Register

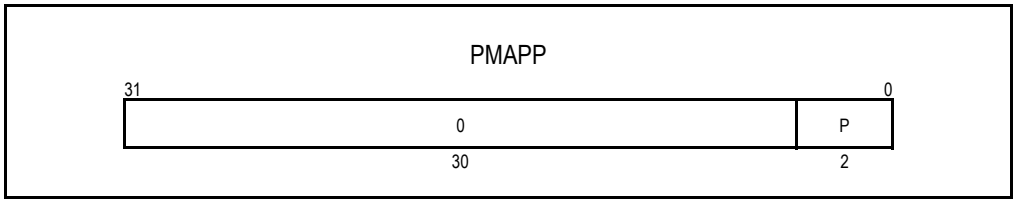


Figure 5.15 PMBus Arbiter Processor Priority Register (PMAPP)

P

Description: **Processor Priority**. This two bit field contains the CPU priority used for PMBus arbitration. Unlike the priority in the IPABM16C register which is used for CPU accesses to the IPBus, this priority is used for access to DDR or devices on the memory and peripheral bus.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PMBus Arbiter Sneak Access Control Register

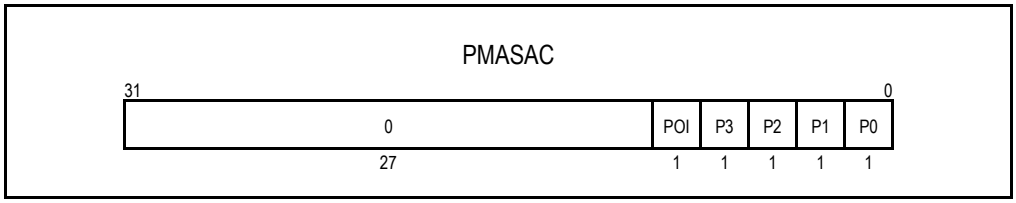


Figure 5.16 PMBus Arbiter Sneak Access Control Register (PMASAC)

P0

Description: **Priority 0 Sneak Transaction Enable**. When this bit is set, the CPU may be granted access to the PMBus during otherwise idle cycles while a priority 0 master is granted ownership of the IPBus or ownership is pending to a priority 0 master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

P1

Description: **Priority 1 Sneak Access Enable**. When this bit is set, the CPU may be granted access to the PMBus during otherwise idle cycles while a priority 1 master is granted ownership of the IPBus or ownership is pending to a priority 1 master.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

P2

Description: **Priority 2 Sneak Transaction Enable**. When this bit is set, the CPU may be granted access to the PMBus during otherwise idle cycles while a priority 2 master is granted ownership of the IPBus or ownership is pending to a priority 2 master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

P3

Description: **Priority 3 Sneak Transaction Enable**. When this bit is set, the CPU may be granted access to the PMBus during otherwise idle cycles while a priority 3 master is granted ownership of the IPBus or ownership is pending to a priority 3 master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

POI

Description: **Park On IPBus**. When the PMBus is idle, it is normally parked on the CPU. When the PMBus is idle and this bit is set, the PMBus is parked on the IPBus.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Memory and Peripheral Bus Arbitration

The RC32438 allows external bus masters on the memory and peripheral bus. An external bus master asserts the bus request (BRN) input to the RC32438 to request ownership of the memory and peripheral bus.[1] The RC32438 responds to the assertion of BRN by relinquishing ownership of the memory and peripheral bus by asserting bus grant (BGN) and simultaneously tri-stating[2] the following signals:

MADDR[25:0],
MDATA[15:0],
BWEN[1:0],
OEN,
RWN,
CSN[5:0],
BOEN,
BDIRN.

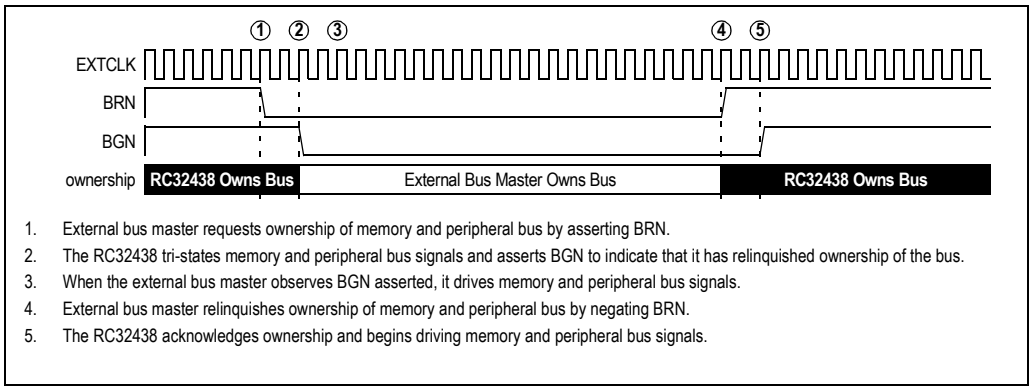
1. Once an external bus master has requested the bus by asserting BRN, it must keep BRN asserted until it is granted the bus (i.e., it observes BGN asserted).
2. CSN[5:0] and BOEN shall have been in their negated state for at least one EXTCLK clock cycle before being tri-stated. This is true when both the RC32438 or the external bus master relinquish ownership.

Notes

When the external bus master observes BGN asserted, it owns the memory and peripheral bus and may drive the above signals. The external bus master maintains BRN asserted during the entire time it owns the memory and peripheral bus. It relinquishes ownership by negating BRN[1] and tri-stating the above memory and peripheral bus signals. The RC32438 acknowledges that external ownership of the bus has been relinquished by negating BGN[2], and it begins driving the memory and peripheral bus signals. This process is illustrated in Figure 5.17.

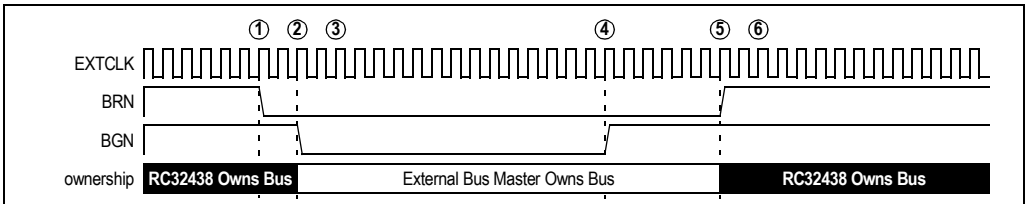
The RC32438 may request that an external bus master relinquish ownership of the memory and peripheral bus early, for example due to a higher priority internal pending transaction, by negating BGN while BRN is asserted. When the external bus master observes this, it relinquishes ownership by negating BRN and tri-stating the memory and peripheral bus signals. The RC32438 regains ownership and may drive the memory and peripheral bus signals when it observes BRN negated. This process is illustrated in Figure 7.17. Since BRN is an asynchronous input to the RC32438, which is double sampled, it must be negated for at least three EXTCLK clock cycles before being asserted.

When the RC32438 owns the memory and peripheral bus and there are no device controller transactions in progress, the RC32438 may drive or tri-state the data bus (MDATA[15:0]).



1. External bus master requests ownership of memory and peripheral bus by asserting BRN.
2. The RC32438 tri-states memory and peripheral bus signals and asserts BGN to indicate that it has relinquished ownership of the bus.
3. When the external bus master observes BGN asserted, it drives memory and peripheral bus signals.
4. External bus master relinquishes ownership of memory and peripheral bus by negating BRN.
5. The RC32438 acknowledges ownership and begins driving memory and peripheral bus signals.

Figure 5.17 External Bus Arbitration



1. External bus master requests ownership of memory and peripheral bus by asserting BRN.
2. The RC32438 tri-states memory and peripheral bus signals and asserts BGN to indicate that it has relinquished ownership of the bus.
3. When the external bus master observes BGN asserted, it drives memory and peripheral bus signals.
4. The RC32438 requests that the external bus master relinquish ownership of the memory and peripheral bus by negating BGN
5. The external bus master relinquishes ownership of the memory and peripheral bus by negating BRN.
6. The RC32438 observes that ownership of the bus has been relinquished and begins driving memory and peripheral bus signals.

Figure 5.18 External Bus Arbitration with RC32438 Requesting that Ownership Be Relinquished

1. Once an external bus master has relinquished ownership of the bus by negating BRN, it should not assert BRN until the RC32438 acknowledges the negation of BRN by negating BGN.
2. It is guaranteed that the RC32438 will assert BGN for no less than three EXTCLK clock cycles.

Notes

Device Controller

Notes

Introduction

The device controller on the RC32438 device provides a glueless interface to: SRAMs, ROMs/PROMs/EEPROMs, dual port memories, and many peripheral devices. The device controller generates all of the signals required to support both Intel and Motorola style peripherals and can directly control up to six devices. Additional devices may be supported through external decoding of the address bus.

Features

- *Provides "glueless" interface to standard SRAM, Flash, ROM, dual-port memory, and peripheral devices*
- *Demultiplexed address and data buses*
  - *16-bit data bus*
  - *26-bit address bus*
  - *6 chip selects*
  - *Supports alternate bus masters*
  - *Control for external data bus buffers*
- *Supports 8-bit and 16-bit width devices*
  - *Automatic byte gathering and scattering*
- *Flexible protocol configuration parameters*
  - *Programmable number of wait states (0 to 63)*
  - *Programmable postread/postwrite delay (0 to 31)*
  - *Supports external wait state generation*
  - *Supports Intel and Motorola style peripherals*
- *Write protect capability per chip select*
- *Programmable bus transaction timer generates warm reset when counter expires*
- *Supports up to 64 MB of memory per chip select*
- *Provides clocking for external devices on the memory and peripheral bus*

Device Controller Register Description

Register Offset[1]	Register Name	Register Function	Size
0x01_0000	DEV0BASE	Device 0 Base	32-bit
0x01_0004	DEV0MASK	Device 0 Mask	32-bit
0x01_0008	DEV0C	Device 0 Control	32-bit
0x01_000C	DEV0TC	Device 0 Timing control	32-bit
0x01_0010	DEV1BASE	Device 1 Base	32-bit
0x01_0014	DEV1MASK	Device 1 Mask	32-bit
0x01_0018	DEV1C	Device 1 Control	32-bit
0x01_001C	DEV1TC	Device 1 Timing control	32-bit
0x01_0020	DEV2BASE	Device 2 Base	32-bit

Table 6.1 Device Controller Register Map

Notes

Register Offset[1]	Register Name	Register Function	Size
0x01_0024	DEV2MASK	Device 2 Mask	32-bit
0x01_0028	DEV2C	Device 2 Control	32-bit
0x01_002C	DEV2TC	Device 2 Timing control	32-bit
0x01_0030	DEV3BASE	Device 3 Base	32-bit
0x01_0034	DEV3MASK	Device 3 Mask	32-bit
0x01_0038	DEV3C	Device 3 Control	32-bit
0x01_003C	DEV3TC	Device 3 Timing control	32-bit
0x01_0040	DEV4BASE	Device 4 Base	32-bit
0x01_0044	DEV4MASK	Device 4 Mask	32-bit
0x01_0048	DEV4C	Device 4 Control	32-bit
0x01_004C	DEV4TC	Device 4 Timing control	32-bit
0x01_0050	DEV5BASE	Device 5 Base	32-bit
0x01_0054	DEV5MASK	Device 5 Mask	32-bit
0x01_0058	DEV5C	Device 5 Control	32-bit
0x01_005C	DEV5TC	Device 5 Timing control	32-bit
0x01_0060	BTCS	Bus Timer Control and Status	32-bit
0x01_0064	BTCOMPARE	Bus Transaction Timer Compare	32-bit
0x01_0068	BTADDR	Bus Transaction Timer Address	32-bit
0x01_006C	DEVDACS	Device Decoupled Access Control and Status	32-bit
0x01_0070	DEVDAA	Device Decoupled Access Address	32-bit
0x01_0074	DEVDAD	Device Decoupled Access Data	32-bit
0x01_0078 through 0x01_7FFF	Reserved		

Table 6.1 Device Controller Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Theory of Operation

The following memory and peripheral bus signals are managed by the device controller during device transactions:

- *MADDR[25:0] (address bus, MADDR[21:0] directly available as I/O pins, MADDR[25:22] are GPIO alternate functions)*
- *MDATA[15:0] (data bus)*
- *OEN (output enable, may be used as Intel style read signal)*
- *BWEN[1:0] (byte write enables, may be used as Intel style write signals)*
- *RWN (Motorola style read/write signal)*
- *CSN[5:0] (chip selects)*
- *WAITACKN (configurable as Intel style wait signal or Motorola style transfer acknowledge signal)*
- *BOEN (external data bus buffer output enable)*
- *BDIRN (external data bus buffer direction).*

All memory and peripheral bus transactions are synchronous to the master clock (EXTCLK). Therefore, all of the timing parameters in the Device Control (DEVxC) and Device Timing Control (DEVxTC) registers are in terms of master clock (EXTCLK) clock cycles.

Notes

The endianess of the RC32438 is selected during boot configuration. Regardless of the selected endianess, devices are connected to the RC32438 data bus in a right aligned manner, as shown in Figure 6.1. 8-bit device data is read and written on MDATA[7:0] and 16-bit device data is read and written on MDATA[15:0].

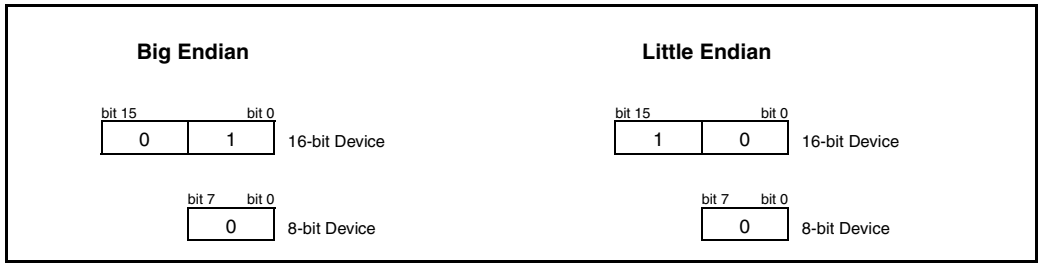


Figure 6.1 Connecting Devices to the RC32438 Data Bus (Right Aligned)

The width of a device, 8-bits or 16-bits, is configured in the device size (DS) field of the device [0..5] control register (DEV[0..5]C). The RC32438 performs byte gathering during read transactions and byte scattering during write transactions, allowing word and half-word read and write operations to any size device. The RC32438's address bus is always driven with a byte address. 8-bit devices use MADDR[25:0], and 16-bit devices use MADDR[25:1]. During write transactions to 16-bit, the byte write enable (BWEN[1:0]) signals are used to select byte lanes to be written.

The RC32438 supports four transaction types: a device read transaction, a burst device read transaction, a device write transaction, and a burst device write transaction. Transaction parameters for each device are programmed in the corresponding device [0..5] control register (DEV[0..5]C) and device [0..5] timing control (DEV[0..5]TC) register. In particular, the wait/ack mode (WAM) bit in the DEVxC register controls whether the WAITACKN signal operates as an Intel style wait signal or as a Motorola style acknowledge signal. Although WAITACKN is classified as an asynchronous input, to support systems that use master clock to generate it, asynchronous input setup and hold times are provided. **If the setup and hold times are met for the assertion of WAITACKN, then the RC32438 is guaranteed to recognize it on a specific rising edge of the clock.**

By configuring the programmable parameters in the DEVxC and DEVxTC registers, Intel and Motorola style bus transactions may be generated. Burst read transactions to devices which do not support burst reads may be disabled by clearing the burst read enable (BRE) bit in the corresponding DEVxC register. Burst write transactions to devices which do not support burst writes may be disabled by clearing the burst write enable (BWE) bit in the corresponding DEVxC register. All writes to a device may be disabled by setting the write protect (WP) bit in the corresponding DEVxC register.

Address decoding for each device chip select is controlled by the device [0..5] base (DEV[0..5]BASE) and device [0..5] mask (DEV[0..5]MASK) registers. The device mask register is used to select which bits are used for address decoding. When a bit in this register is a one, the corresponding address bit is active in address comparisons. If a bit in this register is a zero, then the corresponding address bit does not participate in address comparisons. All of the active address bits not masked by the device mask register are compared to the value in the device base register. If they all match, then the corresponding device chip select is asserted.

The device controller provides the control signals necessary to control external buffers, such as 74FCT245s, on the data bus (MDATA[15:0]). The buffer output enable (BOEN) pin is the enable for such buffers, while the external buffer direction (BDIRN) pin controls the direction. During device transactions, the BDIRN output is always in the opposite state of the RWN pin. The BOEN output is asserted during device transactions if the buffer enable (BE) bit is set in the DEVxC register.

Notes

Device zero is the boot device and contains the boot exception vector. Since read operations to this device must take place before software can initialize the system, the DEV0C and DEV0TC registers must have default values that allow the boot device to be read following a cold reset. Initial values for the DEVxC and DEVxTC registers for all devices are summarized in Table 6.2. These values may be modified during system initialization.

The RC32438 only reads data from a memory and peripheral bus device that is actually requested by the CPU or external DMA. For these transactions, the RC32438 never “reads past” the ending address of a transaction. For example, if the CPU reads a byte from a Memory and Peripheral Bus address, only that byte is actually read from memory.

Note: This is not true for PCI masters and general DMA operations; data may be read past the ending address of a transaction.

Table 6.2 shows the default values for the device configuration registers.

Register	Field	Initial Value	Description/Comment
DEVxC	DS	Boot Configuration	**Device Size**. Boot configuration vector (Refer to the Boot Configuration Vector section in Chapter 3).
	BE	0x1	**Buffer Enable.** Initial value places the boot device on buffered data bus.
	WP	0x1	**Write Protect.** Initial value disables writes to the boot device.
	BRE	0x0	**Burst Read Enable.** Burst reads are disabled from the boot device.
	BWE	0x0	**Burst Write Enable.** Burst writes are disabled to the boot device.
	RWS	0x3F	**Read Wait States.** Initially configured for maximum number of wait states.
	WWS	0x3F	**Write Wait States.** Initially configured for maximum number of wait states.
	WAM	0x0	**Wait/Ack Mode.** Initially configured for wait mode.
	CSD	0xF	**Chip Select Delay.** Initially configured for maximum delay.
	OED	0xF	**Output Enable Delay.** Initially configured for maximum delay.
	BWD	0xF	**Byte Write Enable Delay.** Initially configured for maximum delay.
DEVxTC	PRD	0xF	**Postread Delay.** Initially configured for maximum delay.
	PWD	0xF	**Postwrite Delay.** Initially configured for maximum delay.
	WDH	0x7	**Write Data Hold.** Initially configured for maximum delay.
	CSH	0x3	**Chip Select Hold.** Initially configured for maximum delay.

Table 6.2 Default Values for Device Configuration Registers

Notes

Device Control Registers

Device [0..5] Base Register

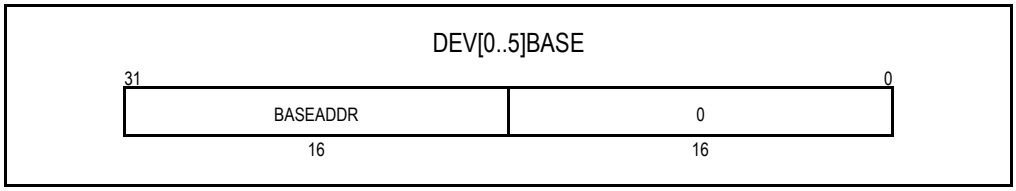


Figure 6.2 Device [0..5] Base Register (DEV[0..5]BASE)

BASEADDR

Description: **Base Address.** This field specifies the upper 16-bits of the device space base address.

Initial Value: 0x0 (Device 0 has an initial value of 0x1C00)

Read Value: Previous value written

Write Effect: Modify value

Device [0..5] Mask Register

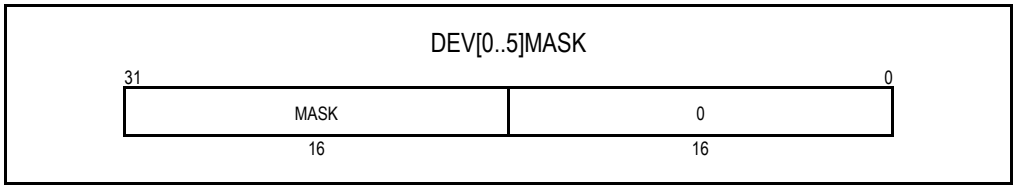


Figure 6.3 Device [0..5] Mask Register (DEV[0..5]MASK)

MASK

Description: **Address Mask.** This field determines which bits of the upper 16-bits of the address participate in address comparisons. When a bit is set in this field, then the corresponding address bit participates in address comparisons. When a bit is cleared in this field, then the corresponding address bit is masked and does not participate in address comparisons.

When the MASK field is zero, the device is disabled and does not appear in the memory map.

Initial Value: 0x0 (Device 0 has an initial value of 0xFC00)

Read Value: Previous value written

Write Effect: Modify value

Notes

Device [0..5] Control Register

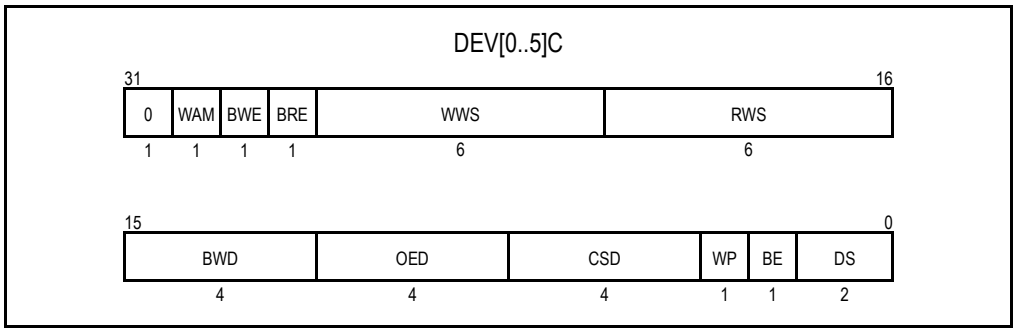


Figure 6.4 Device [0..5] Control Register (DEV[0..5]C)

DS

Description: **Device Size.** This field specifies the data path width of the device.
0 8-bit device
1 16-bit device
2 reserved
3 reserved

Initial Value: Boot configuration parameter (Refer to the Boot Configuration Vector section in Chapter 3).

Read Value: Previous value written

Write Effect: Modify value

BE

Description: **Buffer Enable.** When this bit is set, accesses to the device cause the BOEN signal to be asserted during device transactions.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

WP

Description: **Write Protect.** When this bit is set, writes to the device are disabled.
0 Writes to the device are enabled
1 Writes to the device are disabled

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

CSD

Description: **Chip Select Delay.** This field contains the delay in clock cycles by which the assertion of chip select (CSNx) is delayed from the start of a transaction. Programming this value to be greater than or equal to RWS or WWS causes CSNx not be asserted in the transaction.

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

Notes

OED

Description: **Output Enable Delay.** This field contains the delay in clock cycles by which the assertion of output enable (OEN) is delayed from the start of a read transaction. Programming this value to be greater than or equal to RWS causes OEN not be asserted in the transaction.

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

BWD

Description: **Byte Write Enable Delay.** This field contains the delay in clock cycles by which the assertion of the byte write enable signals (BWEN[1:0]) are delayed from the start of a write transaction. Programming this value to be greater than or equal to WWS causes BWEN[1:0] not be asserted in the transaction.

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

RWS

Description: **Read Wait States.** This field specifies the number of wait states during device read transactions. A value of zero in this field causes read transactions to be performed as though the RWS value was one. The RWS field must be initialized to a value greater than one if WAITACKN is configured as a wait input (see the WAM field below) which may be asserted during the transaction.

Initial Value: 0x3F

Read Value: Previous value written

Write Effect: Modify value

WWS

Description: **Write Wait States.** This field specifies the number of wait states during device write transactions. A value of zero in this field is treated as a WWS value of one.
The WWS field must be initialized to a value greater than one if the device is configured to support burst device write transactions and WAITACKN is configured as a wait input which may be asserted during the transaction.

Initial Value: 0x3F

Read Value: Previous value written

Write Effect: Modify value

BRE

Description: **Burst Read Enable.** When this bit is set, the device controller performs burst device read transactions whenever possible. When this bit is cleared, burst device read transactions are never generated to the device.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

BWE

Description: **Burst Write Enable.** When this bit is set, the device controller performs burst device write transactions whenever possible. When this bit is cleared, burst device write transactions are never generated to the device.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

WAM

Description: **Wait/Ack Mode.** This bit controls the operation of the WAITACKN signal. When this bit is a one, the WAITACKN signal operates as a Motorola style active low transfer acknowledge signal. When this bit is a zero, the WAITACKN signal operates as an Intel style active low wait signal.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Device [0..5] Timing Control Register

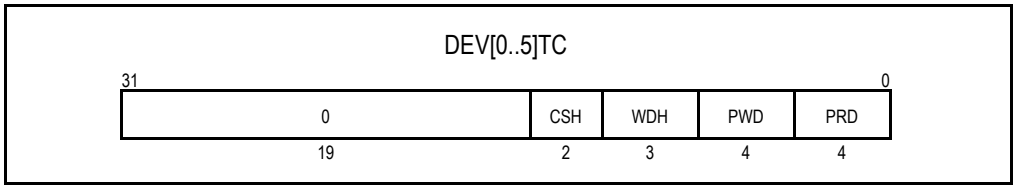


Figure 6.5 Device [0..5] Timing Control Register (DEV[0..5]TC)

PRD

Description: **Postread Delay.** This field contains the delay, in clock cycles, from when the RC32438 clocks in data from the data bus during a device read transaction until the start of a new transaction. Programming this value to zero results in a postread delay of one clock cycle.
If PRD or PWD is equal or less than CSH, chip select may remain asserted between transactions to the same device (i.e., back-to-back transactions).

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

PWD

Description: **Postwrite Delay.** This field contains the delay, in clock cycles, from when the RC32438 negates the byte write enable signals during a device write transaction until the start of a new transaction. Programming this value to zero results in a postread delay of one clock cycle.
If PRD or PWD is equal or less than CSH, chip select may remain asserted between transactions to the same device (i.e., back-to-back transactions).
If PWD is equal or less than WDH and BWD is zero, the byte write enable signals may remain asserted between write transactions to the same device (i.e., back-to-back write transactions).

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

Notes

WDH

Description: **Write Data Hold.** This field contains the delay, in clock cycles, from when the RC32438 negates the byte write enable signals during a device write transaction until the buffer output enable (BOEN) is negated and the data bus (MDATA[15:0]) is tri-stated. Buffer output enable is negated and the data bus is tri-stated when PWD expires regardless of the value of this field.

Initial Value: 0x7

Read Value: Previous value written

Write Effect: Modify value

CSH

Description: **Chip Select Hold.** This field contains the delay, in clock cycles, from when the RC32438 negates the byte write enable signals during a device write transaction or when output enable is negated during a device read transaction until the chip select signal is negated. Chip select is negated when PRD/PWD expires regardless of the value of this field.

Initial Value: 0x3

Read Value: Previous value written

Write Effect: Modify value

Memory And Peripheral Bus Transaction Timer

When enabled, the memory and peripheral bus transaction timer times all the memory and peripheral bus transactions. The memory and peripheral bus transaction timer is enabled by setting the bus transaction timer enable (BTE) bit in the BTCS register.

At the start of each memory and peripheral bus transaction in which the bus transaction timer is enabled, an internal 16-bit counter is initialized to zero. The counter increments with each passing external clock (EXTCLK) clock cycle until the bus transaction completes. If the counter value ever exceeds the value in the Compare (COMPARE) field in the Bus Timer Compare (BTCOMPARE) register, then a bus transaction timer time-out occurs.

When the bus transaction timer times-out, the following actions occur:

- *The bus transaction timer time out (BTO) bit in the BTCS register is set*
- *The address of the transaction which caused the time out is recorded in the bus transaction timer address (BTADDR) register*
- *The type of bus transaction (i.e., read or write) is recorded in the transaction type (TT) field of the BTCS register*
- *A warm reset is generated*
- *Compare field is initialized to 0xFFFF and the bus transaction timer is enabled.*

Only devices on the memory and peripheral bus with an Intel style wait signal or Motorola style transfer acknowledge signal can cause the bus transaction timer to time out.

Notes

Bus Transaction Timer Control and Status Register

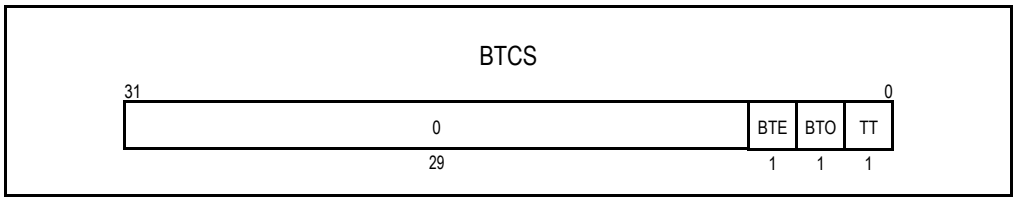


Figure 6.6 Bus Timer Control and Status Register (BTCS)

TT

Description: **Transaction Type.** This bit records the transaction type (read or write) of the first transaction in which the bus transaction timer timed-out.
0 write transaction
1 read transaction

Initial Value: Undefined ***(this field is not modified due to a warm reset)***

Read Value: Current value

Write Effect: Modify Value

BTO

Description: **Bus Transaction Timer Time-out.** When the bus transaction timer times-out, this bit is set.

Initial Value: 0x0

Read Value: Status ***(this field is not modified due to a warm reset)***

Write Effect: Sticky bit[1]

BTE

Description: **Bus Transaction Timer Enable.** When this bit is set, the bus transaction timer is enabled. When the bus transaction timer is enabled all memory and peripheral bus transactions are timed.

Initial Value: 0x1 ***(this field is not modified due to a warm reset)***

Read Value: Previous value written

Write Effect: Modify value

1. A sticky bit is set by the hardware and can only be cleared by the CPU.

Bus Transaction Timer Compare Register

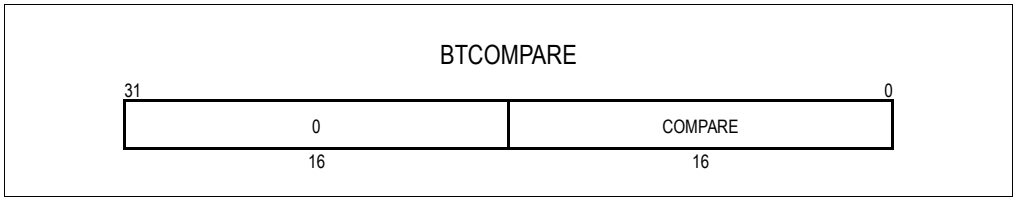


Figure 6.7 Bus Transaction Timer Compare Register (BTCOMPARE)

Notes

COMPARE

Description: **Bus Transaction Timer Compare Value.** This field contains the maximum bus transaction timer count value in the external clock (EXTCLK) clock cycles. If a bus transaction exceeds this number of clock cycles then the bus transaction timer times-out.

Initial Value: 0xFFFF

Read Value: Previous value written

Write Effect: Modify value

Bus Transaction Timer Address Register

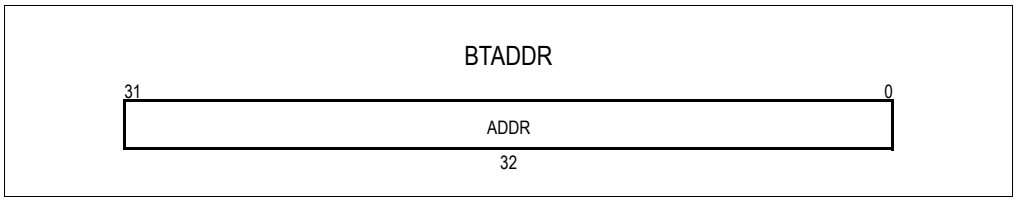


Figure 6.8 Bus Transaction Timer Address Register (BTADDR)

ADDR

Description: **Address.** This field contains the physical address of the transaction in which the bus transaction timer time out occurred.

Initial Value: Undefined ***(this field is not modified due to a warm reset)***

Read Value: Current value

Write Effect: Read-only

Device Read Transaction

This section describes the device read transaction. The transaction involves five programmable timing parameters:

- *Chip Select Delay (**CSD**). CSD may be programmed to be any value between 0 and 15 clock cycles.*
- *Output Enable Delay (**OED**). OED may be programmed to be any value between 0 and 15 clock cycles.*
- *Read Wait States (**RWS**). RWS may be programmed to be any value between 1 and 63 clock cycles.*
- *Postread Delay (**PRD**). PRD may be programmed to be any value between 0 and 15 clock cycles.*
- *Chip Select Hold Delay (**CSH**). CSH may be programmed to be any value between 0 and 3 clock cycles.*

Notes

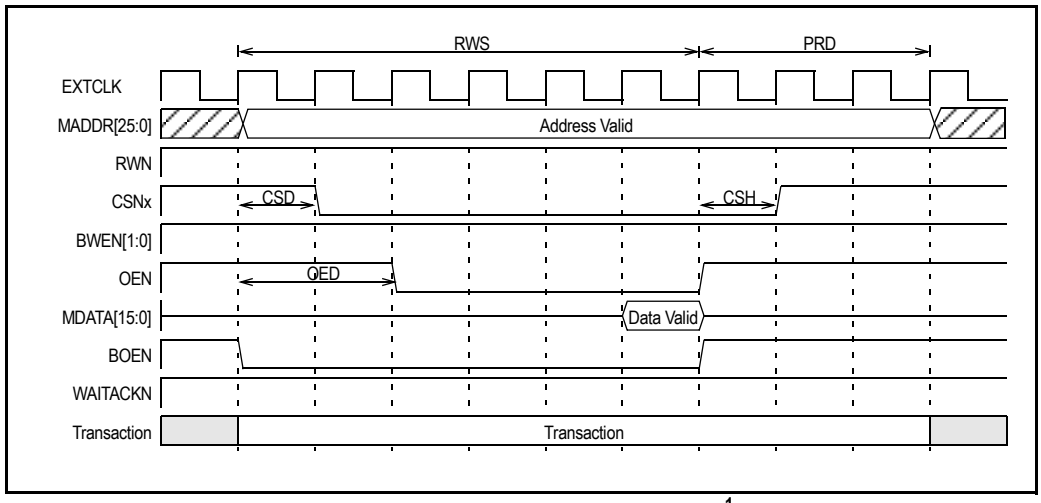


Figure 6.9 Generic Device Read Transaction[1]

The device read transaction, with WAITACKN configured as a wait input, consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN high and BDIRN low, and asserts BOEN[2] on the rising edge of EXTCLK. This indicates the start of a transaction.
2. *CSD* clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. *OED* clock cycles after step one, the RC32438 asserts output enable (OEN).
4. If WAITACKN is not asserted during the transaction, then *RWS* clock cycles after step one the RC32438 clocks in the data from the data bus (MDATA[15:0]), negates OEN and BOEN.
   If WAITACKN is asserted during the transaction, then the *RWS* field is ignored from that point on. The RC32438 clocks in the data on the data bus (MDATA[15:0]), negates OEN and BOEN one clock cycle after it samples WAITACKN negated.
5. CSH clock cycles after step four, the RC32438 negates chip select.
6. *PRD* clock cycles after step four, the RC32438 may modify the address on the address bus (MADDR[25:0]) and may begin a new transaction (the postread delay provides time for slow devices to get off the bus before issuing another transaction).

Figure 6.10 illustrates the effect of asserting the WAITACKN signal when it is configured as a wait signal. In this transaction, even though *RWS* + *PRD* was programed for eight clock cycles the transaction completes in seven clock cycles. This is because WAITACKN was asserted during the third clock cycle in the transaction and was negated during the fourth clock cycle. This caused the RC32438 to clock in the data on the fifth clock cycle and terminate the transaction early. The transaction could have been extended beyond eight clock cycles by holding WAITACKN asserted for several clock cycles.

1. The programmable parameters shown in this figure are for illustrative purposes only and may be varied.
2. BOEN is only asserted if the buffer enable (BE) bit is set in the device control register (DEVxC).

Notes

When configured as a wait signal, WAITACKN must be asserted at least two clock cycles prior to the end of *RWS*. WAITACKN assertions after this point are ignored. Thus, to use WAITACKN in this mode *RWS* must have a value greater than or equal to three.

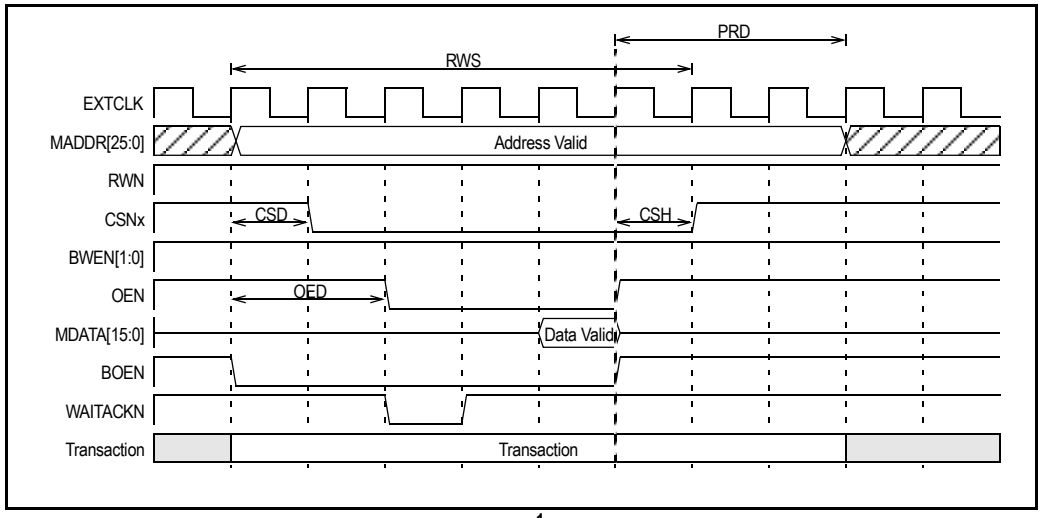


Figure 6.10 Device Read Transaction[1] (WAITACKN Configured As Wait)

The WAITACKN signal may be configured as an Intel style wait signal or as a Motorola style transfer acknowledge signal. Up to this point, this section has only considered WAITACKN configured as a wait signal. When WAITACKN is configured as transfer acknowledge, then the read wait states (*RWS*) value is ignored and the assertion of WAITACKN signals the completion of the transaction.

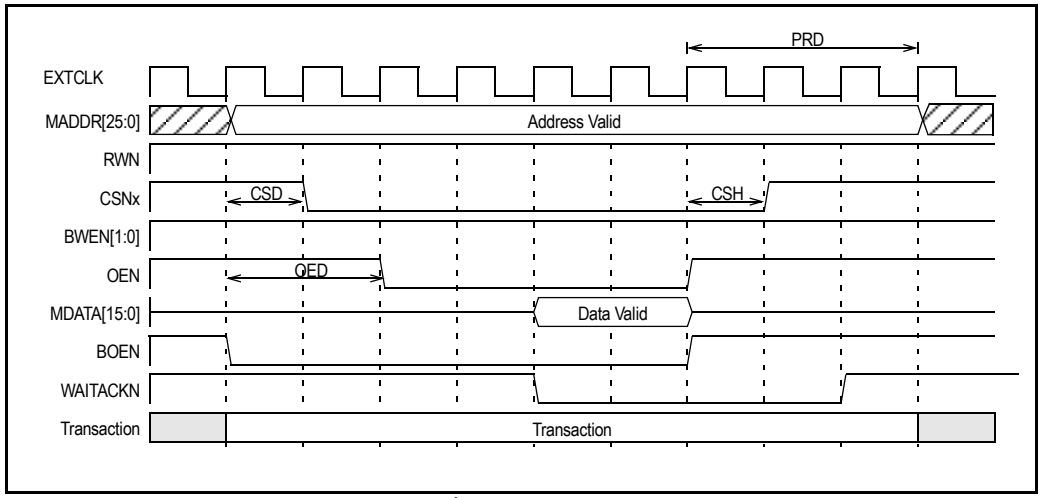


Figure 6.11 Device Read Transaction[1] (WAITACKN Configured As Transfer Acknowledge)

The device read transaction, with WAITACKN configured as a transfer acknowledge input, consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN high and BDIRN low, and asserts BOEN[2] on the rising edge of EXTCLK. This indicates the start of a transaction.
2. *CSD* clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. *OED* clock cycles after step one, the RC32438 asserts output enable (OEN).
4. The external device asserts WAITACKN once it has driven valid data onto the data bus and is ready for the transaction to complete.

1. The programmable parameters shown in this figure are for illustrative purposes only and may be varied.
2. BOEN is only asserted if the buffer enable (BE) bit is set in the device control register (DEVxC).

Notes

5. One clock cycle after the RC32438 samples WAITACKN asserted, it clocks in the data on the data bus (MDATA[15:0]), and negates OEN and BOEN.
6. *CSH* clock cycles after step five, the RC32438 negates CSNx.
7. When the external device observes that CSNx is negated, it tri-states the data bus and negates WAITACKN.
8. *PRD* clock cycles after step five, the RC32438 may modify the address on the address bus (MADDR[25:0]) and may begin a new transaction (the postread delay provides time for slow devices to get off the bus before issuing another transaction).

Burst Device Read Transaction

The burst device read transaction is enabled by setting the burst read enable bit (BRE) in the device control register. When this bit is set, consecutive read transactions to the same device, such as during cache refills and DMA operations, may be performed in a back-to-back manner as shown in Figure 6.12. Burst device read transactions do not support WAITACKN configured as a transfer acknowledge input. Regardless of the state of WAM in the DEVxC register, wait mode is selected. When configured as a wait signal, WAITACKN must be asserted at least two clock cycles prior to the end of RWS. WAITACKN assertions after this point are ignored. Thus, to use WAITACKN in this mode RWS must have a value greater than or equal to three.

During burst device read transactions the CSNx, OEN, and BOEN signals remain asserted between read operations. The postread delay is inserted only after the last read operation in the transaction. All programmable parameters are exactly the same as in a device read transaction described in “Device Read Transaction” on page 6-11. A burst device read transaction may consist of two or more read operations. The RC32438 provides no indication as to the number of read operations in the transaction.

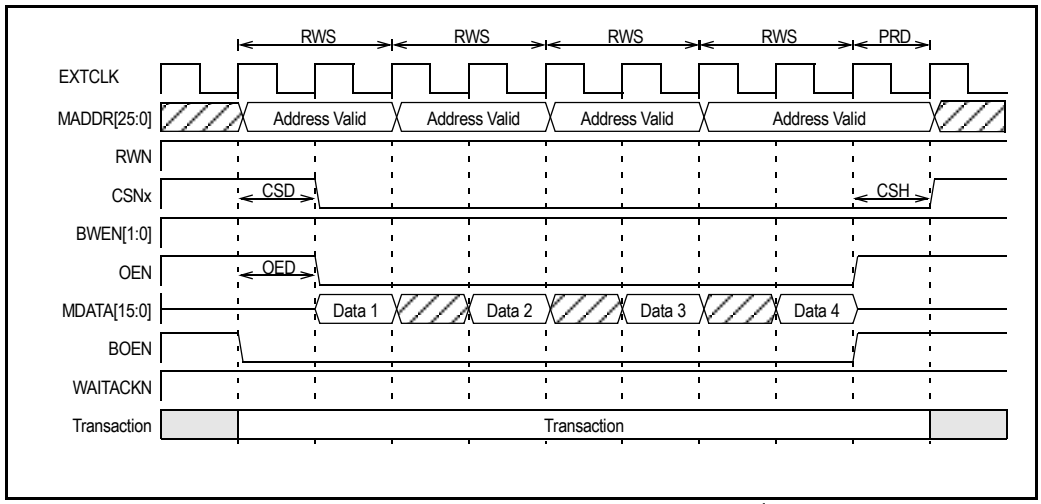


Figure 6.12 Generic Burst Device Read Transaction[1]

The burst device read transaction consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN high and BDIRN low, and asserts BOEN[2] on the rising edge of EXTCLK. This indicates the start of a transaction.
2. *CSD* clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. *OED* clock cycles after step one, the RC32438 asserts output enable (OEN).
4. If WAITACKN is not asserted during the transaction, then RWS clock cycles after step one the RC32438 clocks in the data from the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]).
   If WAITACKN is asserted during the transaction, then the RWS field is ignored from that point until

1. The programmable parameters shown in this figure are for illustrative purposes only and may be varied.
2. BOEN is only asserted if the buffer enable (BE) bit is set in the device control register (DEVxC).

Notes

WAITACKN is negated. The RC32438 clocks in the data on the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]) in the clock cycle after it samples WAITACKN negated.

5. After RWS clock cycles, if WAITACKN is not asserted during the transaction, the RC32438 clocks in the data from the data bus (MDATA[15:0]) and if this is not the last read operation in the transaction, it modifies the address on the address bus (MADDR[25:0]).
   If WAITACKN is asserted during any point during the read operation, the RWS field is ignored from that point until WAITACKN is negated. If this is not the last read operation in the transaction, then in the clock cycle after the RC32438 samples WAITACKN negated it clocks in the data on the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]).
6. If there are more read operations in the burst device read transaction, go to step five.
7. *CSH* clock cycles after step five, the RC32438 negates chip select.
8. *PRD* clock cycles after step five, the RC32438 may modify the address on the address bus (MADDR[25:0]) and may begin a new transaction (the postread delay provides time for slow devices to get off the bus before issuing another transaction).

Figure 6.13 illustrates the effect of asserting the WAITACKN signal when it is configured as a wait signal in a burst device read transaction. The transaction in this example had *RWS* programmed as three clock cycles and consists of two read operations. The first read operation completed in three clock cycles, as programmed. The assertion of WAITACKN during the second read operations extends the operations to four clock cycles.

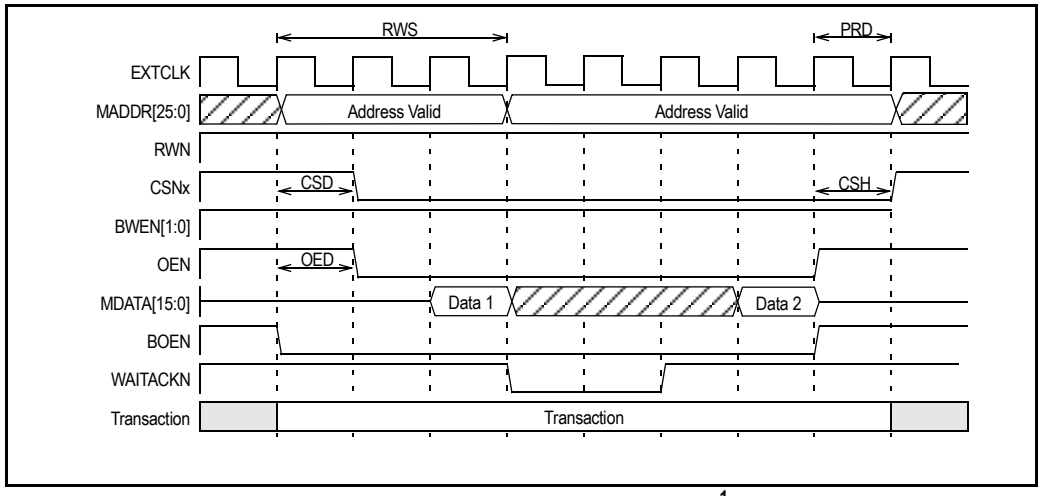


Figure 6.13 Burst Device Read Transaction[1]

Device Write Transaction

This section describes the device write transaction. The transaction involves six programmable timing parameters:

- *Chip Select Delay (**CSD**). CSD may be programmed to be any value between 0 and 15 clock cycles.*
- *Byte Write Enable Delay (**BWD**). BWD may be programmed to be any value between 0 and 15 clock cycles.*
- *Write Wait States (**WWS**). WWS may be programmed to be any value between 1 and 63 clock cycles.*
- *Postwrite Delay (**PWD**). PWD may be programmed to be any value between 0 and 15 clock cycles.*
- *Chip Select Hold Delay (**CSH**). CSH may be programmed to be any value between 0 and 3 clock cycles.*
- *Write Data Hold Delay (**WDH**). WDH may be programmed to be any value between 0 and 7 clock cycles.*

1. The programmable parameters shown in this figure are for illustrative purposes only and may be varied.

Notes

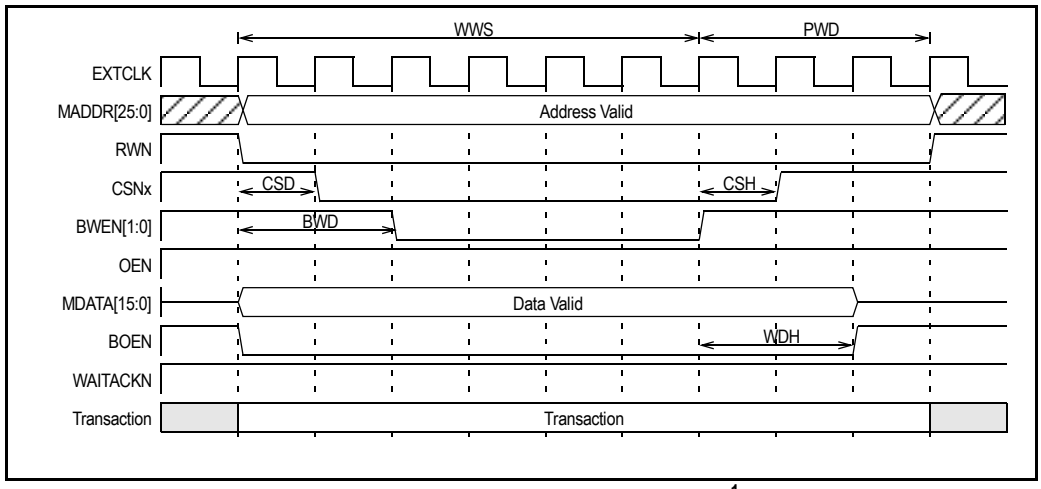


Figure 6.14 Generic Device Write Transaction[1]

The device write transaction, with WAITACKN configured as a wait input, consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN low and BDIRN high, asserts BOEN[1], and drives the data to be written on the data bus (MDATA[15:0]) on the rising edge of EXTCLK. This indicates the start of a transaction.
2. *CSD* clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. *BWD* clock cycles after step one, the RC32438 asserts the appropriate byte write enables (BWEN[1:0]).
4. If WAITACKN is not asserted during the transaction, the WWS clock cycles after step one the RC32438 negates all byte write enables (BWEN[1:0]).
   If WAITACKN is asserted during the transaction, the WWS field is ignored from that point on. The RC32438 negates all byte write enables in the clock cycle after it samples WAITACKN negated.
5. *CSH* clock cycles after step four, the RC32438 negates chip select.
6. *WDH* clock cycles after step four, the RC32438 negates BOEN and tri-states the data bus (MDATA[15:0]).
7. *PWD* clock cycles after step four, the RC32438 may modify the address on the address bus (MADDR[25:0]) and may begin a new transaction.

When configured as a wait signal, WAITACKN must be asserted at least two clock cycles prior to the end of *WWS*. WAITACKN assertions after this point are ignored. Thus, to use WAITACKN in this mode, *WWS* must have a value greater than or equal to three.

The device write transaction, with WAITACKN configured as a transfer acknowledge input, consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN low and BDIRN high, asserts BOEN[1], and drives the data to be written on the data bus (MDATA[15:0]) on the rising edge of EXTCLK. This indicates the start of a transaction.
2. *CSD* clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. *BWD* clock cycles after step one, the RC32438 asserts the appropriate byte write enables (BWEN[1:0]).
4. The external device asserts WAITACKN once it has captured the data on the data bus and is ready for the transaction to complete.
5. *CSH* clock cycles after the RC32438 samples WAITACKN asserted, the RC32438 negates CSNx.
6. When the external device observes that CSNx is negated, it negates WAITACKN.
7. *WDH* clock cycles after the RC32438 samples WAITACKN asserted, the RC32438 negates BOEN.
8. *PWD* clock cycles after the RC32438 samples WAITACKN asserted, it tri-states the data bus (MDATA[15:0]), may modify the address on the address bus (MADDR[25:0]), and may begin a new transaction.

1. BOEN is only asserted if the buffer enable (BE) bit is set in the device control register (DEVxC).

Notes

Burst Device Write Transaction

The burst device write transaction is enabled by setting the burst write enable bit (BWE) in the device control register. When this bit is set, consecutive write transactions to the same device, such as occur during DMA operations, may be performed in a back-to-back manner. Burst device write transactions do not support WAITACKN configured as a transfer acknowledge input. When configured as a wait signal, WAITACKN must be asserted at least two clock cycles prior to the end of *WWS*. WAITACKN assertions after this point are ignored. Thus, to use WAITACKN in this mode, *WWS* must have a value greater than or equal to three.

During burst device write transactions CSNx, appropriate BWEN[1:0], and BOEN signals remain asserted between write operations. The postwrite delay is inserted only after the last write operation in the transaction. All programmable parameters are exactly the same as in a device write transaction described in section "Device Write Transaction" on page 6-15. A burst device write transaction may consist of two or more write operations. The RC32438 provides no indication as to the number of write operations in the transaction.

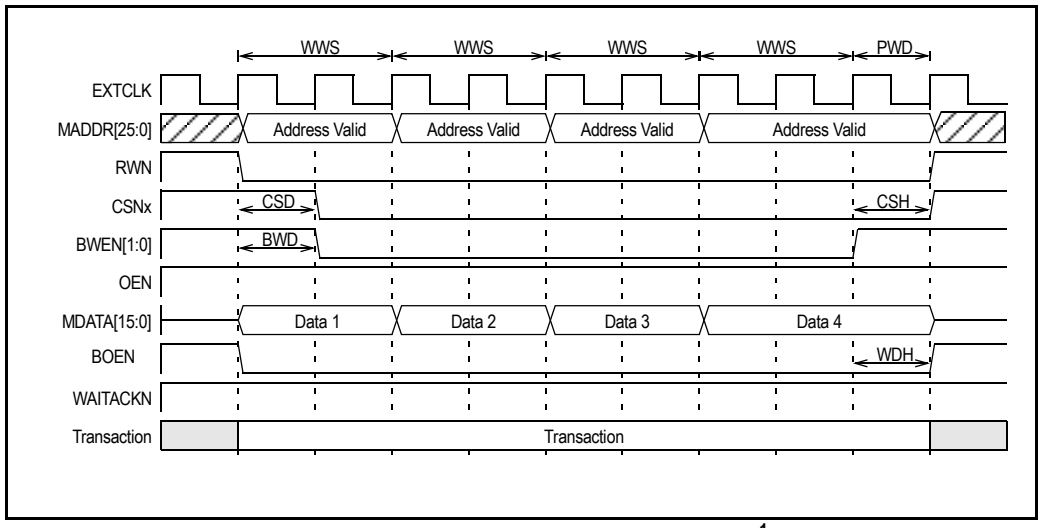


Figure 6.15 Generic Burst Device Write Transaction[1]

The burst device write transaction consists of the following steps.

1. The RC32438 drives the address bus (MADDR[25:0]), drives RWN low and BDIRN high, asserts BOEN[2], and drives the data to be written on the data bus (MDATA[15:0]) on the rising edge of EXTCLK. This indicates the start of a transaction.
2. CSD clock cycles after step one, the RC32438 asserts the appropriate chip select (CSNx).
3. BWD clock cycles after step one, the RC32438 asserts the appropriate byte write enables (BWEN[1:0]).
4. If WAITACKN is not asserted during the transaction, the WWS clock cycles after step one the RC32438 drives the next data to be written on the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]).
   If WAITACKN is asserted during the transaction, the WWS field is ignored from that point until WAITACKN is negated. The RC32438 drives the next data to be written on the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]) in the clock cycle after it samples WAITACKN negated.
5. After WWS clock cycles, if WAITACKN is not asserted during the transaction, the RC32438 clocks in the data from the data bus (MDATA[15:0]) and, if this is not the last write operation in the transaction, modifies the address on the address bus (MADDR[25:0]).
   If WAITACKN is asserted during any point during the read operation, the WWS field is ignored from

1. The programmable parameters shown in this figure are for illustrative purposes only and may be varied.
2. BOEN is only asserted if the buffer enable (BE) bit is set in the device control register (DEVxC).

Notes

that point until WAITACKN is negated. In the clock cycle after the RC32438 samples WAITACKN negated, if this is not the last write operation in the transaction, it drives the next data to be written on the data bus (MDATA[15:0]) and modifies the address on the address bus (MADDR[25:0]).

6. If there are more writes operations in the burst device write transaction, go to step five.
7. *CSH* clock cycles after step five, the RC32438 negates chip select.
8. *WDH* clock cycles after step five, the RC32438 negates BOEN.
9. *PWD* clock cycles after step five, the RC32438 tri-states the data bus (MDATA[15:0]), may modify the address on the address bus (MADDR[25:0]), and may begin a new transaction.

Decoupled CPU Device Transactions

CPU accesses to a device on the memory and peripheral bus may take a significantly longer time to complete than normal PMBus transactions. One reason for this is the fact that the memory and peripheral bus can run at one eighth the frequency of the PMBus. Other reasons are wait states, post read delays, and post write delays.

Locking up the PMBus may have adverse affects on the real-time performance of the system. For example, it may lead to Ethernet FIFO overflows and underflows. Since the PMBus does not support split transactions there is no way to avoid this issue with traditional CPU read and write operations. To avoid locking up the PMBus, the device controller supports decoupled CPU accesses. Decoupled CPU accesses allow CPU device read and write operations to complete without locking up the PMBus. The CPU encodes the type of operation (read or write) in the OP field and the size of the operation (byte, halfword, triple-byte, word) in the SIZE field.

All multi-byte decoupled read and write operations must be contained in a single word (e.g., it is invalid to initiate a decoupled read from a byte address of 0x3 or a word read from a non-word aligned address). Initiating a multi-byte decoupled read or write operation that crosses a word boundary results in undefined data and the Error (ERR) bit being set in the DEVDACS register.

To initiate a read operation, the CPU writes a local address that maps to a device to the DEVDAA register. The CPU write completes on the PMBus without delay. A read of the size specified in the SIZE field is then performed from the device address written. When the read completes, the data read from the device updates the DATA field of the DEVDAD register and the F bit is set.

To initiate a write operation, the CPU writes the data to be written to the DATA field of the DEVDAD register and then writes the address to be written to the DEVDAA register. Both writes complete without delay. A write of the size specified in the SIZE field is then performed to the device using data from the DEVDAD register. When the write completes, the F bit is set. The F bit is presented to the interrupt handler as an interrupt source.

If an error occurs during the device operation or if the address written to the DEVDAA register does not map to a device on the memory and peripheral bus, then the error (ERR) bit is set in the DEVDACS register when the F bit is set.

Note: It is recommended that direct CPU device accesses be used only to execute code from device space and that CPU device accesses to slow external devices use decoupled CPU device transactions.

Notes

Device Decoupled Access Control and Status Register

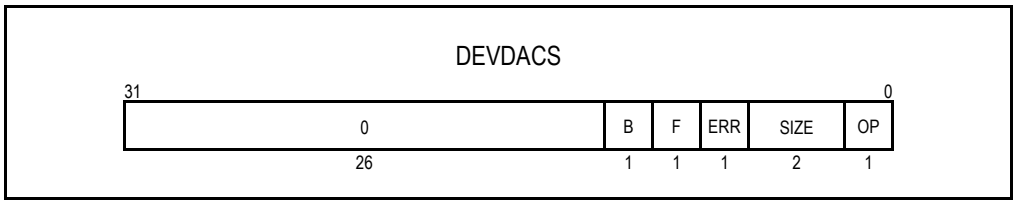


Figure 6.16 Device Decoupled Access Control and Status Register (DEVDACS)

OP

Description: **Operation.** This field encodes the decoupled access operation.
0 - write
1 - read

SIZE

Description: **Size.** This field encodes the size of the decoupled access operation.
0 - byte
1 - halfword
2 - triple byte
3 - word

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

ERR

Description: **Error.** This bit is set if an error occurred while executing a decoupled access operation. The ERR bit is set under the following conditions:
- Decoupled access to an address that does not map to a device
- Multi-byte decoupled access that crosses a word boundary
- Memory and peripheral bus transaction time-out during a decoupled access

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

F

Description: **Finished**. This bit is set when a decoupled access operation completes.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

B

Description: **Busy**. This bit is set when a decoupled access operation is in progress.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Notes

Device Decoupled Access Address Register

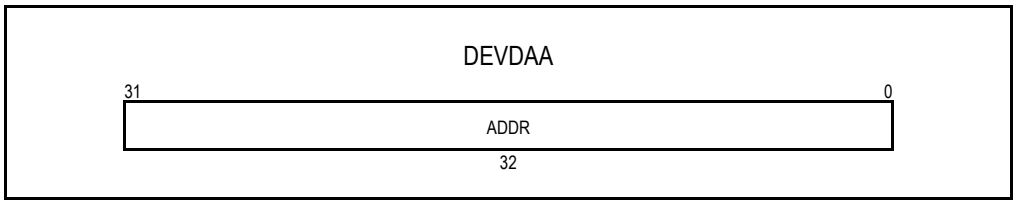


Figure 6.17 Device Decoupled Access Address Register (DEVDAA)

ADDR

Description: **Address Field.** Writing to this register initiates a decoupled access operation to the address written to this field. The type of operation is defined by the OP field in the DEVDACS register.

Initial Value: 0x0

Read Value: 0x0

Write Effect: Initiate a decoupled access operation.

Device Decoupled Access Data Register

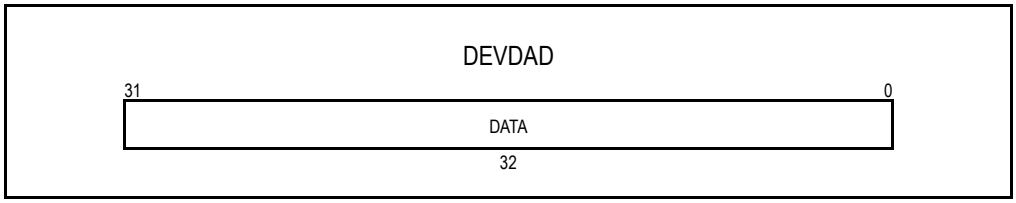


Figure 6.18 Device Decoupled Access Data Register (DEVDAD)

DATA

Description: **Data Field.** This register contains the return value of the previous decoupled access operation or the value to be written to the device. Data quantities in this field are always right aligned. Therefore, word operations use all four byte lanes. Triple-byte operations always use the right three bytes leaving DATA[31:24] undefined. Word operations always use the right two bytes leaving DATA[31:16] undefined. Finally, byte operations always use the right most byte leaving DATA[31:8] undefined.

Initial Value: 0x0

Read Value: Return value of previous decoupled access operation (value read from device for read operations, or value written to device for write operations)

Write Effect: Modify value

DDR Controller

Notes

Introduction

This chapter describes the features, functions, and operations of the Double Data Rate (DDR) controller. A complete description of the DDR registers is also included.

Features

- *Supports up to 2GB of DDR SDRAM (using data bus multiplexing and two chip selects)*
- *2 chip selects (each chip select supports 4 internal DDR banks)*
- *Supports 16-bit or 32-bit data bus width using 8, 16, or 32-bit devices*
- *Supports 64 Mb, 128 Mb, 256 Mb, 512 Mb, and 1Gb DDR SDRAM devices*
- *Data bus multiplexing support allows interfacing to standard DDR DIMMs and SODIMMs*
- *Automatic refresh generation*
- *Provides clock signals required for control of external memory devices*

Additional Resources

IDT has developed an application note that focuses on designing an interface between the RC32438 and DDR memory and provides some layout considerations. This document — AN-371, Interfacing the RC32438 with DDR SDRAM Memory — can be found on the company's web site at www.idt.com.

DDR Controller Register Description

Register Offset[1]	Register Name	Register Function	Size
0x01_8000	DDR0BASE	DDR 0 base	32-bit
0x01_8004	DDR0MASK	DDR 0 mask	32-bit
0x01_8008	DDR1BASE	DDR 1 base	32-bit
0x01_800C	DDR1MASK	DDR 1 mask	32-bit
0x01_8010	DDRC	DDR control	32-bit
0x01_8014	DDR0ABASE	DDR 0 alternate base	32-bit
0x01_8018	DDR0AMASK	DDR 0 alternate mask	32-bit
0x01_801C	DDR0AMAP	DDR 0 alternate mapping	32-bit
0x01_8020	DDRCUST	DDR Custom transaction	32-bit
0x01_8024	DDRRDC	DDR Read Data Capture	32-bit
0x01_8028 through 0x01_FFFF	Reserved		

Table 7.1 DDR Controller Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Theory of Operation

The DDR controller provides a glueless interface to industry standard Double Data Rate (DDR) Synchronous Dynamic Random Access Memories (SDRAMs). The DDR controller may be configured to support a 32-bit or 16-bit data path. When a 16-bit data path is selected, the DDR controller performs byte

Notes

gathering and scattering. The DDR controller provides two chip selects (DDRCSN[1:0]) with each chip select supporting four internal DDR banks. The DDR configuration for both chip selects must be the same. The supported DDR organizations are shown in Table 7.2.

DDR Size and Type	DDR Organization	Total Memory per Chip Select in 16-bit Mode[1]	Total Memory per Chip Select in 32-bit Mode[2]
64Mb Components	2M x 8 x 4 banks	16MB	32MB
	1M x 16 x 4 banks	8MB	16MB
	512K x 32 x 4 banks	Not Applicable	8MB
128Mb Components	4M x 8 x 4 banks	32MB	64MB
	2M x 16 x 4 banks	16MB	32MB
	1M x 32 x 4 banks	Not Applicable	16MB
256Mb Components	8M x 8 x 4 banks	64MB	128MB
	4M x 16 x 4 banks	32MB	64MB
	2M x 32 x 4 banks	Not Applicable	32MB
512Mb Components	16M x 8 x 4 banks	128MB	256MB
	8M x 16 x 4 banks	64MB	128MB
	4M x 32 x 4 banks	Not Applicable	64MB
1024Mb Components	32M x 8 x 4 banks	256MB	512MB
	16M x 16 x 4 banks	128MB	256MB
	8M x 32 x 4 banks	Not Applicable	128MB

Table 7.2 Supported DDR Configurations

1. Four times the memory is available with data bus multiplexing.

2. Twice the memory is available with data bus multiplexing.

The RC32438 has a dedicated DDR bus that is managed by the DDR controller. The DDR bus consist of the following pins:

DDRCKP[1:0] and DDRCKN[1:0] (two sets of differential clock outputs)

DDRCKE (DDR clock enable)

DDRCSN[1:0] (DDR chip selects)

DDRRASN (DDR row address strobe)

DDRCASN (DDR column address strobe)

DDRWEN (DDR write enable)

DDRDM[7:0] (DDR byte write mask)

DDRBA[1:0] (DDR bank address)

DDRADDR[13:0] (multiplexed DDR address bus)]

DDRDATA[31:0] (DDR data bus)

DDRDQS[3:0] (DDR byte data strobes)

DDROEN[3:0] (bus switch enables used when data bus multiplexing is enabled)

DDRVREF (SSTL_2 DDR voltage reference generated by an external source)

Notes

Two sets of differential DDR clocks (DDRCKP[1:0] and DDRCKN[1:0]) are provided to ease loading constraints and board design. Both clocks have the same frequency, which is equal to the IPBus clock (ICLK), and phase relationship. All DDR transactions are synchronous to these clocks. Thus, all of the timing parameters in the DDR Control (DDRC) register are in terms of DDR clock cycles.

The DDR controller contains a single control register (DDRC) since DDRs connected to both chip selects must share a common configuration. The DDR controller supports only sequential burst lengths of two. This burst length refers to the burst length value programmed in the DDR's MODE register. By pipelining addresses issued to the DDR, the RC32438 can support burst read and write transactions of any length. The Data Bus Width (DBW) field in this register selects the width of the DDR controller data bus (either 16-bits or 32-bits).

During DDR transactions, the address bus is multiplexed as shown in Table 7.3 for 32-bit data width mode and in Table 7.4 for 16-bit data width mode. The exact address multiplexing is dependent on the DDR device type selected in the device type (DTYPE) field of the DDRC register. Selecting a DTYPE results in the same multiplexing as that for 64Mb devices organized as 2M x 8 x 4 banks. Address and bank select signals connect directly to the corresponding DDR pins in both 16-bit and 32-bit data path modes (i.e., no address shifting is required for x16 and x32 DDR organizations).

Each chip select supports four page comparators. Although each page comparator is 14 bits in size, not all bits are used in all DDR configurations. When the CPU performs a read or write operation to DDR space, the page comparator associated with the selected DDR bank is checked. If the bank was left active and the value in the comparator matches the DDR row address, then the access can be made without first closing the currently active page and opening a different page. Otherwise, if the active page in the comparator does not match the DDR row address, then the active page must first be closed (i.e., precharged) and the correct page opened (i.e., made active) before the access may be performed. Finally, if no page is active in the bank, the required page must first be opened (i.e., made active) before the access may be performed.

The DDR controller normally operates with a DDR data strobe per byte lane (i.e., DDRDQS[1:0] in 16-bit data bus width mode and DDRDQS[3:0] in 32-bit data bus width mode). Some DDR devices have a single data byte strobe for ALL byte lanes (e.g., x32 DDR devices in a TQFP package). When the Single Data Strobe (SDS) bit is set in the DDRC register, DDRDQS[0] is used for all byte lanes.

DDR Address Multiplexing Scheme

DDR Organization	Cycle	DDR Bank		DDR Address													
		1	0	13	12	11	10	9	8	7	6	5	4	3	2	1	0
64Mb 2Mx8x4 banks (9-bit page)	Row	a24	a23	x[1]	x	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a24	a23	x	x	x	AP[2]	x	a10	a9	a8	a7	a6	a5	a4	a3	a2
64Mb 1Mx16x4 banks (8-bit page)	Row	a23	a22	x	x	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a23	a22	x	x	x	AP	x	x	a9	a8	a7	a6	a5	a4	a3	a2
64Mb 512Kx32x4banks (8-bit page)	Row	a22	a21	x	x	x	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a22	a21	x	x	x	x	x	AP	a9	a8	a7	a6	a5	a4	a3	a2
128Mb 4Mx8x4 banks (10-bit page)	Row	a25	a24	x	x	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a25	a24	x	x	x	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
128Mb 2Mx16x4 banks (9-bit page)	Row	a24	a23	x	x	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a24	a23	x	x	x	AP	x	a10	a9	a8	a7	a6	a5	a4	a3	a2
128Mb 1Mx32x4 banks (8-bit page)	Row	a23	a22	x	x	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a23	a22	x	x	x	x	x	AP	a9	a8	a7	a6	a5	a4	a3	a2

Table 7.3 DDR Address Multiplexing in 32-bit Mode (Part 1 of 2)

Notes

DDR Organization	Cycle	DDR Bank		DDR Address													
		1	0	13	12	11	10	9	8	7	6	5	4	3	2	1	0
256Mb 8Mx8x4 banks (10-bit page)	Row	a26	a25	x	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a26	a25	x	x	x	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
256Mb 4Mx16x4 banks (9-bit page)	Row	a25	a24	x	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a25	a24	x	x	x	AP	x	a10	a9	a8	a7	a6	a5	a4	a3	a2
256Mb 2Mx32x4 banks (8-bit page)	Row	a24	a23	x	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a24	a23	x	x	x	x	x	AP	a9	a8	a7	a6	a5	a4	a3	a2
512Mb 16Mx8x4 banks (11-bit page)	Row	a27	a26	x	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13
	Column	a27	a26	x	x	a12	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
512Mb 8Mx16x4 banks (10-bit page)	Row	a26	a25	x	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a26	a25	x	x	x	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
512Mb 4Mx32x4 banks (9-bit page)	Row	a25	a24	x	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a25	a24	x	x	x	x	a10	AP	a9	a8	a7	a6	a5	a4	a3	a2
1024Mb 32Mx8x4 banks (11-bit page)	Row	a28	a27	a26	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13
	Column	a28	a27	x	x	a12	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
1024Mb16Mx16x4 banks (10-bit page)	Row	a27	a26	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a27	a26	x	x	x	AP	a11	a10	a9	a8	a7	a6	a5	a4	a3	a2
1024Mb 8Mx32x4 banks (9-bit page)	Row	a26	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a26	a25	x	x	x	x	a10	AP	a9	a8	a7	a6	a5	a4	a3	a2

Table 7.3 DDR Address Multiplexing in 32-bit Mode (Part 2 of 2)

1. Don't care.
2. Auto Precharge.

DDR Organization	Cycle	DDR Bank		DDR Address													
		1	0	13	12	11	10	9	8	7	6	5	4	3	2	1	0
64Mb 2Mx8x4 banks (9-bit page)	Row	a23	a22	x[1]	x	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a23	a22	x	x	x	AP[2]	x	a9	a8	a7	a6	a5	a4	a3	a2	a1
64Mb 1Mx16x4 banks (8-bit page)	Row	a22	a21	x	x	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10	a9
	Column	a22	a21	x	x	x	AP	x	x	a8	a7	a6	a5	a4	a3	a2	a1
128Mb 4Mx8x4 banks (10-bit page)	Row	a24	a23	x	x	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a24	a23	x	x	x	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1
128Mb 2Mx16x4 banks (9-bit page)	Row	a23	a22	x	x	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a23	a22	x	x	x	AP	x	a9	a8	a7	a6	a5	a4	a3	a2	a1
256Mb 8Mx8x4 banks (10-bit page)	Row	a25	a24	x	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a25	a24	x	x	x	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1
256Mb 4Mx16x4 banks (9-bit page)	Row	a24	a23	x	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11	a10
	Column	a24	a23	x	x	x	AP	x	a9	a8	a7	a6	a5	a4	a3	a2	a1

Table 7.4 DDR Address Multiplexing in 16-bit Mode (Part 1 of 2)

Notes

DDR Organization	Cycle	DDR Bank		DDR Address													
		1	0	13	12	11	10	9	8	7	6	5	4	3	2	1	0
512Mb 16Mx8x4 banks (11-bit page)	Row	a26	a25	x	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a26	a25	x	x	a11	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1
512Mb 8Mx16x4 banks (10-bit page)	Row	a25	a24	x	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a25	a24	x	x	x	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1
1024Mb 32Mx8x4 banks (11-bit page)	Row	a27	a26	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12
	Column	a27	a26	x	x	a11	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1
1024Mb 16Mx16x4 banks (10-bit page)	Row	a26	a25	a24	a23	a22	a21	a20	a19	a18	a17	a16	a15	a14	a13	a12	a11
	Column	a26	a25	x	x	x	AP	a10	a9	a8	a7	a6	a5	a4	a3	a2	a1

Table 7.4 DDR Address Multiplexing in 16-bit Mode (Part 2 of 2)

1. Don't care.
2. Auto Precharge.

DDR Command Encoding

Command	Description	DDRRASN	DDRCASN	DDRWEN
NOP	No operation	H	H	H
ACTIVE	Select active bank and row	L	H	H
READ	Select bank and column, perform read	H	L	H
WRITE	Select bank and column, perform write	H	L	L
AUTO-REFRESH	Enter auto-refresh mode	L	L	H
PRECHARGE	Deactivate row in bank or banks	L	H	L

Table 7.5 DDR Command Encoding

DDR Registers

DDR Control Register

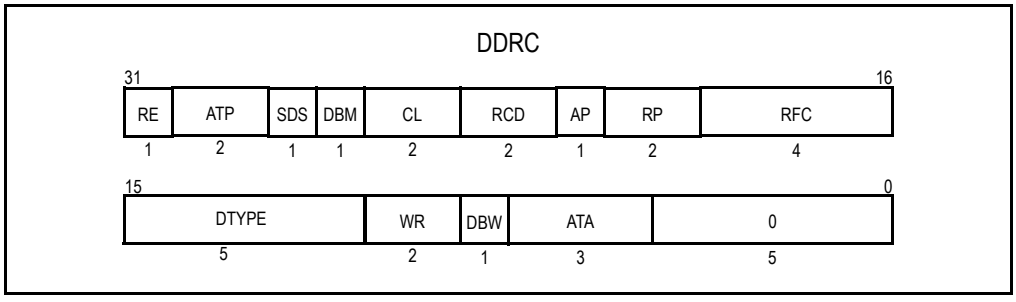


Figure 7.1 DDR Control Register (DDRC)

Notes

ATA

Description: **Active to Active/Auto Refresh.** This field specifies the minimum number of DDR clock cycles between an Active and a subsequent Active or Auto Refresh command.
0 5 clock cycles
1 6 clock cycles
2 7 clock cycles
3 8 clock cycles
4 9 clock cycles
5 10 clock cycles
6 11 clock cycles
7 12 clock cycles

Initial Value: 0x3 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DBW

Description: **Data Bus Width.** This field specifies the width of the DDR control data bus.
0 16-bit data bus width
1 32-bit data bus width

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

WR

Description: Write Recovery. This field specifies the minimum number of DDR clock cycles from the completion of a WRITE operation to a PRECHARGE command.
0 3 clock cycles
1 4 clock cycles
2 5 clock cycles
3 6 clock cycles

Initial Value: 0x3 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Notes

DTYPE

Description: **DDR Device Type**. This field selects the DDR device type.

0 64Mb, 512K x 32 x 4
1 64Mb, 1M x 16 x 4
2 64Mb, 2M x 8 x 4
3 reserved
4 128Mb, 1M x 32 x 4
5 128Mb, 2M x 16 x 4
6 128Mb, 4M x 8 x 4
7 reserved
8 256Mb, 2M x 32 x 4
9 256Mb, 4M x 16 x 4
10 256Mb, 8M x 8 x 4
11 reserved
12 reserved
13 512Mb, 4M x 32 x 4
14 512Mb, 8M x 16 x 4
15 512Mb, 16M x 8 x 4
16 reserved
17 1Gb, 8M x 32 x 4
18 1Gb, 16M x 16 x 4
19 1Gb, 32M x 8 x 4
20 reserved
.
.
.
31 reserved

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

RFC

Description: **Refresh Clock Cycles.** This field specifies the AUTO Refresh command period in DDR clock cycles. Permissible values are zero through 15. A value of zero has the same effect as programming this field to one.

Initial Value: 0xF **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

RP

Description: **Precharge Delay.** This field specifies the number of DDR clock cycles between a PRECHARGE command and a subsequent row access.

0 1 clock cycle
1 2 clock cycles
2 3 clock cycles
3 4 clock cycles

Initial Value: 0x3 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Notes

AP

Description: **Auto Precharge Enable.** This field controls the value driven on Auto Precharge (shown as "AP" in Tables 7.3 and 7.4) bit during DDR transactions. If auto precharge is enabled, the row being accessed is precharged at the completion of a read or write transaction.
0 Auto precharge disabled (AP=0).
1 Auto precharge enabled (AP=1).

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

RCD

Description: **Active to Read or Write Delay.** This field specifies the minimum number of DDR clock cycles between the issuing of a DDR ACTIVE command and a READ or WRITE command.
0 1 clock cycle
1 2 clock cycles
2 3 clock cycles
3 4 clock cycles

Initial Value: 0x2 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

CL

Description: **CAS Latency.** This field contains the CAS latency value in DDR clock cycles.
0 2 clock cycles
1 2.5 clock cycles
2 3 clock cycles
3 4 clock cycles

Initial Value: 0x2 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DBM

Description: **Data Bus Multiplexing.** When this bit is set, data bus multiplexing is enabled. For more information, refer to the DDR Data Bus Multiplexing section in this chapter.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

SDS

Description: **Single Data Strobe.** The DDR controller normally operates with a DDR data strobe per byte lane (i.e., DDRDQS[1:0] in 16-bit data bus width mode and DDRDQS[3:0] in 32-bit data bus width mode). Some DDR devices have a single data byte strobe for ALL byte lanes. When this bit is set, DDRDQS[0] is used for all byte lanes.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Notes

ATP

Description: **Active To Precharge.** This field specifies the minimum number of DDR clock cycles from an ACTIVE command to READ or WRITE command with auto precharge (this field corresponds to the t_{RAS}(MIN) DDR timing parameter).
0 5 clock cycles
1 6 clock cycles
2 7 clock cycles
3 8 clock cycles

Initial Value: 0x3 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

RE

Description: **Refresh Enable.** When this bit is set and the DDR refresh timer expires, a DDR refresh transaction is queued. When this bit is cleared, a DDR refresh transaction is never generated regardless of the state of the refresh timer.

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Value: Modify value

DDR Read Data Capture Register

Figure 7.2 shows the PCLK[1] edges which can be configured for DDR read data capture. The edges shown correspond to the PCLK edges which will capture the first data word of the read transaction (i.e., DDRDATA[31:0] = D0). Subsequent data words are captured with subsequent PCLK positive edges. Note that the capturing edges are relative to the CAS latency (CL) programmed in the DDRC register. Figure 7.2 shows the capturing edges when CL = 2. As a rule, the first capture edge (CES=0) is always the positive PCLK edge corresponding to CL + 1/2 DDRCKP edges from the time the first read command is issued (DDRCMD = READ).[2]

1. PCLK is the internal clock used by the DDR Controller.

2. DDRCMD represents the concatenation of DDRRASN, DDRCASN, and DDRWEN.

Notes

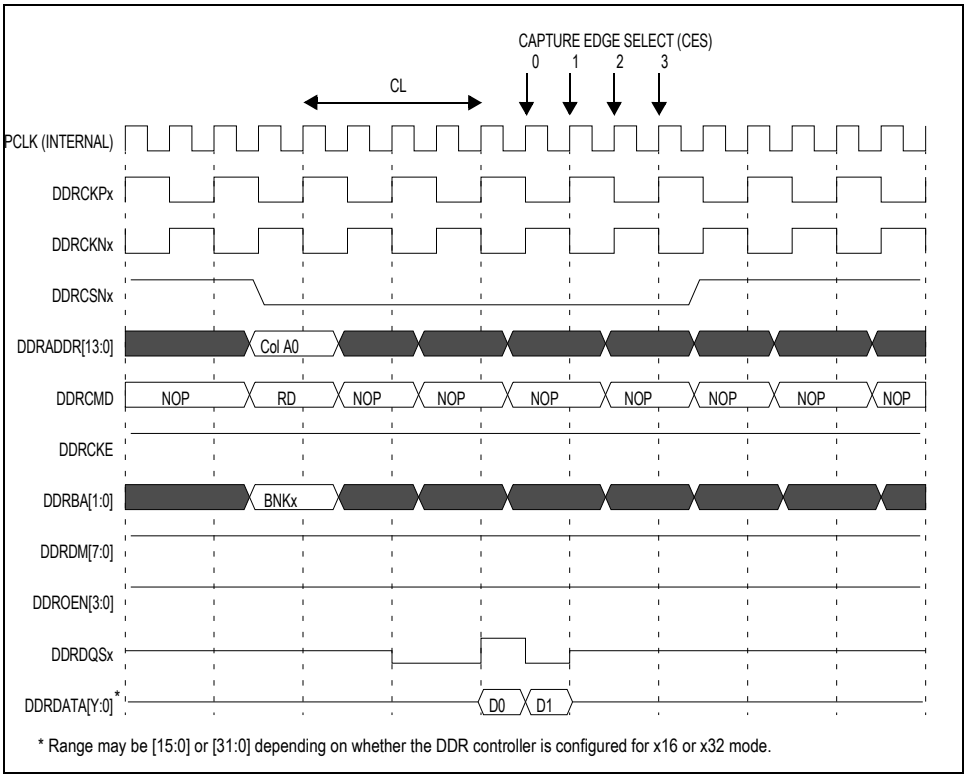


Figure 7.2 DDR Read Data Capture Edge Select Configurations

The selection of which PCLK edge is used to capture data depends on the read data access loop delay (i.e., DDRCKPx -> DDRDATA) of a system. This selection has to take into account the PCLK->DDRCKP delay, as well as DDRCKP and DDRDATA board delays. For systems with a short read data access loop delay, CES may be configured to 0 or 1. For systems with a long read data access loop delay, CES may be configured to 2 or 3. The user must do a careful analysis of the board delays when programming CES.

When the ACE bit is set (recommended), the DDR Controller automatically determines which PCLK edge should be used to capture the read data (i.e., the CES field is ignored). In this mode the user must only ensure that the read data access loop delay does not exceed one DDRCKP cycles.

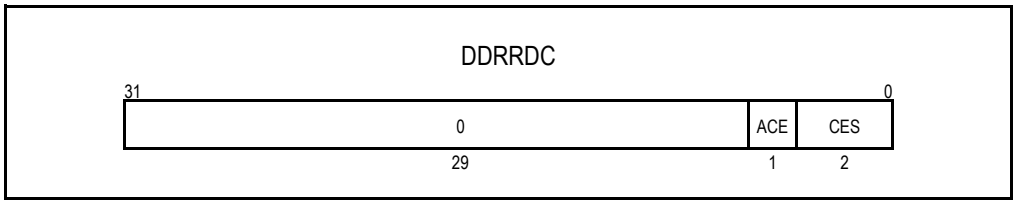


Figure 7.3 DDR Read Data Capture Register (DDRRDC)

CES

Description: **Capture Edge Select.** This bit controls the PCLK edge used to capture data during a DDR read transaction when the Auto Capture Enable (ACE) bit is cleared.

0 - Capture data on early positive edge of PCLK that corresponds to the negative edge of DDRCKP[1:0]

1 - Capture data on early positive edge of PCLK that corresponds to the positive edge of DDRCKP[1:0]

2 - Capture data on late positive edge of PCLK that corresponds to the negative edge of DDRCKP[1:0]

3 - Capture data on late positive edge of PCLK that corresponds to the positive edge of DDRCKP[1:0]

Notes

Initial Value: 0x0 ***(this field is not modified due to a warm reset)***

Read Value: Previous value written

Write Value: Modify value

ACE

Description: **Auto Capture Enable.** When this bit is set the DDR controller automatically determines the PCLK edge used to capture data during a DDR read transaction.

Initial Value: 0x1 ***(this field is not modified due to a warm reset)***

Read Value: Previous value written

Write Value: Modify value

DDR Address Mapping

The DDR banks can be located anywhere in the RC32438's local address space. The address of the DDR banks corresponding to each DDR chip select can be allocated independently.

Address decoding for each DDR chip select is controlled by the DDR base (DDR[1|0]BASE) and DDR mask (DDR[1|0]MASK) registers. The DDR mask register is used to select which bits are used for address decoding. When a bit in this register is a one, the corresponding address bit is active in address comparisons. If a bit in this register is a zero, then the corresponding address bit does not participate in address comparisons. The base address register specifies the base physical address for each DDR chip select. All of the active address bits not masked by the DDR mask register are compared to the value in the DDR base register. If they all match, then the corresponding DDR chip select is asserted.

To facilitate PCI booting from a DDR-only memory system, an alternate address mapping range is supported for DDR chip select zero (see Figure 7.4). The alternate address range is configured using the DDR alternate base (DDR0ABASE) and DDR alternate mask (DDR0AMASK) registers. The DDR alternate mapping (DDR0AMAP) register specifies the value of DDR address bits that are mapped by the DDR mask register. This allows the DDR address to be offset from the RC32438's local address.

The normal and alternate base and mask registers for DDR chip select zero allow two RC32438 local address ranges to be mapped to the same DDR chip select. Care should be exercised when using this feature to ensure data cache coherence.

Notes

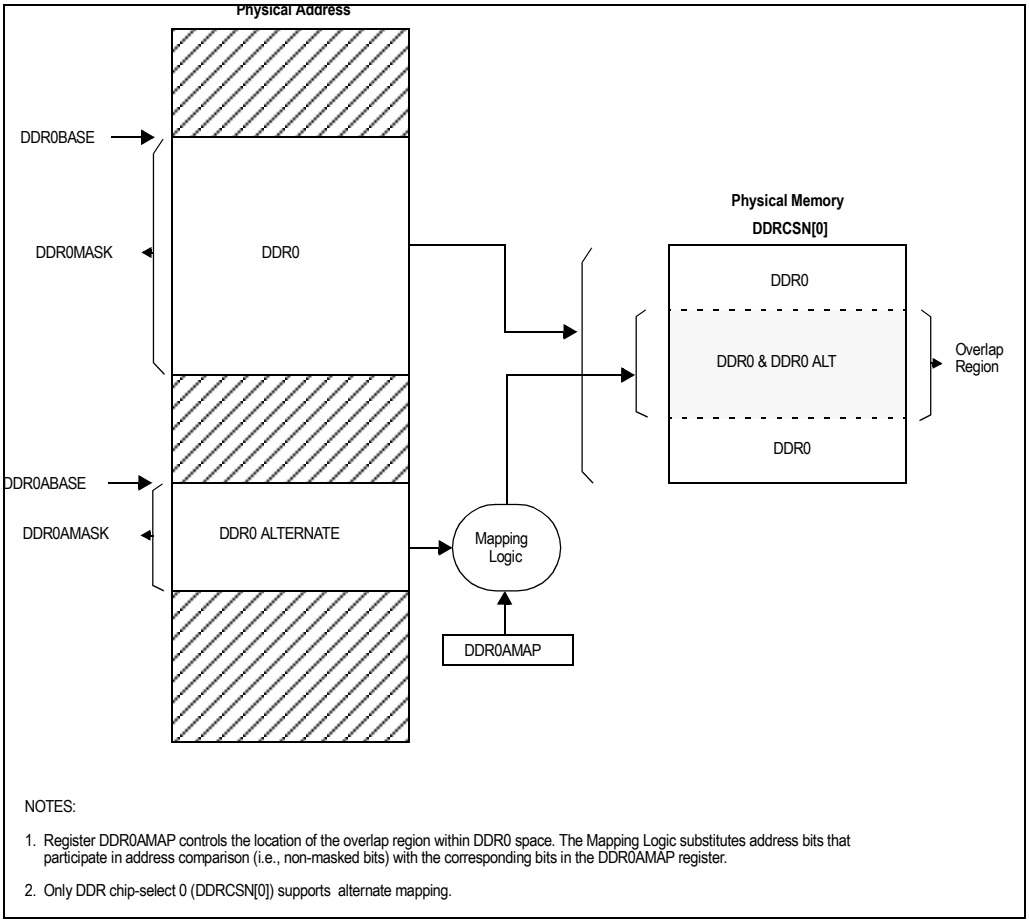


Figure 7.4 DDR0 Alternate Address Mapping

DDR [0|1] Base Register

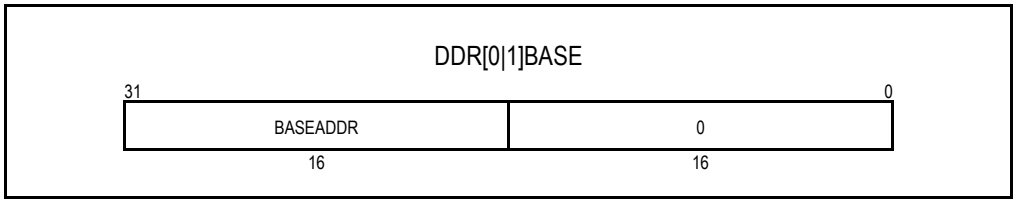


Figure 7.5 DDR [0|1] Base Register (DDR[0|1]BASE)

BASEADDR

Description: **Base Address.** This 16-bit field specifies the upper 16 bits of the DDR base address.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Notes

DDR [0|1] Mask Register

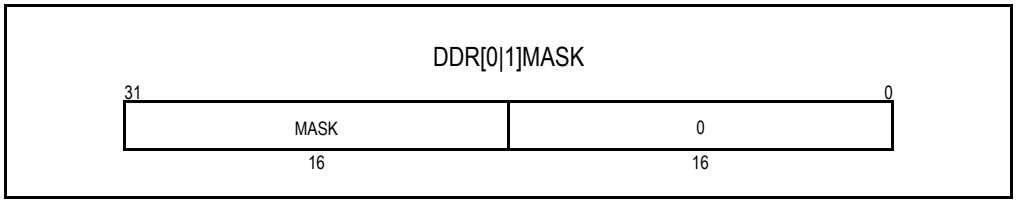


Figure 7.6 DDR [0|1] Mask Register (DDR[0|1]MASK)

MASK

Description: **Address Mask.** This field determines which bits of the upper 16-bits of the address participate in address comparisons. When a bit is set in this field, then the corresponding address bit participates in address comparisons. When a bit is cleared in this field, then the corresponding address bit is masked and does not participate in address comparisons.
When the MASK field is zero, the DDR space is disabled and does not appear in the memory map.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DDR 0 Alternate Base Register

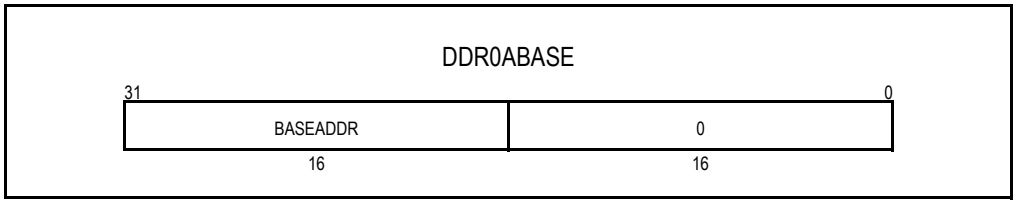


Figure 7.7 DDR 0 Alternate Base Register (DDR0ABASE)

BASEADDR

Description: **Base Address.** This 16-bit field specifies the upper 16 bits of the alternate DDR 0 base address.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Notes

DDR 0 Alternate Mask Register

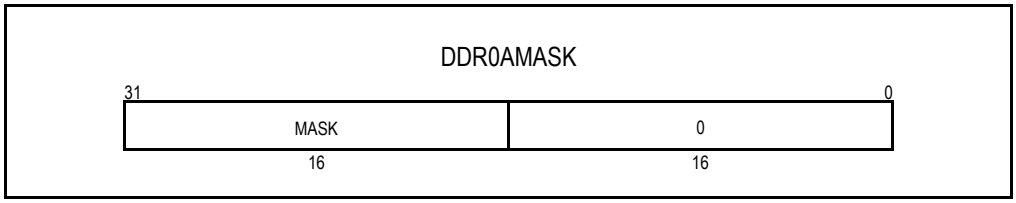


Figure 7.8 DDR 0 Alternate Mask Register (DDR0AMASK)

MASK

Description: **Address Mask.** This field determines which bits of the upper 16-bits of the address participate in address comparisons. When a bit is set in this field, then the corresponding address bit participates in address comparisons. When a bit is cleared in this field, then the corresponding address bit is masked and does not participate in address comparisons.
When the MASK field is zero, the alternate DDR space is disabled and does not appear in the memory map.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DDR 0 Alternate Mapping Register

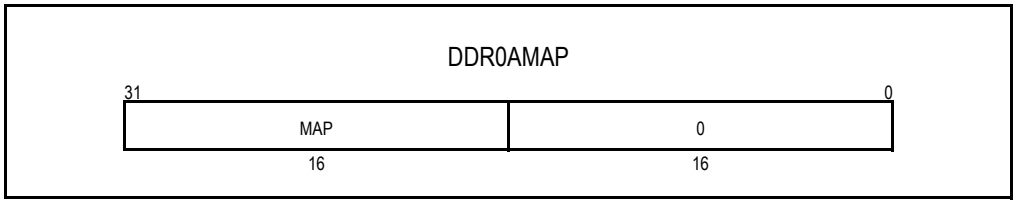


Figure 7.9 DDR 0 Alternate Mapping Register (DDR0AMAP)

MAP

Description: **Map Address.** This field contains the DDR mapping address for transactions mapped to DDR chip select zero using the alternate address mapping range. Address bits that participated in address comparison are substituted with values in this field.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DDR Data Bus Multiplexing

The DDR controller supports data bus multiplexing when the Data Bus Multiplexing (DBM) bit is set in the DDRC register. Data bus multiplexing allows the RC32438's 16-bit or 32-bit data bus[1] to interface to DDR memory systems having a data bus width of 64-bits. This is necessary when interfacing the RC32438 to standard DDR memory modules such as DDR DIMMs and SODIMMs.

To support data bus multiplexing, external bus switches must be placed between the RC32438 and external DDR memory banks. These bus switches are used to isolate unused data bits and strobes from the RC32438 allowing 16-bit or 32-bit data quantities to be read from a 64-bit bus. The RC32438 DDROEN[3:0] pins are output enabled for these buffers.

1. Mode is determined by the state of the Data Bus Width (DBW) bit in the DDRC register.

Notes

When data bus multiplexing is enabled, the address range allocated to a DDR chip select should be expanded to twice the space allocated in a 32-bit mode system or four times the space allocated in a 16-bit mode system by programming the corresponding base and mask registers. The 32-bit Mode section in Figure 7.10 illustrates this address range expansion for a 32-bit mode system using 32M x 8 x 4 bank (i.e., 1Gb) DDRs. Eight of these DDRs create a 64-bit data bus that interfaces to the RC32438's 32-bit DDR data bus through external bus switches as shown in Figure 7.11. The total space allocated for the DDR chip select is 1GB. When an access is made to the lower 512 MB, the DDROEN[1:0] signals are asserted. During writes to this region, the DDRDM[3:0] signals are used to select enabled byte lanes. When an access is made to the upper 512 MB, the DDROEN[3:2] signals are asserted and DDRDM[7:4] are used to select enabled byte lanes during writes.

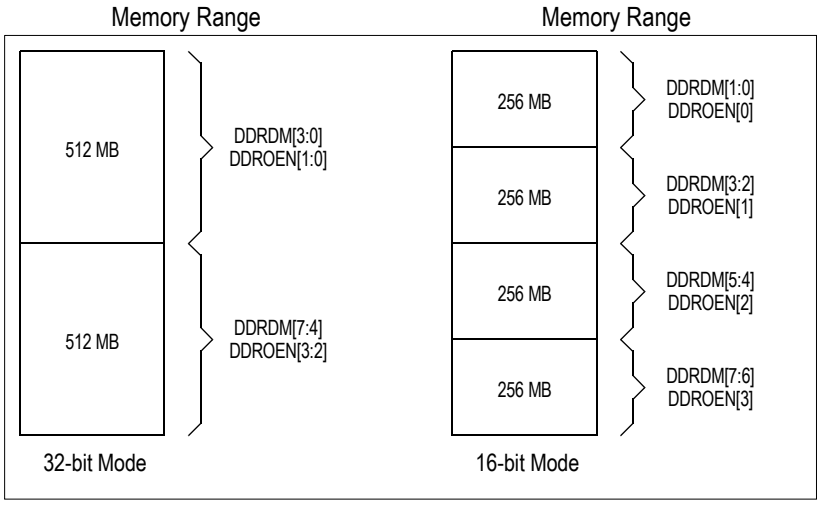


Figure 7.10 DDR Data Bus Multiplexing Address Range Expansion

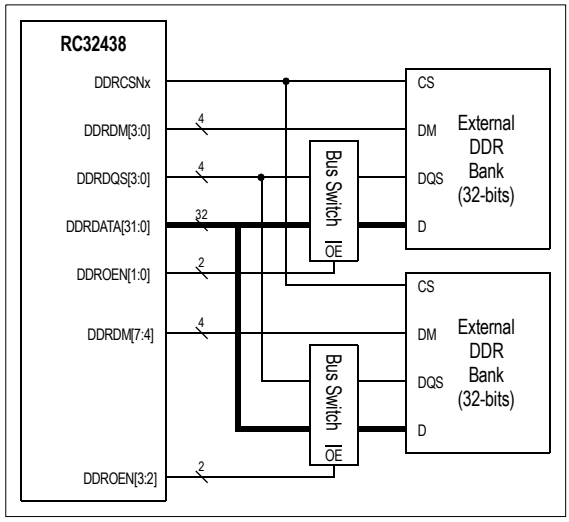


Figure 7.11 32-bit Bank DDR Data Bus Multiplexing

Operation in 16-bit mode parallels that in 32-bit mode. Using the same DDR devices as in the above example, a 16-bit mode system with data bus multiplexing has 4 regions per chip select as shown in the 16-bit mode section of Figure 7.10. Eight of these DDRs create a 64-bit data bus that interfaces to the RC32438's 16-bit DDR data bus through external bus switches as shown in Figure 7.12. When an access is made to the lower 256 MB, DDROEN[0] is asserted and DDRDM[1:0] are used to select byte lanes during writes. When an access is made to the next 256 MB, DDROEN[1] is asserted and DDRDM[3:2] are used to select byte lanes during writes. The pattern continues for the upper two memory regions.

Notes

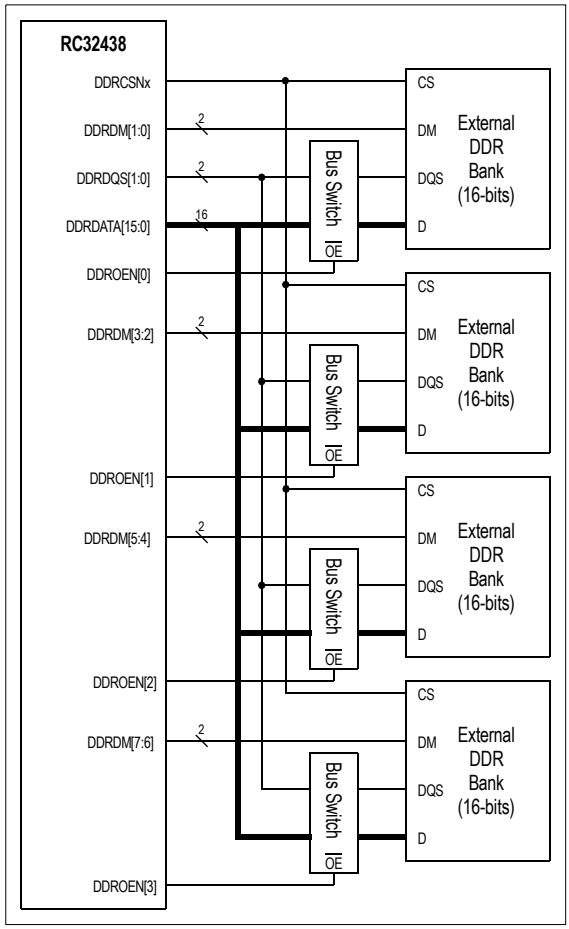


Figure 7.12 16-bit Bank DDR Data Bus Multiplexing

DDR Initialization

DDR SDRAMs must be powered up and initialized in a predefined manner before they may be used. See the DDR data sheet for power sequencing and timing initialization requirements. During a cold reset, the RC32438 maintains DDRCKE at an LVCMOS low level to ensure that the DQ and DQS outputs of any connected DDRs are tri-stated. CKE will remain at a LVCMOS low level until the first DDR custom transaction is performed at which point CKE will take on the appropriate SSTL_2 low or high value or until the first normal DDR transaction at which point CKE will take on an SSTL_2 high value. Note CKE will take on a SSTL_2 high value whenever a non-custom DDR transaction is executed.

Each DDR contains two mode registers that define the specific mode of operation for the DDR. The first mode register selects: the burst length, the burst type, CAS latency, and operating mode. The second, or extended, mode register is used to reset the DLL within the DDR and to configure its operating parameters. Both mode registers are programmed using a DDR LOAD MODE REGISTER command.

> **Note:** Care should be taken when programming these registers. If not properly programmed, the DDR SDRAM chips may inhibit the assertion of the DDRDQS signal, causing the RC32438 device to lock-up.

In order to support compatibility with a wide range of devices, the DDR controller does not directly support DDR LOAD MODE REGISTER commands. Instead, this command must be synthesized using a DDR custom transaction. To initiate a DDR custom transaction, one or both chip selects in the CS field of the DDRCUST register are selected. The desired DDR command is then programmed by setting the BA, CKE, CAS, RAS, WE, and CS fields to the desired state in the DDRCUST register. On the next decoded DDR memory cycle, a transaction will be issued to the DDR with the command programmed in the

Notes

DDRCUST register. The chip select signals selected in the CS field are asserted for one clock cycle but the state of the other control signals — DDRRASN, DDRCASN, DDRCKEN, and DDRWEN — reflect the state programmed in the DDRCUST register until a new transaction is issued by the DDR controller. The DDR address DDR bus (i.e., DDRADDR[13:0]) is driven with the CPU address bits (i.e., A[15:2]) that generated the DDR custom transaction. Using this mechanism, most DDR commands, including LOAD MODE REGISTER, may be synthesized by the CPU. Note that during a DDR custom transaction, no data is read from or written to the DDR (i.e., the DDR data bus remains tri-stated). After the DDR custom transaction completes, the value of the CS field in the DDRCUST register is automatically reset to zero.

DDR Custom Transaction Register

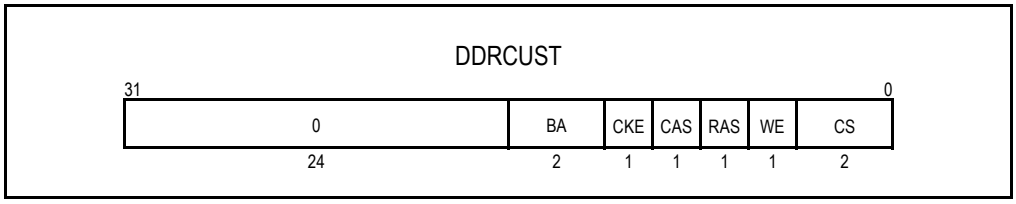


Figure 7.13 DDR Custom Transaction Register (DDRCUST)

CS

Description: **DDR Chip Select.** This field is used to enable a DDR custom transaction and specifies which chip select(s) should be asserted during the transaction. After the DDR custom transaction completes, the value of this field is automatically reset to zero.

0 Neither DDRCSN[0] or DDRCSN[1] are asserted
1 DDRCSN[0] is asserted
2 DDRCSN[1] is asserted
3 DDRCSN[0] and DDRCSN[1] are both asserted

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written (or zero after a DDR custom transaction completes)

Write Effect: Modify value

WE

Description: **DDR Write Enable.** This field specifies the state of the DDRWEN signal during a DDR custom transaction.

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

RAS

Description: **DDR RAS Status.** This field specifies the state of the DDRRASN signal during a DDR custom transaction.

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

CAS

Description: **DDR CAS Status.** This field specifies the state of the DDRCASN signal during a DDR custom transaction.

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Notes

Read Value: Previous value written

Write Effect: Modify value

CKE

Description: **DDR Clock Enable.** This field specifies the state of the DDRCKE signal during a DDR custom transaction.

Initial Value: 0x1 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

BA

Description: **DDR Bank Address.** This field specifies the state of the DDRBA[1:0] signals during a DDR custom transaction.

Initial Value: 0x3 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

DDR Refresh Timer

The DDR controller contains a refresh timer which may be used to automatically issue DDR refresh transactions. The DDR refresh timer is a 16-bit timer which uses the IPBus clock (ICLK) as its time base. When enabled, the counter begins counting up from zero. The current value of the counter may be determined by reading the COUNT field in the RCOUNT register. When the value in this count field is equal to the COMPARE field of the RCOMPARE register, the refresh timer expires. This causes the TO bit in the RTC register to be set, an DDR refresh transaction to be queued if the RE bit in the DDRC register is set, and the counter to reset and begin counting up from zero.

When a refresh transaction is queued, the DDR controller waits for the DDR bus to become available (i.e., current transaction to complete). A refresh transaction is then issued with **both** DDR chip selects asserted. The DDR refresh timer may queue up to a maximum of eight refresh transactions. If the DDR refresh timer attempts to queue more than eight refresh transactions, the Refresh Queue Exceeded (RQE) bit is set in the RTC register and the refresh transaction is discarded.

When automatic generation of DDR refresh transactions is not required, the DDR refresh timer may be used as a general purpose timer. This is done by setting the RE bit in the DDRC register to zero which disables the queueing of DDR refresh transactions. The TO sticky bit in the RTC register is an input to the interrupt controller.

Refresh Timer Count Register

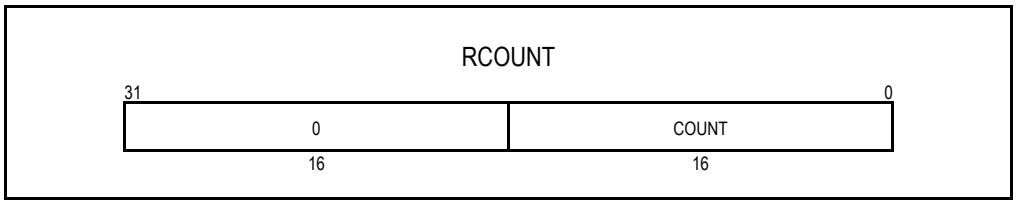


Figure 7.14 Refresh Timer Count Register (RCOUNT)

COUNT

Description: **Current Count.** This 16-bit field contains the current refresh timer count value.

Initial Value: 0x0000 **(this field is not modified due to a warm reset)**

Notes

Read Value: Current refresh timer count

Write Effect: Read-only

Refresh Timer Compare Register

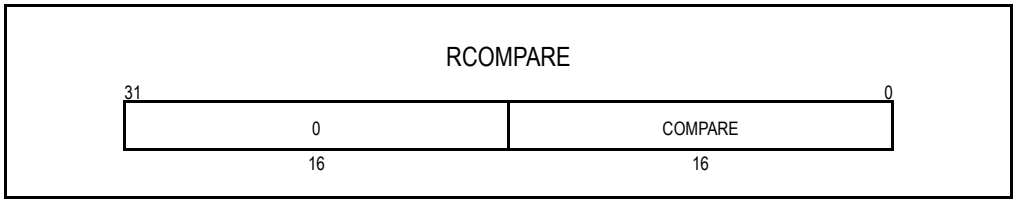


Figure 7.15 Refresh Timer Compare Register (RCOMPARE)

COMPARE

Description: **Compare Value.** This 16-bit field contains the maximum refresh timer count value. When the value in the RCOUNT register equals this value, the refresh timer expires. When the refresh timer is enabled, writing to this register causes the refresh timer to abort its current count and begin counting from zero.

Initial Value: 0xFFFF **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

Refresh Timer Control Register

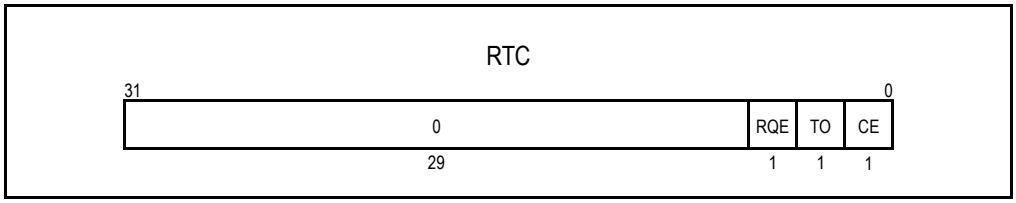


Figure 7.16 Refresh Timer Control Register (RTC)

CE

Description: **Counter Enable.** When this bit is set to a zero the refresh timer is disabled. Setting this bit to a one enables the refresh timer. When enabled the refresh timer begins counting up from zero.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Previous value written

Write Effect: Modify value

TO

Description: **Time-out.** This bit is set to a one to indicate that the refresh timer has expired. Once this bit is set it will remain set until a zero is written into this field by the CPU. This bit is not automatically cleared when the CE bit is cleared. If both the counter timer and the CPU attempt to update this field concurrently, the counter timer will take precedence.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Notes

RQE

Description: **Refresh Queue Exceeded.** This bit is set to a one to indicate that the refresh queue limit of eight refresh transactions has been exceeded and that a DDR refresh transaction has been discarded. This bit should never be set under normal operation.

Initial Value: 0x0 **(this field is not modified due to a warm reset)**

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

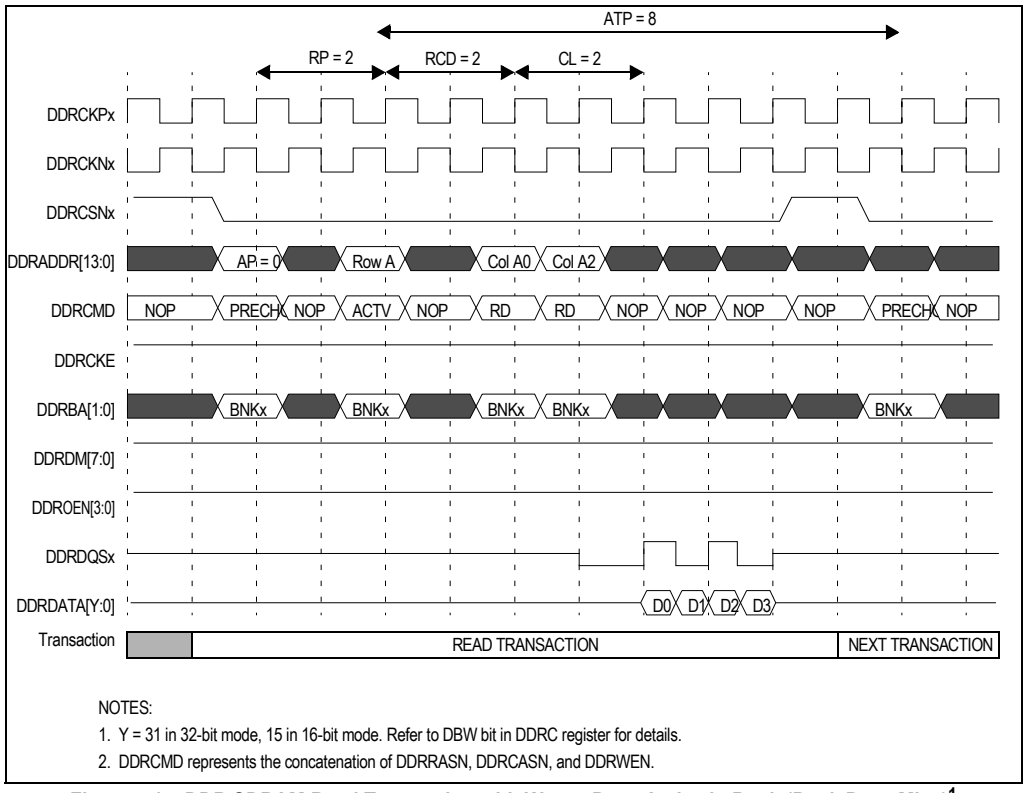
DDR Read Transaction

This section describes the DDR read transaction. All DDR read transactions consist of a burst read of an even number of 16-bit/32-bit data quantities.

The transaction involves four programmable parameters:

- *Active to Read or Write Delay (**RCD**). RCD may be programmed to be any value between 1 and 4 DDR clock cycles.*
- *CAS Latency (CL). CL may be programmed to values between 2 and 4 DDR clock cycles.*
- *Precharge Delay (**RP**). RP may be programmed to be any value between 1 and 4 DDR clock cycles.*
- *Active to Precharge (ATP). ATP may be programmed to be any value between 5 and 8 DDR clock cycles.*

When the auto precharge bit (AP) in the DDRC register is set, only the last read operation in the transaction has the auto precharge address bit (i.e., DDRADDR[10] or DDRADDR[8] depending on the DDR type and organization) address bit set. That is, only the last read operation performs an automatic precharge.



NOTES:
1. Y = 31 in 32-bit mode, 15 in 16-bit mode. Refer to DBW bit in DDRC register for details.
2. DDRCMD represents the concatenation of DDRRASN, DDRCASN, and DDRWEN.

Figure 7.17 DDR SDRAM Read Transaction with Wrong Page Active in Bank (Bank Page Miss)[1]

[1] The programmable parameters shown in Figure 7.17 are for illustrative purposes only and may vary.

Notes

A DDR SDRAM read transaction in which the wrong page is active in a bank is shown in Figure 7.17. If no pages had been active, then the transaction would have started with the ACTIVE command (i.e., step three below). If the correct page had been active (bank page hit), then the transaction would have started with the READ command (i.e., step five below). A DDR SDRAM read transaction in which the wrong page is active in a bank consists of the following steps.

1. The RC32438 asserts the appropriate DDR SDRAM chip select (DDRCSNx), drives the bank select pins (DDRBA[1:0]) with the value of the bank to be precharged, drives the AP address bit low (see Tables 7.3 and 7.4) to indicate that only that bank is to be precharged, and drives the PRECHARGE command (see Table 7.5) on the rising edge of DDRCKPx. This indicates the start of a transaction.
2. One clock cycle after step #1, the RC32438 drives the NOP command (see Table 7.5).
3. RP clock cycles after step #1, the RC32438 drives the bank select pins (DDRBA[1:0]) with the value of the bank to be accessed, drives the address bus (DDRADDR[13:0]) with the DDR SDRAM row address, and drives the ACTIVE command (see Table 7.5) on the rising edge of DDRCKPx. Note that step #2 is skipped if the value of RP = 1 (see DDRC Register).
4. One clock cycle after step #1, the RC32438 drives the NOP command (see Table 7.5).
5. RCD clock cycles after step #3, the RC32438 drives the address bus (DDRADDR[13:0]) with the DDR SDRAM column address, and drives the READ command (see Table 7.5). Note that step #4 is skipped if the value of RCD = 1 (see DDRC register).
6. One clock cycle after step #5, the RC32438 may drive the NOP or READ command depending on the amount of data to be read. Figure 7.17 shows a read of four words, and thus two read commands are issued (each read command returns a pair of data). During the last read command issued, the RC32438 may assert the auto-precharge (AP) bit of the address bus (see Tables 7.3 and 7.4) depending on the state of the AP field in the DDRC register.
7. One clock cycle after step #6, the RC32438 drives the NOP command.
8. CL clock cycles after step #5, the RC32438 opens its input buffers and accepts the read data from the data bus (DDRDATA[31:0]) as well as the DDR read data strobes (DDRDQS[3:0]). The input buffers remain open until the data and strobes corresponding to the last read command reach the RC32438.[1]
9. One clock cycle after the data and strobes for the last read command are accepted into the RC32438, the appropriate DDRCSNx is negated, the transaction is completed, and a new transaction may begin.

DDR Write Transaction

This section describes the DDR write transaction. All DDR write transactions consist of a burst write of an even number of 16-bit/32-bit data quantities. The DDR byte write masks (DDRDM[7:0]) are used to mask bytes which should not be modified.

The transaction involves four programmable parameters:

- *Active to Read or Write Delay (**RCD**). RCD may be programmed to be any value between 1 and 4 DDR clock cycles.*
- *Precharge Delay (**RP**). RP may be programmed to be any value between 1 and 4 DDR clock cycles.*
- *Write Recovery (**WR**). WR may be programmed to any value between 1 and 4 DDR clock cycles.*
- *Active to Precharge (**ATP**). ATP may be programmed to be any value between 5 and 8 DDR clock cycles.*

When the auto precharge bit (AP) in the DDRC register is set, only the last write operation in the transaction has the auto precharge address bit (i.e., DDRADDR[10] or DDRADDR[8] depending on the DDR type and organization) address bit set. That is, only the last write operation performs an automatic precharge.

1. The input buffers remain open for a maximum of (CL+ 2) DDRCKP cycles after the last read command is issued. This puts an upper time limit on the read data access loop (DDRCKPx -> DDRDATA) of a system.

Notes

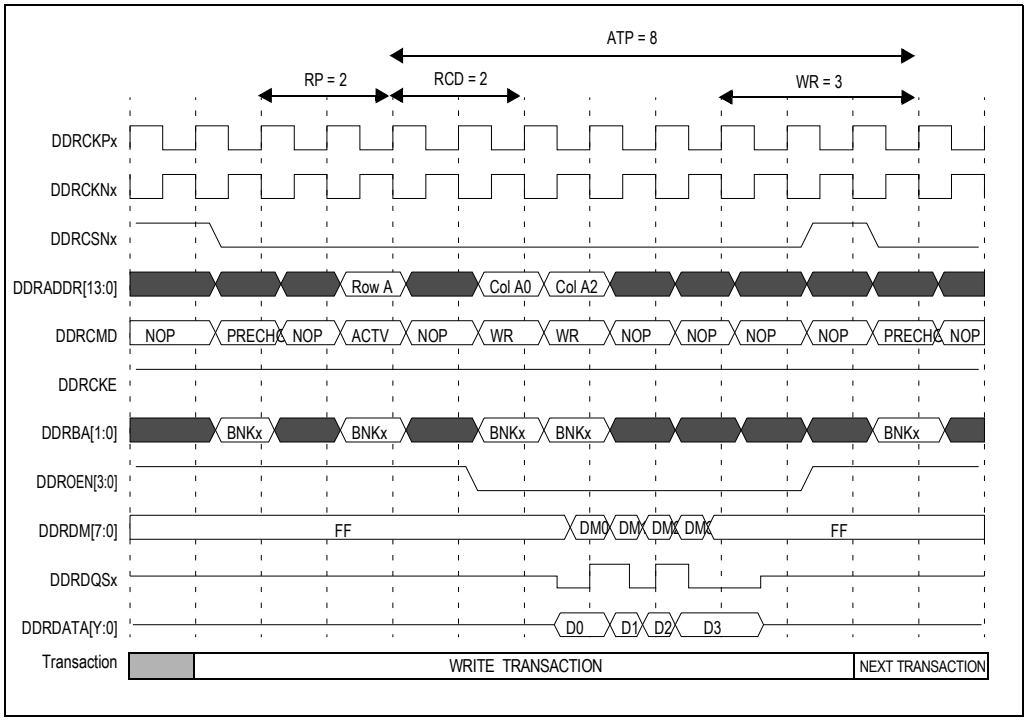


Figure 7.18 DDR SDRAM Write Transaction with Wrong Page Active in Bank (Bank Page Miss)[1]

A DDR SDRAM write transaction in which the wrong page is active in a bank is shown in Figure 7.18. If no pages had been active, then the transaction would have started with the ACTIVE command (i.e., step three below). If the correct page had been active (bank page hit), then the transaction would have started with the WRITE command (i.e., step five below). A DDR SDRAM write transaction in which the wrong page is active consists of the following steps.

1. The RC32438 asserts the appropriate DDR SDRAM chip select (DDRCSNx), drives the bank select pins (DDRBA[1:0]) with the value of the bank to be precharged, drives the AP address bit low (see Tables 7.3 and 7.4) to indicate that only that bank is to be precharged, and drives the PRECHARGE command (see Table 7.5) on the rising edge of DDRCKPx. This indicates the start of a transaction.
2. One clock cycle after step #1, the RC32438 drives the NOP command (see Table 7.5).
3. RP clock cycles after step #1, the RC32438 drives the bank select pins (DDRBA[1:0]) with the value of the bank to be accessed, drives the address bus (DDRADDR[13:0]) with the DDR SDRAM row address, and drives the ACTIVE command (see Table 7.5) on the rising edge of DDRCKPx. Note that step #2 is skipped if the value of RP = 1 (see DDRC Register).
4. One clock cycle after step one, the RC32438 drives the NOP command (see Table 7.5).
5. RCD clock cycles after step #3, the RC32438 drives the address bus (DDRADDR[13:0]) with the DDR SDRAM column address, and drives the WRITE command (see Table 7.5). At this time the RC32438 may also assert the appropriate buffer output enables (DDROEN[3:0]) if the DBM bit in the DDRC register is set. Note that step #4 is skipped if the value of RCD = 1 (see DDRC register).
6. One clock cycle after step #5, the RC32438 may drive the NOP or WRITE command depending on the amount of data to be written. Figure 7.18 shows a write of four words, and thus two write commands are issued (each write command writes a pair of data). During the last write command issued, the RC32438 may assert the auto-precharge (AP) bit of the address bus (see Tables 7.3 and 7.4) depending on the state of the AP field in the DDRC register.

[1] The programmable parameters shown in Figure 7.18 are for illustrative purposes only and may vary.

Notes

7. A half clock cycle after step #6, the RC32438 starts driving the DDR data bus (DDRDATA[31:0]) as well as the DDR data strobes (DDRDQS[3:0]). This ensures that the RC32438 meets the DDR SDRAM's write-preamble requirement.
8. A half clock cycle after step #7, the RC32438 starts to toggle the DDR data strobes (DDRDQS[3:0]). For each write command issued, each strobe is toggled twice (first low to high and then high to low). In Figure 7.18, two write commands are issued and thus each strobe is toggled four times. Note that at this time the RC32438 also drives the DDR data bus (DDRDATA[31:0]) and DDR data masks (DDRDM[7:0]) in such a way that for each data the DDR strobes toggle at the center of the data window.
9. A half clock cycle after the RC32438 stops toggling the DDR data strobes, the RC32438 starts its write recovery count (WR field of the DDRC register).
10. A full clock cycle after the RC32438 stops toggling the DDR data strobes, the RC32438 stops driving the strobes and data bus. This ensures that the RC32438 meets the DDR SDRAM's write-post-amble requirement.[1]
11. WR-2 clock cycles after step #9, the RC32438 negates all buffer output enables (DDROEN[3:0]), negates the appropriate DDRCSNx, the transaction is completed, and a new transaction may begin.

DDR Refresh Transaction

This section describes the DDR refresh transaction. The transaction involves three programmable parameters:

- *Precharge Delay (**RP**). RP may be programmed to be any value between 1 and 4 DDR clock cycles*
- *Refresh Clock Cycles (**RFC**). RFC may be programmed to be any value between 1 and 15 DDR clock cycles.*

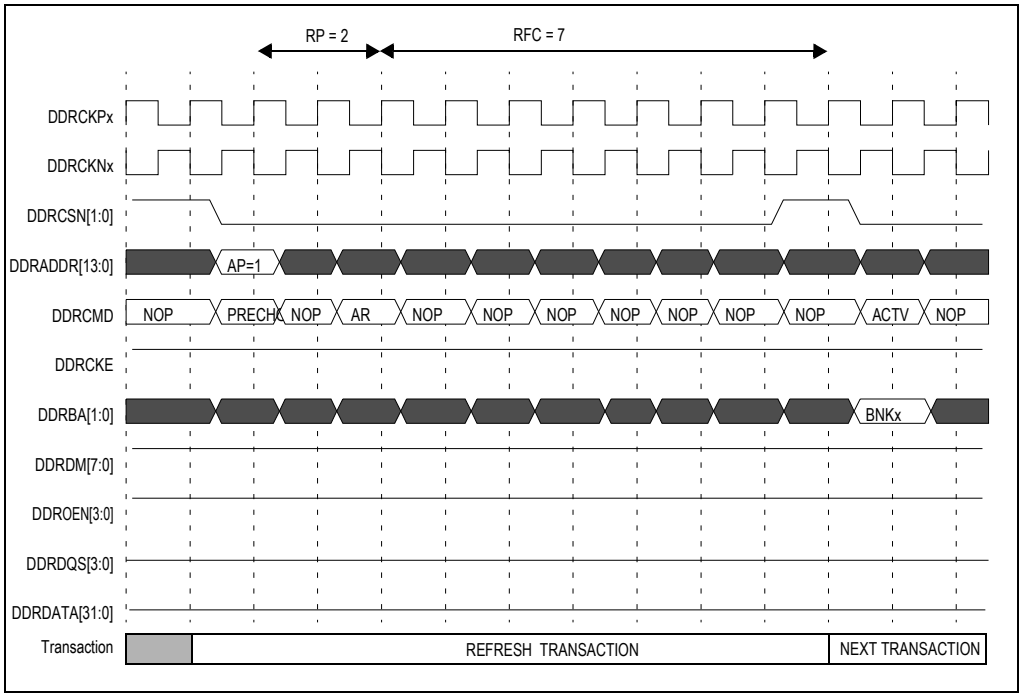


Figure 7.19 DDR SDRAM Refresh Transaction with Active Pages[2]

1. The RC32438 meets the minimum write postamble requirement set by the DDR SDRAM specification. The maximum limit for this parameter is not required to be met, even though DDR SDRAM specification has a value for it. Not meeting this requirement does not affect the DDR SDRAM chip nor the RC32438's bus turn-around time.

2. The programmable parameters shown in Figure 7.18 are for illustrative purposes only and may vary.

Notes

A DDR SDRAM refresh transaction is queued for execution whenever the DDR Refresh Timer expires and the refresh enable bit (RE) in the DDRC register is set. If no active pages exists in any of the DDR SDRAM banks, then the refresh transaction simply consists of an auto refresh command followed by RFC clock cycles (i.e., the transaction starts with step three below). If there exists an active page in any of the DDR SDRAMs, then a precharge-all command is first issued to deactivate all banks in all of the DDRs. This is then followed by an auto-refresh command followed by RFC clock cycles. A DDR SDRAM refresh transaction with active pages is shown in Figure 7.19 and consists of the following steps.

1. The RC32438 asserts both DDR SDRAM chip selects (DDRCSN[1:0]), drives the AP address bit high (see Tables 7.3 and 7.4) to indicate that all banks are to be precharged, and drives the PRECHARGE command (see Table 7.5) on the rising edge of DDRCKPx. This indicates the start of a transaction.
2. One clock cycle after step #1, the RC32438 drives the NOP command (see Table 7.5).
3. RP clock cycles after step #1, the RC32438 drives the AUTO-REFRESH command (see Table 7.5). Note that step two is skipped if the value of RP = 1 (see DDRC register).
4. One clock cycle after step #3, the RC32438 drives the NOP command (see Table 7.5).
5. RFC clock cycles after step #4, the RC32438 negates the DDR SDRAM chip selects (DDRCSN[1:0]), the transaction is completed, and a new transaction may begin.

DDR Custom Transaction

This section describes the SDRAM custom transaction. The transaction involves seven programmable parameters:

- *DDR Chip Select (**CS**). CS may be programmed to select DDRCSN[0], DDRDCSN[1] or both*
- *DDR Write Enable Status (**WE**). WE specifies the state of the DDRWEN pin during a DDR custom transaction*
- *DDR RAS Status (**RAS**). RAS specifies the state of the DDRRASN pin during a DDR custom transaction*
- *DDR CAS Status (**CAS**). CAS specifies the state of the DDRCASN signal during a DDR custom transaction*
- *DDR Clock Enable Status (**CKE**). CKE specifies the state of the DDRCKE signal during a DDR custom transaction.*
- *DDR Bank Address Status (**BA**). BA specifies the state of the DDRBA[1:0] signals during a DDR custom transaction.*
- *DDR Auto Precharge Enable (**AP**). AP specifies the state of the auto precharge address bit during a DDR custom transaction.*

Notes

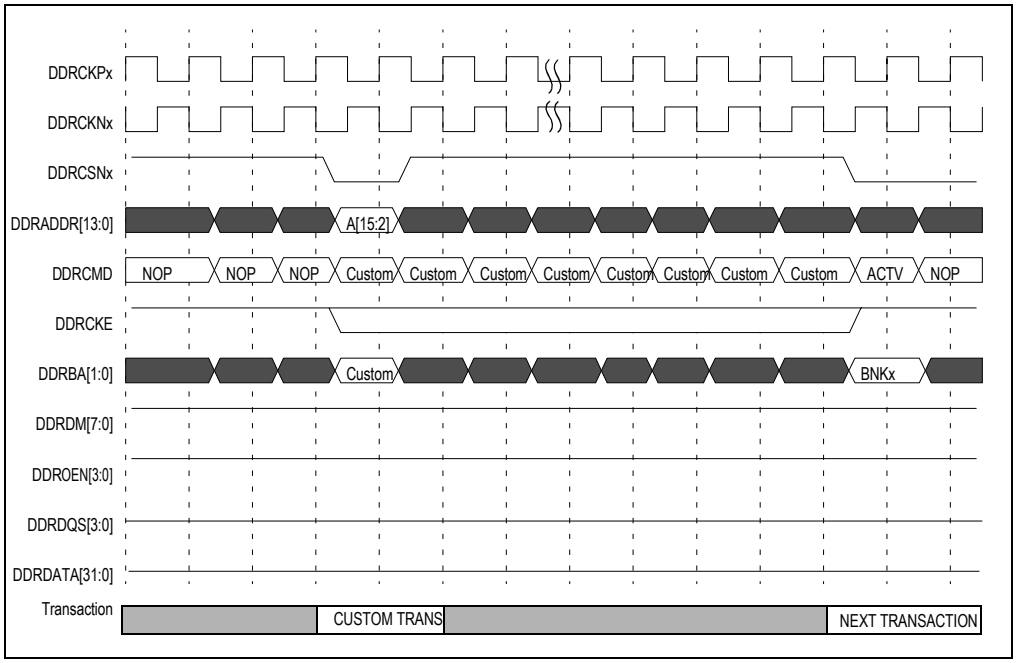


Figure 7.20 DDR SDRAM Custom Transaction

A DDR SDRAM Custom transaction is shown in Figure 7.20 and consists of the following steps.

1. The CPU configures the programmable parameters in the DDRCUST register for the desired DDR SDRAM custom transaction.
2. The CPU performs a write operation to DDR SDRAM space. This causes the RC32438 to assert the chip selects (DDRCSNx) programmed in the CS field of the DDRCUST register, drive the address bus (DDRADDR[13:0]) with the CPU address bits [15:2], drive the bank select pins (DDRBA[1:0]) with the value programmed in the BA field of the DDRCUST register, drive the DDRCKE pin with the value programmed in the CKE field of the DDRCUST register, and drive the DDR SDRAM custom command programmed in the RAS, CAS, and WE fields of the DDRCUST register. Note that the DDRDM[7:0] and DDROEN[3:0] pins are automatically negated during custom transactions, and that the DDRDATA[31:0] and DDRDQS[3:0] pins are not driven.
3. One clock cycle after step #2, the RC32438 negates all of the asserted chip selects and clears the address and bank select pins. The DDR SDRAM custom command programmed in the DDRCUST register continues to be driven until the next DDR transaction. At this point the transaction is completed and a new transaction may begin.
4. Note that step #2 must be a write operation to DDR SDRAM space. Still, the write data for this operation is meaningless. Only the address bits [15:2] of the transaction are meaningful as they are driven onto the DDRADDR[13:0] pins.

Example of DDR SDRAM Initialization

The EB438 board uses two Micron MT46V16M16 (4 Meg x 16 x 4 banks) DDR SDRAM devices tied to DDRCSN[0].

The specifics of the DDR SDRAM devices are listed below:

```
#define DDR_CTL_BASE       PHYS_TO_K1(0x18018010)  /* DDR controller regs */

#define DATA_PATTERN       0xA5A5A5A5
#define RCOUNT             PHYS_TO_K1(0x18028024)
```

Notes

```
#define DDR0_BASE_VAL       0x00000000
#define DDR0_MASK_VAL       0xFC000000
#define DDR1_BASE_VAL       0x04000000
#define DDR1_MASK_VAL       0x00000000
#define DDR0_ABASE_VAL      0x08000000
#define DDR0_AMASK_VAL      0x00000000

#if MHZ == 100000000
#define DDRC_VAL_NORMAL       0x82984940
#define DDRC_VAL_AT_INIT      0x02984940
#define DDR_REF_CMP_VAL       0x0000030c
#elif MHZ == 133000000
#define DDRC_VAL_NORMAL       0xA32A4980
#define DDRC_VAL_AT_INIT      0x232A4980
#define DDR_REF_CMP_VAL       0x0000040e
#endif

#define DDR_REF_CMP_FAST      0x00000080
#define DDR_REF_CMP_VAL_OLD   0x00000080

#define DDR_CUST_NOP          0x0000003F
#define DDR_CUST_PRECHARGE    0x00000033
#define DDR_CUST_REFRESH      0x00000027
#define DDR_LD_MODE_REG       0x00000023
#define DDR_LD_EMODE_REG      0x00000063

/*
 * All generated addresses for DDR init during custom transactions are shifted
 * by two address lines - see spec for used DDR chip
 */
#define DDR_PRECHARGE_OFFSET  0x00001000  /* 0x0400 - 9-bit page*/
#define DDR_EMODE_VAL         0x00000000  /* 0x0000 */
#define DDR_DLL_RES_MODE_VAL  0x00000584  /* 0x0161 - Reset DLL, CL2.5 */
#define DDR_DLL_MODE_VAL      0x00000184  /* 0x0061 - CL2.5 */

#define DELAY_200USEC         25000       /* not exactly */

/*-------------- Initialize DDR Base and Mask Registers --------------------*/
```

Notes

```
    li    t0, DDR_BASE

/* Load the DDRC, reset  Refresh Enable */
    li    t1, DDRC_VAL_AT_INIT
    sw    t1, 0x10(t0)

    sw    zero, 0x4(t0)
    sw    zero, 0xc(t0)
    sw    zero, 0x18(t0)

/* Store DDR0BASE */
    li    t1, DDR0_BASE_VAL
    sw    t1, 0x0(t0)

/* Store DDR0MASK */
    li    t1, DDR0_MASK_VAL
    sw    t1, 0x4(t0)

/* Store DDR1BASE */
    li    t1, DDR1_BASE_VAL
    sw    t1, 0x8(t0)

/* Load DDR1MASK to disable DDR CS1 */
    li    t1, DDR1_MASK_VAL
    sw    t1, 0x0C(t0)

/* Store DDR0ABASE */
    li    t1, DDR0_BASE_VAL
    sw    t1, 0x14(t0)

/* Load DDR0AMASK to disable alternate Mapping */
    li    t1, DDR0_AMASK_VAL
    sw    t1, 0x18(t0)

    li    t1, DDR_CUST_NOP      /* Write to DDR Custom transaction register */
    sw    t1, 0x20(t0)

    li    t2, DATA_PATTERN
```

Notes

```
    li    t1, 0xA0000000 | DDR0_BASE_VAL
    sw    t2, 0x0(t1)

  /* Add 200 microseconds of delay */
    li    t1, 0x0
    li    t2, DELAY_200USEC
1:
    add   t1, 1
    bne   t1, t2, 1b
        nop

  /* Register t0 carries pointer to the DDR_BASE: 0xB8018000 */
    li    t1, DDR_CUST_PRECHARGE
    sw    t1, 0x20(t0)    /* Write to DDR Custom transaction register */

  /* Generate A10 high to pre-charge both the banks */
    li    t2, DATA_PATTERN
    li    t1, 0xA0000000 | DDR_PRECHARGE_OFFSET | DDR0_BASE_VAL
    sw    t2, 0x0(t1)

  /* Register t0 carries pointer to the DDR_BASE: 0xB8018000 */
    li    t1, DDR_LD_EMODE_REG
    sw    t1, 0x20(t0)    /* Write to DDR Custom transaction register */

  /* Generate EMODE register contents on A15-A2 */
    li    t2, DATA_PATTERN
    li    t1, 0xA0000000 | DDR_EMODE_VAL | DDR0_BASE_VAL
    sw    t2, 0x0(t1)

  /* Register t0 carries pointer to the DDR_BASE: 0xB8018000 */
    li    t1, DDR_LD_MODE_REG
    sw    t1, 0x20(t0)    /* Write to DDR Custom transaction register */

  /* Generate Mode register contents on the address bus A15-A2  */
    li    t2, DATA_PATTERN
    li    t1, 0xA0000000 | DDR_DLL_RES_MODE_VAL | DDR0_BASE_VAL
    sw    t2, 0x0(t1)

  /* Delay of  1.6 microseconds ~ 300 delay iteration value */
```

Notes

```
    li   t1, 0x0
    li   t2, 500
1:
    add  t1, 1
    bne  t1, t2, 1b
         nop

 /* Register t0 carries pointer to the DDR_BASE: 0xB8018000 */
    li   t1, DDR_CUST_PRECHARGE
    sw   t1, 0x20(t0)   /* Write to DDR Custom transaction register */

 /* Generate A10 high to pre-charge both the banks */
    li   t2, DATA_PATTERN
    li   t1, 0xA0000000 | DDR_PRECHARGE_OFFSET | DDR0_BASE_VAL
    sw   t2, 0x0(t1)

 /* Implements 9 cycles of Auto refresh allowing
    sufficient margin for stability*/
    li   t4, 9
    li   t3, 0
1:
    li   t1, DDR_CUST_REFRESH
    sw   t1, 0x20(t0)   /* Write to DDR Custom transaction register */

 /* Access DDR */
    li   t2, DATA_PATTERN
    li   t1, 0xA0000000 | DDR0_BASE_VAL
    sw   t2, 0x0(t1)

    add  t3, 1
    bne  t3, t4, 1b
         nop

 /* Register t0 carries pointer to the DDR_BASE: 0xB8018000 */
    li   t1, DDR_LD_MODE_REG
    sw   t1, 0x20(t0)   /* Write to DDR Custom transaction register */

 /* Generate Mode Register contents on the address bus A12-A0 */
    li   t2, DATA_PATTERN
```

Notes

```
    li    t1, 0xA0000000 | DDR_DLL_MODE_VAL | DDR0_BASE_VAL
    sw    t2, 0x0(t1)

  /* Initialize the refresh timer with fast refresh count */
    li    t0, RCOUNT
    li    t1, DDR_REF_CMP_FAST

  /* Set the RCOMPARE register */
    sw    t1, 0x4(t0)

  /* Enable the Refresh timer */
    li    t1, 0x1          /* CE set to enabled the  Refresh counter */
    sw    t1, 0x8(t0)

  /* Enable RE-refresh enable in the DDRC register */
    li    t0, DDR_BASE
    li    t1, DDRC_VAL_NORMAL
    sw    t1, 0x10(t0)

  /* Add 200 microseconds of delay */
    li    t1, 0x0
    li    t2, DELAY_200USEC
1:
    add   t1, 1
    bne   t1, t2, 1b
        nop

    li    t0, RCOUNT

  /* Find Refresh Timer Compare value based on revision - Check for IP7 */
    li    t2, 0x1
    mtc0  t2, C0_COMPARE
    mtc0  zero, C0_COUNT
        nop
        nop
    mfc0  t1, C0_CAUSE
        nop
    li    t3, DDR_REF_CMP_VAL
    andi  t1, 0x8000
```

Notes

```
        bnez  t1, acacia_zb
            nop
        li    t3, DDR_REF_CMP_VAL_OLD
acacia_zb:
 /* Disable the refresh counter before changing the compare value */
        sw    zero, 0x8(t0)

 /* Set the RCOMPARE register with value gotten above */
        sw    t3, 0x4(t0)

 /* Enable the Refresh timer */
        li    t1, 0x1          /* CE set to enabled the  Refresh counter */
        sw    t1, 0x8(t0)
```

Notes

Interrupt Controller

Notes

Introduction

This chapter describes the operation of the Interrupt Controller which multiplexes all the interrupt sources from on-chip modules and the GPIO pins onto the five available interrupt sources of the CPU (IP[6:2]). These interrupt inputs correspond to the IP[6:2] bits of the CPU CP0 CAUSE register. (IP[1:0] are software interrupts, and IP[7] is used by the counter timer in the CPU.)

Each of the IP[6:2] bits in the CPU CAUSE Register has three corresponding registers in the Interrupt Controller:

- *The Interrupt Pending Register, a 32-bit register that indicates the source of the interrupt.*
- *The Interrupt Mask Register, a 32-bit register. Each bit in the Interrupt Mask Register corresponds to the equivalent bit in the Interrupt Pending Register. Setting a bit in the Interrupt Mask Register masks the generation of an interrupt for this source.*
- *The Interrupt Test Register, a 32-bit register. Each bit in the Interrupt Test Register corresponds to a bit in the Interrupt Pending Register. Setting a bit in the Interrupt Test Register causes the same behavior as an interrupt request from the corresponding interrupt source in the Interrupt Pending Register. This register may be used to test software interrupt handlers without the need to actually generate the condition required to produce an interrupt request.*

The Interrupt Controller has no priority levels. All sources have the same priority. If multiple interrupts are pending, it is the responsibility of the software to assign any priority.

The Interrupt Controller multiplexes the interrupt sources to the CPU. The interrupt clearing or assertion may take several clock cycles to show up in the Interrupt Pending Register, depending on the source of the interrupt. To clear the interrupt, the software must clear the source.

Features

- *Allows status of all interrupt sources to be read*
- *Each interrupt source may be masked*
- *Provides interrupt test capability*

Notes

Block Diagram

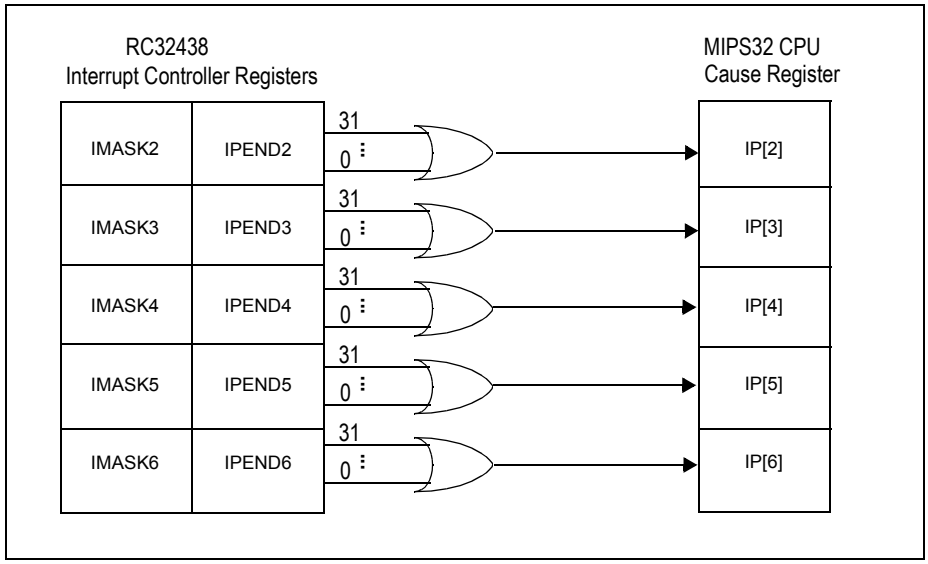


Figure 8.1 Mapping of Interrupts to the CPU Cause Register

Interrupt Controller Register Description

Register Offset[1]	Register Name	Register Function	Size
0x03_8000	IPEND2	Interrupt pending 2	32-bit
0x03_8004	ITEST2	Interrupt test 2	32-bit
0x03_8008	IMASK2	Interrupt mask 2	32-bit
0x03_800C	IPEND3	Interrupt pending 3	32-bit
0x03_8010	ITEST3	Interrupt test 3	32-bit
0x03_8014	IMASK3	Interrupt mask 3	32-bit
0x03_8018	IPEND4	Reserved	32-bit
0x03_801C	ITEST4	Reserved	32-bit
0x03_8020	IMASK4	Reserved	32-bit
0x03_8024	IPEND5	Interrupt pending 5	32-bit
0x03_8028	ITEST5	Interrupt test 5	32-bit
0x03_802C	IMASK5	Interrupt mask 5	32-bit
0x03_8030	IPEND6	Interrupt pending 6	32-bit
0x03_8034	ITEST6	Interrupt test 6	32-bit
0x03_8038	IMASK6	Interrupt mask 6	32-bit
0x03_803C	NMIPS	Non-maskable interrupt pin status	32-bit
0x03_8040 through 0x03_FFFF	Reserved		

Table 8.1 Interrupt Controller Register Map

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Notes

Interrupt Pending [2..6] Register

Note: IPEND4 is reserved. Use only IPEND2, IPEND3, IPEND5, and IPEND6.

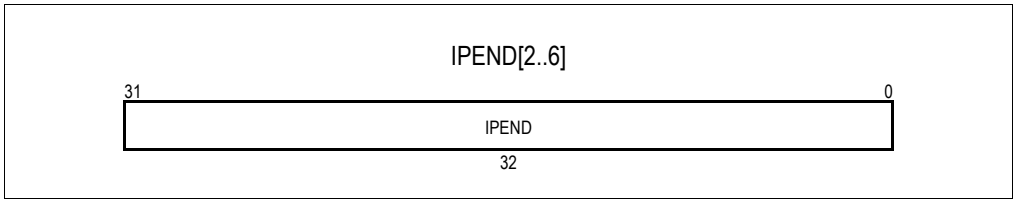


Figure 8.2 Interrupt Pending [2..6] Register (IPEND[2..6])

IPEND

Description: **Interrupt Pending.** Each bit in this field corresponds to an interrupt source. When a bit is set the corresponding interrupt source is requesting service. Note that this register shows interrupts which are currently requesting service but may be “masked” from actually generating an interrupt exception.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

Interrupt Test [2..6] Register

Note: ITEST4 is reserved. Do not use.

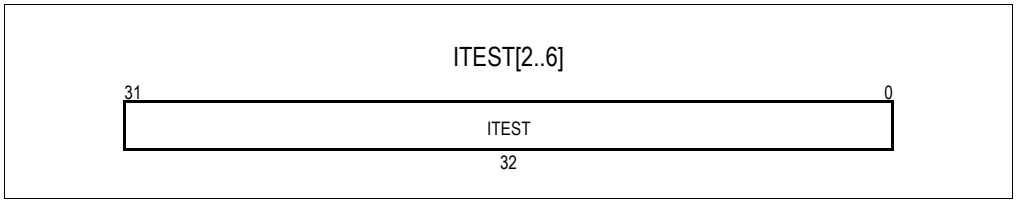


Figure 8.3 Interrupt Test [2..6] Register (ITEST[2..6])

ITEST

Description: **Interrupt Test.** Each bit in this field corresponds to an interrupt source in the corresponding Interrupt Pending (IPEND) register. When a bit in this field is set, it appears to the interrupt controller that the corresponding interrupt source in the IPEND register is requesting service.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Interrupt Mask [2..6] Register

Note: IMASK4 is reserved. Do not use.

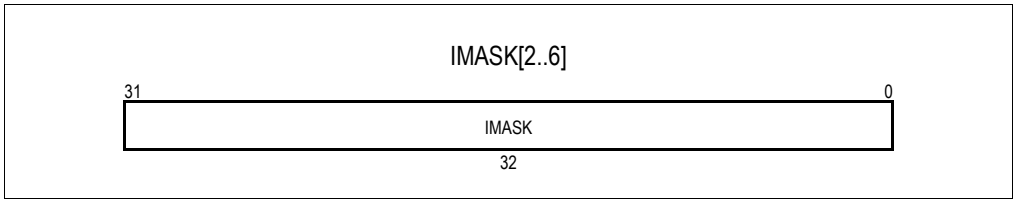


Figure 8.4 Interrupt Mask [2..6] Register (IMASK[2..6])

IMASK

Description: **Interrupt Mask.** Each bit in this register masks the corresponding interrupt source in the IPENDx register. When a bit in this field is set, the corresponding interrupt source (as well as interrupt test bit) is masked from generating an interrupt exception.

Initial Value: Bits that correspond to an interrupt source in the IPENDx register are initialized to 0x1. Reserved bits are initialized to 0x0 and cannot be modified.

Read Value: Previous value written

Write Effect: Modify value

Interrupt Status Description

Bit	Interrupt/Status Description	Refer to
0	**Counter Timer 0.** Corresponds to the TO bit in the CTC0 register.	Chapter 14
1	**Counter Timer 1.** Corresponds to the TO bit in the CTC1 register.	Chapter 14
2	**Counter Timer 2.** Corresponds to the TO bit in the CTC2 register.	Chapter 14
3	**Refresh Timer.** Corresponds to TO bit in the RTC register.	Chapter 7
4	**Watchdog Timer Time-Out.** Corresponds to TO bit in the WTC register.	Chapter 4
5	**Undecoded CPU Write.** Corresponds to UCW bit in the ERRCS register.	Chapter 4
6	**Undecoded CPU Read.** Corresponds to UCR bit in the ERRCS register.	Chapter 4
7	**Undecoded PCI Write.** Corresponds to UPW bit in the ERRCS register.	Chapter 4
8	**Undecoded PCI Read.** Corresponds to UPR bit in the ERRCS register.	Chapter 4
9	**Undecoded DMA Write.** Corresponds to UDW bit in the ERRCS register.	Chapter 4
10	**Undecoded DMA Read.** Corresponds to UDR bit in the ERRCS register.	Chapter 4
11	**IPBUs Slave Acknowledge Error.** Corresponds to SAE bit in the ERRCS register.	Chapter 4
12-31	Reserved	

Table 8.2 IPEND2 Interrupt Source Description

Bit	Interrupt/Status Description	Refer to
0	**DMA Channel 0.** OR of the bits in the DMA0S not masked by DMA0SM.	Chapter 9
1	**DMA Channel 1.** OR of the bits in the DMA1S not masked by DMA1SM.	Chapter 9
2	**DMA Channel 2.** OR of the bits in the DMA2S not masked by DMA2SM.	Chapter 9

Table 8.3 IPEND3 Interrupt Source Description

Notes

Bit	Interrupt/Status Description	Refer to
3	**DMA Channel 3.** OR of the bits in the DMA3S not masked by DMA3SM.	Chapter 9
4	**DMA Channel 4.** OR of the bits in the DMA4S not masked by DMA4SM.	Chapter 9
5	**DMA Channel 5.** OR of the bits in the DMA5S not masked by DMA5SM.	Chapter 9
6	**DMA Channel 6.** OR of the bits in the DMA6S not masked by DMA6SM.	Chapter 9
7	**DMA Channel 7.** OR of the bits in the DMA7S not masked by DMA7SM.	Chapter 9
8	**DMA Channel 8.** OR of the bits in the DMA8S not masked by DMA8SM.	Chapter 9
9	**DMA Channel 9.** OR of the bits in the DMA9S not masked by DMA9SM.	Chapter 9
10-31	Reserved	

Table 8.3 IPEND3 Interrupt Source Description

Bit	Interrupt/Status Description	Refer to
0	**UART General Interrupt 0**.	Chapter 13
1	**UART TXRDY 0 Interrupt**.	Chapter 13
2	**UART RXRDY 0 Interrupt**.	Chapter 13
3	**UART General Interrupt 1**.	Chapter 13
4	**UART TXRDY 1 Interrupt**.	Chapter 13
5	**UART RXRDY 1 Interrupt**.	Chapter 13
6	**PCI Interrupt**. OR of bits in PCIS not masked by PCISM.	Chapter 10
7	**PCI Decoupled Access Interrupt.** OR of bits in the PCIDAS register not masked by PCIDASM.	Chapter 10
8	**SPI Interrupt.** Corresponds to SPIF and MODF bits in the SPS register.	Chapter 16
9	**Device Decoupled Operation Done.** Corresponds to the F bit in the DEVDACS register.	Chapter 6
10	**I2C-bus Master Interface Interrupt**. OR of bits in I2CMS not masked by I2CMSM.	Chapter 15
11	**I2C-bus Slave Interface Interrupt**. OR of bits in I2CSS not masked by I2CSSM.	Chapter 15
12	**Ethernet 0 Input FIFO Overflow**. Corresponds to OVR bit in ETH0INTFC register.	Chapter 11
13	**Ethernet 0 Output FIFO Underflow**. Corresponds to UND bit in ETH0INTFC register.	Chapter 11
14	**Ethernet 0 Pause Frame Done.** Corresponds to PFD bit in ETH0OS register.	Chapter 11
15	**Ethernet 1 Input FIFO Overflow**. Corresponds to OVR bit in ETH1INTFC register.	Chapter 11
16	**Ethernet 1 Output FIFO Underflow**. Corresponds to UND bit in ETH1INTFC register.	Chapter 11
17	**Ethernet 1 Pause Frame Done.** Corresponds to PFD bit in ETH1OS register.	Chapter 11
18-31	Reserved	

Table 8.4 IPEND5 Interrupt Source Description

Bit	Interrupt/Status Description	Refer to
0	**GPIO 0.** Corresponds to bit 0 of the GPIOISTAT register.	Chapter 12
1	**GPIO 1.** Corresponds to bit 1 of the GPIOISTAT register.	Chapter 12
2	**GPIO 2.** Corresponds to bit 2 of the GPIOISTAT register.	Chapter 12
3	**GPIO 3.** Corresponds to bit 3 of the GPIOISTAT register.	Chapter 12

Table 8.5 IPEND6 Interrupt Source Description (Part 1 of 2)

Notes

Bit	Interrupt/Status Description	Refer to
4	**GPIO 4.** Corresponds to bit 4 of the GPIOISTAT register.	Chapter 12
5	**GPIO 5.** Corresponds to bit 5 of the GPIOISTAT register.	Chapter 12
6	**GPIO 6.** Corresponds to bit 6 of the GPIOISTAT register.	Chapter 12
7	**GPIO 7.** Corresponds to bit 7 of the GPIOISTAT register.	Chapter 12
8	**GPIO 8.** Corresponds to bit 8 of the GPIOISTAT register.	Chapter 12
9	**GPIO 9.** Corresponds to bit 9 of the GPIOISTAT register.	Chapter 12
10	**GPIO 10.** Corresponds to bit 10 of the GPIOISTAT register.	Chapter 12
11	**GPIO 11.** Corresponds to bit 11 of the GPIOISTAT register.	Chapter 12
12	**GPIO 12.** Corresponds to bit 12 of the GPIOISTAT register.	Chapter 12
13	**GPIO 13.** Corresponds to bit 13 of the GPIOISTAT register.	Chapter 12
14	**GPIO 14.** Corresponds to bit 14 of the GPIOISTAT register.	Chapter 12
15	**GPIO 15.** Corresponds to bit 15 of the GPIOISTAT register.	Chapter 12
16	**GPIO 16.** Corresponds to bit 16 of the GPIOISTAT register.	Chapter 12
17	**GPIO 17.** Corresponds to bit 17 of the GPIOISTAT register.	Chapter 12
18	**GPIO 18.** Corresponds to bit 18 of the GPIOISTAT register.	Chapter 12
19	**GPIO 19.** Corresponds to bit 19 of the GPIOISTAT register.	Chapter 12
20	**GPIO 20.** Corresponds to bit 20 of the GPIOISTAT register.	Chapter 12
21	**GPIO 21.** Corresponds to bit 21 of the GPIOISTAT register.	Chapter 12
22	**GPIO 22.** Corresponds to bit 22 of the GPIOISTAT register.	Chapter 12
23	**GPIO 23.** Corresponds to bit 23 of the GPIOISTAT register.	Chapter 12
24	**GPIO 24.** Corresponds to bit 24 of the GPIOISTAT register.	Chapter 12
25	**GPIO 25.** Corresponds to bit 25 of the GPIOISTAT register.	Chapter 12
26	**GPIO 26.** Corresponds to bit 26 of the GPIOISTAT register.	Chapter 12
27	**GPIO 27.** Corresponds to bit 27 of the GPIOISTAT register.	Chapter 12
28	**GPIO 28.** Corresponds to bit 28 of the GPIOISTAT register.	Chapter 12
29	**GPIO 29.** Corresponds to bit 29 of the GPIOISTAT register.	Chapter 12
30	**GPIO 30.** Corresponds to bit 30 of the GPIOISTAT register.	Chapter 12
31	**GPIO 31.** Corresponds to bit 31 of the GPIOISTAT register.	Chapter 12

Table 8.5 IPEND6 Interrupt Source Description (Part 2 of 2)

Non-Maskable Interrupts

- *Sources of non-maskable interrupts*
  - Watchdog timer time-out
  - Setting the NMI bit in the PCI Management (PMGT) register
  - GPIO pin(s) programmed to generate an NMI
- *The source of an NMI may be determined by checking corresponding status registers*

Notes

Non-Maskable Interrupt Pin Status Register

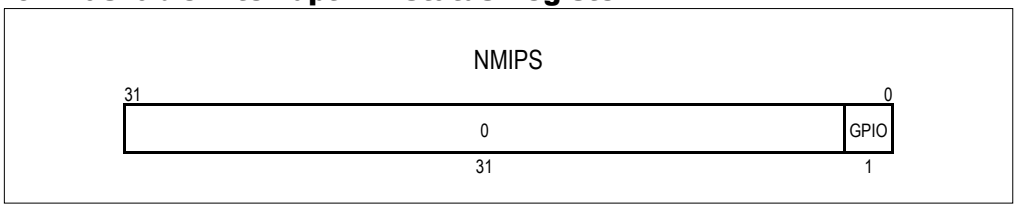


Figure 8.5 Non-Maskable Interrupt Pin Status

GPIO

Description: **GPIO Non-Maskable Interrupt.** A GPIO non-maskable interrupt causes this sticky bit to be set. A GPIO non-maskable interrupt occurs when a bit in GPIOSTAT register is set and the corresponding bit is set in GPIONMIEN register (see Chapter 12). The assertion of this bit results in a non-maskable interrupt.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Notes

DMA Controller

Notes

Introduction

The DMA controller consists of 10 independent DMA channels, all of which operate in exactly the same manner. All DMA channels support fly-by DMA operations between memory and a peripheral device.[1] A single DMA channel may be multiplexed among two different devices using the device select (DS) field in a DMA descriptor (refer to Table 9.2). The external DMA channels (i.e., DMA channels 0 and 1) use the device select field to determine the direction of the DMA transfer (memory to external peripheral or external peripheral to memory). The DS field is unused by the other DMA channels and must be set to zero.

Features

- *10 DMA channels*
  - *Two channels for PCI (PCI to Memory and Memory to PCI)*
  - *Four Ethernet channels — two for each Ethernet interface (transmit/receive)*
  - *Two DMA channels for memory to memory DMA operations*
  - *Two DMA channels for external DMA operations*
- *Provides flexible descriptor based operation*
- *Supports external peripheral DMA operations*
- *Supports unaligned transfers (i.e., source or destination address may be on any byte boundary) with arbitrary byte length*

DMA Registers

Register Offset[1]	Register Name	Register Function	Size
0x04_0000	DMA0C	DMA 0 control	32-bit
0x04_0004	DMA0S	DMA 0 status	32-bit
0x04_0008	DMA0SM	DMA 0 status mask	32-bit
0x04_000C	DMA0DPTR	DMA 0 descriptor pointer	32-bit
0x04_0010	DMA0NDPTR	DMA 0 next descriptor pointer	32-bit
0x04_0014	DMA1C	DMA 1 control	32-bit
0x04_0018	DMA1S	DMA 1 status	32-bit
0x04_001C	DMA1SM	DMA 1 status mask	32-bit
0x04_0020	DMA1DPTR	DMA 1 descriptor pointer	32-bit
0x04_0024	DMA1NDPTR	DMA 1 next descriptor pointer	32-bit
0x04_0028	DMA2C	DMA 2 control	32-bit
0x04_002C	DMA2S	DMA 2 status	32-bit

Table 9.1 DMA Register Map (Part 1 of 3)

1. DMA operations are automatically supported across memory regions (for example, across DDR bank 0 and DDR bank 1) as long as the physical addresses are contiguous and the memory regions have a size which is greater than 64 KB.

Notes

Register Offset[1]	Register Name	Register Function	Size
0x04_0030	DMA2SM	DMA 2 status mask	32-bit
0x04_0034	DMA2DPTR	DMA 2 descriptor pointer	32-bit
0x04_0038	DMA2NDPTR	DMA 2 next descriptor pointer	32-bit
0x04_003C	DMA3C	DMA 3 control	32-bit
0x04_0040	DMA3S	DMA 3 status	32-bit
0x04_0044	DMA3SM	DMA 3 status mask	32-bit
0x04_0048	DMA3DPTR	DMA 3 descriptor pointer	32-bit
0x04_004C	DMA3NDPTR	DMA 3 next descriptor pointer	32-bit
0x04_0050	DMA4C	DMA 4 control	32-bit
0x04_0054	DMA4S	DMA 4 status	32-bit
0x04_0058	DMA4SM	DMA 4 status mask	32-bit
0x04_005C	DMA4DPTR	DMA 4 descriptor pointer	32-bit
0x04_0060	DMA4NDPTR	DMA 4 next descriptor pointer	32-bit
0x04_0064	DMA5C	DMA 5 control	32-bit
0x04_0068	DMA5S	DMA 5 status	32-bit
0x04_006C	DMA5SM	DMA 5 status mask	32-bit
0x04_0070	DMA5DPTR	DMA 5 descriptor pointer	32-bit
0x04_0074	DMA5NDPTR	DMA 5 next descriptor pointer	32-bit
0x04_0078	DMA6C	DMA 6 control	32-bit
0x04_007C	DMA6S	DMA 6 status	32-bit
0x04_0080	DMA6SM	DMA 6 status mask	32-bit
0x04_0084	DMA6DPTR	DMA 6 descriptor pointer	32-bit
0x04_0088	DMA6NDPTR	DMA 6 next descriptor pointer	32-bit
0x04_008C	DMA7C	DMA 7 control	32-bit
0x04_0090	DMA7S	DMA 7 status	32-bit
0x04_0094	DMA7SM	DMA 7 status mask	32-bit
0x04_0098	DMA7DPTR	DMA 7 descriptor pointer	32-bit
0x04_009C	DMA7NDPTR	DMA 7 next descriptor pointer	32-bit
0x04_00A0	DMA8C	DMA 8 control	32-bit
0x04_00A4	DMA8S	DMA 8 status	32-bit
0x04_00A8	DMA8SM	DMA 8 status mask	32-bit
0x04_00AC	DMA8DPTR	DMA 8 descriptor pointer	32-bit
0x04_00B0	DMA8NDPTR	DMA 8 next descriptor pointer	32-bit
0x04_00B4	DMA9C	DMA 9 control	32-bit
0x04_00B8	DMA9S	DMA 9 status	32-bit
0x04_00BC	DMA9SM	DMA 9 status mask	32-bit

Table 9.1 DMA Register Map (Part 2 of 3)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x04_00C0	DMA9DPTR	DMA 9 descriptor pointer	32-bit
0x04_00C4	DMA9NDPTR	DMA 9 next descriptor pointer	32-bit
0x04_00C8 through 0x04_3FFF	Reserved		

Table 9.1 DMA Register Map (Part 3 of 3)

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Data Flow within the RC32438

The RC32438 is primarily an engine designed to efficiently move data between interfaces. Data is received from one of the interfaces, stored in the main memory, then transferred out on another interface. Thus, understanding the operation data flow within the RC32438 is very important in understanding the behavior of the device and how to optimize the internal resources to meet the needs of the various applications.

The IPBus™

The internal IPBus in the RC32438 is the backbone of the device and is connected to every module in the RC32438. It is used to transfer all the data within the device and to make the connection between the external main memory and the on-chip peripherals. There are two potential bus masters on the IPBus: The CPU core and the DMA Controller (through one of its DMA channels). The processor core and the DMA Controller must arbitrate to acquire ownership of the IPBus (as described in Chapter 5, Bus Arbitration). Once the IPBus is granted to a master, data can be transferred within the RC32438. All other interfaces connected to the IPBus are slaves, including the Device Controller. To transfer data, one of the bus masters must request data from or send data to the slave.

None of the on-chip peripherals on the RC32438 have IPBus mastership capability. Rather, each has its internal FIFO to buffer the incoming and the outgoing data. The peripheral receives output data from the IPBus (either DMA or CPU) in its transmit FIFO and sends it out the interface bus. Or it receives input data from the interface bus in its receive FIFO and requests service from an IPBus master through an interrupt or status flag to the CPU or a request to the DMA Controller. The internal FIFOs are only used to compensate for the IPBus arbitration and access latency. The external memory (DDR or memory/IO) is used as the primary storage location for the incoming and outgoing data. Thus, all the data movement within the RC32438 must pass through the memory — either DDR through the DDR controller, or SRAM / dual port through the Device Controller. The DMA Controller can transfer data between peripherals via external memory. As an example, input data from the Ethernet port will be stored in external memory first. The CPU will then process the data for appropriate protocol conversion. The data will then be transferred from the DDR memory to the PCI interface.

The CPU core can access any of the on-chip peripherals for data transfer and reception. Some peripherals, like the Ethernet interface and PCI interface, have associated DMA channels that can be used to transfer and receive data.

4Kc Core as Bus Master

When the 4Kc processor core is the IPBus master, it can read and write data from or to any peripheral to transmit and receive the data. This is accomplished through the execution of the standard load and store instructions of the 4Kc core. This usually includes several steps: The 4Kc core loads the data from main memory into one of its internal registers and then writes it to the peripherals for transmission. The reverse occurs for the reception of data. Usually, the internal peripherals will be accessed as non-cached entries by the processor core. However, the use of the Prefetch-with-ignore-Hit instruction enables the processor core to treat some of the peripherals as cached entries, thus speeding up the processing of the data by the 4Kc core. This usually is used when the 4Kc core needs to process the header of a packet for decision making. For most of the slow peripherals (like I^2C), using the processor core is more than adequate to maintain the

Notes

speed requirements of the interface. However, for fast interfaces like Ethernet, using the core to transfer the data is not recommended. Rather, the associated DMA channels should be used to maintain the wire speed of these interfaces.

DMA Controller

As mentioned above, a DMA channel should be used with a fast peripheral to maintain the wire speed on the interface. The DMA Controller plays a critical role in the data movement within the RC32438 and in maintaining the wire speed on the various interfaces. The DMA Controller is one of the most complex blocks on the RC32438 and offers a number of capabilities tailored to enhance data movement capabilities. Understanding the operation of the DMA Controller is critical to understanding the operation and the data movement within the RC32438. The DMA Controller is tightly coupled to the internal IPBus and to the various on chip peripherals to enable the RC32438 to meet the wire speed of the various interfaces. Figure 9.1 illustrates a simplified block diagram of the DMA Controller and the internal IPBus on the RC32438.

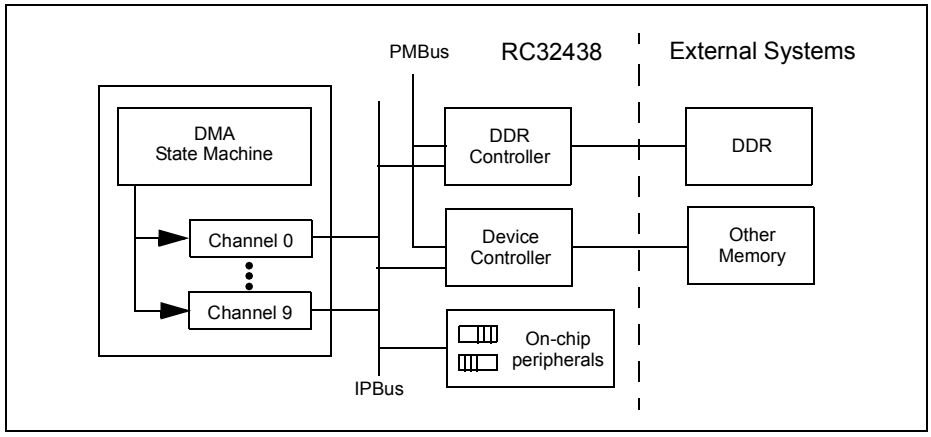


Figure 9.1 DMA Block Diagram

The DMA Controller supports ten DMA channels. These DMA channels can be grouped into two categories: dedicated channels and multiplexed channels. Each of the dedicated DMA channels service only one peripheral in one direction (input or output). As an example, DMA channel 2 services the Ethernet Controller in the input direction only. The multiplexed DMA channels service more than one peripheral in both directions.

The DMA Controller implements fly-by DMA operations. A fly-by operation transfers data between an on-chip peripheral and memory using a single transaction. Non-fly-by operations require two transactions:

- *One to move data between an on-chip peripheral and an internal buffer*
- *Another to move the data from the internal buffer to memory.*

The DMA Controller arbitrates for the IPBus and then monitors the fly-by transfer of data between the Memory Controller and the on-chip peripheral. The fly-by implementation enhances the bandwidth of the DMA because it eliminates the extra clock cycles that would be needed to temporarily store the data.

The DMA Controller supports any length of packet transfer. Each packet is divided into bursts of up to 16 words maximum. Some interfaces can generate smaller bursts. The DMA Controller re-arbitrates for the IPBus at the end of each burst transfer. The maximum burst size of 16 words enables the software to maintain a balance between the DMA transfers and the 4Kc core instruction fetches and data transfers.

No Alignment Restrictions

To support the needs of most data communication protocols and standard data communication drivers, the DMA Controller does not impose any alignment restrictions on the data. The data in memory to be transferred by the DMA Controller can be located anywhere in the main memory and start on any byte boundary. For example, the data to be transferred can start at byte 2 within a word and be 1000 bytes long. Similarly, the received data can be stored anywhere in the main memory without any byte alignment or

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length restrictions. Further, there is no relationship required between the alignment or length of the transmitted data and the received data. For example, the received data can start at byte 3 within the word and be 561 bytes long.

Data Flow Using the DMA Controller

The reception and transmission of data using the DMA Controller follows a series of standard steps. For the data reception, the following steps highlight the data and control flow within the RC32438.

1. The 4Kc processor core initializes the DMA channel for the desired peripheral.
2. The peripheral starts receiving the data in its input FIFO. Depending on the peripheral used, once the required number of bytes are received in the FIFO or when an “end of packet” is received, the peripheral places a DMA request with its associated DMA channel.
3. The DMA channel transfers the data from the peripheral to memory.
4. The DMA Controller can be configured to generate an interrupt to the 4Kc core when it completes transferring a packet to memory. This signals the 4Kc core to begin executing software for higher level protocol processing.

The transmission of the data follows the same steps in reverse order. The following steps highlight the data and control flow within the RC32438 when data is transmitted.

1. The upper layer software stacks ready the data for transmission.
2. The 4kc core sets up the DMA channel for transmission.
3. The DMA channel transfers the data from memory to the output FIFO of the peripheral.
4. The peripheral transmits the data on its bus.
5. The operation continues until the end of the packet. This usually triggers an interrupt to the 4Kc core which ends the DMA operation.

Figure 9.2 illustrates the simplified data movement operation within the RC32438.

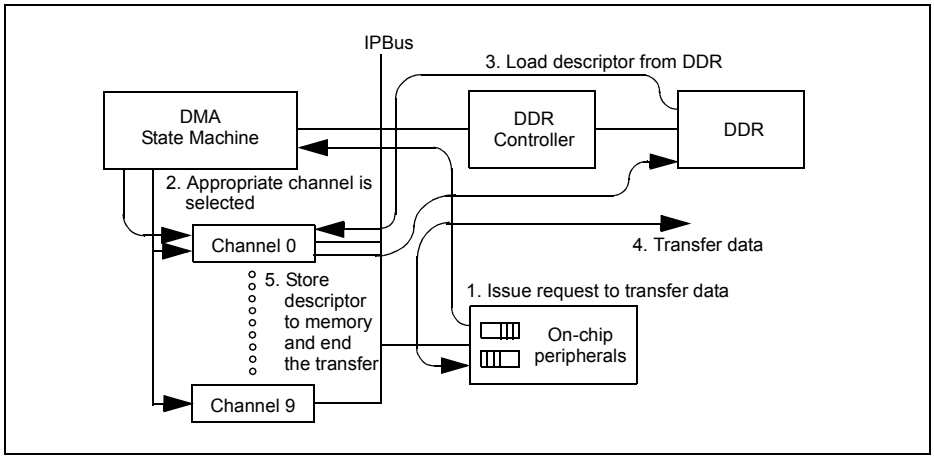


Figure 9.2 Anatomy of DMA Operations

Note: A DMA operation should not be started if the corresponding interface is disabled. Disabling and re-enabling an interface should not be done without first disabling the corresponding DMA channel, otherwise the DMA controller may generate undefined behavior.

Memory-to-Memory Transfer

The DMA Controller has a 16-word internal FIFO that is only used during memory-to-memory transfers. This FIFO is needed to temporarily store the data between transfers. To do a memory-to-memory DMA operation, the data is read from the source memory, stored in the DMA FIFO, then written in the destination memory. Only DMA channels 6 and 7 can be used for memory-to-memory DMA operations.

Note: Memory-to-memory DMA operations using channel 6 will not start until channel 7 is started.

Notes

The maximum burst size is limited by the DMA FIFO size and is fixed at 16 words. Source and destination memories can be any type of memory or device connected to the DDR Controller or the Device Controller. Endianness swapping is not supported during memory-to-memory DMA. Memory-to-memory DMA is illustrated in Figure 9.3.

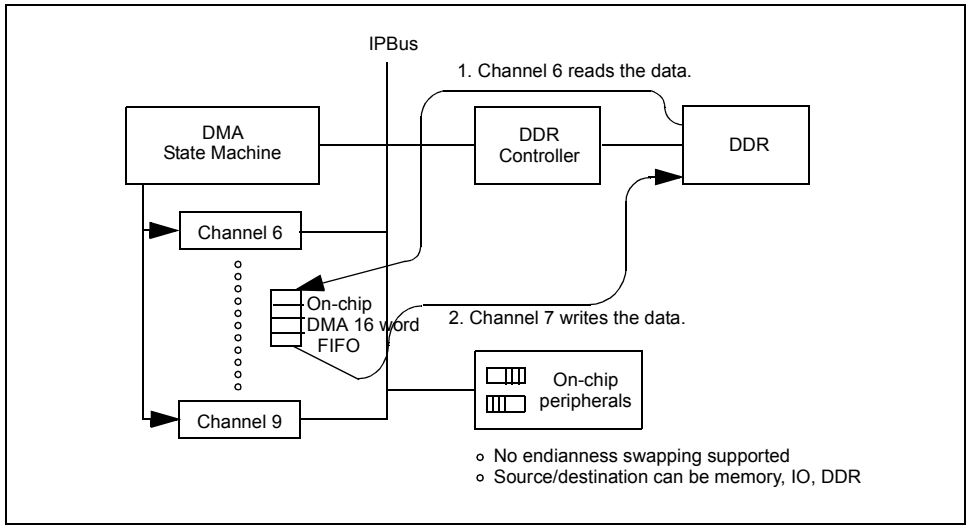


Figure 9.3 Memory to Memory DMA Transfers

DMA Channels

DMA Channel	Device Select	Device Description
Channel 0	0	External DMA Channel 0 (external peripheral to memory)
	1	External DMA Channel 0 (memory to external peripheral)
	2	*reserved*
	3	*reserved*
Channel 1	0	External DMA Channel 1 (external peripheral to memory)
	1	External DMA Channel 1 (memory to external peripheral)
	2	*reserved*
	3	*reserved*
Channel 2	0	Ethernet Channel 0 Receive
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 3	0	Ethernet Channel 0 Transmit
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 4	0	Ethernet Channel 1 Receive
	1	*reserved*
	2	*reserved*
	3	*reserved*

Table 9.2 DMA Channels and Device Selects (Part 1 of 2)

Notes

DMA Channel	Device Select	Device Description
Channel 5	0	Ethernet Channel 1 Transmit
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 6	0	Memory to Memory (Memory to Holding FIFO)
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 7	0	Memory to Memory (Holding FIFO to Memory)
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 8	0	PCI (PCI to Memory)
	1	*reserved*
	2	*reserved*
	3	*reserved*
Channel 9	0	PCI (Memory to PCI)
	1	*reserved*
	2	*reserved*
	3	*reserved*

Table 9.2 DMA Channels and Device Selects (Part 2 of 2)

Internal DMA Operation

All DMA operations are performed by reading DMA descriptors from memory. A DMA descriptor is read from memory to determine control information when a DMA descriptor operation begins, and is written back to memory with updated status information when a DMA descriptor operation completes. As shown in Figure 9.4, a DMA descriptor consists of four words and must be word aligned.[1] The first word of a descriptor contains general DMA control and status information, such as the COUNT field which holds the number of bytes to transfer.[2] The three bit device command (DEVCMD) field is used to pass device specific control information to a peripheral at the start of a DMA descriptor operation, and to record peripheral status information at the end of a DMA descriptor operation. When a DMA descriptor operation begins, DEVCMD is read from memory and transferred to the selected device. When a DMA descriptor operation completes, updated status information is read from the selected device and written back to the DEVCMD field of the DMA descriptor in memory. The device select (DS) field selects the peripheral device to be used during the DMA descriptor operation. The encoding of this field for each of the ten DMA channels is shown in Table 9.2.

The second word of a DMA descriptor, the current address (CA) field, is initialized with the address of a data buffer to which data DMAed from a peripheral is written, or from which data DMAed to a peripheral is read. When a DMA descriptor operation begins, the starting address is loaded into a current address register in the DMA controller. After each DMA data transfer, the current address register is modified by the size of the data transfer. Thus, when a DMA descriptor operation completes, the CA field of the DMA descriptor in memory contains the address of the next data quantity to be transferred had the DMA descriptor operation not completed. For example, if CA is initialized to *x* and COUNT is initialized to *y* during

1. The address 0x0000_0000 is used to indicate the end of a DMA descriptor list. Therefore, a DMA descriptor may begin at any word address except 0x0000_0000.
2. The DMA controller supports zero length DMA operations (i.e., descriptors with the COUNT field equal to zero). Zero length DMA operations result in the transfer of DEVCMD and DEVCS as well as the updating of the DMA descriptor but cause no data to be transferred.

Notes

a DMA operation from a peripheral to memory, then the first data quantity from the peripheral would be written to physical address *x*. Assuming the DMA descriptor operation runs until the COUNT field reaches zero, the value of the CA field in memory when the DMA operation completes would be *x* + *y*.

The third word of a DMA descriptor, the device control and status (DEVCS) field, is used to pass device specific control information to a peripheral at the start of a DMA descriptor operation, and to record peripheral status information at the end of a DMA descriptor operation. When a DMA descriptor operation begins, DEVCS is read from memory and transferred to the selected device. When a DMA descriptor operation completes, updated status information is read from the selected device and written back to the DEVCS field of the DMA descriptor in memory. The fourth word of a DMA descriptor, the link (LINK) field, contains the physical address of the next DMA descriptor in a descriptor list (i.e., the next DMA descriptor in a linked list of DMA descriptors).The link field is set to zero in the last descriptor within a descriptor list.

DMA Descriptor Register

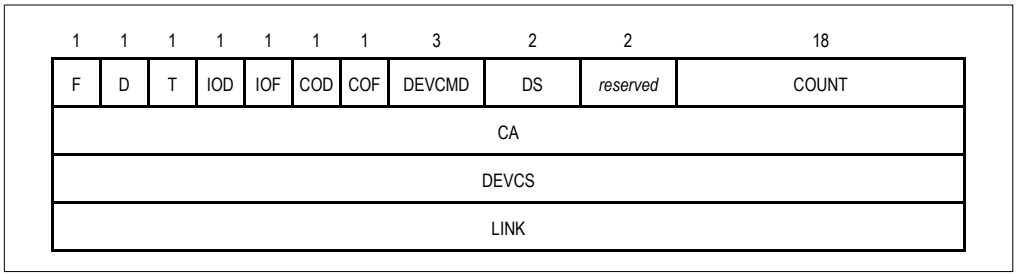


Figure 9.4 DMA Descriptor Register

F **Finished.** This bit is set when the DMA controller finishes descriptor processing due to a finished event (COUNT equal to zero). Note that this bit is not cleared if the condition did not occur. If this bit is initially set in the Descriptor Register and the condition causing the DMA transaction to stop is not related to this bit, then this bit will remain set in the DMA Descriptor written back to memory.

D **Done.** This bit is set when the DMA controller finishes descriptor processing due to a done event (selected device generates done). Note that this bit is not cleared if the condition did not occur. If this bit is initially set in the Descriptor Register and the condition causing the DMA transaction to stop is not related to this bit, then this bit will remain set in the DMA Descriptor written back to memory.

T **Terminated.** This bit is set when DMA descriptor processing is abnormally terminated. This occurs when the RUN bit in the DMA control register is cleared during a DMA operation, or when the bus transaction timer times-out during a DMA bus transaction. Note that this bit is not cleared if the condition did not occur. If this bit is initially set in the Descriptor Register and the condition causing the DMA transaction to stop is not related to this bit, then this bit will remain set in the DMA Descriptor written back to memory.

IOD **Interrupt On Done.** When this bit is set, and the DMA controller finishes descriptor processing due to a done event, then the D bit in the DMAxS register is set.

IOF **Interrupt On Finished.** When this bit is set, and the DMA controller finishes descriptor processing due to a finished event, then the F bit in the DMAxS register is set.

COD **Chain On Done.** When this bit is set, and the DMA controller finishes descriptor processing due to a done event, then the DMA controller loads the next descriptor pointed to by the DMAxNDPTR register.

COF **Chain On Finished.** When this bit is set and the DMA controller finishes descriptor processing due a finished event, then the DMA controller loads the next descriptor pointed to by the DMAxNDPTR register.

DEVCMD **Device Command.** This field is a device specific command field which is passed to the selected device at the start of a DMA operation.

DS **Device Select.** This field selects the peripheral device used during the DMA descriptor operation. See Table 9.2 on page 9-6 for the encoding of this field.

Notes

COUNT **Byte Count.** This field specifies the number of bytes to transfer during the DMA descriptor operation.

CA **Current Address.** This 32-bit field is initialized with the DMA starting address at the start of a DMA operation and is updated when descriptor processing is completed.

DEVCS **Device Control and Status.** This 32-bit field is initialized with peripheral device specific control information. When descriptor processing completes, this field is updated with peripheral specific status information.

LINK **Link.** This 32-bit field points to the next descriptor in the descriptor list.

DMA Registers

Each DMA channel has five registers. A channel is controlled by a DMA control (DMA[0..9]C) register, and the status of a DMA channel is reported in a DMA status (DMA[0..9]S) register. The bits in a DMA status register, which are not masked by the corresponding DMA status mask (DMA[0..9]SM) register, are ORed together and presented to the interrupt controller. A DMA operation is begun by writing the starting address of the first descriptor in a descriptor list into the DMA descriptor pointer (DMA[0..9]DPTR) register of a DMA channel. As a side effect of writing this register, a DMA operation begins and the run (RUN) bit in the corresponding DMAxC register is set. The DMA channel performs DMA descriptor processing, executing the dictated DMA descriptor operations until a DMA descriptor is reached with a zero in its LINK field. This signals the completion of DMA operation and causes the RUN bit in the DMAxC register to be cleared and the halt (H) bit in the DMAxS register to be set. During DMA descriptor processing, the DMAxDPTR register may be read to determine the address of the descriptor currently being processed.

DMA Stopping Conditions

A DMA descriptor operation has three stopping conditions: *finished, done*, and *terminated*. The stopping conditions which cause a descriptor operation to complete is recorded in the finished (F), done (D), and terminated (T) bits of the first word in a descriptor. When the DMA controller updates the first word of a descriptor, only the F, D, and T bits are set. For example, if the T bit was initially set in the descriptor and the DMA stopping condition was *finished*, the T bit would remain set in the descriptor written back to memory.

Finished Condition: When a DMA operation begins, the COUNT field is loaded from the descriptor in memory into a byte counter associated with the DMA channel. The byte counter is decremented by the DMA transfer size after each data transfer. The finished stopping condition occurs when the byte counter reaches zero (i.e., there are no more bytes to transfer). This causes the F bit in the DMA descriptor to be set. If the interrupt on finished (IOF) bit in the descriptor has been initialized to a one, then the F bit in the DMAxS register is also set. If the chain on finished (COF) bit in the descriptor has been initialized to a one, then a DMA chaining operation takes place.

Done Condition: The done stopping condition occurs when the selected device signals a done event. Done events allow a selected peripheral to terminate a DMA operation at an arbitrary point (for example, at the end of packet). The done stopping condition occurs when a done event is signalled by the selected peripheral device. This causes the D bit in the DMA descriptor to be set. If the interrupt on done (IOD) bit in the descriptor has been initialized to a one, then the D bit in the DMAxS register is also set. If the chain on done (COD) bit in the descriptor has been initialized to a one, then a DMA chaining operation takes place.

It is possible for a DMA descriptor operation to complete due to multiple stopping conditions. For example, it is possible to have a simultaneous finished and done stopping condition which causes both the F and D bits in the DMA descriptor to be set.

Terminated Condition: A DMA operation is halted when the RUN bit in the DMAxC register is cleared. A halted DMA operation results in a terminated stopping condition for the descriptor being processed and causes the DMA operation to complete. When this occurs, the DMA controller performs the following: discontinues the current DMA descriptor operation, sets the T bit, and updates all other status information in the descriptor. The descriptor contents are then written back to memory. When the descriptor write completes, the halt (H) bit in the DMAxS register is set to acknowledge that the DMA operation has been halted. When a DMA operation is halted by clearing the RUN bit, writes to the DMAxDPTR and DMAxNDPTR should not be performed until the halt (H) bit is set.

Notes

Note: Under certain conditions the Terminated status bit is not set. An example is when a zero length DMA operation is performed.

The DMA controller may be incorrectly programmed with an address which does not map to a valid device. When this occurs, the address space monitor reports an error to the DMA controller. If the DMA controller attempts to read a DMA descriptor from an un-decoded address, the DMA operation is terminated causing the error (E) bit and the halt (H) bit to be set in the DMAxS register and the RUN bit to be cleared the DMAxC register. If the DMA controller attempts to read or write a DMA data buffer that corresponds to an undecoded address, then the DMA operation is terminated. This results in the DMA discontinuing the current DMA descriptor operation, clearing the RUN bit in the DMAxS register, setting the T bit in the descriptor, and updating all other status information in the descriptor. Once the descriptor contents are written back to memory, the halt (H) bit and error (E) bit in the DMAxS register are set.

Clearing the RUN bit in the DMAxC register provides a means of orderly halting a DMA operation but sometimes a need exists to abort a DMA operation without cooperation from the peripheral. For example, resetting a peripheral during a DMA operation may make it impossible to halt a DMA operation since the DMA will wait indefinitely for the peripheral to supply updated DEVCS and DEVCMD values. A DMA operation may be aborted without cooperation from a peripheral by writing a one to the Abort (A) bit in the DMAxC register. This causes the DMA channel to complete the current DMA transaction on the bus if one is in progress, write back the descriptor[1] with the terminated (T) bit set, set the Halt (H) bit in the DMAxS register, and clear the run bit. If a DMA operation is aborted while the DMA is in the process of following a link or performing a chaining operation, the terminated bit will not be set in any descriptor.

DMA Request Event

A DMA request event causes a data quantum to be transferred by the DMA controller between a peripheral device and memory. The amount of data contained in a DMA quantum is defined by the DMA transfer size. The DMA transfer size is specified for each peripheral device and is the amount of data transferred by the DMA controller when it gains ownership of the IP bus.

The mode field in the DMAxC register allows the DMA to be configured to operate in one of three modes: auto request, burst request, and transfer request. In auto request mode, DMA request events generated by the selected peripheral device are ignored, and the DMA controller generates internal request events at the maximum possible rate. This causes a block of data to be transferred by the DMA controller without the need for DMA request events to be generated by the peripheral device.

In burst request mode, a DMA request event signalled by the selected peripheral device causes the DMA controller to begin internally generating request events until the DMA operation completes. Thus, in this mode the first request event generated by the peripheral signals the start of a burst transfer. This mode allows the peripheral device to externally signal the beginning of a burst DMA operation.

In transfer request mode, a DMA request event signalled by the selected peripheral device causes the DMA controller to transfer a single data quantum between the peripheral device and memory. Thus, for each data quantum of a DMA operation, the peripheral must signal to the DMA controller when the transfer should take place. All of the DMA peripheral devices internal to the RC32438 operate in transfer request mode. Configuring an internal peripheral device for auto request or burst request modes will produce undesirable consequences. External DMA operations, described later in this chapter, support all three modes.

DMA Descriptor List and Chaining

A DMA descriptor list consists of a linked list of DMA descriptors, with the LINK field of each descriptor pointing to the next descriptor in the list. The LINK field of the last descriptor in a descriptor list is zero. Descriptor list processing begins when the address of a DMA descriptor is written to the DMAxDPTR register. This causes the DMA controller to read a descriptor from memory, performs the specified DMA operation, update the descriptor status information, and follows the LINK field to the next descriptor in the descriptor list. The DMAxDPTR register may be read at any time to determine the currently active descriptor in the descriptor list.

1. Aborting a DMA operation may result in undefined values in the DEVCS and DEVCMD fields.

Notes

DMA chaining is enabled by initializing the DMA next descriptor pointer (DMAxNDPTR) with the starting address of a DMA descriptor list. When the DMA controller completes the operation associated with the last descriptor in a descriptor list, and DMA chaining is not enabled (that is, DMAxNDPTR is zero), then the halt (H) bit in the DMAxS register is set and the DMA halts. If DMA chaining is enabled, then the DMA controller loads the address in the DMAxNDPTR into the DMAxDPTR register, sets the value of the DMAxNDPTR register to zero, sets the chain (C) bit in the DMAxS register, and begins processing the descriptor pointed to by DMAxDPTR. The DMA controller continues processing descriptors until it once again reaches the end of a descriptor list, at which point the above process repeats.

An example of DMA chaining is shown in Figure 9.5. In this example DMAxDPTR is initialized with the starting address of the descriptor list ABC, and DMAxNDPTR is initialized with a pointer to the starting address of descriptor list XYZ. When the DMA controller completes the operation associated with descriptor C, the value in DMAxNDPTR is loaded into DMAxDPTR, DMAxNDPTR is set to zero, the C bit in the DMAxS register is set, and the DMA continues with the DMA operation specified by descriptor X. If the DMAxNDPTR register is not updated by the CPU during the processing of descriptor list XYZ, then the completion of the DMA operation associated with descriptor Z causes the H bit in the DMA status register to be set and the DMA to halt.

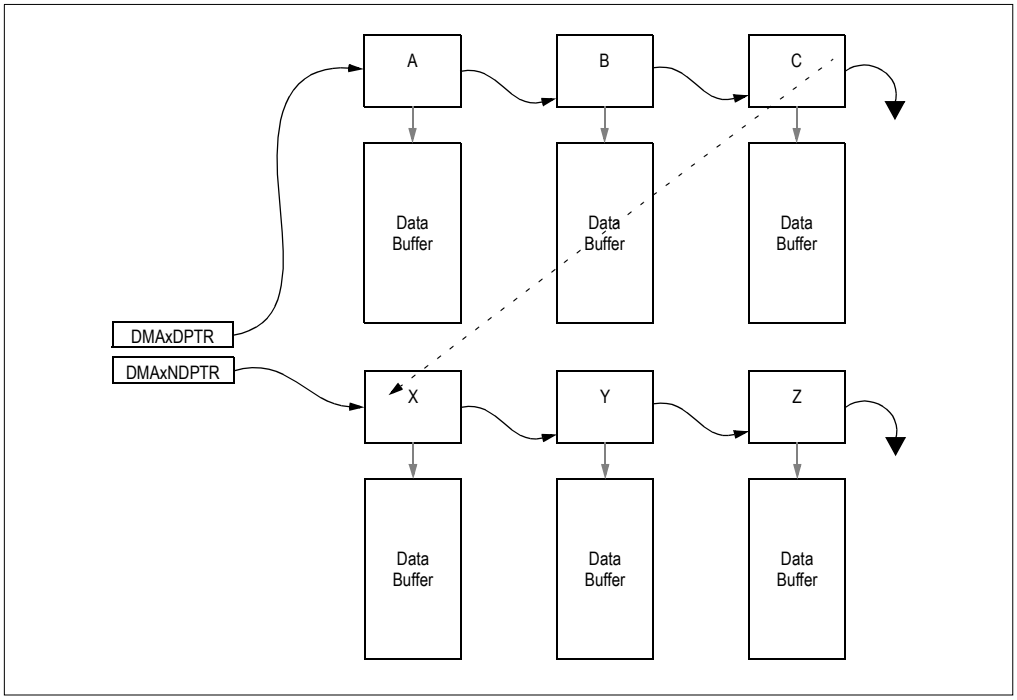


Figure 9.5 DMA Chaining Example

DMA chaining may be initiated in the middle of a descriptor list based on the descriptor stopping condition. If the chain on done (COD) bit is set in a descriptor and the DMA stopping condition for the descriptor is due to a done event, DMA chaining takes place. This causes the DMA controller to stop processing descriptors in the current descriptor list and to continue with those in the descriptor list pointed to by DMAxNDPTR. If DMAxNDPTR is zero, the DMA halts. Finished events may also be programmed to cause DMA chaining. If the chain on finished (COF) bit is set in a descriptor and the DMA stopping condition for the descriptor is due to a finished event, DMA chaining occurs.

Writing to the DMAxNDPTR register while the DMA is running (i.e., the RUN bit is set) simply modifies the value of the register. Writing to the DMAxNDPTR register while the DMA is not running (i.e., the RUN bit is cleared) not only modifies the value of DMAxNDTPR but also causes a chaining operation to take place. This causes: DMAxNDPTR to be loaded into DMAxDPTR, the value of DMAxNDPTR to be set to zero, the chain (C) bit to be set, the RUN bit to be set, and a DMA operation to begin.

Notes

DMA [0..9] Control Register

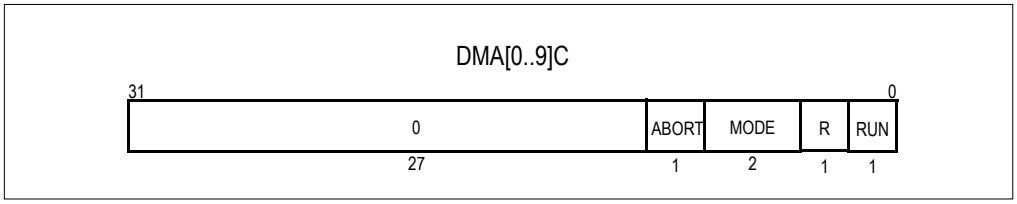


Figure 9.6 DMA [0..9] Control Register (DMA[0..9]C)

RUN

Description: RUN. This bit is automatically set to a one when a DMA operation begins (i.e., when a value is written into the DMAxDPTR register). If this bit is set, writing a zero into it halts DMA descriptor processing. The halting of DMA descriptor processing is acknowledged when the H bit in the DMAxS register is set. When the RUN bit is cleared, writes should not be performed to the DMAxDPTR and DMAxNDPTR registers until the H bit is set.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Writing a one has no effect; writing a zero clears the bit if it is set.

R

Description: **Reserved.** This bit performs no function.

Initial Value: Undefined. Must be set to zero.

Read Value: NA

Write Effect: NA

MODE

Description: **DMA Mode.** This field controls the operating mode of external DMA operations. All other DMA operations ignore this field and use Transfer Request Mode.
0 **Auto Request Mode**. In this mode, DMA request events from the selected device are ignored and the DMA controller automatically generates a continuous request event.
1 **Burst Request Mode**. In this mode, a DMA request event from the selected device initiates a burst transfer (i.e., the transfer automatically progresses until a done or finished event). When the DMA controller observes a request event, it automatically generates a continuous request event for the remainder of the DMA operation.
2 **Transfer Request Mode**. In this mode, a DMA request event signals that a DMA transfer is requested. The amount of data moved by the DMA is defined by the DMA transfer size for the selected device.
3 ***Reserved***

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Notes

ABORT

Description: **Abort.** Writing a one to this field causes the DMA controller to abort the current DMA operation if one is in progress. The aborting of a DMA operation is acknowledged when the H bit in the DMAxS register is set. When a DMA operation is in the process of being aborted, writes should not be performed to the DMAxDPTR and DMAxNDPTR registers until the H bit is set.
Aborting a DMA operation may result in an undefined value in the DEVCS and DEVCMD fields of the descriptor currently being processed. In addition, the associated peripheral may be left in an undefined state. Therefore, the corresponding peripheral should always be reset following the abortion of a DMA operation.[1]

Initial Value: Undefined

Read Value: 0x0

Write Effect Writing a one to this field causes the DMA controller to abort the current DMA operation.

1. Following the abortion of a memory to memory DMA operation, the DMA holding FIFO may contain undefined data. This data must be emptied by initiating DMA operations to empty the FIFO.

DMA [0..9] Status Register

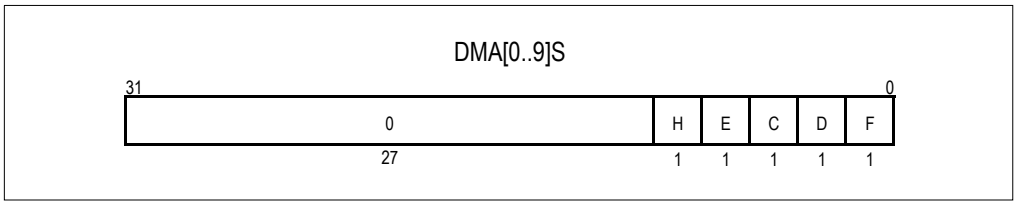


Figure 9.7 DMA [0..9] Status Register (DMA[0..9]S)

F

Description: **Finished.** This bit is set when a descriptor with the IOF bit set completes due to a finished event.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

D

Description: **Done.** This bit is set when a descriptor with the IOD bit set completes due to a done event.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

C

Description: **Chain.** This bit is set when a descriptor chaining operation takes place.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

E

Description: **Error.** This bit is set when an error is detected by the DMA during descriptor processing.

Notes

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

H

Description: **Halt.** This bit is set when the DMA halts descriptor processing and is idle.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

DMA [0..9] Status Mask Register

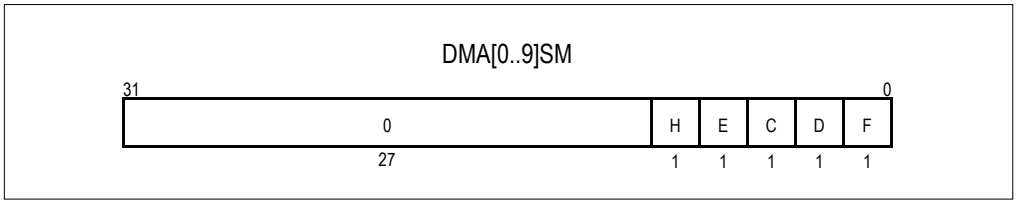


Figure 9.8 DMA [0..9] Status Mask Register (DMA[0..9]SM)

F

Description: **Finished.** When this bit is set, the F bit in the DMAxS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

D

Description: **Done.** When this bit is set, the D bit in the DMAxS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

C

Description: **Chain.** When this bit is set, the C bit in the DMAxS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

E

Description: **Error.** When this bit is set, the E bit in the DMAxS register is masked from generating an interrupt.

Notes

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

H

Description: **Halt.** When this bit is set, the H bit in the DMAxS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

DMA [0..9] Descriptor Pointer Register

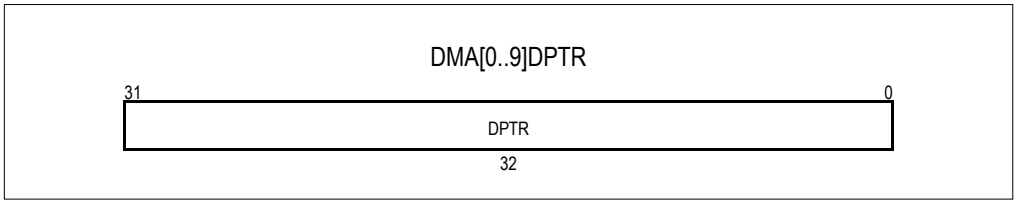


Figure 9.9 DMA [0..9] Descriptor Pointer Register (DMA[0..9]DPTR)

DPTR

Description: **Descriptor Pointer.** This 32-bit field is written with the physical address of the first descriptor in a descriptor list. Writing a value to this register automatically starts DMA descriptor processing and causes the RUN bit in the DMAxC register to be set. This register should not be modified while the DMA is active (i.e., the RUN bit is set). The value read from this register is the address of the currently active DMA descriptor if the DMA is running or the address of the last descriptor processed if the DMA has halted.
Writing a zero to this field modifies its contents but does not cause DMA descriptor processing to start.
The NDPTR field in the DMAxNDPTR register should be initialized to zero prior to initializing the DPTR field since writing a descriptor address to DPTR will start DMA descriptor processing.

Initial Value: Undefined

Read Value: Physical address of currently active descriptor or last descriptor processed

Write Effect: Modify value and start DMA operation

DMA [0..9] Next Descriptor Pointer Register

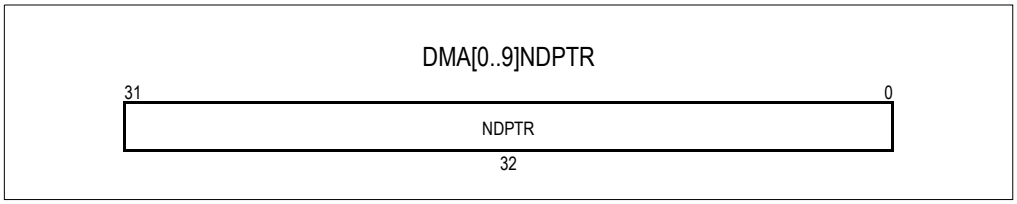


Figure 9.10 DMA [0..9] Next Descriptor Pointer Register (DMA[0..9]NDPTR)

Notes

NDPTR

Description: **Next Descriptor Pointer.** This 32-bit field contains the address of the first descriptor in the descriptor list to be used for chaining. If this field is a zero, DMA chaining is disabled.
Writing to this register when the DMA is not running causes the DMA to start and a chaining operation to take place.
Writing a zero to this field modifies its contents but does not cause DMA descriptor processing to start.

Initial Value: Undefined

Read Value: Address of next descriptor in descriptor chain

Write Effect: Modify value

External DMA Operations

An external DMA operation is one in which the DMA controller is used to transfer data between an external peripheral and memory. The DMA controller supports two external DMA channels: external DMA channel 0 (uses DMA channel 0) and external DMA channel one (uses DMA channel 1).

The DMA descriptor DS field is used to select the direction of the DMA transfer. When DS is zero, data is transferred from the external peripheral to memory. When the DS field is one, data is transferred from memory to the external peripheral.

The DMA descriptor DEVCS field, shown in Figure 9.11, holds the address of the external DMA peripheral. The DMA descriptor DEVCMD field, shown in Figure 9.12, contains a Transfer Size (TS) field that specifies the DMA transfer burst size for external peripherals. The width of the TS field must be greater than or equal to the width of the external DMA peripheral. During DMA burst transactions on the memory and peripheral bus, the address field remains constant throughout the entire transaction and is equal to the value in the Peripheral Address (ADDR) field.

Device Control and Status Field for External DMA

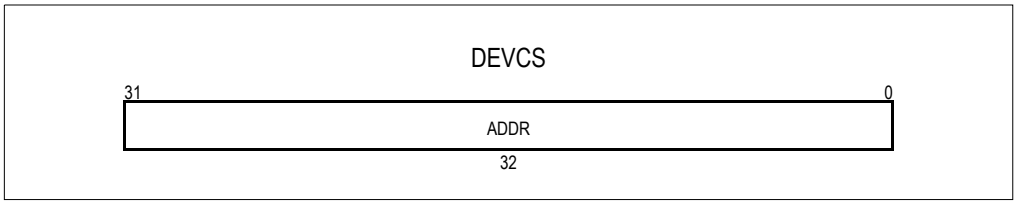


Figure 9.11 Device Control and Status Value for External DMA Descriptors

ADDR **Peripheral Address.** This 32-bit field specifies the address of the external DMA peripheral. The address must map to a device on the memory and peripheral bus. The address should be aligned to the size of the external DMA peripheral (e.g., address bit zero must be zero for a 16-bit external DMA peripheral).

Device Command Field for External DMA

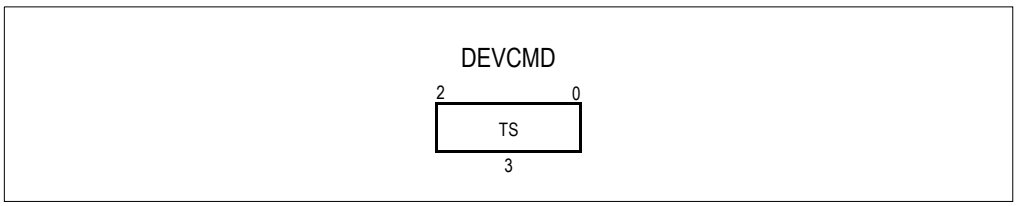


Figure 9.12 Device Command Field for External DMA Descriptors

Notes

TS **Transfer Size.** This field specifies the DMA burst transfer size used to access the external peripheral.
0 - byte
1 - halfword
2 - word
3 - 2 words
4 - 4 words
5 - 6 words
6 - 8 words
7 - 16 words

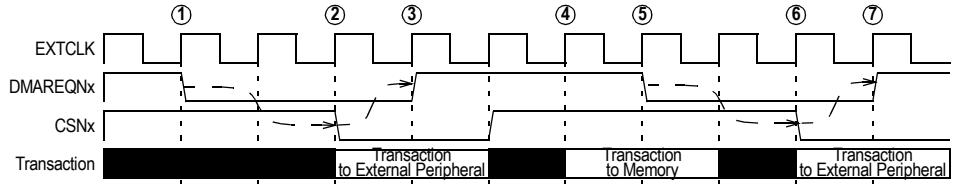
DMA Request Event	Assertion of DMAREQNx pin.
DMA Done Event	Assertion of DMADONENx pin.
DMA Terminated Event	An external device cannot signal a terminated event.
DMA Transfer Size	Value programmed in the transfer size (TS) field of DEVCMD.
Limitations	The width of the TS field must be greater than or equal to the width of the external DMA peripheral.

Table 9.3 External DMA Operations

An external peripheral generates a DMA request event by asserting a DMA request (DMAREQNx) input. The DMAREQNx inputs are GPIO alternate functions (see Chapter 12, General Purpose I/O Controller).

Transfer Request: When the DMA is configured to operate in transfer request mode, a DMA request instructs the DMA controller to perform one burst transaction to the external peripheral address in DEVCS. The size of the burst transfer is selected in the TS field.

The assertion of chip select to the external peripheral acknowledges the DMA request and causes the external peripheral to negate DMAREQNx. When the external peripheral samples chip select negated, it may once again assert DMAREQNx. An example of a peripheral-to-memory external DMA operation in transfer request mode is shown in Figure 9.13

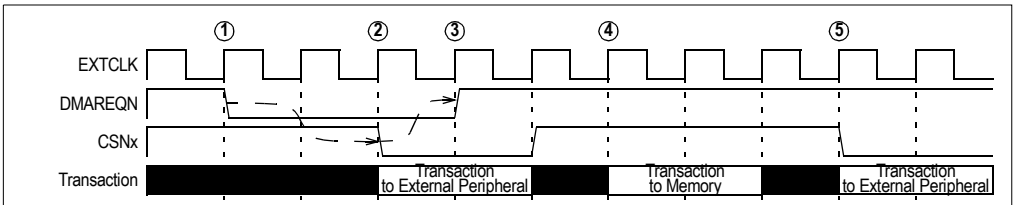


1. DMA requests data transfer by asserting DMAREQNx
2. The RC32438 acknowledges DMA request by asserting chip select (CSNx) to external peripheral. DMA controller reads a transfer size data quantity from the external peripheral
3. External peripheral reacts to acknowledgment of DMA request (i.e., assertion of chip select) by negating DMAREQNx
4. DMA controller writes data quantity read from external peripheral to memory
5. DMA requests next data transfer by asserting DMAREQNx
6. The RC32438 acknowledges next DMA request by asserting chip select and reading a transfer size data quantity from the external peripheral
7. External peripheral reacts to acknowledgement of DMA request by negating DMAREQNx.

Figure 9.13 External DMA Operation (Transfer Request Mode)

Burst Request: When the DMA is configured to operate in burst request mode, then the first DMA request initiates the entire DMA transfer between the external peripheral and memory. An example of a peripheral-to-memory DMA operation in burst request mode is shown in Figure 9.14.

Notes



1. DMA requests data transfer by asserting DMAREQNx
2. The RC32438 acknowledges DMA request by asserting chip select (CSNx) to external DMA peripheral and performing the burst transfer specified in the TS field.
3. External peripheral reacts to acknowledgment of DMA request by negating DMAREQNx
4. DMA controller writes data quantity read from external peripheral to memory
5. DMA controller performs remaining transfers in DMA operation without further DMA requests. A DMA operation is completed when the byte count reaches zero or DMADONENx is asserted.

Figure 9.14 External DMA Operation (Burst Request Mode)

The DMA done (DMADONENx) inputs are GPIO alternate functions (see Chapter 12, General Purpose I/O Controller) may be asserted by an external peripheral to signal a done event to the DMA controller. As shown in Figure 9.15, during external peripheral read operations, DMADONENx is sampled on the same clock edge as the data. As shown in Figure 9.16, during external peripheral write operations, DMADONENx is sampled on the same clock edge as the byte writes are negated. The DMADONEx inputs are only sampled in the last data transfer on the memory and peripheral bus of a burst transfer. In other words, if the specified transfer size results in multiple memory and peripheral bus data transfers, the external peripheral can only signal a done event during the last data transfer of the burst.

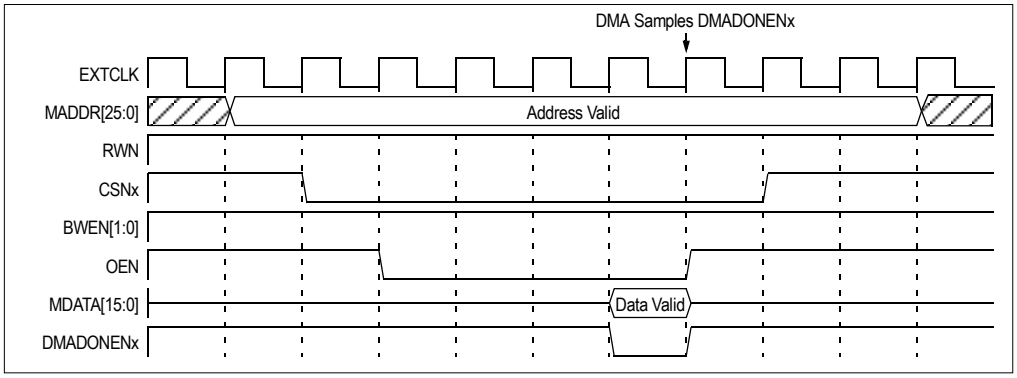


Figure 9.15 Sampling of DMADONENx During External Peripheral Read Transactions

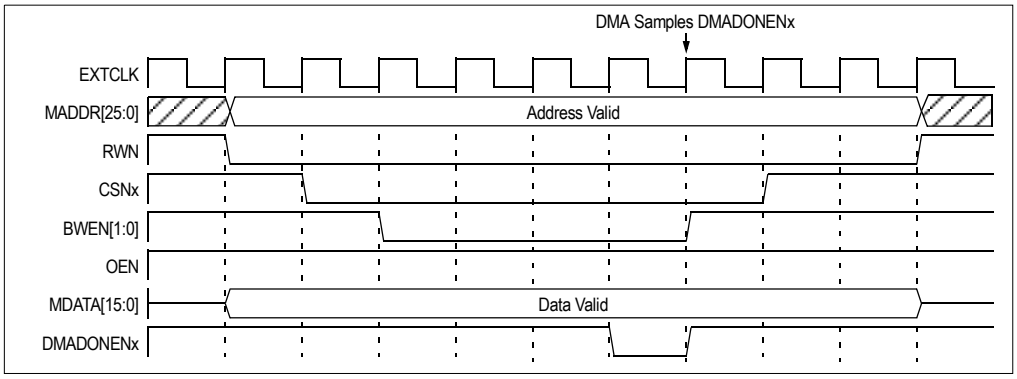


Figure 9.16 Sampling of DMADONENx During External Peripheral Write Transactions

The DMA finished (DMAFINNx) outputs are GPIO alternate functions (See Table 12.1 in Chapter 12, General Purpose I/O Controller). A DMA finished output is asserted by the DMA controller to signal a finished event to an external peripheral. During a read transaction, DMAFINNx is asserted for one clock

Notes

cycle corresponding to a clock edge during which the final data quantity is read (i.e., the data quantity that causes the byte counter to reach zero). This is shown in Figure 9.17 for a non-burst read transaction. During a write transaction, DMAFINNx is asserted throughout the entire transaction in which the byte counter reaches zero. This is shown in Figure 9.18.

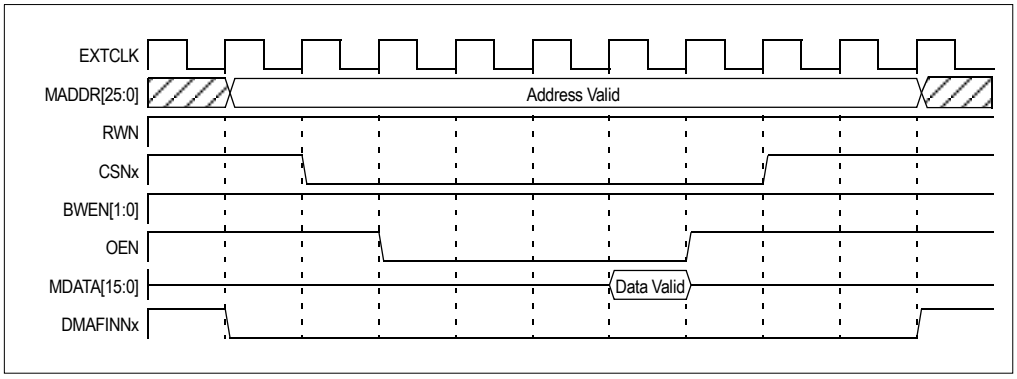


Figure 9.17 Assertion of DMAFINNx During External Peripheral Read Transactions

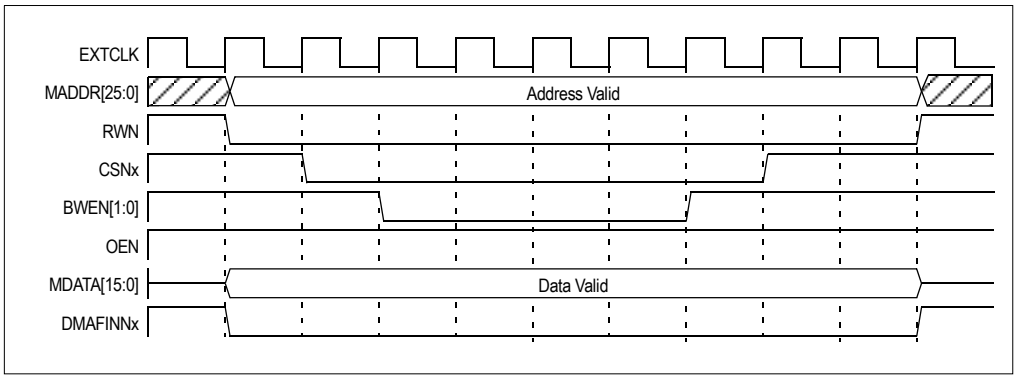


Figure 9.18 Assertion of DMAFINNx During External Peripheral Write Transactions

Memory to Memory DMA Operations

A FIFO between DMA channels six and seven allows the DMA controller to be used for memory to memory DMA transfers. When DMA channel six device zero is selected, data is read from memory and written into a DMA FIFO. When DMA channel seven device zero is selected, data is read from the DMA FIFO and written to memory. Thus, by using these DMA channels together, data may be DMAed from memory to memory.

The DMA FIFO allows burst transfers of up to 16 words (64-bytes) to be buffered between DMA channels six and seven. The DMA channel six and seven descriptor DEVCMD field, shown in Figure 9.12, contains a Transfer Size (TS) field that specifies the DMA transfer burst size. The DMA transfer burst size for the two DMA channels need not be the same values.

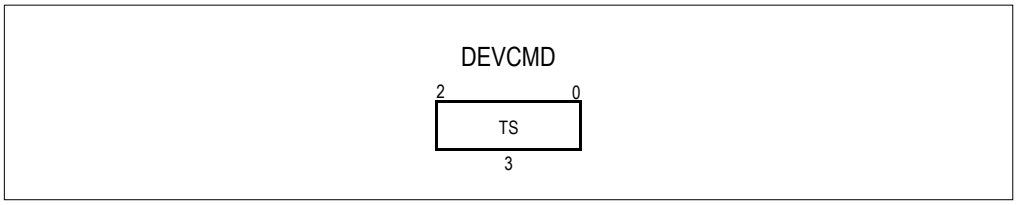


Figure 9.19 Device Command Field for Memory to Memory DMA Descriptors

Notes

TS **Transfer Size.** This field specifies the DMA burst transfer size used to access memory during memory to memory DMA operations.
0 - Reserved
1 - Reserved
2 - word
3 - 2 words
4 - 4 words
5 - 6 words
6 - 8 words
7 - 16 words

The DEVCS field is not used during memory to memory DMA operations. Table 9.4 summarizes the memory to DMA FIFO DMA operations and Table 9.5 summarizes DMA FIFO to memory DMA operations.

DMA Request Event	DMA FIFO has room for a burst transfer of the size specified by the TS field.
DMA Done Event	DMA done event is never generated.
DMA Terminated Event	DMA terminated event is never generated by the FIFO.
DMA Transfer Size	The DMA controller will attempt to transfer a burst of the size specified in the TS field from memory to the DMA FIFO. Fewer words will be transferred if the byte count reaches zero.
Limitations	None. A DMA operation may start and end on any byte boundary and may contain any number of words.

Table 9.4 Memory to DMA FIFO DMA Operations

DMA Request Event	DMA FIFO contains enough data for a burst transfer of the size specified by the TS field, or the last word of a DMA operation has been transferred to the FIFO.
DMA Done Event	DMA done event is never generated.
DMA Terminated Event	DMA terminated event is never generated.
DMA Transfer Size	The DMA controller will attempt to transfer a burst of the specified size in the TS field from the DMA FIFO to memory. Fewer words will be transferred if the byte count reaches zero, or the last word of a DMA operation has been transferred to the FIFO.
Limitations	None. A DMA operation may start and end on any byte boundary and may contain any number of words.

Table 9.5 DMA FIFO to Memory DMA Operations

Examples

Example 1: DMA operation using one descriptor list
(program DMAxDPTR register)

```
Set up interrupt controller
Set up descriptor

DMAxNDPTR = 0
DMAxDPTR = starting address of the descriptor list
while (DMA done or finished interrupt is not detected) {
  perform DMA descriptor operation
  DMA updates descriptor status
```

Notes

DMA follows LINK field to next DMA descriptor
}

Read the status from DMAxS register and descriptors

Example 2: DMA operation using one descriptor list
(program DMAxNDPTR register)

Set up interrupt controller
Set up descriptor

DMAxNDPTR = starting address of the descriptor list
while (DMA done or finished interrupt is not detected) {
perform DMA descriptor operation
DMA updates descriptor status
DMA follows LINK field to next DMA descriptor
}

Read the status from DMAxS register and descriptors

Example 3: DMA operation using multiple descriptor lists
(program DMAxNDPTR register)

Set up interrupt controller
Set up descriptors

DMAxNDPTR = starting address of the first descriptor list

while (DMA transfer is not completed) {
while (DMA chain interrupt is not detected) {
prepare the next descriptor list
}

clear the chain bit in DMAxS register
DMAxNDPTR = starting address of the next descriptor list
}

Example 4: DMA operation using multiple descriptor lists
(program DMAxDPTR & DMAxNDPTR register)

Set up interrupt controller
Set up descriptors

DMAxNDPTR = 0
DMAxDPTR = starting address of the first descriptor list

Notes

DMAxNDPTR = starting address of the second descriptor list

```
while (DMA transfer is not completed) {
    while (DMA chain interrupt is not detected) {
      prepare the next descriptor list
    }

    clear the chain bit in DMAxS register
    DMAxNDPTR = starting address of the next descriptor list
}
```

PCI Bus Interface

Notes

Introduction

PCI bus interface complies with PCI Local Bus Specification Revision 2.2 and provides a bus bridge between the RC32438's internal IPBus and the PCI bus. The PCI bus interface may be configured to operate in host or satellite mode. This is controlled by the PCI mode selected during boot configuration. The operating mode can be determined by reading the PCI Mode (PCIM) field in the PCIC register.

The PCI clock is always an input and may be asynchronous to the master clock input. The PCI interface supports operation at frequencies from 16 MHz to 66 MHz. The PCI clock may be stopped and there is no minimum master clock to PCI clock ratios. The interface implements 3.3V PCI compliant pads. The PCI bus interface never merges separate writes into a single transaction.

Figure 10.1 shows a block diagram of the PCI bus interface.

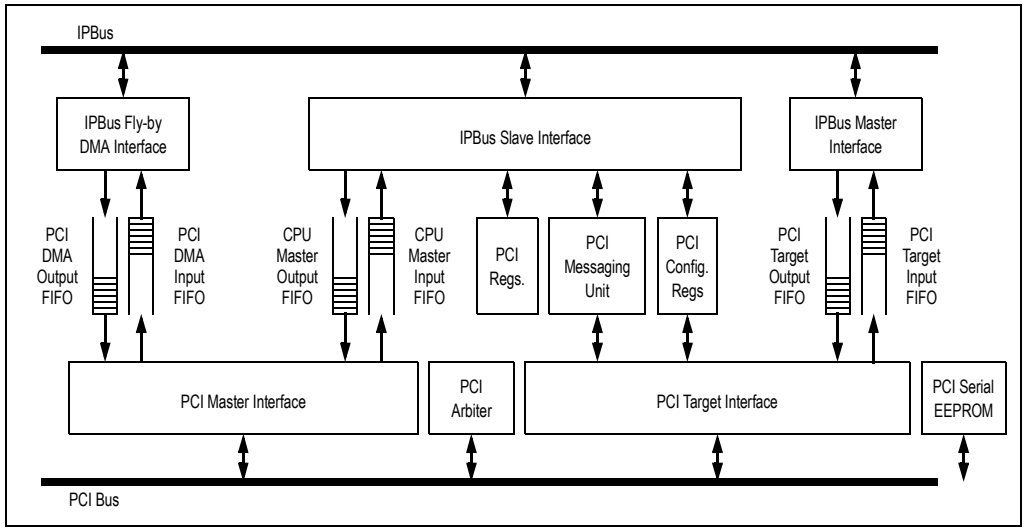


Figure 10.1 PCI Interface Block Diagram

Features

- *32-bit PCI revision 2.2 compliant*
- *Supports host or satellite operation in both master and target modes*
- *PCI clock*
  - *Supports PCI clock frequencies from 16 MHz to 66 MHz*
  - *PCI clock may be asynchronous to master clock (CLK)*
- *PCI arbiter in Host mode*
  - *Supports 6 external masters*
  - *Fixed priority or round robin arbitration*
  - *Bus parking*
- *I_2O "like" PCI Messaging Unit*

Notes

Use of Decoupled PCI Transactions

The PCI portion of the system controller sits on the IPBus. Therefore, read and write transactions to and from this block consume some of the available IPBus bandwidth and must be factored into the overall system bus utilization for a given system. To maximize performance, the number of local IPBus cycles consumed for a given transaction should be minimized. The PCI system controller is designed to automatically do this for most types of transactions.

In the case of DMA operations to or from the PCI, the transaction is initiated by the DMA. Prior to taking control of the IPBus, the DMA automatically waits for the data to become available in the master read case or for space to be available in the output FIFO for the master write case. This prevents the DMA from wasting bandwidth sitting on the IPBus waiting for data to become available. In the case of target reads and target writes from an external PCI master to the RC32438 as a PCI target, data is fetched or queued efficiently. No user intervention is required.

However, in the case where the CPU core rather than the DMA controller initiates a master read or a master write, users must be careful not to monopolize the IPBus which will reduce available bandwidth. The RC32438 contains the following mechanism for decoupling both CPU master reads and CPU master writes.

In the master write case, the CPU core can check the status of the master write FIFO prior to beginning the write via the OFE (Output FIFO Empty) bit, bit[3], of the PCI Decoupled Access Status Register (PCIDAS). If this bit is set, the FIFO is empty. Then the CPU core can safely initiate a master write or a burst of 4 writes, since enough space is guaranteed for the transaction to be queued immediately without stalling the IPBus.

In the master read case, the user can enable the Decoupled Access Mode via the DEN bit in the PCI Decoupled Access Control Register (PCIDAC). When the DEN bit is set, any master read to the PCI memory space will return a "0" immediately. The program can then either rely on polling or use an interrupt generated from the PCI Decoupled Access Status Register (PCIDAS) Done bit (D) to indicate that the read has been completed. Upon completion, the data will be available in the PCI Decoupled Access Data Register (PCIDAD).

If the user opts not to enable this mode, some amount of efficiency will be lost waiting for CPU-initiated master reads to complete. In most applications, this is probably acceptable as the number of CPU-initiated master reads is generally small. However, in the case of PCI bridges, failure to use the decoupled master read mechanism could result in the read timing out and causing a bus error. This error occurs when the CPU core attempts a master read while the bridge has data queued in its write FIFO and is attempting to initiate target writes to the RC32438 device to clear the queue. The bridge will pass the read to the device on the other side, but when that target PCI device returns the requested read data to the bridge, the bridge will hold the data until the bridge manages to clear its write FIFO. However, since the CPU core is not using decoupled reads, the CPU holds the IPBus until the transaction completes. As long as the CPU is sitting on the IPBus, the bridge can only do writes until the target write FIFO fills up on the RC32438. When the target write FIFO is full, the RC32438 refuses to take any further target writes. The RC32438 cannot empty the target write FIFO — the IPBus must do that — and the CPU continues to wait for the read to complete. Because the RC32438 will not take any more target writes and the bridge will not pass the read data through until it completes its writes, the RC32438 and the bridge are now "deadlocked".

The deadlock will only be broken when the RC32438 PCI master transaction retry counter is exceeded. At that point, the system will generate a bus error. The interrupt handler must correct the problem. This obviously imposes a significant performance penalty.

Therefore, IDT strongly recommends the use of decoupled master reads and checking the status of the output FIFO empty bit prior to generating CPU-initiated master reads or master writes, especially when the RC32438 is being used with a PCI bridge.

IPBus Access

Access to the IPBus is determined by the IPBus arbiter.

Notes

The PCI interface contains six FIFOs. The PCI DMA output FIFO is used for memory to PCI DMA operations. The PCI DMA input FIFO is used for PCI to memory DMA operations. The IPBus master output FIFO is used for IPBus master (e.g., CPU) PCI write operations while the IPBus master input FIFO is used for IPBus master PCI read operations. The PCI target output FIFO is used for external PCI master reads of the RC32438 local address space while the PCI target input FIFO is used for external PCI master writes to the RC32438 local address space.

FIFO	Size
PCI DMA Output FIFO	64 words
PCI DMA Input FIFO	64 words
CPU Master Output FIFO	4 words
CPU Master Input FIFO	8 words
PCI Target Output FIFO	64 words
PCI Target Input FIFO	64 words

Table 10.1 PCI Bus Interface FIFO Sizes

PCI Register Description

Register Offset[1]	Register Name	Register Function	Size
PCI Bus Interface			
0x08_0000	PCIC	PCI control	32-bit
0x08_0004	PCIS	PCI status	32-bit
0x08_0008	PCISM	PCI status mask	32-bit
0x08_000C	PCICFGA	PCI configuration address	32-bit
0x08_0010	PCICFGD	PCI configuration data	32-bit
0x08_0014	PCILBA0	PCI local base address 0	32-bit
0x08_0018	PCILBA0C	PCI local base address 0 control	32-bit
0x08_001C	PCILBA0M	PCI local base address 0 mapping	32-bit
0x08_0020	PCILBA1	PCI local base address 1	32-bit
0x08_0024	PCILBA1C	PCI local base address 1 control	32-bit
0x08_0028	PCILBA1M	PCI local base address 1 mapping	32-bit
0x08_002C	PCILBA2	PCI local base address 2	32-bit
0x08_0030	PCILBA2C	PCI local base address 2 control	32-bit
0x08_0034	PCILBA2M	PCI local base address 2 mapping	32-bit
0x08_0038	PCILBA3	PCI local base address 3	32-bit
0x08_003C	PCILBA3C	PCI local base address 3 control	32-bit
0x08_0040	PCILBA3M	PCI local base address 3 mapping	32-bit
0x08_0044	PCIDAC	PCI decoupled access control	32-bit
0x08_0048	PCIDAS	PCI decoupled access status	32-bit

Table 10.2 PCI Register Map (Part 1 of 2)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x08_004C	PCIDASM	PCI decoupled access status mask	32-bit
0x08_0050	PCIDAD	PCI decoupled access data	32-bit
0x08_0054	PCIDMA8C	PCI DMA channel 8 configuration	32-bit
0x08_0058	PCIDMA9C	PCI DMA channel 9 configuration	32-bit
0x08_005C	PCITC	PCI target control	32-bit
0x08_0060 through 0x08_7FFF	Reserved		
PCI Messaging Unit			
0x08_8000 through 0x08_800C	Reserved		
0x08_8010	PCIIM0	PCI Inbound Message 0	32-bit
0x08_8014	PCIIM1	PCI Inbound Message 1	32-bit
0x08_8018	PCIOM0	PCI Outbound Message 0	32-bit
0x08_801C	PCIOM1	PCI Outbound Message 1	32-bit
0x08_8020	PCIID	PCI Inbound Doorbell	32-bit
0x08_8024	PCIIIC	PCI Inbound Interrupt Cause	32-bit
0x08_8028	PCIIIM	PCI Inbound Interrupt Mask	32-bit
0x08_802C	PCIOD	PCI Outbound Doorbell	32-bit
0x08_8030	PCIOIC	PCI Outbound Interrupt Cause	32-bit
0x08_8034	PCIOIM	PCI Outbound Interrupt Mask	32-bit
0x08_8038 through 0x8_FFFF	Reserved		

Table 10.2 PCI Register Map (Part 2 of 2)

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

PCI Control Register

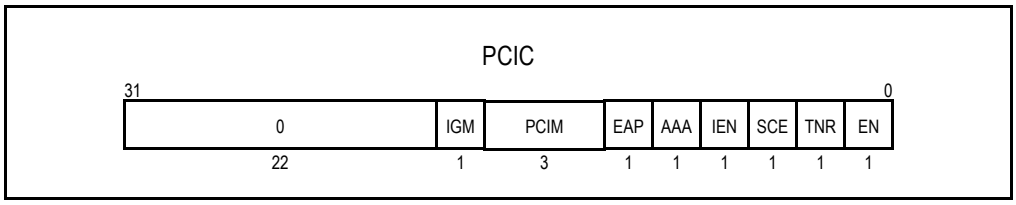


Figure 10.2 PCI Control Register (PCIC)

EN

Description: **Enable.** When this bit is set, the PCI bus interface is enabled. When this bit is cleared, the PCI bus interface is disabled and enters a benign low power mode. While in this mode, all transactions except for configuration accesses will be ignored. Configuration accesses will receive a retry response. Disabling and then re-enabling the PCI bus interface resets all of the logic associated with the PCI bus interface.

Notes

Initial Value: The enable bit is set when the PCI mode boot configuration selects a PCI satellite mode. In all other modes, the enable bit is cleared. See PCI mode boot configuration in Table 3.3 of Chapter 3.
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Previous value written

Write Effect: Modify value

TNR

Description: **Target Not Ready.** When this bit is set, the PCI bus interface issues a retry to all target transactions. When this bit is set, delayed reads are never performed.
0x0 - Normal operation
0x1 - Target not ready (retry all target transactions)

Initial Value: See PCI mode boot configuration inTable 3.3 of Chapter 3.

Read Value: Previous value written

Write Effect: Modify value

SCE

Description: **Suspend CPU Execution**. When this bit is set, CPU execution is suspended.

Note: Software should never set this bit because it may cause the system to lock-up.

Initial Value: See PCI mode boot configuration in Table 3.3 of Chapter 3.
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Previous value written

Write Effect: Modify value

IEN

Description: **IPBus Error Enable**. When this bit is set, the PCI interface will signal IPBus slave acknowledge errors during CPU master read transactions when an error occurs. When this bit is cleared, IPBus slave acknowledge errors are masked.

Initial Value: 0x1
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Previous value written

Write Effect: Modify value

AAA

Description: **Arbiter Arbitration Algorithm**. When the PCI bus interface is configured to operate in PCI host with internal arbiter mode, this bit selects the arbitration algorithm used by the internal arbiter. This bit has no effect in PCI satellite mode or in PCI host mode using an external arbiter.
0x0 - Round robin arbitration algorithm
0x1 - Fixed priority arbitration algorithm

Notes

Initial Value: See PCI mode boot configuration in Table 3.3 of Chapter 3.
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Previous value written

Write Effect: Modify value

EAP

Description: **Enable Arbiter Parking**. When this bit is set and the PCI bus interface is configured to operate in PCI host mode with an internal arbiter, then PCI bus parking is enabled. Enabling bus parking causes the internal PCI arbiter to "park" the bus on the last master granted the bus as long as no other master requests the bus.

Initial Value: 0x0
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Previous value written

Write Effect: Modify value

PCIM

Description: **PCI Mode**. This field indicates the PCI operating mode selected during boot configuration.
0x0 - Disabled (EN bit in PCIC register is cleared)
0x1 - PCI satellite mode with PCI target not ready
0x2 - PCI satellite mode with suspended CPU execution
0x3 - PCI host mode with external arbiter
0x4 - PCI host mode with internal arbiter using fixed priority arbitration algorithm
0x5 - PCI host mode with internal arbiter using round robin arbitration algorithm
0x6 - reserved
0x7 - reserved

Initial Value: See PCI mode boot configuration in Table 3.3 of Chapter 3.

Read Value: Status

Write Effect: Read-only

IGM

Description: **Idle Grant Mode**. This bit controls the operation of the internal arbiter when the PCI interface is configured to operate in a PCI host mode with internal arbiter. When the internal arbiter is used and this bit is cleared, the arbiter operates in a static idle grant mode. This means that once a grant is asserted to a given master, the grant will remain asserted until the requested transaction completes and 16 PCI clock cycles have elapsed. When the internal arbiter is used and this bit is set, the arbiter operates in a dynamic idle grant mode. This means that while the PCI bus is idle, the arbiter may take away a grant from one master and pass it to another. For optimal PCI throughput, this bit should be set to one.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI Status Register

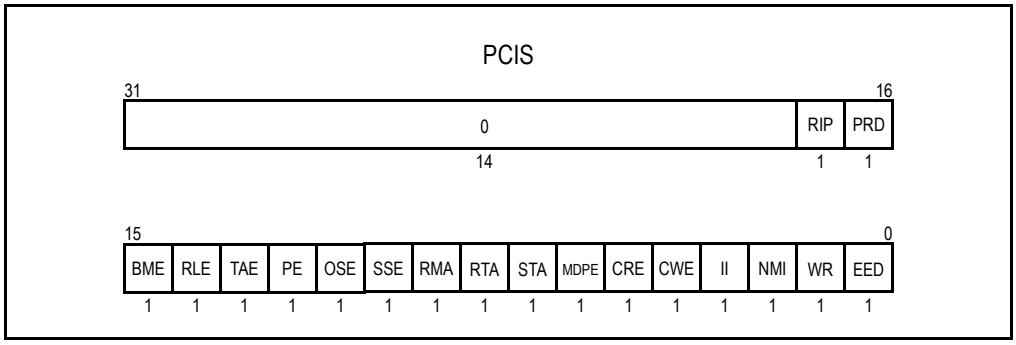


Figure 10.3 PCI Status Register (PCIS)

EED

Description: **PCI Serial EEPROM Done.** This bit is set while the PCI bus interface has completed using the PCI serial EEPROM interface. After a cold reset in PCI satellite mode with suspended CPU execution, this bit is cleared and remains cleared until the PCI interface completes loading configuration information from the PCI serial EEPROM. This bit is always cleared in the other PCI modes.

Initial Value: 0x0

Read Value: Status

Write Effect: Read only

WR

Description: **Warm Reset.** This bit is set when a PCI master or the CPU writes a one to the Warm Reset (WR) bit in the PCI Management (PMGT) register. The state of this bit is preserved across warm resets.

Initial Value: 0x0
(A warm reset does not modify this field except under the following conditions: the warm reset occurs as a result of the assertion of the PCI reset signal and the RC32438 is operating in PCI satellite mode. When a warm reset occurs under the above conditions, this field takes on its initial value.)

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

NMI

Description: **Non-maskable Interrupt.** This bit is set when a PCI master or the CPU writes a one to the Non-maskable Interrupt (NMI) bit in the PCI Management (PMGT) register.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

II

Description: **Inbound Interrupt.** This bit represents the OR of all of the bits in the PCI Inbound Interrupt Cause (PCIIC) register which are not masked in the PCI Inbound Interrupt Mask (PCIIM) register.

Initial Value: 0x0

Notes

Read Value: Status

Write Effect: Read only

CWE

Description: **CPU Write Error.** This bit is set if a CPU PCI write transaction experienced an error and the IPBus Error Enable (IEN) bit is set in the PCIC register.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

CRE

Description: **CPU Read Error.** This bit is set if a CPU PCI read transaction experienced an error and the IPBus Error Enable (IEN) bit is set in the PCIC register.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

MDPE

Description: **Master Data Parity Error Detected.** This bit is set whenever the MDPE bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

STA

Description: **Signalled Target Abort Status.** This bit is set whenever the STA bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

RTA

Description: **Received Target Abort Status.** This bit is set whenever the RTA bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit. When set, this bit cannot be cleared until the corresponding bit in the Status Register is cleared.

RMA

Description: **Received Master Abort Status.** This bit is set whenever the RMA bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Notes

Read Value: Status

Write Effect: Sticky bit. When set, this bit cannot be cleared until the corresponding bit in the Status Register is cleared.

SSE

Description: **Signalled System Error.** This bit is set whenever the SSE bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

OSE

Description: **Observed System Error.** This bit is set whenever a system error is observed on the PCI bus (i.e., the SERRN pin is asserted).

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

PE

Description: **Parity Error.** This bit is set whenever the PE bit in the PCI Configuration STATUS register is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

TAE

Description: **Target Address Error.** This bit is set if the PCI bus interface terminates a target transaction with a Target Abort due to an invalid transaction local address reported by the address space monitor.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

RLE

Description: **Retry Limit Exceeded.** This bit is set if the PCI bus interface terminated a master transaction with an error because the retry limit specified in the RETRY_LIMIT register in PCI configuration space was exceeded.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

BME

Description: **Bus Master Error.** This bit is set if the PCI bus interface terminated a master transaction with an error because the transaction could not be completed since the Bus Master Enable (BM) bit in the COMMAND register in PCI configuration space was not set.

Initial Value: 0x0

Notes

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

PRD

Description: **Pending Read Discarded.** This bit is set if a pending read was discarded because the discard timer expired.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

RIP

Description: **Reset In Progress.** When the EN bit is cleared, the PCI interface is reset (note that this does NOT result in a PCI reset). This bit is set to indicate that a PCI interface reset is in progress. This reset may take several clock cycles to complete due to the crossing of clock domains. When the PCI interface reset has completed, this bit is cleared and the PCI interface may be re-enabled by setting the EN bit.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

PCI Status Mask Register

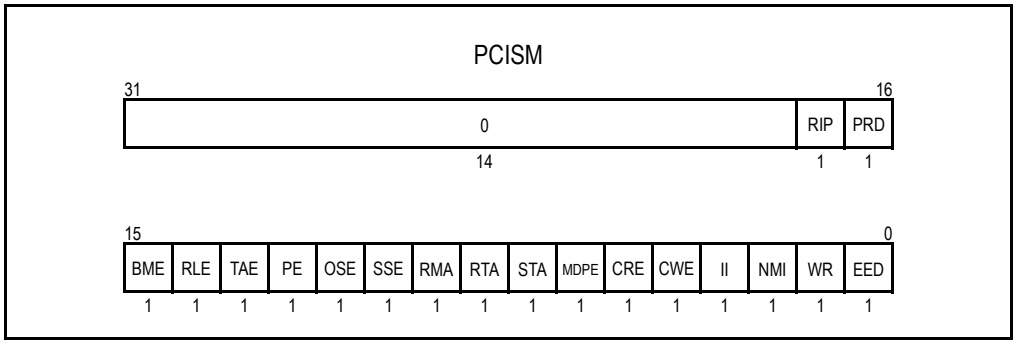


Figure 10.4 PCI Status Mask Register (PCISM)

EED

Description: **PCI Serial EEPROM Done.** When this bit is set, the EED bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

WR

Description: **Warm Reset.** When this bit is set, the WR bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Notes

Read Value: Previous value written

Write Effect: Modify value

NMI

Description: **Non-maskable Interrupt.** When this bit is set, the NMI bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

II

Description: **Inbound Interrupt.** When this bit is set, the II bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

CWE

Description: **CPU Write Error.** When this bit is set, the CWE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

CRE

Description: **CPU Read Error.** This bit is set if a CPU PCI read transaction experienced an error and the IPBus Error Enable (IEN) bit is set in the PCIC register.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

MDPE

Description: **Master Data Parity Error.** When this bit is set, the MDPE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

STA

Description: **Signalled Target Abort.** When this bit is set, the STA bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Notes

Read Value: Previous value written

Write Effect: Modify value

RTA

Description: **Received Target Abort.** When this bit is set, the RTA bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

RMA

Description: **Received Master Abort Status.** When this bit is set, the RMA bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

SSE

Description: **Signalled System Error.** When this bit is set, the SSE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

OSE

Description: **Observed System Error.** When this bit is set, the OSE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

PE

Description: **Parity Error.** When this bit is set, the PE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

TAE

Description: **Target Address Error.** When this bit is set, the TAE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Notes

Read Value: Previous value written

Write Effect: Modify value

RLE

Description: **Retry Limit Exceeded.** When this bit is set, the RLE bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

BME

Description: **Bus Master Error.** When this bit is set, the BME bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

PRD

Description: **Pending Read Discard.** When this bit is set, the PRD bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

RIP

Description: **Reset In Progress.** When this bit is set, the RIP bit in the PCIS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

Reset

Upon assertion of the PCI reset, either a warm or cold reset causes all of the PCI interface pins to be tri-stated during the reset condition.[1] This reaction is asynchronous to the PCI clock or master clock input (CLK) and is immediate.

A warm or cold reset and the subsequent enabling of the PCI interface may result in the PCI bus interface being enabled during an active bus (e.g., in the middle of a burst transfer between two other devices). This may also occur due to the delay in locking the PLL following a PCI reset when the RC32438 is used in satellite mode. The PCI bus interface handles this condition. If the RC32438 becomes active during a PCI transaction, the RC32438 will ignore events on the PCI bus until the transaction is completed. For additional information, refer to the Reset Implementation note in section 4.3.2 of PCI Specification 2.2.

1. An exception to this is the PCI reset signal PCIRSTN. When the RC32438 is configured to operate in PCI host mode, PCIRSTN will be asserted whenever the EN bit is cleared (set to zero).

Notes

During a cold reset, the RC32438's PCI reset output is tri-stated since it is not yet known if the RC32438 will be operating in host or satellite mode. Therefore, system designers should pull the PCI reset signal down so that it is held low following the application of power to the system.

Disabled Mode

When the EN bit in the PCIC register is cleared, the PCI bus interface is disabled. The PCI bus interface may be permanently disabled during boot configuration by selecting the disable PCI mode. When disabled, the PCI bus interface enters a benign low-power mode. While in this mode, all transactions except for configuration accesses will be ignored. Configuration accesses will receive a retry response. The values on all PCI input pins are ignored. The PCI clock (PCICLK) should be driven to a valid logic level on the board.

When the PCI bus interface is disabled, all of the PCI pins are tri-stated, except PCIGNTN[3:1], and thus should be held at a valid logic level on the board. PCIGNTN[3:1] signals are driven high when the interface is disabled. The PCI bus interface may be disabled at any time after a cold reset by clearing the enable (EN) bit in the PCI configuration (PCIC) register.

Disabling and then re-enabling the PCI bus interface resets all of the logic associated with the PCI bus interface and causes all FIFOs to be reset. The states of all status registers are reset to their initial values, but the states of all configuration registers are preserved.

PCI Host Mode

Reset and Initialization

In PCI host mode, the PCI reset pin (PCIRSTN) is an output. The PCIRSTN pin is asserted whenever the EN bit in the PCIC register is cleared (e.g., as the result of a warm or cold reset). Software should ensure that the PCIRSTN pin is asserted for a minimum of 1 ms after power has stabilized and 100 µs after the PCI clock has stabilized.

After reset, the RC32438 boots from the boot device. The PCI interface is then enabled, causing the PCI reset pin to be de-asserted (i.e., taking the PCI bus out of reset). Initially, the Target Not Ready (TNR) bit is set in the PCIC register. This causes all PCI bus interface target transactions to be retried and allows the RC32438 to initialize the PCI interface and configuration registers. Once the RC32438 device completes the initialization sequence, it clears the Target Not Ready (TNR) bit, allowing PCI masters to access the RC32438.

A warm reset may be initiated by writing to the Warm Reset (WR) bit in the PCI Management (PMGT) register in PCI configuration space. An NMI to the CPU core may be initiated by writing to the Non-Maskable Interrupt (NMI) bit in the PMGT register. A PCI host may use these features to reset/reboot the RC32438 device.

The CPU core may generate a PCI reset by clearing the EN bit in the PCIC register or by initiating a warm or cold reset. Note that system designers may choose to generate the PCI reset signal using external logic rather than the RC32438 PCIRSTN signal to reset other external devices. In such a configuration, the externally generated reset should be configured to generate a warm or cold reset.

Bus Arbitration

PCI arbitration mode in host mode is determined by the PCI mode selected during boot configuration. The PCI host can be configured to use an external arbiter or internal arbiter. The function of the PCIREQN[5:0] and PCIGNTN[5:0] signals is determined by the PCI mode selected [1] and is dependent on whether the internal arbiter is used or an external arbiter is selected.

1. PCIREQN[4] is an alternate function of GPIO[24], PCIREQN[5] is an alternate function of GPIO[27], PCIGNTN[4] is an alternate function of GPIO[26], and PCIGNTN[5] is an alternate function of GPIO[28].

Notes

Pin Name	Type	Description
PCIREQN[5:0]	I	**PCI Request**. The assertion of these signals indicates to the internal RC32438 arbiter that an agent desires use of the PCI bus.
PCIGNTN[5:0]	O	**PCI Grant**. The assertion of these signals indicates to the agent that the internal RC32438 arbiter has granted the agent access to the PCI bus.

Table 10.3 PCI Arbitration Pin Functionality in PCI Host Mode with Internal Arbiter Enabled

Pin Name	Type	Description
PCIREQN[0]	O	**PCI Request**. This signal is asserted by the RC32438 to request use of the PCI bus. While PCIRSTN is asserted, the RC32438 tri-states this signal.
PCIREQN[5:1]	O	**Unused**. These signals are unused in this mode and driven high.
PCIGNTN[0]	I	**PCI Grant**. This signal is asserted by an external arbiter to indicate to the RC32438 that access to the PCI bus has been granted. While PCIRSTN is asserted, the RC32438 ignores the state of this signal.
PCIGNTN[5:1]	O	**Unused**. These signals are unused in this mode and driven high.

Table 10.4 PCI Arbitration Pin Functionality in PCI Host Mode Using External Arbiter

The internal arbiter supports up to six external devices. The default arbitration algorithm used by the internal arbiter is selected by the PCI mode during boot configuration. The algorithm may be modified through the Arbiter Arbitration Algorithm (AAA) bit in the PCIC register. The two algorithms are:

Round robin arbitration algorithm - ownership is granted in a fixed rotating sequence (RC32438, PCIREQN[0], PCIREQN[1], PCIREQN[2], PCIREQN[3], PCIREQN[4], PCIREQN[5]).

Fixed priority arbitration algorithm - the priority order (highest to lowest) is RC32438, PCIREQN[0], PCIREQN[1], PCIREQN[2], PCIREQN[3], PCIREQN[4], PCIREQN[5].

The RC32438 internal arbiter will guarantee that the PCI “Trhff” (time from reset high-to-first-frame# assertion) specification will be met by not granting the bus for at least eight clock cycles after negation of the PCI reset or the enabling of the PCI interface.

Interrupts

In host mode, the RC32438 does not provide any dedicated interrupt inputs. GPIO pins may be used as interrupt inputs. Although no GPIO pins are dedicated for PCI interrupts, GPIO pins GPIO[29:26] have PCI buffers (refer to Table 1.3 in Chapter 1).

The PCI messaging unit operates in both satellite and host modes. The PCI messaging unit interrupt output (i.e., PCIMUINTN) is a GPIO alternate function output (refer to Table 12.1 in Chapter 12). When configured as an alternate function, this pin is tri-stated when not asserted (i.e., it acts as an open collector output).

PCI Satellite Mode

Reset and Initialization

In PCI satellite mode, the PCI reset pin (PCIRSTN) is an input. Assertion of the PCI reset pin causes the RC32438 to perform a warm reset and to reset the state of all registers in the PCI interface to their initial value (including PCI configuration registers).

The PCI bus interface supports two PCI satellite operating modes. The two satellite operating modes are: PCI satellite mode with target not ready, and PCI satellite mode with suspended CPU execution. The operating mode is selected by the PCI mode field during boot configuration.

Notes

An RC32438 warm reset may be initiated by writing to the Warm Reset (WR) bit in the PCI Management (PMGT) register in PCI configuration space. A CPU NMI may be initiated by writing to the Non-Maskable Interrupt (NMI) bit in the PMGT register. A PCI host may use this feature to reset/reboot the RC32438.

PCI Satellite Mode with Target Not Ready

In this mode, the sequence of events after reset is as follows: the RC32438 boots from the boot device. Initially the Target Not Ready (TNR) bit is set in the PCIC register. This causes all PCI bus interface target transactions to be retried. It also allows the RC32438 to boot, initialize the system, and initialize the PCI interface and configuration registers. Once the initialization is completed, it clears the Target Not Ready (TNR) bit, allowing PCI masters to access the RC32438.

PCI Satellite Mode with Suspended CPU execution

In this mode, the execution of the RC32438 device is suspended when the system is reset because the Suspend CPU Execution (SCE) bit is set in the PCIC register. Since execution of the CPU core is suspended in this mode, the watchdog timer should be initially disabled by setting the Disable Watchdog Timer bit in the boot configuration vector (refer to Table 3.3 in Chapter 3).

In addition, the Target Not Ready (TNR) bit is initially set in the PCIC register. The PCI configuration registers are loaded from the PCI Serial EEPROM. Once the PCI configuration registers are initialized, the TNR bit is automatically cleared, allowing PCI hosts to access all of the RC32438's memory mapped registers and local memory.

The PCI host can configure a significant proportion of the RC32438 device. For example, it can initialize the device controller or DDR controller and load boot code into memory. The PCI host can also change PCI and device address mapping, allowing the CPU to boot directly from PCI memory.

Note that there are two address mapping regions for DDR0. This allows DDR0 space to be mapped to address 0x0000_0000 using the normal mapping mechanism and it allows the CPU core boot exception vector memory space starting at 0x1FC0_00000 to be mapped to DDR0 using the second mapping region. For more information, refer to Chapter 7, DDR Controller.

When the PCI host has completed configuring the RC32438 device and/or loading boot code, it clears the SCE bit, allowing the CPU core to begin execution. The CPU begins executing at the MIPS reset exception vector whose physical address is 0x1FC0_0000. The CPU core can only boot from a 32-bit wide device on the PCI bus. There is no need to disable the bus timer in this mode since setting the SCE bit disables CPU accesses to the PMBus. Since there is no CPU transaction on the PMBus or IPBus, there is no possibility of a bus time-out.

Bus Arbitration

In satellite mode, the RC32438 device always uses an external arbiter. Table 10.5 summarizes the function of the bus arbitration pins in satellite mode.

Pin Name	Type	Description
PCIREQN[0]	O	**PCI Request**. This signal is asserted by the RC32438 to request use of the PCI bus. While PCIRSTN is asserted, the RC32438 tri-states this signal.
PCIREQN[1]	I	**Initialization Device Select**. In satellite mode this signal takes on the alternate function of PCIIDSELP and is used as a chip select during configuration read and write transactions.
PCIREQN[5:2]	O	**Unused**. These signals are unused in this mode and driven high.

Table 10.5 PCI Arbitration Pin Functionality in PCI Satellite Mode (Part 1 of 2)

Notes

Pin Name	Type	Description
PCIGNTN[0]	I	**PCI Grant**. This signal is asserted by an external arbiter to indicate to the RC32438 that access to the PCI bus has been granted. While PCIRSTN is asserted, the RC32438 ignores the state of this signal.
PCIGNTN[1]	O	**PCI EEPROM Chip Select**. In satellite mode this signal takes on the alternate function of PCIEECS and is used as a PCI Serial EEPROM chip select.
PCIGNTN[5:2]	O	**Unused**. These signals are unused in this mode and driven high.

Table 10.5 PCI Arbitration Pin Functionality in PCI Satellite Mode (Part 2 of 2)

Interrupts

In satellite mode, the RC32438 device does not provide any dedicated interrupt outputs. The PCI messaging unit operates in both satellite and host modes. The PCI messaging unit interrupt output (i.e., PCIMUINTN) is a GPIO alternate function output (refer to Table 12.1 in Chapter 12). Although no GPIO pins are dedicated for PCI interrupts, GPIO pins 29:26 have PCI buffers (refer to Table 1.3 in Chapter 1).

PCI Serial EEPROM Interface

When the RC32438 device is booted in PCI satellite mode with the execution of the CPU core suspended, the PCI serial EEPROM is used to load PCI configuration registers whose addresses are less than 0x40 in PCI configuration space. The PCI serial EEPROM interface provides a National Semiconductor MICROWIRE™ compatible serial EEPROM interface. The interface only supports 93C46-compatible serial EEPROMs. The PCI Serial EEPROM done bit (EED) in the PCIS register is set when the loading of configuration information has been completed and the Serial I/O signals have been released. Only EEPROMs which are 2048-bits in size should be used.

Each EEPROM address corresponds to a 16-bit data quantity. This is in contrast to PCI configurations which correspond to 8-bit quantities. For this reason, corresponding EEPROM addresses are equal to one half of their PCI configuration space addresses. Unused EEPROM locations (i.e., those whose initial values are don't care) may be used to store application-specific information. Application-specific information may be accessed after PCI initialization from EEPROM using the PCI interface.

For information on the operation of the PCI serial EEPROM I/O pins, see Chapter 16, Serial Peripheral Interface.

PCI Transactions

Table 10.6 summarizes the PCI command codes supported by the PCI bus interface. The sections following this table describe how these transactions are generated for master and target configurations.

CBEN[3:0]	Command	IPBus Master	DMA Ch. 8 PCI Master	DMA Ch. 9 PCI Master	PCI Target
0000	Interrupt Acknowledge	No	No	No	Ignored
0001	Special Cycle	No	No	No	Ignored
0010	I/O Read	Yes	Yes	No	Yes
0011	I/O Write	Yes	No	Yes	Yes
0100	Reserved	No	No	No	Ignored
0101	Reserved	No	No	No	Ignored
0110	Memory Read	Yes	Yes	No	Yes

Table 10.6 Supported PCI Transactions (Part 1 of 2)

Notes

CBEN[3:0]	Command	IPBus Master	DMA Ch. 8 PCI Master	DMA Ch. 9 PCI Master	PCI Target
0111	Memory Write	Yes	No	Yes	Yes
1000	Reserved	No	No	No	Ignored
1001	Reserved	No	No	No	Ignored
1010	Configuration Read	Yes	No	No	Yes
1011	Configuration Write	Yes	No	No	Yes
1100	Memory Read Multiple	No	Yes	No	Yes
1101	Dual Address Cycle	No	No	No	Ignored
1110	Memory Read Line	Yes	Yes	No	Yes
1111	Memory Write-and-Invalidate	No	No	Yes	Yes

Table 10.6 Supported PCI Transactions (Part 2 of 2)

Endianness and PCI Swapping

When the RC32438 acts as a PCI master or target, its endianness may be different from that of the PCI bus. A PCI bus typically operates in little endian while the CPU may operate in either big or little endian. To support systems in which the endianness of the CPU differs from that of the PCI bus, the RC32438 provides swap bits as follows.

- *SB bits in the PCI Base Address Control (PBA[0|1|2|3]C) registers. These bits control swapping of data during RC32438 PCI target transactions.*
- *SB bits in the PCI Local Base Address (PCILBA[0|1|2|3]C) registers. These bits control swapping of data during the RC32438 PCI master transactions generated by the CPU.*
- *SB bits in the DEVCMD field of the PCI DMA descriptors. These bits control swapping of data during the RC32438 PCI master transactions generated by the DMA.*

PCI Master

The PCI master interface, shown in Figure 10.1, provides the ability for the CPU core to read and write to PCI memory and I/O space. In addition, it allows the CPU core to perform PCI configuration operations. Although the PCI master interface is an IPBus slave interface, it does not support transactions from masters other than the CPU core itself. A transaction to memory by any IPBus master other than the CPU core that maps to PCI space is not acknowledged by the PCI interface and results in an undecoded address error.

The PCI bus interface provides four mapping regions from an IPBus local address space to the PCI bus. Each mapping region has a corresponding PCI Local Base Address (PCILBAx) register, PCI Local Base Address Control (PCILBAxC) register, and PCI Local Base Address Mapping (PCILBAxM) register. The PCILBAx holds the local address space base address. The PCILBAxC register holds the configuration information for the mapping region. The PCILBAxM register holds the base address of PCI transactions that map to the PCI Bus address space through PCILBAx. Local Base Addresses in PCILBAx registers should be non-overlapping. If they are overlapping, one will be chosen. The PCI addresses which are mapped by one or more PCILBAxM registers may overlap.

The PCI master interface does not support PCI locking and thus will never assert the PCILOCKN signal. The PCI master interface will queue a maximum of four writes to the PCI bus and one read from the PCI bus. The PCI master interface honors byte enables, allowing individual bytes to be read and written using I/O and memory PCI transactions.

When a PCI master interface issues a memory read, memory read line, or a memory read multiple transaction that is terminated early (e.g., a target disconnect), the PCI master may reissue the read using the preferred read transaction. See the PCI specification 2.2 section 3.1.2 for the definition of preferred read transactions.

Notes

Master I/O Read

All IPBus read transactions whose addresses match the base address in a PCI Local Base Address (PCILBAx) register configured for I/O space (i.e., the MSI bit is set in the corresponding PCI Local Base Address Control (PCILBAxC) register) result in an I/O read transaction on the PCI bus. The value in the corresponding PCI Local Base Address Map (PCILBAxM) register maps the upper bits of the local IPBus address to the PCI I/O read address, as indicated by the SIZE field of the PCILBAxC register. The byte enables on the PCI bus correspond to the size/byte enables of the IPBus read operation (i.e., byte, half-word, triple-byte or word). All IPBus initiated I/O read transactions translate into single data phase PCI transactions even if a burst transaction was generated on the IPBus (i.e., bursts are not supported).

Master I/O Write

All IPBus write transactions whose addresses match the base address in a PCI Local Base Address (PCILBAx) register configured for I/O space (i.e., the MSI bit is set in the corresponding PCI Local Base Address Control (PCILBAxC) register) result in an I/O write transaction on the PCI bus. The value in the corresponding PCI Local Base Address Map (PCILBAxM) register maps the upper bits of the local IPBus address, as indicated by the SIZE field of the PCILBAxC register, to the PCI I/O read address. The value written on the PCI bus corresponds to the data value of the IPBus write transaction. The byte enables on the PCI bus correspond to the size/byte enables of the IPBus write operation (i.e., byte, halfword, triple-byte, or word). IPBus initiated I/O write transactions may contain one or more data phases (i.e., bursts are supported).

Master Memory Read

An IPBus read transaction will result in a memory read transaction on the PCI Bus when the following conditions are met:

- *The address matches the base address in a PCI Local Base Address (PCILBAx) register that is configured for memory space (i.e., the MSI bit is cleared in the corresponding PCI Local Base Address Control (PCILBAxC) register)*
- *Read Transaction (RT bit in corresponding PCILBAxC) bit is cleared, resulting in a memory read transaction on the PCI bus.*

The value in the corresponding PCI Local Base Address Map (PCILBAxM) register maps the upper bits of the local IPBus address, as indicated by the SIZE field of the PCILBAxC register, to the PCI memory read address. The byte enables on the PCI bus correspond to the size/byte enables of the IPBus read operation (i.e., byte, halfword, triple-byte, or word).

Master Memory Write

All IPBus write transactions whose addresses match the base address in a PCI Local Base Address (PCILBAx) register that is configured for memory space (i.e., the MSI bit is cleared in the corresponding PCI Local Base Address Control (PCILBAxC) register) result in a memory write transaction on the PCI bus. The value in the corresponding PCI Local Base Address Map (PCILBAxM) register maps the upper bits of the local IPBus address, as indicated by the SIZE field of the PCILBAxC register, to the PCI memory write address. The value written on the PCI bus corresponds to the data value of the IPBus write transaction. The byte enables on the PCI bus correspond to the size/byte enables of the IPBus write operation (i.e., byte, halfword, triple-byte, or word).

The PCI bus interface will attempt to perform burst PCI memory write transactions whenever possible. The PCI interface will add a data phase to the memory write transaction in progress if:

- *Data exists in the CPU master output FIFO whose address is equal to that of the current data quantity being transferred plus four*
- *The Master Latency Timer has not expired.*

Master Configuration Read

To generate a PCI configuration read transaction, an IPBus master (e.g., CPU core) writes the desired configuration register address to the PCI Configuration Address (PCICFGA) register and performs a read from the PCI Configuration Data (PCICFGD) register. The value returned to the IPBus master will be that

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received from the configuration read transaction. During the configuration read transaction, the PCI byte enables will correspond to the size of the data read from the PCICFGD register (i.e., byte, halfword, triple-byte, or word).

If the BUS field in the PCI Configuration Address (PCICFGA) register is zero, a Type 0 configuration read transaction is performed. If the BUS field is non-zero, a Type 1 configuration read transaction is performed. See section 3.2.2.3 of PCI Specification 2.2 for more information. For Type 1 configuration transactions, the PCIAD[30:2] takes on the value of the corresponding bit positions in the PCICFGA register. PCIAD[1:0] takes on the value 0x01 and PCIAD[31] takes on the value 0x0. For Type 0 configuration transactions, the DEVICE field in the PCI Configuration Address (PCICFGA) register is used to select the IDSEL line of the PCI satellite to be configured. The DEVICE field to IDSEL mapping is shown in Table 10.7.

Device Number	Address Line
0x00	Internal Access
0x01	PCIAD[11]
0x02	PCIAD[12]
0x03	PCIAD[13]
0x04	PCIAD[14]
0x05	PCIAD[15]
0x06	PCIAD[16]
0x07	PCIAD[17]

Device Number	Address Line
0x08	PCIAD[18]
0x09	PCIAD[19]
0x0A	PCIAD[20]
0x0B	PCIAD[21]
0x0C	PCIAD[22]
0x0D	PCIAD[23]
0x0E	PCIAD[24]
0x0F	PCIAD[25]

Device Number	Address Line
0x10	PCIAD[26]
0x11	PCIAD[27]
0x12	PCIAD[28]
0x13	PCIAD[29]
0x14	PCIAD[30]
0x15	PCIAD[31]

Table 10.7 PCI Device Fields to IDSEL Mapping

A Type 0 configuration transaction whose corresponding DEVICE field is 0x00 corresponds to the RC32438 and is handled internally without generating a PCI transaction. When one of the PCI address bits (PCIAD[31:11]) is set to one and PCIAD[1:0] are both zero, a PCI configuration read transaction is generated for the corresponding DEVICE field.

All PCI configuration transactions use address stepping to allow for IDSEL predriving. Refer to PCI Specification 2.2, section 3.2.2.5 for more information. Performing a PCI configuration read from a nonexisting device results in the DEVSELN signal not being asserted by a PCI target. This results in a master abort of the transaction and the setting of the Receive Master Abort Status (RMA) bit in the STATUS register in PCI configuration space, value 0xFFFF_FFFF being returned to the IPBus master, and an IPBus slave acknowledge error if the IPBus Error Enable (IEN) bit is set in the PCICFG register. The setting of the RMA bit may be used to signal a CPU interrupt.

The RC32438 does not support the generation of burst configuration read transactions. All configuration read transactions have a single data phase. When the PCI interface is set to operate in decoupled mode (i.e., the Decoupled Access Enable (DEN) bit is set in the PCI Decoupled Access Control (PCIDAC) register), then the value read from the PCICFGD is not valid until the Done (D) bit is set in the PCI Decoupled Access Status (PCIDAS) register. The Error (E) and Busy (B) bits in the PCIDAS register reflect the status of the operation.

Master Configuration Write

To generate a PCI configuration write transaction, an IPBus master (e.g., CPU core) writes the desired configuration register address to the PCI Configuration Address (PCICFGA) register and performs a write to the PCI Configuration Data (PCICFGD) register. The value written by the IPBus master will be used for the PCI configuration write, and the PCI byte enables will correspond to the size of the data written (i.e., byte, halfword, triple-byte, or word).

Notes

If the BUS field in the PCI Configuration Address (PCICFGA) register is zero, a Type 0 configuration read transaction is performed. If the BUS field is non-zero, a Type 1 configuration read transaction is performed. See section 3.2.2.3 of PCI Specification 2.2 for more information. For Type 1 configuration transactions, the PCIAD[30:2] takes on the value of the corresponding bit positions in the PCICFGA register. PCIAD[1:0] takes on the value 0x01 and PCIAD[31] takes on the value 0x0. For Type 0 configuration transactions, the DEVICE field in the PCI Configuration Address (PCICFGA) register is used to select the IDSEL line of the PCI satellite to be configured. The DEVICE field to IDSEL mapping is shown in Table 10.7. A Type 0 configuration transaction whose corresponding DEVICE field is 0x00 corresponds to the RC32438 and is handled internally without generating a PCI transaction. When one of the PCI address bits (PCIAD[31:11]) is set to one and PCIAD[1:0] are both zero, a PCI configuration write transaction is generated for the corresponding DEVICE field.

All PCI configuration transactions use address stepping to allow for IDSEL predriving. Refer to the PCI Specification 2.2, section 3.2.2.5 for more information. Performing a PCI configuration write to a nonexisting device results in the DEVSELN signal not being asserted by a PCI target. This results in a master abort of the transaction and the setting of the Receive Master Abort Status (RMA) bit in the STATUS register in PCI configuration space. The setting of the RMA bit may be used to signal a CPU interrupt. The RC32438 does not support generation of burst configuration write transactions. All configuration write transactions have a single data phase.

When the PCI interface is set to operate in decoupled mode (i.e., the Decoupled Access Enable (DEN) bit is set in the PCI Decoupled Access Control (PCIDAC) register), then the Done (D), Error (E), and Busy (B) bits in the PCI Decoupled Access Status (PCIDAS) register reflect the status of the operation.

Master Memory Read Line

All IPBus read transactions whose address matches the base address in a PCI Local Base Address (PCILBAx) register that is configured for memory space (i.e., the MSI bit is cleared in the corresponding PCI Local Base Address Control (PCILBAxC) register) and whose Read Transaction (RT bit in corresponding PCILBAxC) bit is set result in a memory read line transaction on the PCI bus. The value in the corresponding PCI Local Base Address Map (PCILBAxM) register maps the upper bits of the local IPBus address, as indicated by the SIZE field of the PCILBAxC register, to the PCI memory read address.

Setting the Read Transaction (RT) bit in the corresponding PCILBAxC register indicates to the PCI interface that a memory read line transaction should be used to prefetch data when the read transaction maps to the corresponding PCILBAx register. The PCI bus interface will supply the data quantity requested by the IPBus master read and will queue prefetch data in the IPBus Master PCI input FIFO. Subsequent sequential reads that map to PCILBAx will result in queued data being returned.

The memory read line is used when a PCI master will read more than one word but no more than a cache line. Memory read line transactions resulting from IPBus master read transactions will cause the PCI bus interface to issue a memory read line burst transaction that transfers either an entire cache line or eight words, whichever is smaller. The 8 word limit allows the CACHE_LINE_SIZE register in PCI configuration space to be set larger than the size of the IPBus master PCI input FIFO. For example, setting the CACHE_LINE_SIZE register to 16 words still results in only 8 words being transferred.

Prefetch data in the CPU master input FIFO is flushed when an IPBus write transaction maps to the PCI bus.

Master Error Handling

IPBus master fatal errors are: target timeout error, PCI target terminates with a Target Abort, transaction could not be completed because the RETRY_LIMIT was exceeded, parity error, and the transaction could not be completed because the BM bit is not set in the COMMAND register.

An IPBus master fatal error is not propagated to the IPBus on prefetched data that is not subsequently read by an IPBus master (i.e., if the error occurs on prefetched data, it is ignored unless the data is actually used). If a CPU generated PCI master read transaction experiences a fatal error, the CPU master input

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FIFO is flushed and an IPBus slave acknowledge error is generated if the IPBus Error Enable (IEN) bit is set in the PCI Control (PCIC) register. When a slave acknowledge error is generated, the CPU Read Error (CRE) bit is set in the PCI Status (PCIS) register. If IEN is not set, the error is ignored.

If a CPU generated PCI master write transaction experiences a fatal error, an IPBus slave acknowledge error is generated and the CPU Write Error (CWE) bit is set in the PCIS register. A slave acknowledge error is not generated.

PCI Configuration Address Register

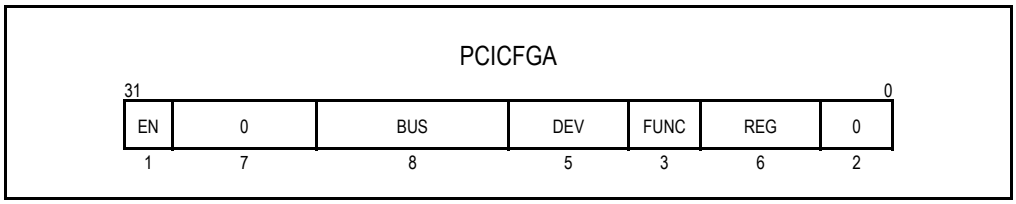


Figure 10.5 PCI Configuration Address Register (PCICFGA)

REG

Description: **Register.** This field specifies the PCI register address (i.e., the address of a 32-bit quantity within the target function's configuration space).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

FUNC

Description: **Function.** This field specifies the PCI function number.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DEV

Description: **Device.** This field specifies the PCI device number. PCI address bits 31 through 11 (i.e., PCIAD[31:11]) are all set to one for device numbers 0x1 through 0x15. PCI device number 0 refers to the RC32438's host device (i.e., itself).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

BUS

Description: **Bus.** This field specifies the PCI bus number.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

EN

Description: **Enable.** When this bit is set, accesses to the PCI Configuration Data (PCICFGD) register are translated into PCI configuration accesses. Since there is no analogous PC-AT I/O address space in the MIPS architecture, this bit cannot be cleared and is read-only.

Initial Value: 0x1

Read Value: 0x1

Write Effect: Read-only

PCI Configuration Data Register

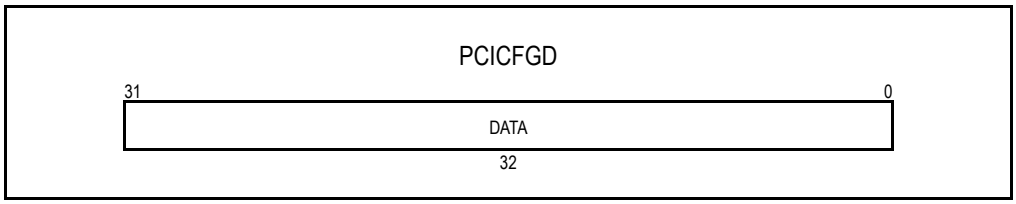


Figure 10.6 PCI Configuration Data Register (PCICFGD)

DATA

Description: **Data.** Reading this register results in a PCI configuration read transaction using the information in the PCI Configuration Address (PCICFGA) register. The value returned to the processor is the result of the read. Writing this register results in a PCI configuration write transaction using the data value written to this register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PCI Local Base Address [0|1|2|3] Register

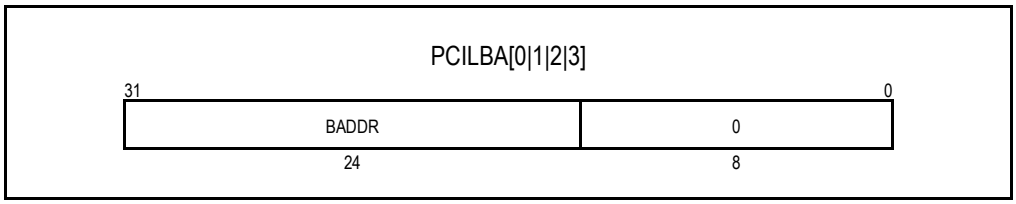


Figure 10.7 PCI Local Base Address [0|1|2|3] Register (PCILBA[0|1|2|3])

BADDR

Description: **Base Address.** This field specifies the local address bits to use for decoding IPBus transactions to PCI transactions. All of the local address bits that are active (i.e., those whose bit position is greater than or equal to size) are compared to the corresponding bits in this field. If they all match, then the corresponding transaction is mapped to the PCI bus.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

PCI Local Base Address [0|1|2|3] Control

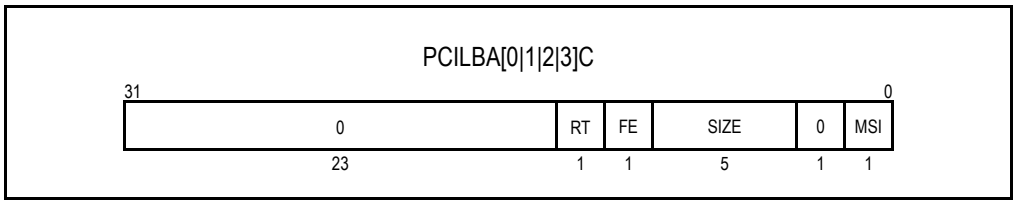


Figure 10.8 PCI Local Base Address [0|1|2|3] Control (PCILBA[0|1|2|3]C)

MSI

Description: **Memory Space Indicator.** The value of this bit determines the type of transaction issued on the PCI bus for local transactions that map to the PCI bus through PCILBAx.
0x0 - Memory transactions
0x1 - I/O transactions

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SIZE

Description: **Address Space Size.** This field indicates the size (in bits) of the address space for the corresponding local base address register. A size value less than eight disables the address space (i.e., no addresses will match).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

FE

Description: **Force Endianess.** This bit controls the endianess for local transactions that map the PCI bus through the PCIBLAx register. This register overrides the system controller endianess settings and will swap bytes as needed to maintain the desire endianess for all PCI transactions that map through the affected register.
0x0 - Big Endian
0x1 - Little Endian

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

RT

Description: **Read Transaction.** This bit controls the type of PCI transaction(s) issued in response to IPBus master reads that map through PCILBAx to the PCI bus when the MSI bit configures PCILBAx to use memory transactions. When the MSI bit is set, IPBus read operations use PCI I/O read transactions regardless of the state of this bit.
0x0 - Issue memory read transaction(s) on PCI bus and pass data to IPBus as it becomes available.
0x1 - Issue memory read line transaction(s) on the PCI bus and prefetch entire cache lines in anticipation of future IPBus reads.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PCI Local Base Address [0|1|2|3] Mapping Register

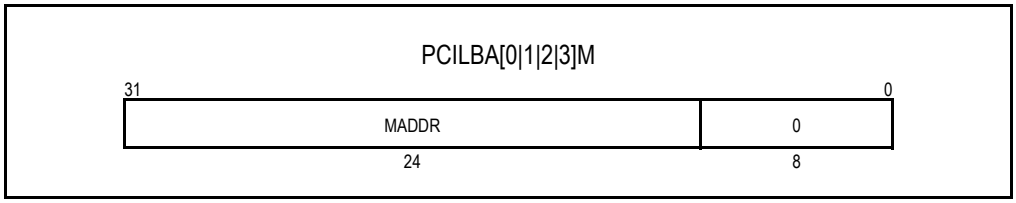


Figure 10.9 PCI Local Base Address [0|1|2|3] Mapping Register (PCILBA[0|1|2|3]M)

MADDR

Description: **Mapping Address.** This field contains the PCI base address for local transactions mapped to the PCI bus through the PCILBAx register. Local transaction address bits 31 through the value of the SIZE field in the PCILBAxC register are replaced by corresponding bits in this field for local transactions that map to the PCI bus through the PCILBAx register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Decoupled PCI Master Transactions

CPU core accesses to the PCI bus may take a significantly longer time to complete than normal IPBus transactions. One reason for this is the fact that the PCI bus can run at one quarter the frequency of the IPBus. Other reasons are: PCI arbitration delays, retried PCI transactions, and PCI wait states.

Reads from the CPU core to the PCI bus will lock up the IPBus until the transaction completes. Writes from the CPU core to the PCI bus when the CPU master output FIFO is full will also lock up the IPBus until a write transaction completes and space becomes available in the FIFO. Locking up the IPBus may have adverse affects on the real-time performance of the system. For example, it may lead to Ethernet FIFO overflows and underflows.

The programmer may avoid locking up the IPBus due to CPU core-initiated writes to the PCI bus by making sure that the CPU master output FIFO is not full prior to performing a write. This may be determined by observing the state of the Output FIFO Full (OFF) bit in the PCI Decoupled Access Status (PCIDAS) Register. Since the IPBus does not support split transactions, there is no way to avoid locking up the IPBus using traditional CPU reads of the PCI bus.

Notes

To overcome this difficulty, the PCI bus interface supports decoupled read accesses. Decoupled read accesses are enabled when the Decoupled Access Enable (DEN) bit is set in the PCI Decoupled Access Control (PCIDAC) register. When the DEN bit is set, any CPU core-initiated read of an address that maps to PCI space is completed immediately with a value of zero being returned to the CPU core. The PCI bus interface then performs the read operation on the PCI bus. While a decoupled access is in progress, the Busy (B) bit is set in the PCIDAS register. When the read operation completes, the Done (D) bit is set in the PCIDAS register, the B bit is cleared, and the value read from the PCI bus is available in the PCI Decoupled Access Data (PCIDAD) register. The CPU may read this value, thus completing the decoupled PCI read operation. If an error was detected while performing the PCI read, the Error (E) bit is set and the value in the PCIDAD register is undefined. Note that the D bit will not be set under this condition.

The state of the PCI CPU input and output FIFOs may be determined by examining the state of the OFE, OFF, IFE, and IFF bits in the PCI decoupled access status register. All of the bits in the PCIDAS register not masked by the PCI decoupled access status mask register are ORed together and presented to the interrupt controller as the PCI decoupled access interrupt.

Note that when the DEN bit is set in the PCIDAC register, configuration read and write transactions to devices other than the RC32438 are also performed in a decoupled manner. Configuration read and writes to internal RC32438 configuration registers are never performed in a decoupled manner. Also note that IPBus bursts from the CPU core do not translate into PCI bus burst transactions. In general, IPBus burst transactions are split into a series of PCI transactions. The exception to this is when a decoupled transaction maps to a PCI region that is configured to perform prefetching (i.e., a memory read line transaction). When this occurs, a PCI burst transaction is generated to prefetch the data.

PCI Decoupled Access Control Register

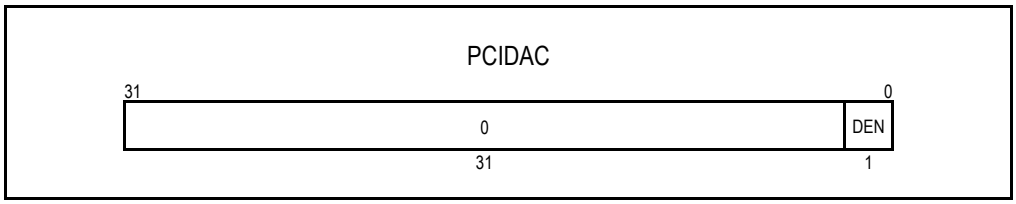


Figure 10.10 PCI Decoupled Access Control Register (PCIDAC)

DEN

Description: **Decoupled Access Enable.** When this bit is set, PCI decoupled mode is enabled and all CPU PCI read transactions are decoupled. This mode affects all IPBus read transactions that map to the IPBus including those generated by the DMA.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI Decoupled Access Status Register

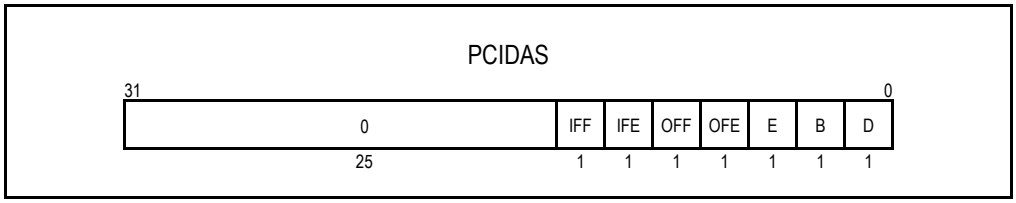


Figure 10.11 PCI Decoupled Access Status Register (PCIDAS)

D

Description: **Done.** This bit is set when a decoupled CPU PCI read operation has completed and a valid value may be read from the PCIDAD register.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

B

Description: **Busy.** This bit is set while a decoupled CPU PCI read operation is being processed.

Initial Value: 0x0

Read Value: Status

Write Effect: Read Only

E

Description: **Error.** This bit is set if an error was detected while performing a decoupled access PCI read.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit

OFE

Description: **Output FIFO Empty.** This bit is set while the CPU master output FIFO is empty.

Initial Value: 0x1

Read Value: Status

Write Effect: Read Only

OFF

Description: **Output FIFO Full.** This bit is set while the CPU master output FIFO is full.

Initial Value: 0x0

Read Value: Status

Write Effect: Read Only

IFE

Description: **Input FIFO Empty.** This bit is set while the CPU Master Input FIFO is empty.

Initial Value: 0x1

Notes

Read Value: Status

Write Effect: Read Only

IFF

Description: **Input FIFO Full.** This bit is set while the CPU Master Input FIFO is full.

Initial Value: 0x0

Read Value: Status

Write Effect: Read Only

PCI Decoupled Access Status Mask Register

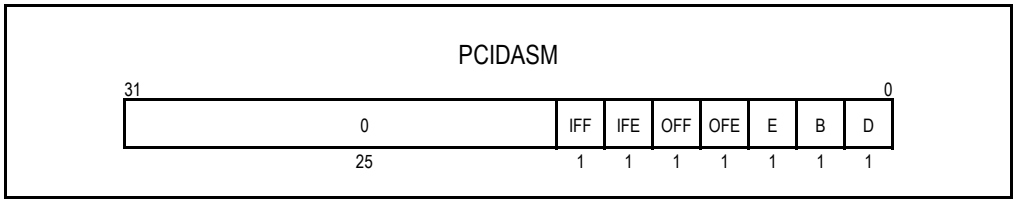


Figure 10.12 PCI Decoupled Access Status Mask Register (PCIDASM))

D

Description: **Done.** When this bit is set, the D bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

B

Description: **Busy.** When this bit is set, the B bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

E

Description: **Error.** When this bit is set, the E bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

OFE

Description: **Output FIFO Empty.** When this bit is set, the OFE bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Notes

Read Value: Previous value written

Write Effect: Modify value

OFF

Description: **Output FIFO Full.** When this bit is set, the OFF bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

IFE

Description: **Input FIFO Empty.** When this bit is set, the IFE bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

IFF

Description: **Input FIFO Full.** When this bit is set, the IFF bit in the PCIDAS register is masked from generating a PCI decoupled access interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

PCI Decoupled Access Data Register

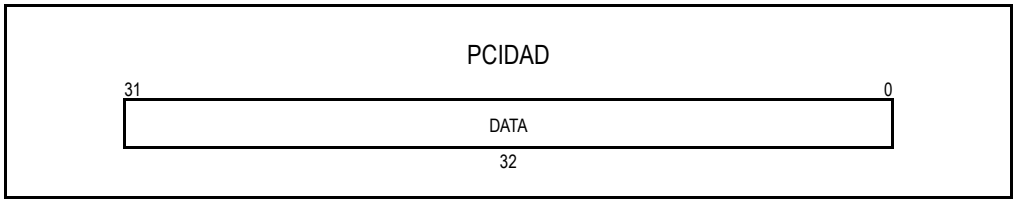


Figure 10.13 PCI Decoupled Access Data Register (PCIDAD)

DATA

Description: **Data Field.** This register contains the return value of a decoupled PCI CPU read operation.

Initial Value: 0x0

Read Value: Return value of previously initiated decoupled PCI CPU read operation

Write Effect: Modify value

Notes

PCI Master—PCI to Memory DMA (DMA Channel 8)

DMA channel 8 allows DMA operations to be performed that transfer data from the PCI bus to either the DDR or local memory. PCI DMA operations do not use local mapping registers. The starting PCI address for a DMA operation is specified in the DEVCS field of the DMA descriptor. This starting address is used for I/O as well as memory PCI transactions. The PCI starting address in DEVCS and the local starting address (specified in the CA field of the descriptor) may start on **any** byte boundary. These DMA operations are limited to 32KB minus 8 bytes (0x7FF8 bytes) per DMA descriptor. Initiating a PCI to memory DMA operation with more than 32KB minus 8 bytes (0x7FF8 bytes) per DMA descriptor produces undefined results.

The PT field in the DEVCMD field of the DMA descriptor specifies the type of PCI transaction to use for the DMA operation. The SB field indicates whether bytes read from the PCI bus should be swapped or passed unmodified into the PCI DMA input FIFO. The PCI bus interface will begin issuing PCI bus transactions based on the type specified in the PT field of the DMA descriptor's DEVCMD field, starting at the address specified in the DEVCS field. Data will be read from the PCI bus whenever there is space for at least 16 words in the PCI DMA input FIFO.

The PCI bus interface will attempt to burst as much data from the PCI bus as possible during a transaction. The PCI burst length is determined by system conditions. The transaction will continue as long as the following conditions exist:

- *it is not terminated by the PCI target*
- *there exists at least one free word in the PCI DMA input FIFO*
- *the byte count specified in the COUNT field of the DMA descriptor has not reached zero*
- *the number of data phases has not exceeded that specified in the Maximum Burst Size (MBS) field of the PCIDMA8C register, and the Master Latency Timer has not expired.*

The DMA controller transfers data from the PCI DMA input FIFO to memory whenever a DMA request event is generated. The PCI bus interface generates a DMA request event to the DMA controller for DMA channel 8 whenever there are 16 words of data or data corresponding to the end of a DMA operation in the PCI DMA input FIFO. A summary of DMA events is shown in Table 10.8.

Event	Description
DMA Request Event	A request event is generated whenever 16 words of data or data corresponding to the end of a DMA operation are present in the PCI DMA input FIFO. PCI to memory DMA operations will generate DMA request events during IPBus transactions as long as the above conditions are met for subsequent data in the FIFO.
DMA Done Event	A DMA done event is never generated.
DMA Terminated Event	A DMA terminated event is generated if any of the following occur: PCI master terminates transaction with a Master Abort (i.e., no target responds to transaction), PCI target terminates transaction with a Target Abort, transaction could not be completed because the RETRY_LIMIT was exceeded, the transaction could not be completed because the BM bit is not set in the COMMAND register, and detection of a PCI parity error.
DMA Transfer Size	16 words.
Limitations	None. A DMA operation may start and end on any local address or PCI address byte boundary and may contain any number of bytes

Table 10.8 PCI to Memory DMA Operations

Notes

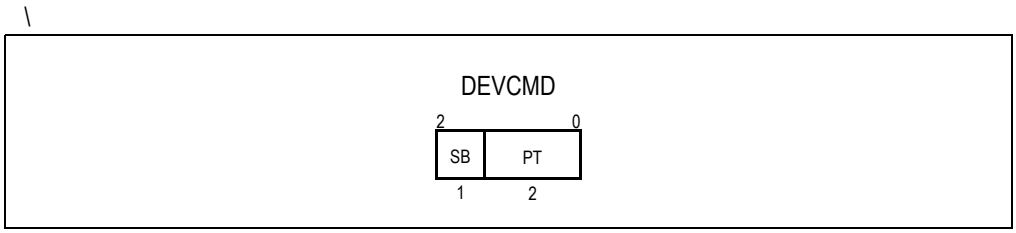


Figure 10.14 Device Command Field for PCI to Memory DMA Descriptors

PT **PCI Transaction.** This field specifies the PCI transaction to use to read data from the PCI bus.
0x0 Memory Read
0x1 Memory Read Line
0x2 Memory Read Multiple
0x3 I/O Read

SB **Swap Bytes.** This field controls byte swapping for a data read from the PCI bus during a PCI to memory DMA operation.

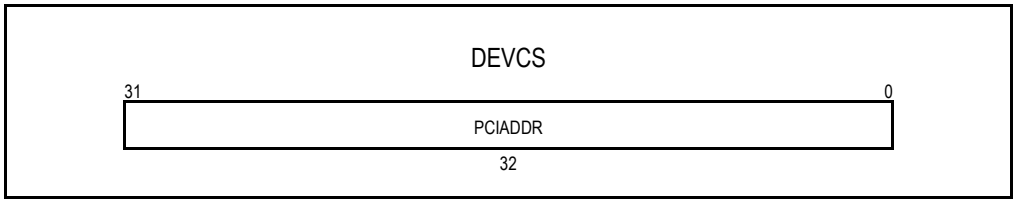


Figure 10.15 Device Control and Status Value for PCI to Memory DMA Descriptors

PCIADDR **PCI Address.** This field specifies the starting PCI address for PCI to memory DMA operations.

Channel 8 Memory Read

PCI memory read transactions are generated during PCI to memory DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to memory read. The PCI bus interface will attempt to generate a burst transaction when possible.

Channel 8 Memory Read Multiple

PCI memory read transactions are generated during PCI to memory DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to memory read multiple. The PCI bus interface will attempt to generate a burst transaction when possible. After a PCI disconnect, the PCI to memory DMA operation may generate a “preferred” memory read transaction (i.e., a memory read line or memory read transaction). For a definition of preferred memory, refer to PCI Specification 2.2.

Channel 8 Memory Read Line

PCI memory read transactions are generated during PCI to memory DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to memory read line. The PCI bus interface will attempt to generate a burst transaction when possible. After a PCI disconnect, the PCI to memory DMA operation may generate a preferred memory read transaction (i.e., a memory read transaction.)

Channel 8 I/O Read

PCI/IO read transactions are generated during PCI to memory DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to I/O read. The PCI bus interface will attempt to generate a burst transaction when possible.

Notes

Channel 8 Error Handling

PCI to memory fatal errors are:

- *PCI target terminates with a Target Abort*
- *transaction could not be completed because the RETRY_LIMIT was exceeded*
- *transaction could not be completed because the BM bit is not set in the COMMAND register*
- *detection of a PCI parity error.*

If any of the above fatal errors are detected during a DMA operation, the DMA operation is halted with a terminated condition (i.e., the T bit is set in the descriptor) and the DMA descriptor's DEVCS field is updated with the address of the error. The DMA descriptor's Current Address (CA) field contains the address to which the data (where the error occurred) should have been written. Note that no write actually takes place. The COUNT field contains the actual number of bytes transferred. All data queued in the PCI DMA input FIFO before the error occurred is written to memory before the DMA operation is halted.

PCI DMA Channel 8 Configuration Register

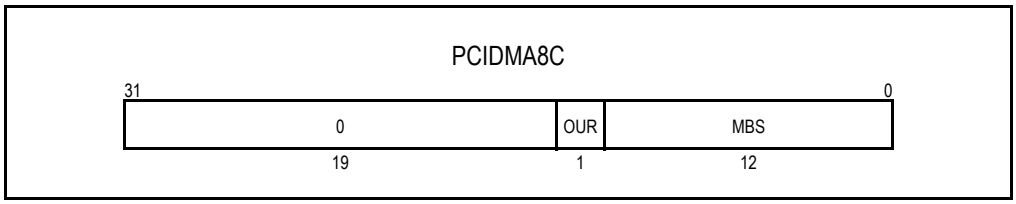


Figure 10.16 PCI DMA Channel 8 Configuration Register (PCIDMA8C)

MBS

Description: **Maximum Burst Size.** This field specifies the maximum number of words allowed in a PCI to memory DMA operation. A value of 0x0 corresponds to 0x1000 (i.e., 4K word transfer).

Initial Value: 0x8

Read Value: Previous value written

Write Effect: Modify value

OUR

Description: **Optimize Unaligned Burst Reads.** When this bit is cleared, the PCI interface honors byte enables at the start and end of unaligned PCI burst read transfers generated by the DMA controller. This results in the PCI interface potentially generating three separate transactions for a single unaligned DMA burst read transfer; one PCI transaction for the partial byte transfer at the start of the burst, one PCI transaction for the aligned portion of the burst transfer, and one PCI transaction for the partial byte transfer at the end of the burst transfer. These three transactions are treated by the PCI interface as three independent transactions.
In most cases, byte enables generated during partial word PCI memory transactions are irrelevant as they have no side effect. Thus, entire words could simply have been read from memory and unneeded data discarded. When this bit is set during a DMA read transfer that is programmed to generate Memory Read, Memory Read Line, or Memory Read Multiple transactions, then the PCI interface will read complete words and discard unneeded data. This improves unaligned PCI burst read transfer performance as it allows an entire burst read transfer generated by the DMA controller to be serviced as one PCI transaction.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI Master — Memory to PCI DMA (DMA Channel 9)

DMA channel 9 allows DMA operations to be performed that transfer data from either the DDR or local memory to the PCI bus. PCI DMA operations do not use local mapping registers. The starting PCI address for a DMA operation is specified in the DEVCS field of the DMA descriptor. This starting address is used for I/O as well as memory PCI transactions. The PCI starting address in DEVCS and the local starting address (specified in the CA field of the descriptor) may start on **any** byte boundary. These DMA operations are limited to 32KB minus 8 bytes (0x7FF8 bytes) per DMA descriptor. Initiating a PCI to memory DMA operation with more than 32KB minus 8 bytes (0x7FF8 bytes) per DMA descriptor produces undefined results.

The PT field in the DEVCMD field of the DMA descriptor specifies the type of PCI transaction to use for the DMA operation. The SB field indicates whether bytes read from the RC32438's memory and written to the PCI bus should be swapped or passed unmodified. The PCI bus interface will begin issuing PCI bus transactions of the type specified in the PT field of the DMA descriptor's DEVCMD field and starting at the address specified in the DEVCS field. Data will be written to the PCI bus whenever there are at least 16 words in the PCI DMA output FIFO or the PCI DMA output FIFO contains the last word of a DMA transfer.

The PCI bus interface will attempt to burst as much data to the PCI bus as possible during a transaction. For memory write, memory write and invalidate, and I/O write transactions, the PCI burst transaction length is determined by system conditions. The transaction will continue as long as the following conditions exist:

- *it is not terminated by the PCI target*
- *there exists at least one available word in the PCI DMA output FIFO*
- *the byte count specified in the COUNT field of the DMA descriptor has not reached zero*
- *the number of data phases has not exceeded that specified in the Maximum Burst Size (MBS) field of the PCIDMA9C register*
- *the Master Latency Timer has not expired.*

The DMA controller transfers data from the RC32438's memory to the PCI DMA output FIFO whenever a DMA request event is generated. The PCI bus interface generates a DMA request event to the DMA controller for DMA channel 9 whenever there are 16 free words available in the PCI DMA output FIFO. A summary of DMA events is shown in Table 10.9.

Event	Description
DMA Request Event	A request event is generated whenever 16 free words are available in the PCI DMA output FIFO. Memory to PCI DMA operations will generate DMA request events during IPBus transactions as long as the above conditions are met for subsequent data in the FIFO.
DMA Done Event	A DMA done event is never generated.
DMA Terminated Event	A DMA terminated event is generated if any of the following occur: PCI master terminates transaction with a Master Abort (i.e., no target responds to transaction), PCI target terminates with a Target Abort, transaction could not be completed because the RETRY_LIMIT was exceeded, the transaction could not be completed because the BM bit is not set in the COMMAND register, and detection of a PCI parity error.
DMA Transfer Size	16 words.
Limitations	None. A DMA operation may start and end on any local address or PCI address byte boundary and may contain any number of bytes

Table 10.9 Memory to PCI DMA Operations

Notes

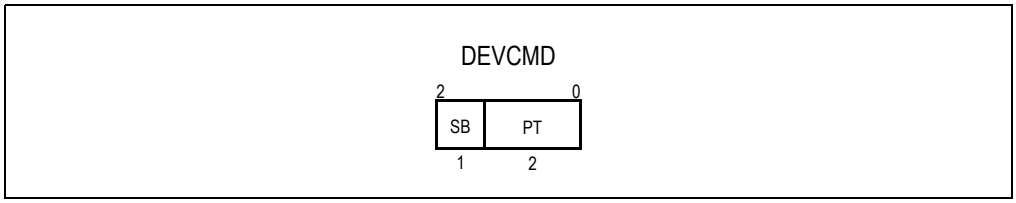


Figure 10.17 Device Command Field for Memory to PCI DMA Descriptors

PT **PCI Transaction.** This field specifies the PCI transaction to use to write data to the PCI bus.
0x0 Memory Write
0x1 Memory Write and Invalidate
0x2 *Reserved*
0x3 I/O Write

SB **Swap Bytes.** This field control byte swapping for data written to the PCI bus during a memory to PCI DMA operation.

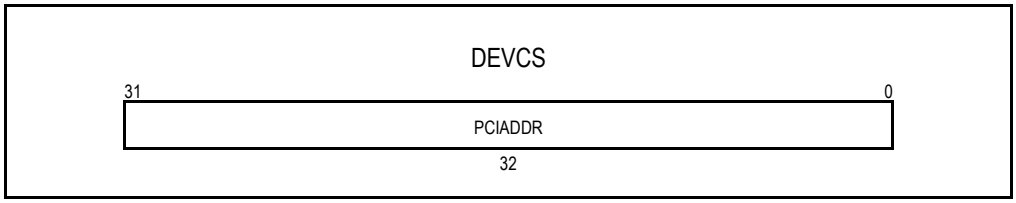


Figure 10.18 Device Control and Status Value for Memory to PCI DMA Descriptors

PCIADDR **PCI Address.** This field specifies the starting PCI address for memory to PCI DMA operations.

Channel 9 Memory Write

PCI memory write transactions are generated during memory to PCI DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to memory write. The PCI bus interface will attempt to generate a burst transaction when possible.

Channel 9 Memory Write and Invalidate

PCI memory write and invalidate transactions are generated during memory to PCI DMA operations if the PCI Transaction (PT) field is set to memory write and invalidate and the MWI bit is set in the COMMAND register in PCI configuration space. If the Memory Write and Invalidate Enable (MWI) bit is not set in the COMMAND register in PCI configuration space and the PT field indicates memory write and invalidate transactions, the DMA will perform the operation using memory write transactions.

It is the responsibility of software to make sure that memory to PCI DMA operations that use memory write and invalidate transactions start on a cache line boundary and transfer an integral number of cache lines. To ensure this, the PCI bus interface will wait until the required number of words for a cache line are present in the PCI DMA output FIFO before initiating a memory write and invalidate transaction on the PCI bus.

If the starting address for a DMA transfer is not on a cache line boundary or does not contain the number of words required for a complete cache line, the PCI bus interface will use memory write transactions. If the MWI bit is not set in the COMMAND register in PCI configuration space, the PCI bus interface will use memory write transactions. If a target disconnects before a complete cache line is transferred, the PCI bus interface will complete the remainder of the transfer using memory write transaction(s).

Notes

Channel 9 I/O Write

PCI I/O write transactions are generated during memory to PCI DMA operations if the PCI Transaction (PT) field in the DEVCMD field of the DMA descriptor is set to I/O write. The PCI bus interface will attempt to generate a burst transaction when possible.

Channel 9 Error Handling

Memory to PCI fatal errors are:

- *PCI target terminates with a Target Abort*
- *transaction could not be completed because the RETRY_LIMIT was exceeded*
- *transaction could not be completed because the BM bit is not set in the COMMAND register*
- *detection of a PCI parity error.*

If any of the above fatal errors are detected during a DMA operation, the DMA operation is halted with a terminated condition (i.e., the T bit is set in the descriptor) and the DMA descriptor's DEVCS field is updated with the approximate address of the error. The address is approximate as it may be off by several words. The DMA descriptor's Current Address (CA) field contains the address of the last data quantity transferred to the PCI DMA output FIFO, not the corresponding address of where the PCI error occurred. Similarly, the COUNT field contains the number of bytes transferred to the PCI DMA output FIFO, not the number of bytes written to the PCI bus. All data queued in the PCI DMA output FIFO is discarded (i.e., the FIFO is flushed) when a fatal error is detected.

PCI DMA Channel 9 Configuration Register

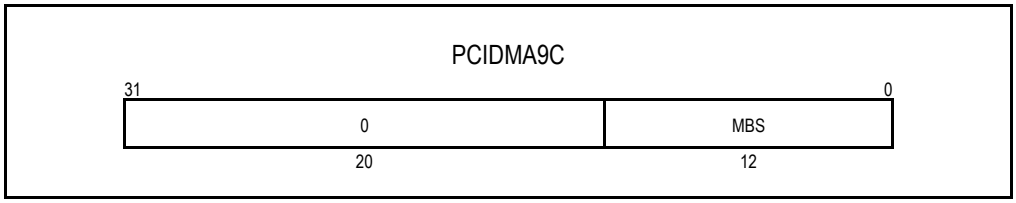


Figure 10.19 PCI DMA Channel 9 Configuration Register (PCIDMA9C)

MBS

Description: **Maximum Burst Size.** This field specifies the number the maximum number of words allowed in a memory to PCI DMA operation. A value of 0x0 corresponds to 0x1000 (i.e., 4K word transfers).

Initial Value: 0x8

Read Value: Previous value written

Write Effect: Modify value

PCI Target

PCI target mode will support up to 11 queued commands. These commands can be either 11 queued writes or 10 queued writes and one queued read. Exceeding these queue limits will result in the PCI host transaction being retried until the command can be accepted.

The PCI target interface, shown in Figure 10.1, allows an external PCI master to read and write any RC32438 local memory address in the same manner as the CPU core. This allows a PCI master to access the RC32438's memory (i.e., DDR or a device) or any internal register. The PCI target interface allows PCI masters to access 8/16/32-bit memory. The PCI target interface will automatically perform byte scattering (writes) and gathering (reads) for devices on the memory and peripheral bus and DDR SDRAM. The PCI target interface is expected to obey the same access and alignment rules as the CPU for accesses to internal RC32438 registers.

Notes

The PCI bus interface provides four mapping regions from the PCI space to the RC32438's local address space. Each mapping region has a corresponding PCI Base Address (PBAx) register, PCI Base Address Control (PBAxC) register, and PCI Base Address Mapping (PBAxM) register. These registers are all part of the PCI configuration. The PBAx registers correspond to the BAR registers in PCI Specification 2.2. Their initial values and configuration, however, are controlled by the PBAxC register. The PBAxC register holds the configuration information for the mapping region.

The Memory Space Indicator (MSI) field in a PBAxC controls how space is advertised (I/O or memory). If the space is advertised by the MSI as memory, the Prefetchable (P) bit controls prefetching. If the space is advertised as I/O, the Prefetchable bit is inactive. The Swap Bytes (SB) field in a PBAxC controls whether bytes are swapped or passed unmodified between the IPBus and the PCI bus when the PCI bus interface is accessed as a target. The PBAxM register holds the local address space base address of PCI transactions that map to the local address space through PBAx.

The local address mapped by a PBAxM register may be any valid local address. These local addresses are decoded in the same manner as CPU physical addresses. The local addresses mapped by one or more PBAxM registers may be overlapping. PCI Base Addresses in PBAx registers should be non-overlapping. If they are overlapping, one will be chosen.

PCI target burst transactions which attempt to burst data beyond the address space allocated to a PBAx will terminate with a target disconnect without data. The PCI address spaces mapped by two PBAx registers may be contiguous. PCI target burst transactions which attempt to burst data across adjacent address spaces mapped by PBAx registers will terminate with a target disconnect without data. The PCI Target Control Register (PCITC) contains fields which control the behavior of the PCI bus interface when acting as a PCI target.

The retry timer controls the number of PCI clock cycles the PCI interface will wait for the first data of an access before issuing a retry. This is used during read operations (i.e., memory read, memory read multiple, memory read line, and I/O read) to specify the number of PCI clock cycles the PCI bus interface is allowed (delay supplying the first data quantity of a transaction) before the transaction must be retried. During write operations (i.e., memory write, memory write and invalidate, and I/O write), this field specifies the number of PCI clock cycles the PCI bus interface is allowed to wait for space to appear in the PCI target input FIFO before a transaction must be retried.

The initial value for the retry timer is specified in the Retry Timer (RTIMER) field of the PCITC register. PCI Specification 2.2 sets the maximum to 16 PCI clock cycles, but the RC32438 allows this limit to be extended to 255 clock cycles. The disconnect timer controls the number of PCI clock cycles the PCI interface will wait for between data transfers. If the PCI bus interface is unable to accept data before the timer expires, it issues a disconnect. PCI Specification 2.2 sets the maximum to 8 PCI clock cycles, but the RC32438 allows this limit to be extended to 255 clock cycles.

The PCI bus interface supports target delayed reads. The PCI bus interface supports only one pending delayed read. If a read is attempted while a delayed read is pending, the transaction is retried and a delayed read is not initiated for the transaction. The PCI master that initiates a delayed read is expected to retry the transaction until the read completes. The PCI bus interface contains a discard timer. If the master does not repeat a delayed read request within 2^{15} clock cycles, the discard timer will expire and discard the pending read. This is necessary to ensure that a malfunctioning PCI master (e.g., one which has a pending delayed read) does not cause the RC32438 to deadlock. If the discard timer expires and a pending read is discarded, the Pending Read Discarded (PRD) bit is set in the PCIS register. The discard timer may be disabled by setting the Disable Discard Timer (DDT) bit in the PCITC register.

The PCI transaction ordering constraints may be viewed as favoring target write operations since only a single delayed read is allowed when there are posted writes. By contrast, multiple posted writes are allowed when there is a delayed read. In an effort to provide some level of fairness, the PCI bus interface supports a mode in which all transactions are retried when there is a delayed read. When the Retry when Delayed Read (RDR) bit is set in the PCITC register, all PCI target transactions are retired as long as there is a pending delayed read.

Notes

The PCI bus interface allows normal PCI target transaction ordering constraints to be overridden for improved efficiency in some system scenarios. For more information, see the Transaction Ordering section later in this chapter. The PCI bus interface supports target locking. Once a lock has been established, all PCI target transactions to the RC32438 are retried until the lock has been released. The RC32438 does not implement locked operations on the IPBus. Therefore, lock operations are only useful for creating atomic sequences as seen by masters on the PCI bus.

The RC32438 does not support IPBus master accesses to PCI addresses that map to its PCI target interface. An IPBus master access to a PCI address that maps to the RC32438's PCI target interface results in a master abort. Also, the RC32438 does not support PCI bus master accesses to the RC32438's local memory that maps to PCI space. These operations do not damage hardware, but their results are undefined.

Target I/O Read

PCI I/O read transactions that map to a PCI Base Address (PBAx) register are converted to local IPBus read operations. Data from an I/O read transaction is translated using the PBAxM register into a local IPBus address. PCI I/O read transactions are not allowed to burst.

The PCI memory write maximum completion time limit of 10 microseconds (see section 3.5.3 in PCI Specification 2.2) is met under normal system conditions, but this limit may be violated in some system configurations. For example, setting the RDR bit may violate this specification. Another example is when PCI target bus requests are masked in the IPBus arbiter. It is the responsibility of the system designer (hardware and software) to guarantee adherence to this requirement.

Target I/O Write

PCI I/O write transactions that map to a PCI Base Address (PBAx) register are converted to local IPBus write operations and posted to the PCI target input FIFO. PCI I/O write transactions are posted to the PCI target input FIFO and are not allowed to burst.

Target Memory Read

PCI memory read transactions that map to a PCI Base Address (PBAx) register are mapped to local IPBus read operation(s). The behavior of PCI target memory read operations is determined by the state of the Memory Read Behavior (MR) field in the corresponding PBAxC register. If MR field is 0x0, the memory read behaves as described below. If the MR field is 0x1, the memory read transaction behaves in the same manner as a memory read line transaction. If the MR field is 0x2, the memory read transaction behaves in the same manner as a memory read multiple transaction.

PCI memory read transactions that map to a PCI Base Address (PBAx) register are mapped to a local IPBus word read operation. PCI memory read transactions are not allowed to burst unless the memory read is mapped to a memory read line or memory read multiple.

Target Memory Write

PCI memory write transactions that map to a PCI Base Address (PBAx) register are mapped to a local IPBus write operation(s) and posted into the PCI target input FIFO. The PCI bus interface will attempt to extend memory write burst transaction for as long as possible. A burst transaction will be retried by the RC32438 if the PCI target input FIFO is full for a period of time which exceeds the programmed RTIMER/ DTIMER value in the PCITC register.

Target Configuration Read

PCI configuration read transactions return the value of the register in PCI configuration space with address PCIAD[7:2]. The PCI bus interface does not support target burst configuration read transactions. If a configuration read transaction consists of more than a single data phase, the target will terminate the transaction with a disconnect.

Notes

Target Configuration Write

PCI configuration write transactions return the value of the register in PCI configuration space with address PCIAD[7:2]. The PCI bus interface will use the byte enables to determine which bytes of the word address by PCIAD[7:2] are being modified. The PCI bus interface does not support target burst configuration write transaction. If a configuration write transaction consists of more than a single data phase, the target will terminate the transaction with a disconnect.

Target Memory Read Multiple

PCI memory read multiple transactions that map to a PCI Base Address (PBAx) register are mapped to local IPBus read operations. Memory read multiple transactions fetch not only the data requested by the data phase of the transaction but cause the PCI bus interface to prefetch additional data. The prefetching behavior is controlled by the Memory Read Multiple Prefetching Behavior (MRM) bit. If cleared, the PCI bus interface performs conservative prefetching. Otherwise, the PCI bus interface performs aggressive prefetching.

In conservative prefetching, the PCI bus interface will prefetch 16 words whenever a memory read multiple transaction is in progress and there are less than 8 words available in the PCI target output FIFO. In aggressive prefetching, the PCI bus interface will continue prefetching bursts of 16 words as long as room exists in the PCI target output FIFO. The PCI target output FIFO will discard prefetched data in the FIFO when a memory read line multiple burst transaction completes.

Target Memory Read Line

PCI memory read multiple transactions that map to a PCI Base Address (PBAx) register are mapped to local IPBus read operations. The prefetching behavior is controlled by the Memory Read Line Prefetching Behavior (MRL) bit. If cleared, the PCI bus interface will prefetch data to the end of the cache line. If the MRL bit is set, the PCI bus interface will translate a memory read line transaction to a memory read multiple transaction.

Target Memory Write and Invalidate

PCI memory write and invalidate transactions that map to a PCI Base Address (PBAx) register are translated into memory write transactions.

Target Error Handling

Data parity errors detected during target transactions are handled as defined in PCI Specification 2.2 (i.e., the PE bit in the STATUS register is set and PERRN is asserted if the PEN bit is set in the COMMAND register) and the transaction is completed as though no error was detected (i.e., writes are performed and reads deliver possibly corrupted data).

Address parity errors detected during target read transactions result in termination of the transaction with a Target Abort. An IPbus transaction is not generated when an address parity error is detected during a target read transaction. Address parity errors detected during target write transactions result in termination of the transaction with a Target Abort. An IPbus transaction is not generated when an address parity error is detected during a target write transaction.

The PCI bus interface terminates a target read or write transaction with a Target Abort if the address space monitor detects a PCI master attempting to access an invalid local address range. For more information, refer to the Address Space Monitor section in Chapter 4, System Integrity Functions. If the transaction was a delayed read, a target abort is signaled when the transaction is retried. If the PCI transaction was a posted write, the transaction is viewed as completed by the PCI bus master and results in the PCI bus interface signalling a PCI system error by asserting SERRN for one PCI clock cycle if the System Error Enable (SEN) and Parity Error Enable (PEN) bits are set in the COMMAND register.

An address space monitor error detected during servicing of a posted target write transaction may result in multiple assertions of SERRN. Data for a posted write transaction is queued in the PCI target input FIFO and segmented into one or more IPBus transactions. Each IPBus transaction is treated independently. If an undecoded address is detected in an IPBus transaction, the remaining IPBus transaction data in the input

Notes

FIFO is discarded and SERRN is asserted for one PCI clock cycle if the SEN and PEN bits are set. Since a posted PCI write transaction may result in multiple IPBus transactions, this may result in multiple assertions of SERRN.

PCI Target Control Register

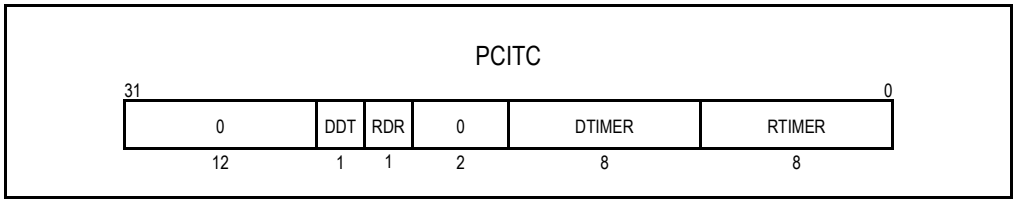


Figure 10.20 PCI Target Control Register (PCITC)

RTIMER

Description: **Retry Timer.** This field specifies the number of PCI clock cycles the PCI interface will wait for the first data of an access before issuing a retry. PCI Specification 2.2 sets the maximum limit of this timer at 16 PCI clock cycles, but in some systems it may be necessary to extend this limit.
The minimum retry timer value is eight. Values less than eight are aliased to eight.

Initial Value: 0x10

Read Value: Previous value written

Write Effect: Modify value

DTIMER

Description: **Disconnect Timer.** This field specifies the number of PCI clock cycles the PCI interface will wait between data phases in an access before issuing a disconnect. PCI Specification 2.2 sets the maximum limit of this timer at 8 PCI clock cycles, but in some systems it may be necessary to extend this limit.
The minimum disconnect timer value is four. Values less than four are aliased to four.

Initial Value: 0x8

Read Value: Previous value written

Write Effect: Modify value

RDR

Description: **Retry When Delayed Read.** When this bit is set, all transactions are retried as long as there is an uncompleted delayed read.
***W*arning: setting this bit may violate PCI Specification 2.2 -- see implementation note in PCI Specification 2.2, section 3.3.3.3.4.**
0x0 - Post writes
0x1 - Retry writes when delayed read

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DDT

Description: **Disable Discard Timer.** When a master does not repeat a delayed read request within 2^{15} PCI clock cycles the PCI interface discards the delayed completion. When this bit is set, delayed completions are never discarded.
0x0 - Discard timer enabled
0x1 - Discard timer disabled

Notes

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Transaction Ordering

IPBus master (i.e., CPU) reads and writes to the PCI bus maintain the total ordering defined by the ordering of transactions on the IPBus. IPBus master PCI read and write transactions are given precedence over PCI DMA read and write operations.

PCI DMA read and write operations are given fair access to the PCI bus. This means that if PCI to Memory and Memory to PCI DMA operations are in progress, access to the PCI bus will alternate between PCI DMA reads and PCI DMA writes. Prefetched data in the CPU master input FIFO is flushed if an IPBus master write is performed that maps to the PCI bus. IPBus master writes may be posted in the CPU master output FIFO. A IPBus master read from the PCI bus cannot complete until all posted writes in the CPU master output FIFO have completed.

Software may use the IPbus master (i.e., CPU) read/write ordering constraints to flush the CPU master output FIFO. A CPU read will not complete until all writes in the CPU master output FIFO have completed. No ordering constraints are enforced between CPU and DMA transactions. No ordering constraints are enforced between PCI to Memory and Memory to PCI DMA operations.

A PCI to Memory DMA operation completes when the last data quantity of the DMA operation is written to the RC32438's local memory (i.e., DDR or device). A Memory to PCI DMA operation completes when the last data quantity of the DMA operation is written to the PCI. This implies that the PCI DMA output FIFO can only contain data associated with one DMA operation at a time.

Target writes which are posted by the PCI bus interface must complete in the order in which they occurred on the PCI bus. No ordering constraints are enforced between writes posted by an IPBus master (i.e., CPU core) and by an external PCI master to the RC32438's PCI target interface.

Due to transaction ordering constraints, a PCI target read is not allowed to complete as long as there are posted writes in the PCI target input FIFO. The RC32438 will retry the read if it cannot be completed in the allotted time. The PCI target interface supports one delayed read. The delayed read cannot complete until all previous posted writes have completed.

The PCI transaction ordering constraints may be viewed as favoring target write operations since only a single delayed read is allowed when there are posted writes, while multiple posted writes are allowed when there is a delayed read. In an effort to provide some level of fairness, the PCI bus interface supports a mode in which all transactions are retried when there is a delayed read. When the Retry when Delayed Read (RDR) bit is set in the PCITC register, all PCI target transactions are retired as long as there is a pending delayed read.

In some system scenarios, it may be desirable to violate PCI target transaction ordering constraints in order to improve performance. Normally, a PCI target read is not allowed to complete until all previously posted writes to the target have completed. In situations where one can guarantee that input and output buffers never overlap, this constraint may be overly restrictive.

When the Target Read Priority (TRP) bit is set in a PCI Base Address Control (PBAxC) register, target read transactions that map to the RC32438's local address space using that PCI base address are allowed to complete even if there are posted targeted write transactions. Since the TRP bit only affects target reads that map using that PCI base address, a synchronization barrier may be implemented by performing a target read to a different PCI base address that does not have the TRP bit set.

Notes

PCI Messaging Unit

The RC32438 provides message and doorbell registers to facilitate efficient communication between PCI agents and the CPU. The messaging unit is a subset of the I_2O Messaging Unit as well as that implemented by the Intel i960Rx. There are different behaviors for some of the registers depending on if they are written by the CPU or by a PCI master. All of the bits in the PCI Inbound Interrupt Cause (PCIIIC) register which are not masked by the PCI Inbound Interrupt Mask (PCIIIM) register are ORed and result in the status of the Inbound Interrupt (II) bit in the PCI Status (PCIS) register. All of the bits in the PCI Outbound Interrupt Cause (PCIOIC) register which are not masked by the PCI Outbound Interrupt Mask (PCIOIM) register are ORed together. If this ORed value is a one, the PCI Messaging Unit Interrupt (PCIMUINTN) signal is driven low. Otherwise, if the ORed value is a zero, the PCIMUINTN signal is tri-stated. The PCIMUINTN signal is a GPIO alternate function output (for more information, refer to Chapter 12, General Purpose I/O Controller).

PCI Inbound Message [0|1] Register

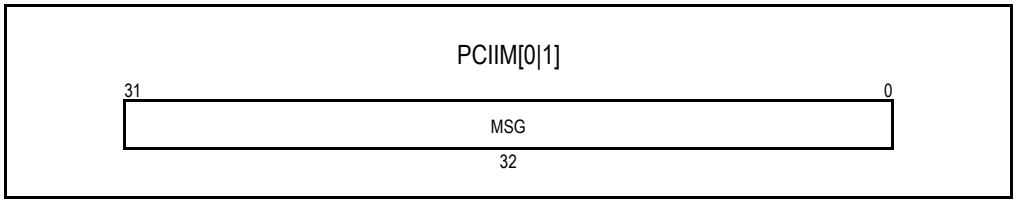


Figure 10.21 PCI Inbound Message [0|1] Register (PCIIM[0|1])

MSG

Description: **Message.** When written, the value of the register is modified and the corresponding message bit (IM0 or IM1) is set in the PCI Inbound Interrupt Cause (PCIIIC) register. This register is intended for passing messages from the PCI bus to the CPU and thus can only be written by PCI bus masters. The CPU may read this register, but CPU writes are ignored.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value (CPU writes are ignored)

PCI Outbound Message [0|1] Register

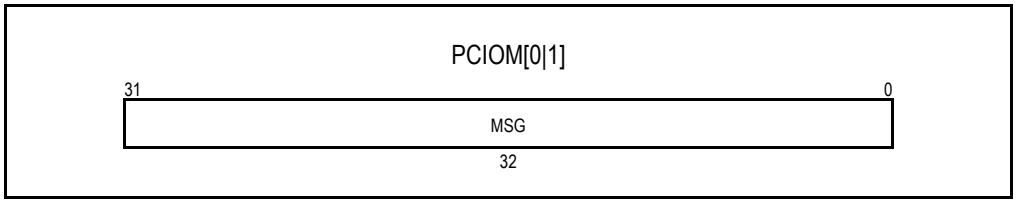


Figure 10.22 PCI Outbound Message [0|1] Register (PCIOM[0|1])

MSG

Description: **Message.** When written, the value of the register is modified and the corresponding message bit (OM0 or OM1) is set in the PCI Outbound Interrupt Cause (PCIOIC) register. This register is intended for passing messages from the CPU to the PCI bus and thus may only be written by the CPU. PCI bus masters may read this register, but PCI bus master writes are ignored.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value (PCI bus master writes are ignored)

PCI Inbound Doorbell Register

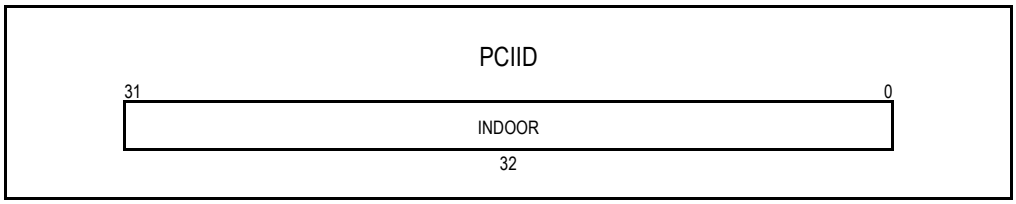


Figure 10.23 PCI Inbound Doorbell Register (PCIID)

INDOOR

Description: **Inbound Doorbell.** Writing a one to a bit in this field by a PCI bus master causes the bit to be set. Writing a one to a bit in this field by the CPU clears the bit if it was set. The Inbound Doorbell (ID) bit in the PCI Inbound Interrupt Cause (PCIIIC) register is set if any of the bits in this register are set.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value (PCI bus master writes one to set bit, CPU writes one to clear bit)

PCI Inbound Interrupt Cause Register

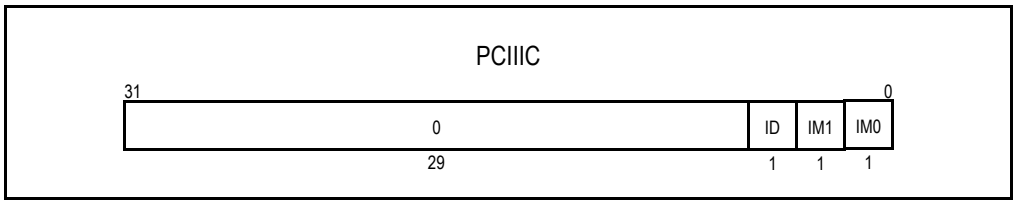


Figure 10.24 PCI Inbound Interrupt Cause Register (PCIIIC)

IM0

Description: **Inbound Message 0.** This bit is set when the PCI Inbound Message 0 (PCIIM0) register is written by a PCI bus master.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky, writing a one clears this bit

IM1

Description: **Inbound Message 1.** This bit is set when the PCI Inbound Message 1 (PCIIM1) register is written by a PCI bus master.

Initial Value: 0x0

Notes

Read Value: Status

Write Effect: Sticky, writing a one clears this bit

ID

Description: **Inbound Doorbell.** This bit is set when any bit in the PCI Inbound Doorbell (PCIID) register is set. This bit is read-only and simply represents the OR of all the bits in the PCIID register.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

PCI Inbound Interrupt Mask Register

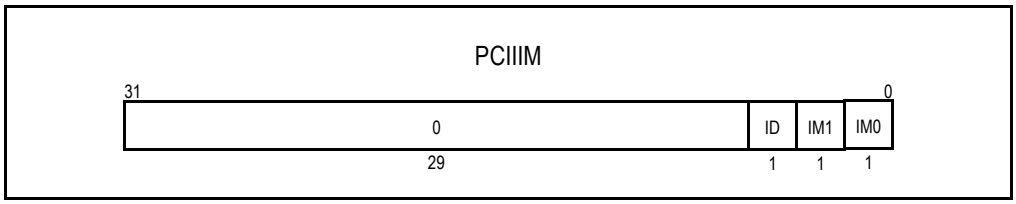


Figure 10.25 PCI Inbound Interrupt Mask Register (PCIIIM)

IM0

Description: **Inbound Message 0.** When this bit is set, the IM0 bit in the PCIIC register is masked from setting the Inbound Interrupt (II) bit in the PCI Status (PCIS) register.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

IM1

Description: **Inbound Message 1.** When this bit is set, the IM1 bit in the PCIIC register is masked from setting the Inbound Interrupt (II) bit in the PCI Status (PCIS) register.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

ID

Description: **Inbound Doorbell.** When this bit is set, the ID bit in the PCIIC register is masked from setting the Inbound Interrupt (II) bit in the PCI Status (PCIS) register.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI Outbound Doorbell Register

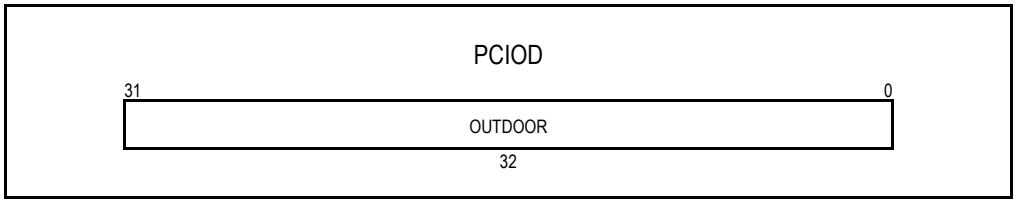


Figure 10.26 PCI Outbound Doorbell Register (PCIOD)

OUTDOOR

Description: **Outbound Doorbell.** Writing a one to a bit in this field by the CPU causes the bit to be set. Writing a one to a bit in this field by a PCI master clears the bit if it was set. The Outbound Doorbell (OD) bit in the PCI Outbound Interrupt Cause (PCIOIC) register is set if any of the bits in this register are set.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value (CPU writes one to set bit, PCI bus master writes one to clear bit)

PCI Outbound Interrupt Cause Register

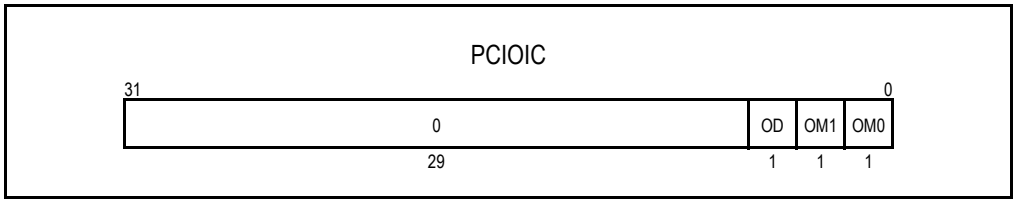


Figure 10.27 PCI Outbound Interrupt Cause Register (PCIOIC)

OM0

Description: **Outbound Message 0.** This bit is set when the PCI Outbound Message 0 (PCIOM0) register is written by the CPU.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky, writing a one clears this bit

OM1

Description: **Outbound Message 1.** This bit is set when the PCI Outbound Message 1 (PCIOM1) register is written by the CPU.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky, writing a one clears this bit

OD

Description: **Outbound Doorbell.**This bit is set when the OD bit in the PCIOIC register is masked from generating a PCI interrupt output.

Notes

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

PCI Outbound Interrupt Mask Register

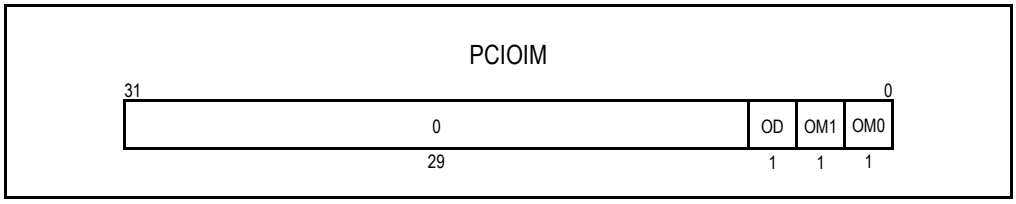


Figure 10.28 PCI Outbound Interrupt Mask Register (PCIOIM)

OM0

Description: **Outbound Message 0.** This bit is set when the OM0 bit in the PCIOIC register is masked from generating a PCI interrupt output.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

OM1

Description: **Outbound Message 1.** This bit is set when the OM1 bit in the PCIOIC register is masked from generating a PCI interrupt output.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

OD

Description: **Outbound Doorbell.** This bit is set when the OD bit in the PCIOIC register is masked from generating a PCI interrupt output.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PCI Configuration Registers

The registers in this section are not memory mapped in the RC32438's memory space. They may be read and written by the CPU core or the Ethernet PCI master using PCI configuration read and write operations.Table 10.10 shows the PCI configuration space registers.

Addresses between 0x00 and 0x3F follow the Type 00h Configuration Space Header defined by PCI Specification 2.2. Addresses between 0x40 and 0x7F contain device dependent registers. Addresses between 0x80 and 0xFF are not used. Shaded fields are read-only to an external PCI bus master. The CPU core may read and modify any PCI configuration register or field in either host or satellite mode.

Notes

The PCI serial EEPROM interface loads the initial value of all PCI configuration registers, shown as shaded in Table 10.10. Values shown as "xxxxxxxx" are don't care values. Registers in PCI configuration space are unaffected by a warm reset except when the warm reset is the result of the assertion of the PCI reset signal when operating in PCI satellite mode. When this occurs, all PCI registers are set to their initial values.

Address	31			0
0x00	DEVICE_ID		VENDOR_ID	
0x04	STATUS		COMMAND	
0x08	CLASS _CODE			REVISION_ID
0x0C	BIST	HEADER_TYPE	MASTER_LATENCY	CACHE_LINE_SIZE
0x10	PBA0			
0x14	PBA1			
0x18	PBA2			
0x1C	PBA3			
0x20	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
0x24	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
0x28	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
0x2C	SUBSYSTEM_ID		SUBSYSTEM_VENDOR_ID	
0x30	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
0x34	Reserved[1]			
0x38	Reserved[1]			
0x3C	MAX_LAT	MIN_GNT	INTERRUPT_PIN	INTERRUPT_LINE
0x40	Reserved[1]		RETRY_LIMIT	TRDY_TIMEOUT
0x44	PBA0C			
0x48	PBA0M			
0x4C	PBA1C			
0x50	PBA1M			
0x54	PBA2C			
0x58	PBA2M			
0x5C	PBA3C			
0x60	PBA3M			
0x64	PMGT			
0x68 - 0x7F	Reserved[1]			
0x80 - 0xFF	Reserved (not loaded from PCI Serial EEPROM)[1]			

Table 10.10 PCI Configuration Registers

1. Writes to reserved fields are ignored. Reserved fields always return a value of zero when read.

Notes

Vendor ID Register

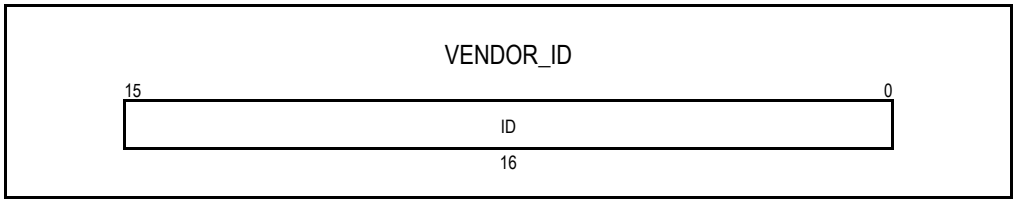


Figure 10.29 Vendor ID Register (VENDOR_ID)

ID

Description: **ID.** This field specifies the vendor of the device. It should be initialized to 0x111D which corresponds to the vendor IDT.

Initial Value: 0x111D or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Device ID Register

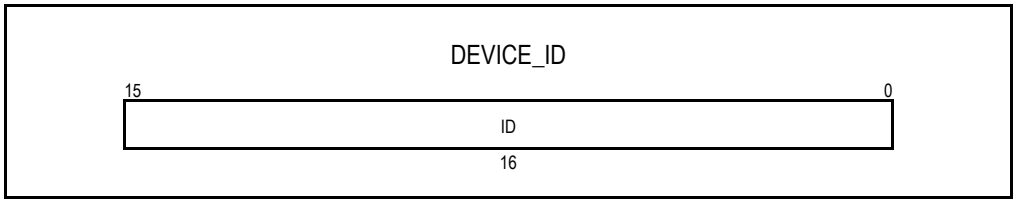


Figure 10.30 Device ID Register (DEVICE_ID)

ID

Description: **ID.** This field specifies the device ID. Initialize this field to:
0x0207 — RC32438

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Command Register

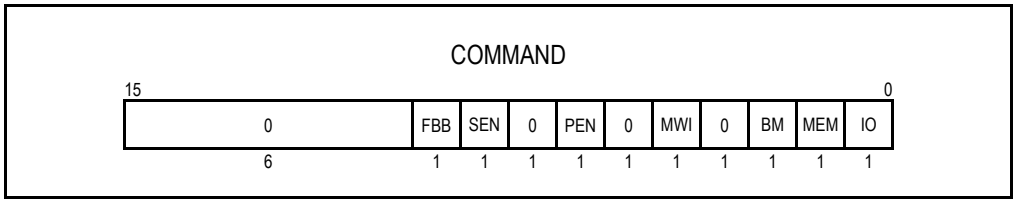


Figure 10.31 Command Register (COMMAND)

I/O

Description: **I/O Enable.** When this bit is set the device responds to I/O space accesses.

Notes

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MEM

Description: **Memory Enable.** When this bit is set the device responds to memory space accesses.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

BM

Description: **Bus Master Enable.** When this bit is set, the device is allowed to act as a PCI master.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MWI

Description: **Memory Write and Invalidate Enable.** When this bit is set, the PCI bus interface may generate memory write and invalidate transactions on the PCI bus.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PEN

Description: **Parity Error Enable.** When this bit is set, the device must take its normal action when a parity error is detected (See PCI Specification 2.2). When this bit is cleared, the devices sets its Parity Error (PE) bit in the PCI STATUS register, does not assert PERRN, and continues normal operation.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SEN

Description: **System Error Enable.** When this bit is set, the SERRN drive is enabled. When this bit is cleared, the SERRN driver is disabled.
This bit and the PEN bit must be set to report address phase parity errors.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

FBB

Description: **Fast Back to Back Enable.** When this bit is set, the PCI bus interface is allowed to generate fast back-to-back transactions to different agents as described in PCI Specification 2.2, section 2.4.2. When this bit is cleared, fast back-to-back transactions are only performed to the same agent. **Note**: RC32438 never generates fast back-to-back transactions.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Status Register

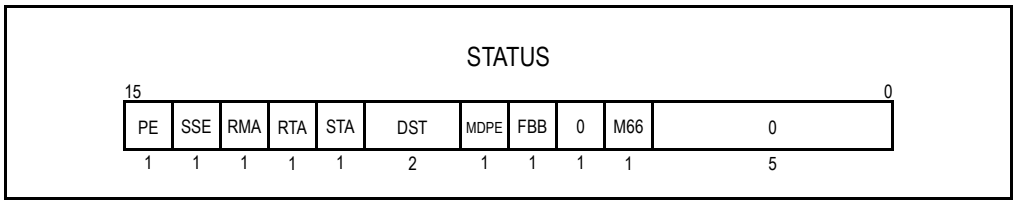


Figure 10.32 Status Register (STATUS)

M66

Description: **66 MHz Capable.** When this bit is set, it indicates that the device PCI bus interface can be operated at 66 MHz.

Initial Value: 0x1

Read Value: Current value

Write Effect: No effect, this bit is hardwired to a one.

FBB

Description: **Fast Back-to-Back Capable.** When this bit is set it indicates the target is capable of accepting fast back-to-back transactions when the transactions are not to the same agent.

Initial Value: 0x1

Read Value: Current value

Write Effect: No effect, this bit is hardwired to a one.

MDPE

Description: **Master Data Parity Error Detected.** This bit is set when three conditions are met: (1) the bus agent asserted PERRN on a read or observed PERRN asserted on a write; (2) the agent setting the bit acted as the bus master for the operation in which the error occurred; and (3) the PEN bit is set in the COMMAND register.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

DST

Description: **Device Select Timing.** This field indicates the slowest timing of PCIDEVSELN when the PCI bus interface responds to a PCI transaction as a target.

Notes

Initial Value: 0x1

Read Value: 0x1

Write Effect: No effect, this field is hardwired to a 0x1.

STA

Description: **Signalled Target Abort Status.** This bit is set by the PCI bus interface whenever it acts as a PCI target and terminates a transaction with a Target-Abort.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

RTA

Description: **Received Target Abort Status.** This bit is set by the PCI bus interface whenever it acts as a master and a transaction is terminated with a Target-Abort.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

RMA

Description: **Received Master Abort Status.** This bit is set by the PCI bus interface whenever it acts as a PCI master and terminates a host-to-PCI transaction with a Master Abort.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

SSE

Description: **Signaled System Error.** This bit is set by the PCI bus interface whenever it asserts PCISERRN.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

PE

Description: **Parity Error.** This bit is set by the device whenever it detects a parity error, even if parity error handling is disabled.

Initial Value: 0x0

Read Value: Status

Write Effect: PCI Sticky bit (set by hardware: write of one clears bit, write of zero has no effect).

Notes

Device Revision ID Register

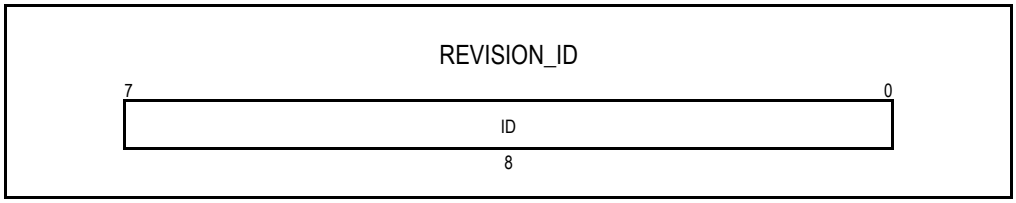


Figure 10.33 Device Revision ID Register (REVISION_ID)

ID

Description: **ID.** This register contains the current revision identifier for the device.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Class Code Register

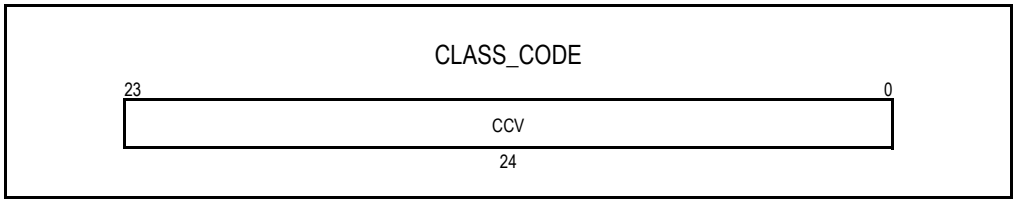


Figure 10.34 Class Code Register (CLASS_CODE)

CCV

Description: **Class Code Value.** This field identifies the function of the device. See Appendix D in the PCI Specification 2.2 for a complete list of class codes.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Notes

Cache Line Size Register

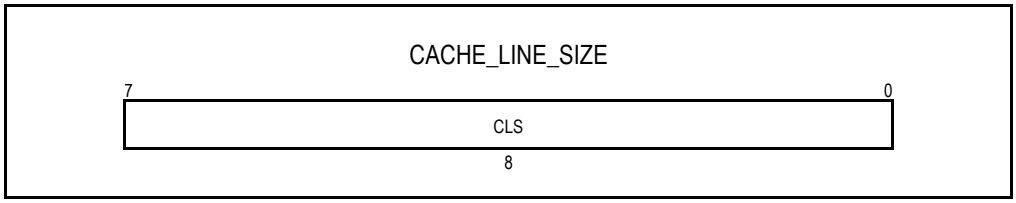


Figure 10.35 Class Code Register (CLASS_CODE)

CLS

Description: **Cache Line Size.** This field specifies the size of a cache line in 32-bit words. This field may only be initialized to the following values: 0, 1, 2, 4, 8, 16, 32, 64, 128. Initializing this field to any other value results in the same behavior as initializing this field to zero.
Note: The PCI master and PCI target transactions use these values differently. For PCI master transactions where the processor is the master initiating a read from another device on the PCI bus, initializing this field to 4 or less results in a 4 word prefetch on the PCI bus while initializing this field to 8 or greater results in an 8 word prefetch (see "Master Memory Read Line" on page 10-21). For PCI target read transactions where the processor is the target device, this field directly controls the number of bytes prefetched. A setting of zero results in a one byte prefetch, otherwise the prefetch matches the setting, e.g., 1 if setting is 1, 2 if setting is 2 ..... 64 if setting is 64, and 128 if setting is 128.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Master Latency Register

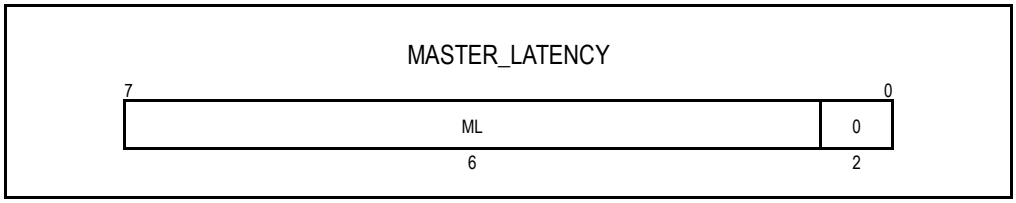


Figure 10.36 Master Latency Register (MASTER_LATENCY)

ML

Description: **Master Latency.** This field specifies the minimum time the PCI bus interface, when operating as a PCI bus master, is allowed to retain ownership of the bus after it has acquired bus ownership and initiated a transaction. In the RC32438, the minimum value is four PCI bus clock cycles.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Header Type Register

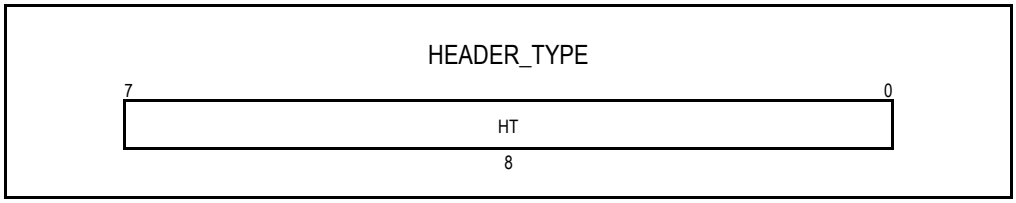


Figure 10.37 Header Type Register (HEADER_TYPE)

HT

Description: **Header Type.** This field identifies the layout of the second part of the predefined header (beginning at byte 0x10 in PCI configuration space). See section 6.2.1 of PCI Specification 2.2 for information on this field.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

BIST Register

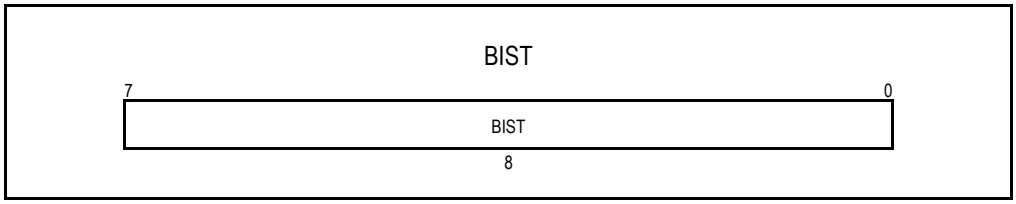


Figure 10.38 Header Type Register (BIST)

BIST

Description: **Built In Self Test.** The RC32438 does not implement this optional PCI register and functionality. Thus, the value of this field should be zero.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Current value

Write Effect: No effect, this bit is hardwired to a 0x0.

Notes

PCI Base Address [0|1|2|3] Register

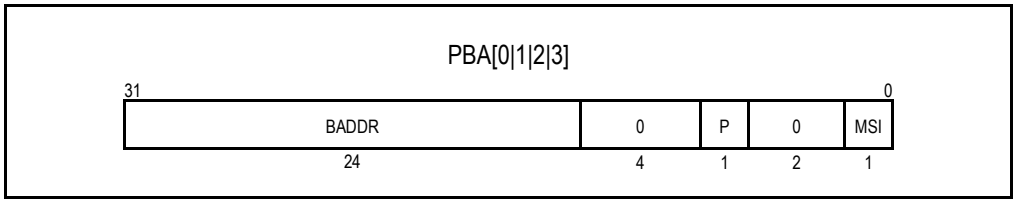


Figure 10.39 PCI Base Address [0|1|2|3] Register (PBA[0|1|2|3])

MSI

Description: **Memory Space Indicator.** This bit determines if the base address register maps into memory or I/O space.
0x0 - Memory space
0x1 - I/O space

Initial Value: 0x0

Read Value: Value in MSI field of corresponding PBAxC register

Write Effect: Read only

P

Description: **Prefetchable.** When the MSI field indicates that the base address register maps into memory space, this bit indicates if the memory is prefetchable.
0x0 - Non-prefetchable
0x1 - Prefetchable (no side effect on reads and write merging is allowed)

Initial Value: 0x0

Read Value: Value in P field of corresponding PBAxC register

Write Effect: Read only

BADDR

Description: **Base Address.** This field specifies the PCI address bits to use for decoding a PCI transaction to a local transaction. See the PCI specification for more information.
The value of the SIZE field in the corresponding PBAxC register controls which bits in this field may be modified by a PCI master or the CPU. Bits that cannot be modified are always zero.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Subsystem Vendor ID

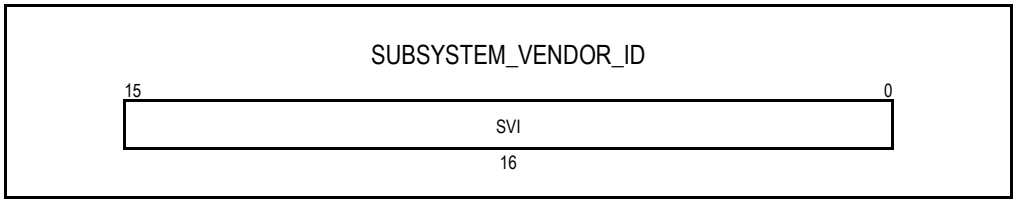


Figure 10.40 Subsystem Vendor ID Register (SVI)

SVI

Description: **Subsystem Vendor ID.** This field identifies the vendor of the PCI device subsystem.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Subsystem ID Register

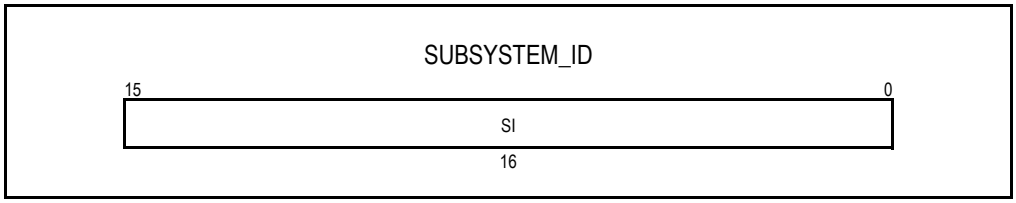


Figure 10.41 Subsystem ID Register (SUBSYSTEM_ID)

SI

Description: **Subsystem ID.** This field identifies the subsystem of the PCI device subsystem.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus.

Interrupt Line Register

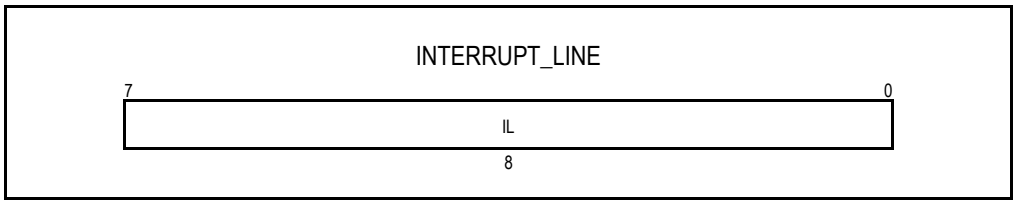


Figure 10.42 Interrupt Line Register (INTERRUPT_LINE)

IL

Description: **Interrupt Line.** The value of this field identifies the system controller(s) input to which the interrupt pin of the device is connected.

Notes

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Interrupt Pin Register

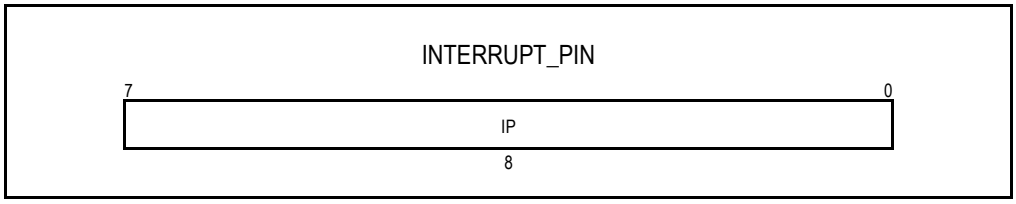


Figure 10.43 Interrupt Pin Register (INTERRUPT_PIN)

IP

Description: **Interrupt Pin.** This field identifies the interrupt pin the device (or device function) uses.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Minimum Grant Register

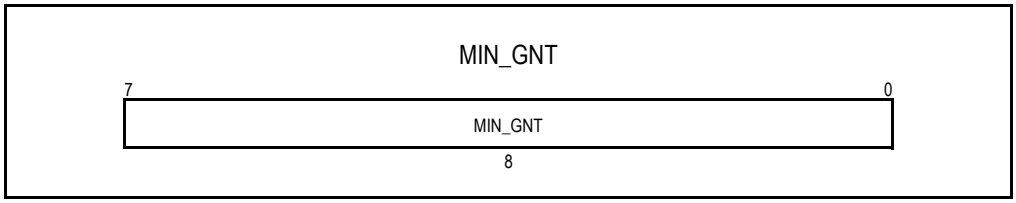


Figure 10.44 Minimum Grant Register (MIN_GNT)

MIN_GNT

Description: **Minimum Grant.** This field identifies how long of a burst period is needed. Units are in 0.25 µsec increments assuming a 33 MHz PCI clock. A value of 0 indicates no restriction is needed. See PCI Specification 2.2, Section 6.2.4 for details and a FIFO resource example.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Notes

Maximum Latency Register

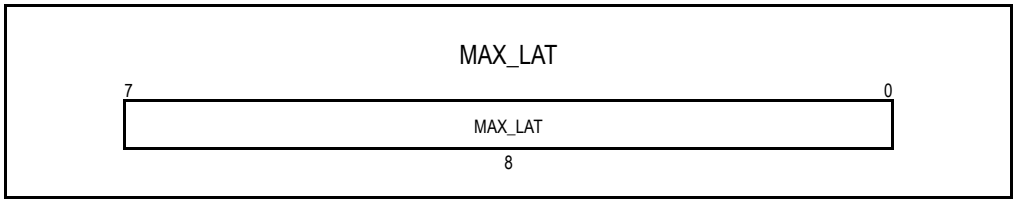


Figure 10.45 Maximum Latency Register (MAX_LAT)

MAX_LAT

Description: **Maximum Latency.** This field identifies how often access to the PCI bus is needed. Units are in 0.25 µsec increments assuming a 33 MHz PCI clock. A value of 0 indicates no restrictions are needed. See PCI Specification 2.2, Section 6.2.4 for details and a FIFO resource example.

Initial Value: 0x0 or value initialized from PCI serial EEPROM

Read Value: Previous value written

Write Effect: CPU can modify value, read-only from PCI bus

Target Ready Time-out Register

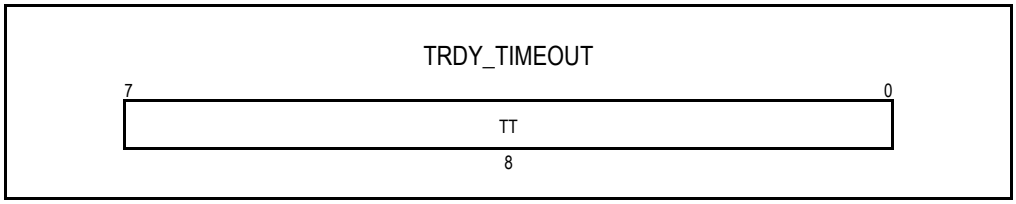


Figure 10.46 Target Time-out Register (TRDY_TIMEOUT)

TT

Description: **Target Time-out.** This field indicates how many PCI clock cycles the PCI bus interface will wait as a master for the assertion of TRDYN. Setting this field to zero results in an infinite time-out period (i.e., no time-out).

Initial Value: 0x80

Read Value: Previous value written

Write Effect: Modify value

Notes

Retry Limit Register

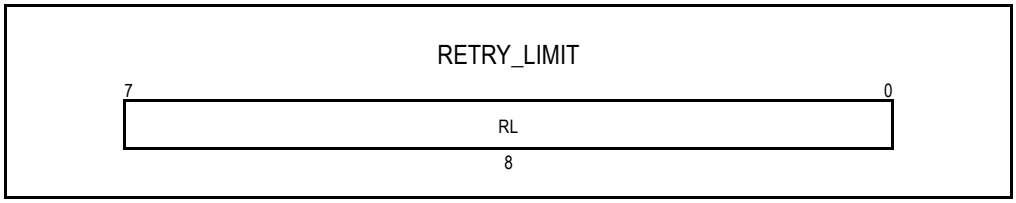


Figure 10.47 Retry Limit Register (RETRY_LIMIT)

RL

Description: **Retry Limit.** This field indicates how many times the PCI bus interface will retry a transaction. Setting this field to zero results in an infinite retry limit (i.e., no limit).

Initial Value: 0x80

Read Value: Previous value written

Write Effect: Modify value

PCI Base Address [0|1|2|3] Control

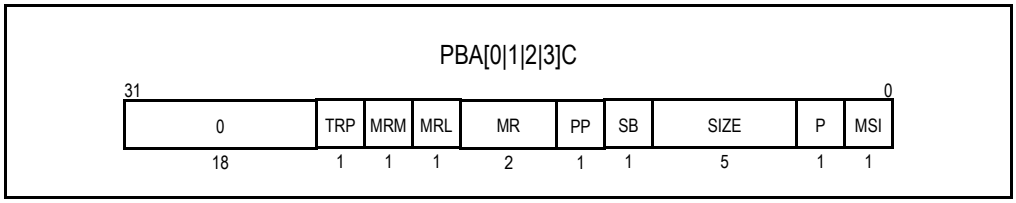


Figure 10.48 PCI Base Address [0|1|2|3] Control (PBA[0|1|2|3]C)

MSI

Description: **Memory Space Indicator.** The value of this bit determines the value advertised in the MSI bit of the corresponding PBAx register.
0x0 - Memory space
0x1 - I/O space

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

P

Description: **Prefetchable.** The value of this bit determines the value advertised in the P bit of the corresponding PBAx register. This bit does not affect operation of the PCI interface (i.e., it may not actually perform pefetching). Prefetching operation for PCI PARx mapped transactions is controlled by the Perform Prefetch (PP) bit in this register.
0x0 - Non-prefetchable
0x1 - Prefetchable

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

SIZE

Description: **Address Space Size.** This field indicates the size of the address space for the corresponding PCI base address register. All bits greater than or equal to SIZE in PBAx may be modified. Bits less than SIZE and greater than or equal to bit four always return a value of zero when read and cannot be modified. Setting the SIZE field to a value less than eight results in all bits in the corresponding PBAx register taking on a zero value. This effectively disables the PCI base address register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SB

Description: **Swap Bytes.** This bit controls byte swapping for PCI transactions that map to the local bus through the PBAx register.
0x0 - No byte swapping
0x1 - Swap bytes

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PP

Description: **Perform Prefetching.** This bit controls the prefetching behavior for PCI read transactions that map to the local bus through PBAx.
0x0 - Do not perform prefetching for any transactions
0x1 - Perform prefetching as indicated by the MR, MRL, and MRM fields in this register

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

MR

Description: **Memory Read Behavior.** This bit controls the behavior of PCI memory read transactions.
0x0 - Read data indicated by transaction (no prefetching)
0x1 - Treat memory read transactions as memory read line transaction
0x2 - Treat memory read transactions as memory read multiple transaction
0x3 - reserved

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MRL

Description: **Memory Read Line Prefetching Behavior.** This bit controls the behavior of PCI memory read line transactions.
0x0 - Prefetch data to end of cache line
0x1 - Treat memory read line transactions as memory read multiple transactions

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

MRM

Description: **Memory Read Multiple Prefetching Behavior.** This bit controls the behavior of PCI memory read multiple transactions on the local bus.
0x0 - Conservative Prefetching. Prefetch a 16 word burst from local address space whenever there are less than 8 words in the PCI target output FIFO.
0x1 - Aggressive Prefetching. Keep prefetching 16 word bursts from local address space as long as room exists for them in the PCI target output FIFO.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TRP

Description: **Target Read Priority.** When this bit is set, PCI target read transactions that map to the RC32438's local address space using the corresponding base address are given priority over posted writes in the PCI target input buffer. When this bit is set, PCI transaction ordering constraints are violated. For more information, see section "Transaction Ordering" on page 10-40. **Warning: setting this bit will violate the PCI Specification 2.2 since read transactions will be completed before posted write transactions.**

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PCI Base Address [0|1|2|3] Mapping Register

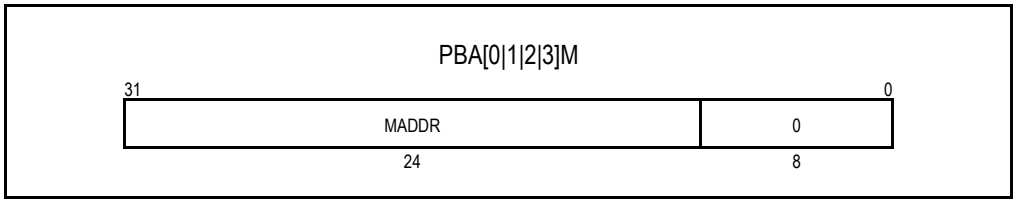


Figure 10.49 PCI Base Address [0|1|2|3] Mapping Register (PBA[0|1|2|3]M)

MADDR

Description: **Mapping Address.** This field contains the local base address for PCI transactions mapped to the local bus through the PBAx register. PCI transaction address bits 31 through the value of the SIZE field in the PBAxC register are replaced by corresponding bits in this field for PCI transactions that map to the local bus through the PBAx register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI Management Register

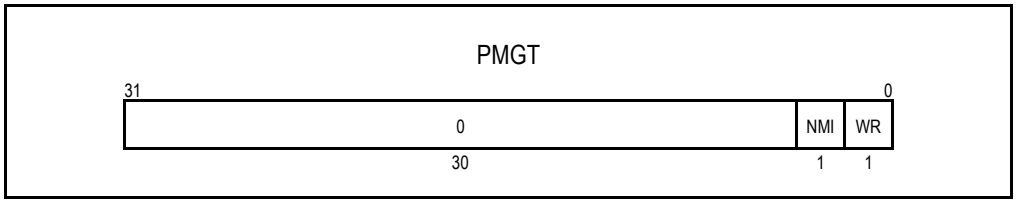


Figure 10.50 PCI Management Register (PMGT)

WR

Description: **Warm Reset.** Writing a one to this register generates a warm reset.

Initial Value: 0x0

Read Value: Current warm reset state
0x0 - normal operation
0x1 - warm reset

Write Effect: Writing a one generates a warm reset.

NMI

Description: **Non-Maskable Interrupt.** Writing a one to this register causes the NMI bit to be set in the PCI Status (PCIS) register and results in a CPU non-maskable interrupt.

Initial Value: 0x0

Read Value: 0x0

Write Effect: Writing a one generates a non-maskable interrupt.

Notes

Ethernet Interfaces

Notes

Introduction

This chapter describes the two Ethernet interfaces on the RC32438 device. Both channels are nearly identical (Ethernet 0 channel has MII management functions; Ethernet 1 channel does not).

Features

- *10 and 100 Mb/s ISO/IEC 8802-3:1996 compliant*
- *Two IEEE 802.3u compatible Media Independent Interfaces (MII) with serial management interface*
- *MII supports IEEE 802.3u auto-negotiation speed selection*
- *Supports 64 entry hash table based multicast address filtering*
- *512 byte transmit and receive FIFOs*
- *Supports flow control functions outlined in IEEE Std. 802.3x-1997*

Block Diagram

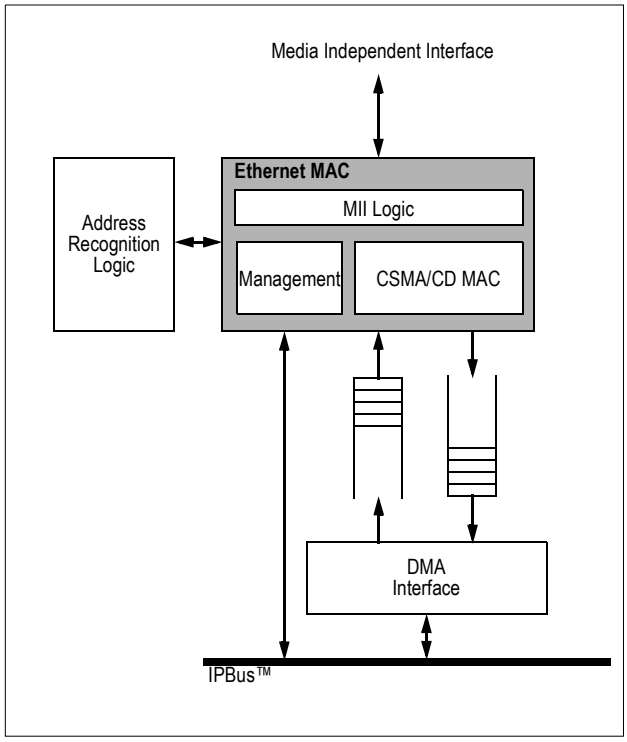


Figure 11.1 Ethernet Interface with Management Feature

Functional Overview

The RC32438 contains two nearly identical 10/100 Mb/s ISO/IEC 8802-3:1996 compliant Ethernet interfaces (only 0 channel has MII management functions). Figure 11.1 shows a block diagram with a management function. An external Ethernet physical layer device (PHY) connects to each Ethernet interface through an IEEE Std 802.3u-1995 Media Independent Interface (MII). This allows each Ethernet interface to be used with a multitude of physical layers such as: 10BASE-T, 100BASE-TX, and 100BASE-FX. Each Ethernet interface is capable of performing control flow functions outlined in IEEE Std 802.3x-1997.

Notes

Since both Ethernet interfaces are nearly identical, the remainder of this chapter describes the functionality of a single interface. It should be understood that there are two copies of all Ethernet registers, one for Ethernet interface zero (denoted by the prefix ETH0 or MII0) and one for interface one (denoted by the prefix ETH1 or MII1).

As illustrated in Figure 11.1, an Ethernet interface consists of five major blocks:

- *An Ethernet MAC (medium access controller), which includes a CSMA/CD MAC, a management interface, and a MII pin level interface*
- *A 512 byte input FIFO connected to the MAC*
- *A 512 byte output FIFO connected to the MAC*
- *Address recognition logic, which determines if an Ethernet frame received on the MII should be passed to the input FIFO*
- *DMA interface, which allows the input and output FIFOs to be read and written by the DMA Controller.*

The Ethernet interface is enabled by setting the EN bit in the Ethernet interface control (ETH[0|1]INTFC) register.

Input and Output FIFOs

The input and output FIFOs are not intended to hold entire packets, but merely to compensate for latency in accessing data by the DMA Controller. Each 512 byte FIFO is organized as 128 32-bit words. During boot configuration, the system may be configured to operate in either big endian or little endian mode. Although Ethernet packet data is packed into words in the FIFOs, packet data is referenced as bytes (also called octets) by the CPU core and Ethernet MAC. Data is always stored in big endian format within FIFO data words, with endianness conversion taking place as data is transferred between the IPBus and the FIFOs. Thus, data stored in the FIFOs always appears to the programmer in the endianness selected during boot configuration.

Packet data to be transmitted is written by the DMA Controller into the output FIFO. When the amount of packet data in the output FIFO exceeds the threshold programmed in the transmit threshold (TTH) field of the Ethernet FIFO transmit threshold register (ETH[0|1]FIFOTT), or when the last byte of a packet is written to the output FIFO, the MAC will check if the line is busy. If the line is not busy, the MAC will begin transmitting the preamble, start of frame delimiter, and the packet data.

If a collision is detected during the collision window, the MAC will back off and attempt to retransmit the frame. Attempts are made to retransmit the frame until the collision threshold specified in the maximum retransmissions (MAXRET) field of the ETH[0|1]CLRT register is reached. When this occurs, the excessive collisions (EC) bit is set in the DEVCS field of the DMA descriptor.

For correct operation, the transmit threshold (TTH) must be set to a value equal to or greater than the value selected for the collision window size in the COLWIN field of the Ethernet collision window and retry (ETH[0|1]CLRT) register minus two words or eight bytes (the collision window size includes the preamble and SFD which are generated by the MAC and are not part of a packet).

Ethernet Register Description

Register Offset[1]	Register Name	Register Function	Size
0x05_8000	ETH0INTFC	Ethernet 0 interface control	32-bit
0x05_8004	ETH0FIFOTT	Ethernet 0 FIFO transmit threshold	32-bit
0x05_8008	ETH0ARC	Ethernet 0 address recognition control	32-bit
0x05_800C	ETH0HASH0	Ethernet 0 hash table 0	32-bit
0x05_8010	ETH0HASH1	Ethernet 0 hash table 1	32-bit
0x05_8014 through 0x05_8020	Reserved		

Table 11.1 Ethernet Register Map (Part 1 of 4)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x05_8024	ETH0PFS	Ethernet 0 pause frame status	32-bit
0x05_8028	ETHMCP	Ethernet management clock prescalar	32-bit
0x05_802C through 0x05_80FF	Reserved		
0x05_8100	ETH0SAL0	Ethernet 0 station address 0 low	32-bit
0x05_8104	ETH0SAH0	Ethernet 0 station address 0 high	32-bit
0x05_8108	ETH0SAL1	Ethernet 0 station address 1 low	32-bit
0x05_810C	ETH0SAH1	Ethernet 0 station address 1 high	32-bit
0x05_8110	ETH0SAL2	Ethernet 0 station address 2 low	32-bit
0x05_8114	ETH0SAH2	Ethernet 0 station address 2 high	32-bit
0x05_8118	ETH0SAL3	Ethernet 0 station address 3 low	32-bit
0x05_811C	ETH0SAH3	Ethernet 0 station address 3 high	32-bit
0x05_8120	ETH0RBC	Ethernet 0 receive byte count	32-bit
0x05_8124	ETH0RPC	Ethernet 0 receive packet count	32-bit
0x05_8128	ETH0RUPC	Ethernet 0 receive undersized packet count	32-bit
0x05_812C	ETH0RFC	Ethernet 0 receive fragment count	32-bit
0x05_8130	ETH0TBC	Ethernet 0 transmit byte count	32-bit
0x05_8134	ETH0GPF	Ethernet 0 generate pause frame	32-bit
0x05_8138 through 0x05_81FF	Reserved		
0x05_8200	ETH0MAC1	Ethernet 0 MAC configuration 1	32-bit
0x05_8204	ETH0MAC2	Ethernet 0 MAC configuration 2	32-bit
0x05_8208	ETH0IPGT	Ethernet 0 back-to-back inter-packet gap	32-bit
0x05_820C	ETH0IPGR	Ethernet 0 non back-to-back inter-packet gap	32-bit
0x05_8210	ETH0CLRT	Ethernet 0 collision window retry	32-bit
0x05_8214	ETH0MAXF	Ethernet 0 maximum frame length	32-bit
0x05_8218	Reserved		
0x05_821C	ETH0MTEST	Ethernet 0 MAC test	32-bit
0x05_8220	MIIMCFG	MII management configuration	32-bit
0x05_8224	MIIMCMD	MII management command	32-bit
0x05_8228	MIMMADDR	MII management address	32-bit
0x05_822C	MIIMWTD	MII management write data	32-bit
0x05_8230	MIIMRDD	MII management read data	32-bit
0x05_8234	MIIMIND	MII management indicators	32-bit
0x05_8238 through 0x05_823c	Reserved		
0x05_8240	ETH0CFSA0	Ethernet 0 control frame station address 0	32-bit
0x05_8244	ETH0CFSA1	Ethernet 0 control frame station address 1	32-bit
0x05_8244	ETH0CFSA2	Ethernet 0 control frame station address 2	32-bit

Table 11.1 Ethernet Register Map (Part 2 of 4)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x05_824C through 0x05_FFFF	Reserved		
0x06_0000	ETH1INTFC	Ethernet 1 interface control	32-bit
0x06_0004	ETH1FIFOTT	Ethernet 1 FIFO transmit threshold	32-bit
0x06_0008	ETH1ARC	Ethernet 1 address recognition control	32-bit
0x06_000C	ETH1HASH0	Ethernet 1 hash table 0	32-bit
0x06_0010	ETH1HASH1	Ethernet 1 hash table 1	32-bit
0x06_0014 through 0x06_0020	Reserved		
0x06_0024	ETH1PFS	Ethernet 1 pause frame status	32-bit
0x06_0028 through 0x6_00FF	Reserved		
0x06_0100	ETH1SAL0	Ethernet 1 station address 0 low	32-bit
0x06_0104	ETH1SAH0	Ethernet 1 station address 0 high	32-bit
0x06_0108	ETH1SAL1	Ethernet 1 station address 1 low	32-bit
0x06_010C	ETH1SAH1	Ethernet 1 station address 1 high	32-bit
0x06_0110	ETH1SAL2	Ethernet 1 station address 2 low	32-bit
0x06_0114	ETH1SAH2	Ethernet 1 station address 2 high	32-bit
0x06_0118	ETH1SAL3	Ethernet 1 station address 3 low	32-bit
0x06_011C	ETH1SAH3	Ethernet 1 station address 3 high	32-bit
0x06_0120	ETH1RBC	Ethernet 1 receive byte count	32-bit
0x06_0124	ETH1RPC	Ethernet 1 receive packet count	32-bit
0x06_0128	ETH1RUPC	Ethernet 1 receive undersized packet count	32-bit
0x06_012C	ETH1RFC	Ethernet 1 receive fragment count	32-bit
0x06_0130	ETH1TBC	Ethernet 1 transmit byte count	32-bit
0x06_0134	ETH1GPF	Ethernet 1 generate pause frame	32-bit
0x06_0138 through 0x06_01FF	Reserved		
0x06_0200	ETH1MAC1	Ethernet 1 MAC configuration 1	32-bit
0x06_0204	ETH1MAC2	Ethernet 1 MAC configuration 2	32-bit
0x06_0208	ETH1IPGT	Ethernet 1 back-to-back inter-packet gap	32-bit
0x06_020C	ETH1IPGR	Ethernet 1 non back-to-back inter-packet gap	32-bit
0x06_0210	ETH1CLRT	Ethernet 1 collision window retry	32-bit
0x06_0214	ETH1MAXF	Ethernet 1 maximum frame length	32-bit
0x06_0218	Reserved		
0x06_021C	ETH1MTEST	Ethernet 1 MAC test	32-bit
0x06_0220 through 0x06_023C	Reserved		
0x06_0240	ETH1CFSA0	Ethernet 1 control frame station address 0	32-bit

Table 11.1 Ethernet Register Map (Part 3 of 4)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x06_0244	ETH1CFSA1	Ethernet 1 control frame station address 1	32-bit
0x06_0248	ETH1CFSA2	Ethernet 1 control frame station address 2	32-bit
0x06_024C through 0x06_FFFF	Reserved		

Table 11.1 Ethernet Register Map (Part 4 of 4)

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

Ethernet Interface Control Register

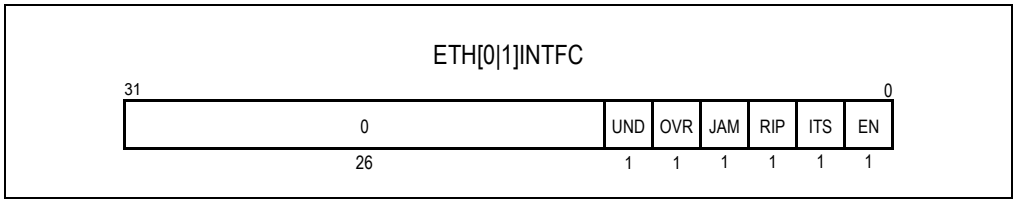


Figure 11.2 Ethernet Interface Control Register (ETH[0|1]INTFC)

EN

Description: **Enable.** When this bit is set to 1, the Ethernet interface is enabled. When this bit is set to 0, the Ethernet interface is disabled. Disabling and then re-enabling the Ethernet interface initializes all of the Ethernet interface logic to its initial default state (i.e., all registers are set to their initial values and input and output FIFOs are empty.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

ITS

Description: **Ignore Transmit Status.** When this bit is set to 1, multiple Ethernet packets may be queued by the DMA Controller in the output FIFO. In this mode, control bits in the DEVCS field of the DMA descriptor should be initialized to 0, and status information is not written back to the DEVCS field when a packet is transmitted. When this bit is set to 0, the output FIFO can only hold one packet. The DMA controller will update the status information in the DEVCS field after the packet has been transmitted.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RIP

Description: **Reset In Progress.** When the EN bit is cleared to 0, an Ethernet interface reset is generated, and this bit is set to indicate that an Ethernet interface reset is in progress. The reset may take several clock cycles to complete due to the crossing of multiple clock domains. When the reset has completed, this bit is cleared to 0 and the Ethernet interface may be re-enabled by setting the EN bit to 1.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Notes

JAM

Description: **Transmit Half Duplex Flow Control.** When this bit is set to 1, the Ethernet MAC transmits a preamble on the wire causing other MACs to defer. This may be used as a means of achieving half duplex flow control. When this bit is set to 0, the preamble is not transmitted.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

OVR

Description: **Input FIFO Overflow.** This bit is set to 1 when the input FIFO overflows. If the overflow occurs before 64-bytes of a packet are received and written into the input FIFO, then the entire contents of the packet are discarded. If more than 64-bytes of the packet are received and written into the input FIFO and an overflow occurs, then the remaining bytes of the packet are discarded and the OVR bit is set in the DMA descriptor when the packet is transferred to memory. Once the input FIFO overflows, all subsequent packets are discarded until space becomes available in the input FIFO. Note that for all other errors, packets are received.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

UND

Description: **Output FIFO Underflow.** This bit is set to 1 if frame transmission is aborted due to an output FIFO underflow. An output FIFO underflow condition would typically be due to latencies within the system and should not occur under normal operating conditions. When this condition occurs, the remainder of the data for the current frame is discarded. However, subsequent frames are transmitted properly.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Because the packet portion of the collision window for a frame to be transmitted fits entirely in the output FIFO, and remains there until it is transmitted without collision, there is never a need to re-fetch data to be transmitted.

When an output FIFO underflow occurs during packet transmission, then the UND bit is set in the ETH[0|1]INTFC register and also in the DEVCS field of the DMA descriptor if the ITS bit is not set in the ETH[0|1]INTFC register. The state of the UND bit in the ETH[0|1]INTFC register is presented to the interrupt controller as an interrupt source.

When the MAC observes a valid preamble and start of frame delimiter, it begins receiving an Ethernet frame. If the destination address in the packet is not rejected by the address recognition logic, the packet data is written by the MAC into the input FIFO. Once data beyond the collision window is received without error, the DMA Controller is signalled that valid packet data exists in the input FIFO. If a collision is detected within the collision window programmed in the COLWIN field, the resulting runt frame is automatically flushed from the input FIFO by the MAC.

> **Note:** Collision frames, runt frames, and frames whose destination addresses are not accepted by the address recognition logic are never passed to the DMA Controller.

When an input FIFO overflow occurs during packet reception, the OVR bit is set in the ETH[0|1]INTFC register. If less than 64-bytes of the packet have been written into the FIFO, then the packet is discarded from the input FIFO. If 64-bytes or more have been written into the FIFO, the remaining bytes of the packet are discarded but data already written to the FIFO is not flushed. When the DMA transfers a packet in which an overflow occurred to memory, the OVR bit is set in the DEVCS field of the DMA descriptor. The state of the OVR bit in the ETH[0|1]INTFC register is presented to the interrupt controller as an interrupt source.

Notes

Ethernet FIFO Transmit Threshold Register

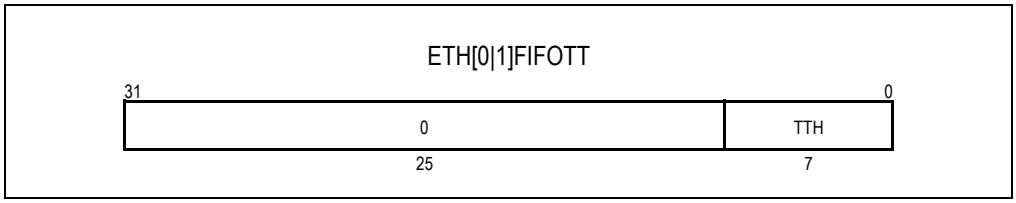


Figure 11.3 Ethernet FIFO Transmit Threshold Register (ETH[0|1]FIFOTT)

TTH

Description: **Transmit Threshold.** This field contains the number of words which must be present in the Ethernet output FIFO in order for the MAC to start transmitting the frame. The MAC will begin transmitting the frame before the threshold is reached if the last byte of a packet is written into the FIFO.
For correct operation of the Ethernet interface, this field should be set to a value greater than or equal to the number of words programmed in the COLWIN field in the ETH[0|1]CLRT register minus two words (that is, do not count SFD or preamble).
Care should be exercised in determining the value selected for the transmit threshold, since misconfiguration could lead to a deadlock. For example, if this field is set to 125 words and the transmit FIFO contains 120 words, then further DMA transmit requests will not be generated since the remaining space in the transmit FIFO is not at least 16 words. In addition, the Ethernet MAC will not start transmitting the frame since the transmit threshold has not been reached, thus resulting in a deadlock.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Address Recognition Logic

Ethernet frames contain the address of the source and of the destination. Both addresses are 48-bits in length and are typically represented as a series of six bytes separated by hyphens in the order that they are transmitted (left to right) on the wire. The bits within bytes are transmitted on the wire from right to left (that is, least significant bit first and most significant bit last). These addresses are referred to as Medium Access Control (MAC) addresses.

An example of a MAC address, and the order in which its bits are transmitted on the wire, is shown in Figure 11.4.

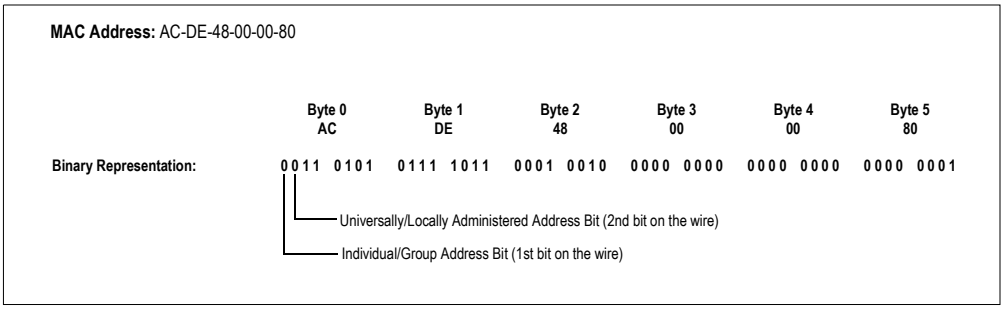


Figure 11.4 Representation of MAC Address

Based on the destination address in a received Ethernet frame, the address recognition logic determines if the packet should be accepted by the Ethernet interface and passed to the DMA Controller or if the frame should be rejected.

Notes

There are two types of destination addresses, individual addresses and group addresses. An individual address is associated with a particular station on the network, while a group address is associated with one or more stations on the network. A group address can be further classified as either a multicast address (an address associated by a higher level convention with a group of logically related stations) or a broadcast address (an address that denotes the set of all stations on a given LAN).

The Ethernet interface contains four station address registers. A station address is a 48-bit MAC address stored in a station address low and high register pair. There are four station address register pairs:

ETHSAL[0|1|2|3]

ETHSAH[0|1|2|3]

> **Note:** To ensure proper operation, all four Ethernet station address registers MUST be programmed with the same value.

The MAC address used for control frames is contained in the ETHCFSA[0|1|2] registers.

A hash table approach is used to determine if multicast group destination address packets should be accepted.[1] When a packet with a multicast group destination address is received, a 6-bit hash value is computed by passing the 48-bit destination address through the frame check sequence CRC calculator. The hash value, consisting of bits 26 through 31 of the computed CRC, is used as an index into a 64 bin hash table in which each bin is represented by a single bit. If the selected bit in the hash table is a one and the Accept Filtered Multicast Packets (AFM) bit in the Ethernet address recognition control (ETH[0|1]ARC) register is set, the packet is accepted.

The 64-bit hash table is stored in the HASH[0|1] registers. HASH0 contains bits 0 through 31 of the hash table, while HASH1 contains bits 32 through 63 of the hash table.

The hash table filtering algorithm is not perfect, and therefore packets must be further filtered by software to determine if they do, in fact, match a multicast address that should be accepted. If the Accept All Multicast Packets (AM) bit in the ETH[0|1]ARC register is set, all multicast packets are accepted regardless of whether or not they pass the hash table filtering algorithm.

A broadcast address is a MAC address consisting of all ones (that is, FF-FF-FF-FF-FF-FF). If the Accept Broadcast Packets (AB) bit in the ETH[0|1]ARC register is set, all broadcast packets are accepted by the Ethernet interface. When this bit is cleared, all broadcast packets are rejected. When a packet is accepted by the Ethernet interface, three bits are updated in the DEVCS field of a DMA descriptor.

The Filter Match (FM) bit is set when one of the following conditions occurs:

- *The packet matches an individual station address*
- *The packet passes the hash table filtering algorithm described above*
- *The packet is a multicast packet and was accepted because the AM bit in the ETH[0|1]ARC register was set*
- *The packet is a broadcast packet and was accepted because the AB bit in the ETH[0|1]ARC register was set.*

The Multicast Packet (MP) bit is set when the accepted packet is a multicast packet, and the Broadcast Packet (BP) bit is set when the accepted packet is a broadcast packet.

The Ethernet interface has a promiscuous mode which is enabled by setting the Promiscuous Mode (PRO) bit in the ETH[0|1]ARC register. In this mode, the address recognition logic accepts all incoming packets regardless of their destination address. While in this mode, the Filter Match (FM) bit in the DEVCS field of a DMA descriptor is still set only in the conditions outlined above. The address filtering algorithm is summarized in Figure 11.6.

1. The only exception to this is the multicast address 01-80-c2-00-00-01 which is always received regardless of the setting of the corresponding Ethernet hash table entry.

Notes

Ethernet Address Recognition Control Register

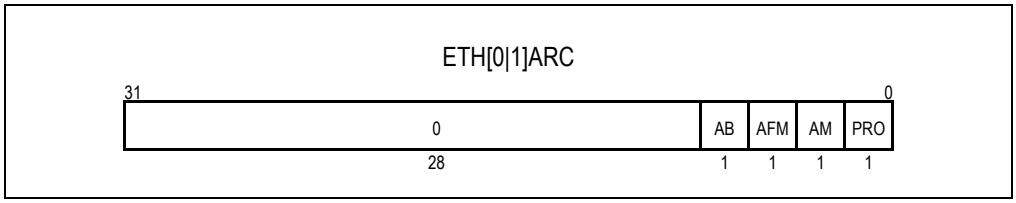


Figure 11.5 Ethernet Address Recognition Control Register (ETH[0|1]ARC)

PRO

Description: **Promiscuous Mode.** When this bit is set to 1, all incoming packets are received regardless of their destination address and other address registers are overridden. When this bit is set to 0, this function is disabled.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

AM

Description: **Accept All Multicast Packets.** When this bit is set to 1, all incoming packets with a multicast destination address are accepted. When this bit is set to 0, this function is disabled.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

AFM

Description: **Accept Filtered Multicast Packets.** When this bit is set to 1, multicast packets which pass address filtering are accepted. When this bit is set to 0, this function is disabled.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

AB

Description: **Accept Broadcast Packets.** When this bit is set to 1, all incoming packets with a broadcast destination address are received. When this bit is set to 0, this function is disabled.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Notes

```
match = FALSE

if (DA == individual address) {
        if (    DA == local station address 1 or
                DA == local station address 2 or
        DA == local station address 3 or
        DA == local station address 4 ) {
                accept packet
                set FM bit in descriptor/status register
                match = TRUE
        }
} else {
        if (DA == broadcast address ) {
                if (AB bit set in ETHxARC ) {
                        accept packet
                        set FM bit in descriptor/status register
                        set BP bit in descriptor/status register
                        match = TRUE
                }
        } else if ( AFM bit set in ETHxARC && hash_table[hash(DA)] == 1 ) {
                accept packet
                set FM bit in descriptor/status register
                set MP bit in descriptor/status register
                match = TRUE
        } else if ( AM bit set in ETHxARC ) {
                accept packet
                clear FM bit in descriptor/status register
                set MP bit in descriptor/status register
                match = TRUE
        }
}

if ( PRO bit set in ETHxARC and match == FALSE ) {
        accept packet
        clear FM bit in descriptor/status register
        if ( DA == broadcast address ) {
                set BP bit in descriptor/status register
        } else if ( DA == multicast address ) {
                set MP bit in descriptor/status register
        }
}
```

Figure 11.6 Ethernet Address Filtering Algorithm

Notes

Ethernet Hash Table [0|1] Register

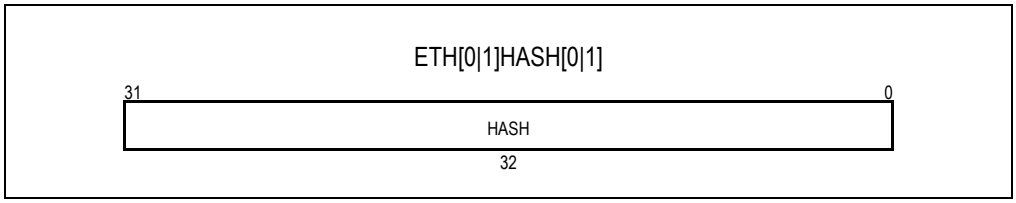


Figure 11.7 Ethernet Hash Table [0|1] Register (ETH[0|1]HASH[0|1])

HASH

Description: **Hash Table Bit Vector.** This 32-bit field contains a hash table used for multicast address filtering. The hash table is 64 bits in size with the lower 32 bits stored in HASH0 and the upper 32 bits stored in HASH1. Bit *x* in the HASH*y* register corresponds to bit 32*y*+*x* in the hash table.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Ethernet Station Address [0|1|2|3] Low Register

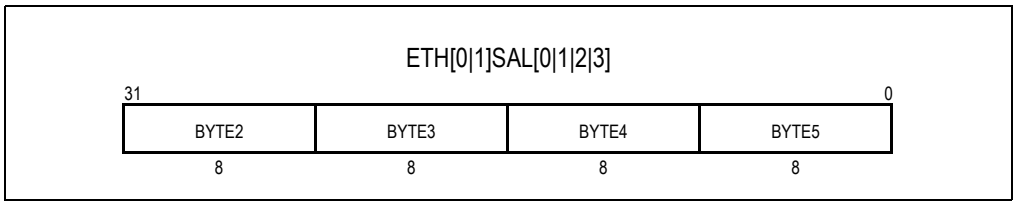


Figure 11.8 Ethernet Station Address [0|1|2|3] Low Register (ETH[0|1]SAL[0|1|2|3])

BYTE5

Description: **Byte Five.** This field contains byte five of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 80.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

BYTE4

Description: **Byte Four.** This field contains byte four of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 00.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

BYTE3

Description: **Byte Three.** This field contains byte three of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 00.

Initial Value: Undefined

Notes

Read Value: Previous value written

Write Effect: Modify value

BYTE2

Description: **Byte Two.** This field contains byte Two of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 48.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Ethernet Station Address [0|1|2|3] High Register

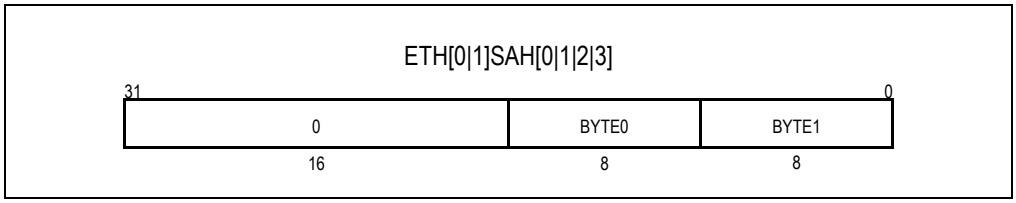


Figure 11.9 Ethernet Station Address [0|1|2|3] High Register (ETH[0|1]SAH[0|1|2|3])

BYTE1

Description: **Byte One.** This field contains byte one of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value DE.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

BYTE0

Description: **Byte Zero.** This field contains byte zero of the 48-bit MAC address. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value AC.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

DMA Interface

An Ethernet interface supports DMA operations from the input FIFO to memory, and DMA operations from memory to the output FIFO (See Chapter 9, DMA Controller). Ethernet DMA operations do not use the DMA descriptor device command (DEVCMD) field.

Ethernet Input DMA Operations

Table 11.2 summarizes Ethernet interface input DMA operations. As shown in Figure 11.10, the DMA descriptor device control and status (DEVCS) field is used to record status information for received packets.

A DMA request event is generated whenever 16 full FIFO data words exist in the input FIFO or when a FIFO data word tagged as an end-of-packet is present in the input FIFO. This causes the DMA to transfer data from the input FIFO to memory.

Notes

A DMA done event is generated whenever a FIFO data word tagged as an end-of-packet is transferred from the input FIFO to memory. The Last Descriptor (LD) bit in the DEVCS field is set in the last descriptor of a DMAed packet (that is, one in which a done event was generated).

The remaining status fields in the DEVCS field are updated in the last DMA descriptor of a packet (i.e., the LD bit is set to 1). All other DMA descriptors of a packet contain zeros in these fields.

DMA Request Event	A request event is generated whenever 16 full FIFO data words are present in the input FIFO, or when less than 16 full FIFO data words are present in the input FIFO but one exists which is tagged as an end-of-packet.
DMA Done Event	A DMA done event is generated after an end-of-packet tagged FIFO data word has been transferred.
DMA Terminated Event	A DMA terminated event is never generated.
DMA Transfer Size	The DMA Controller usually transfers 16 FIFO data words from the input FIFO to memory. Fewer FIFO data words are transferred if a FIFO data word tagged as an end-of-packet is reached or if the byte count reaches zero.
Limitations	None. A DMA operation may start and end on any byte boundary and may contain any number of bytes.

Table 11.2 Ethernet Interface Input DMA Operations

Device Control and Status Value for Ethernet Receive Descriptors

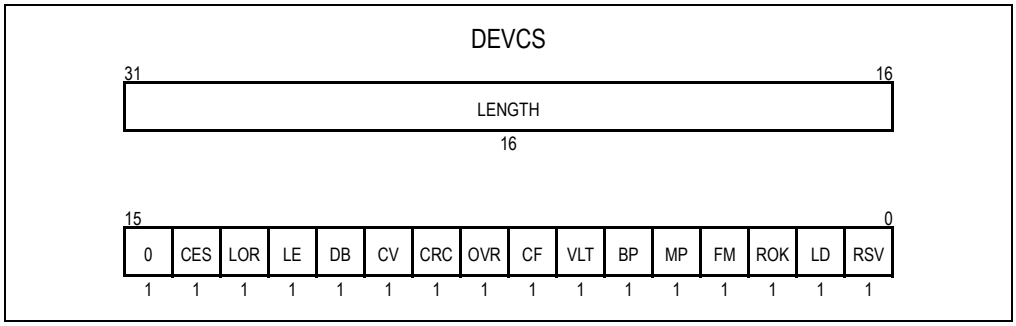


Figure 11.10 Device Control and Status Value for Ethernet Receive Descriptors

RSV **Reserved.**

LD **Last Descriptor.** This bit is set to 1 if this descriptor is the last descriptor of a packet.

ROK **Received OK.** This bit is set to 1 if the packet was received without error. This bit is set if and only if the OVR, CRC, CV, and LE bits are all cleared to 0. This field is valid only in the last descriptor of a packet.

FM **Filter Match.** This bit is set to 1 if the packet passed address recognition filtering. This field is valid only in the last descriptor of a packet.

MP **Multicast Packet.** This bit is set to 1 when the packet has a multicast address. This field is valid only in the last descriptor of a packet.

BP **Broadcast Packet.** This bit is set to 1 when the packet has a broadcast address. This field is valid only in the last descriptor of a packet.

VLT **VLAN Tag Detected.** This bit is set to 1 when the packet is a VLAN tagged packet. This field is valid only in the last descriptor of a packet.

CF **Control Frame.** This bit is set to 1 to indicate that the packet was recognized as a control frame. Received control frames are normally discarded unless the PAF bit is set in the ETH[0|1]MAC1 register. This field is valid only in the last descriptor of a packet.

Notes

OVR	**Receive FIFO Overflow.** This bit is set to 1 when the input FIFO overflowed during packet reception. Once an overflow occurs, the remaining contents of the packet are discarded.
CRC	**CRC Error.** This bit is set to 1 when the received packet has a CRC error. This field is valid only in the last descriptor of a packet. CRC error packets are not discarded.
CV	**Code Violation.** This bit is set to 1 when a coding violation was detected somewhere in the packet. This field is valid only in the last descriptor of a packet. Code violation error packets are not discarded.
DB	**Dribble Bits Detected.** This bit is set to 1 when between one and seven dribbling bits are detected at the end of the packet. This field is valid only in the last descriptor of a packet. Dribble bit error packets are not discarded
LE	**Length Error.** This bit is set to 1 when the packet length field does not match the actual length of the packet. This field is valid only in the last descriptor of a packet. Length error packets are not discarded.
LOR	**Length Out of Range.** This bit is set to 1 when the packet type/length field is larger than 1518. This field is valid only in the last descriptor of a packet. If this bit is set, type/length field is used as type field. Length out of range error packets are not discarded.
CES	**Carrier Event Seen.** This bit is set to 1 to indicate that something less than a well formed preamble or start of frame delimiter has been received (as specified in IEEE 802.3 clause 24.2.4.4.2). This field is valid only in the last descriptor of a packet. Carrier error packets are not discarded.
LENGTH	**Length.** This 16-bit field contains the length of the received frame. This field is valid only in the last descriptor of a packet.

Ethernet Output DMA Operations

Table 11.3 summarizes Ethernet interface output DMA operations. As shown in Figure 11.11, the DMA descriptor DEVCS field is used to record status information for transmitted packets.

A DMA request event is generated whenever 16 free FIFO data words exist in the output FIFO. This causes the DMA to transfer data from memory to the output FIFO.

A DMA done event is never generated during Ethernet output DMA operations. The last descriptor (LD) bit in the DEVCS field is set in the last descriptor of a packet.

DMA Request Event	A request event is generated whenever 16 free FIFO data words are present in the output FIFO.
DMA Done Event	A DMA done event is never generated.
DMA Terminated Event	A DMA terminated event is never generated.
DMA Transfer Size	The DMA Controller usually transfers 16 FIFO data words from memory to the output FIFO. Fewer words are transferred if the byte count reaches zero.
Limitations	None. A DMA operation may start and end on any byte boundary and may contain any number of bytes.

Table 11.3 Ethernet Interface Output DMA Operations

When the byte count in a DMA descriptor reaches zero, a finished event is generated. This causes the FIFO data word associated with the last byte transferred prior to the finished event to be tagged as an end-of-packet in the output FIFO if this descriptor is the last descriptor of the packet. Because the number of bytes in a packet need not be an integer multiple of four, the FIFO data word tagged with an end-of-packet need not have all bytes valid.

The FD, LD, OEN, PEN, CEN, and HEN fields of the DEVCS field are packet control bits initialized by the CPU prior to an Ethernet output DMA operation. The remaining bits of the DEVCS field are status bits which are zero for all DMA descriptors except the last one of a packet.

Notes

The packet override enable bit (OEN) allows MAC control settings to be overridden on a per packet basis. This bit is examined in the first DMA descriptor of a packet, one in which the FD bit has been set in the descriptor. If the OEN bit is set, then the pad enable (PE), CRC enable (CE), and huge frame enable (HFE) bits in the Ethernet MAC configuration register #2 (ETH[0|1]MAC2) are overridden by the values in the PEN, CEN, and HEN fields in the DEVCS field for the entire packet. The packet padding enable (PEN) field controls whether or not short frames are padded by the MAC. The packet CRC enable (CEN) field controls whether or not the CRC is computed and appended by the MAC. The huge frame enable (HEN) field controls if large Ethernet frames are transmitted by the MAC.

The status information contained in the DEVCS field of the last DMA descriptor in a packet is updated when the Ethernet packet is transmitted by the MAC, or when transmission of the packet is aborted. This allows only a single packet to be buffered in the transmit FIFO at a time, since a DMA operation for the next packet cannot begin until the last descriptor of the previous packet has been written to memory.

Some applications may not require the status values contained in the DEVCS field. Setting the Ignore Transmit Status (ITS) bit in the ETH[0|1]INTFC register causes the status fields of the DEVCS field in the descriptor to always be written back to memory with zeros and allows multiple packets to be queued by the DMA Controller in the output FIFO. This implies that the status information for the last descriptor of a packet may not be updated for quite some time after the data has been transferred from memory to the output FIFO.

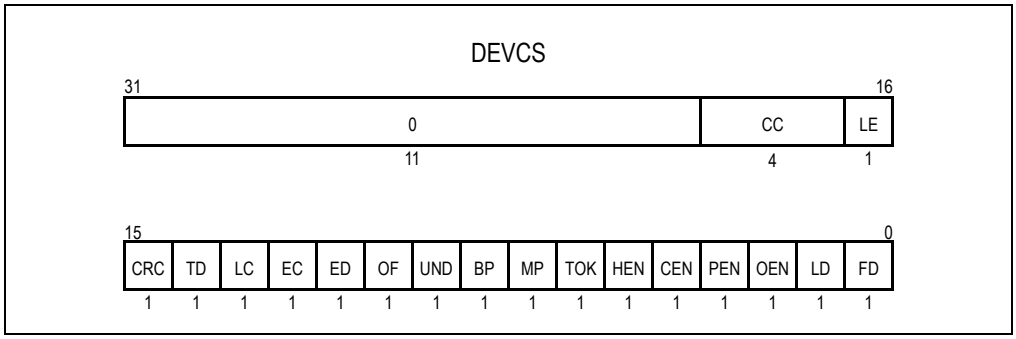


Figure 11.11 Device Control and Status Value for Ethernet Transmit Descriptors

FD **First Descriptor.** This bit is set to 1 if this descriptor is the first descriptor of a packet. This bit is examined in every descriptor and is initialized by the CPU prior to an Ethernet output DMA operation.

LD **Last Descriptor.** This bit is set to 1 if this descriptor is the last descriptor of a packet. This bit is examined in every descriptor and is initialized by the CPU prior to an Ethernet output DMA operation.

OEN **Override Enable.** When this bit is set to 1, PEN, CEN, and HEN are enabled. This bit is examined in the first packet descriptor and is initialized by the CPU prior to a Ethernet output DMA operation.

PEN **Packet Padding Enable.** When the OEN bit is set, the PEN bit controls whether or not short Ethernet packets are padded and a CRC is appended. When PEN is set, short transmit frames are padded and a CRC is computed and appended to all transmit frames. When PEN is cleared, short packets are not padded and a CRC is appended only if CEN is set. The PEN bit is examined in the first packet descriptor and is initialized by the CPU prior to an Ethernet output DMA operation.

CEN **Packet CRC Enable.** When the OEN bit is set to 1, it controls whether the MAC appends an CRC to the Ethernet packet. If CEN is set, then the CRC is appended to the packet. When CEN is cleared, CRC is not appended to the packet. This bit is examined in the first packet descriptor and is initialized by the CPU prior to an Ethernet output DMA operation.

HEN **Huge Frame Enable.** When the OEN bit is set to 1, this bit controls whether large Ethernet packets (that is, packets that exceed the value in the ETH[0|1]MAXF register) are transmitted. When HEN is set, then large Ethernet frames are transmitted. If HEN is cleared to 0, then transmission is aborted after the length in ETH[0|1]MAXF has been reached and the remainder of the frame is discarded. This bit is examined in the first packet descriptor and is initialized by the CPU prior to an Ethernet output DMA operation.

Notes

TOK **Transmit OK.** This bit is set to 1 when the packet is transmitted without error. This bit is set if and only if the UND, OF, ED, EC, and LC bits are all cleared. This field is valid only in the last descriptor of a packet.

MP **Multicast Packet.** This bit is set to 1 when the transmitted packet has a multicast address. This field is valid only in the last descriptor of a packet.

BP **Broadcast Packet.** This bit is set to 1 when the transmitted packet has a broadcast address. This field is valid only in the last descriptor of a packet.

UND **Transmit FIFO Underflow.** This bit is set to 1 if frame transmission was aborted due to an output FIFO underflow. This field is valid only in the last descriptor of a packet.

OF **Oversized Frame.** This bit is set to 1 if transmission was aborted due to an attempt to transmit a frame larger than the value in the ETH[0|1]MAXF register. The contents of the frame beyond ETH[0|1]MAXF are discarded. This field is valid only in the last descriptor of a packet.

ED **Excessive Deferral.** This bit is set to 1 if *t*ransmission was aborted due to excessive deferrals. This field is valid only in the last descriptor of a packet.

EC **Excessive Collisions.** This bit is set to 1 if transmission was aborted due to excessive collisions. This field is valid only in the last descriptor of a packet.

LC **Late Collision.** This bit is set to 1 if transmission was aborted due to a collision beyond the collision window. This field is valid only in the last descriptor of a packet.

TD **Transmit Deferred.** This bit is set to 1 if transmission of the frame was deferred on the first transmission attempt. This field is valid only in the last descriptor of a packet.

CRC **CRC Error.** This bit is set to 1 if the CRC in the transmitted frame does not match the CRC computed by the MAC. If the MAC is configured to automatically compute and append the CRC to transmitted frames, then the value of this bit should be ignored. This field is valid only in the last descriptor of a packet.

LE **Length Error.** This bit is set to 1 if the value of the length field of the transmitted frame does not match the actual length. This field is valid only in the last descriptor of a packet.

CC **Collision Count.** This 4-bit field indicates the number of collisions that the successfully transmitted frame experienced. This field is not valid if frame transmission was aborted due to excessive collisions. This field is valid only in the last descriptor of a packet.

Ethernet Statistics

The Ethernet interface contains five 32-bit counters which may be used to gather statistics. Each counter increments by one each time the specified receive or transmit event occurs. The CPU may read these counters at any time, provided that the MII clocks are supplied and the RIP bit in the ETH[0|1]INTFC register is not set to 1. The act of reading a counter causes its value to be reset to zero as an atomic operation. This prevents the loss of events due to non-atomic read and clear operations.

Ethernet Receive Byte Count Register

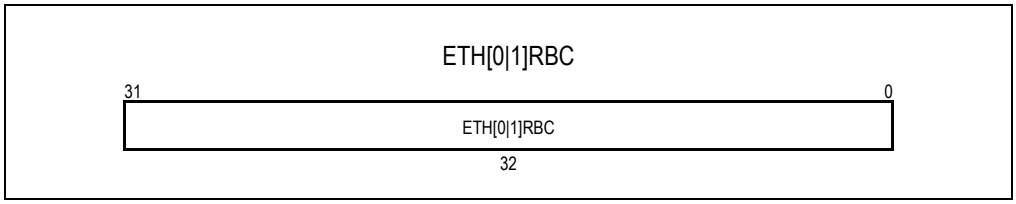


Figure 11.12 Ethernet Receive Byte Count (ETH[0|1]RBC)

ETHRBC

Description: **Ethernet Receive Byte Count.** Total number of bytes in all packets received by the Ethernet interface (including bad packets, packets discarded by hardware, and control frames). This value does not include SFD or preamble bytes. Reading this register atomically clears its value to zero.

Notes

Initial Value: Undefined

Read Value: Return value and reset field to zero

Write Effect: Read-only

Ethernet Receive Packet Count Register

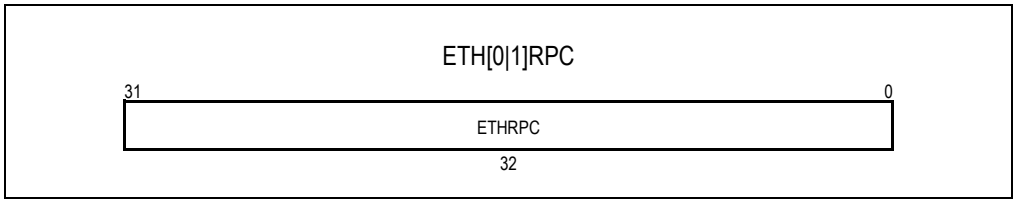


Figure 11.13 Ethernet Receive Packet Count (ETH[0|1]RPC)

ETHRPC

Description: **Ethernet Receive Packet Count.** Total number of Ethernet packets received (including packets discarded by hardware as well as control packets). Reading this register automatically clears its value to zero.

Initial Value: Undefined

Read Value: Return value and reset field to zero

Write Effect: Read-only

Ethernet Receive Undersized Packet Count Register

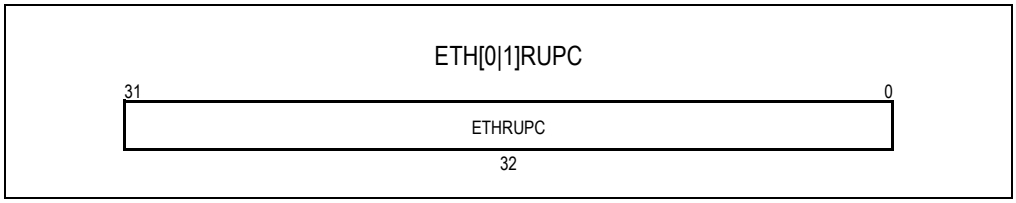


Figure 11.14 Ethernet Receive Undersized Packet Count (ETH[0|1]RUPC)

ETHRUPC

Description: **Ethernet Receive Undersize Packet Count**. Total number of Ethernet packets discarded by hardware since they were less than 64 bytes in size but were otherwise well formed. Reading this register atomically clears its value to zero.

Initial Value: Undefined

Read Value: Return value and reset field to zero

Write Effect: Read-only

Notes

Ethernet Receive Fragment Count Register

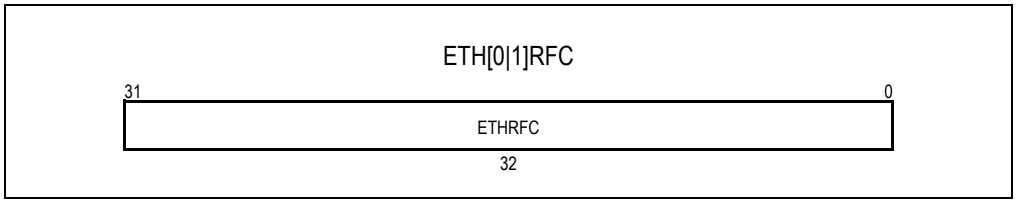


Figure 11.15 Ethernet Receive Fragment Count (ETH[0|1]RFC)

ETHRFC

Description: **Ethernet Receive Fragment Count**. Total number of Ethernet packets discarded by hardware since they were less than 64 bytes in size and had either a CRC error or an alignment error (that is, not an integral number of bytes). Reading this register atomically clears its value to zero.

Initial Value: Undefined

Read Value: Return value and reset field to zero

Write Effect: Read-only

Ethernet Transmit Byte Count Register

Figure 11.16 Ethernet Transmit Byte Count (ETH[0|1]TBC)

ETHTBC

Description: **Ethernet Transmit Byte Count.** Total number of bytes transmitted by the Ethernet interface (includes control frames and retransmissions). This value does not include SFD, preamble, or jam bytes. Reading this register atomically clears its value to zero.

Initial Value: Undefined

Read Value: Return value and reset field to zero

Write Effect: Read-only

PAUSE Control Frames

The Ethernet interface supports PAUSE control frames as defined by IEEE Std 802.3x-1997. Received PAUSE control frames are handled by the Ethernet MAC. A control frame is a frame with a type/length field that identifies a control frame (i.e., 0x88_08). Control frames are accepted or rejected in the same manner as all other frames (i.e., using the method specified in the Address Recognition Logic section of this chapter). The only exception to this is the multicast address 01-80-c2-00-00-01 which is always received regardless of the setting of the corresponding Ethernet hash table entry.

A PAUSE control frame is a control frame with a multicast address of 01-80-c2-00-00-01 and an opcode field that corresponds to a PAUSE frame (i.e., 0x00_01). The MAC normally processes PAUSE control frames but it may be configured to ignore PAUSE control frames by clearing the Receive Flow Control (RFC) bit in the Ethernet MAC 1 (ETH[0|1]MAC1) register. Control frames are normally discarded after required processing by the MAC. However, if the Pass All Frames (PAF) bit is set in the ETH[0|1]MAC

Notes

register, all frames (i.e., normal frames and control frames) are passed to the Ethernet input FIFO. When the MAC is configured to ignore control frames, they are still passed to the Ethernet input FIFO if the PAF bit is set.

A PAUSE control frame may be generated either by transferring the contents of such a frame to the output FIFO using the DMA or by writing to the Ethernet Generate Pause Frame (ETH[0|1]GPF) register. A write to the ETH[0|1]GPF register causes the MAC to transmit a PAUSE control frame with the PAUSE timer value set to the value written to the PAUSE Timer Value (PTV) field of the ETH[0|1]GPF register.

The Source Address (SA) of the MAC generated PAUSE frame is equal to that specified by ETH[0|1]CFSA0, ETH[0|1]CFSA1, and ETH[0|1]CFSA2. When the MAC completes transmission of a PAUSE control frame, the PAUSE Frame Done (PFD) bit is set in the Ethernet Pause Frame Status (ETH[0|1]PFS) register. The PFD bit is presented to the interrupt handler as an interrupt source.

Writes to the ETH[0|1]PGF register before the MAC has completed transmitting a PAUSE control frame due to a prior write are ignored (that is, they neither modify the register's contents nor result in the generation of a PAUSE control frame). The MAC may be blocked from generating pause control frames by clearing the Transmit Flow Control (TFC) bit in the ETH[0|1]MAC1 register.

Ethernet Generate Pause Frame Register

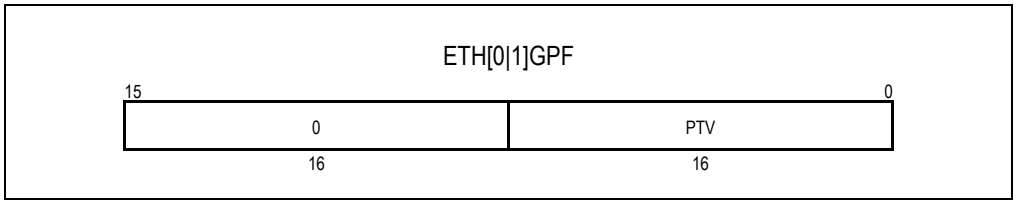


Figure 11.17 Ethernet Generate Pause Frame Register (ETH[0|1]GPF)

PTV

Description: **Pause Timer Value.** Writing any value into this register causes a PAUSE control frame to be generated by the MAC. The value written to this field (PTV) is used as the PAUSE timer value for the generated frame. Once the MAC has completed transmitting the PAUSE control frame, the Pause Frame Done (PFD) bit is set in the ETH[0|1]PFS register.
Writes to this register before the MAC has completed transmitting a PAUSE control frame due to a prior write are ignored (that is, they neither modify the register's contents nor result in the generation of a PAUSE control frame).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value and generate PAUSE control frame

Ethernet Pause Frame Status Register

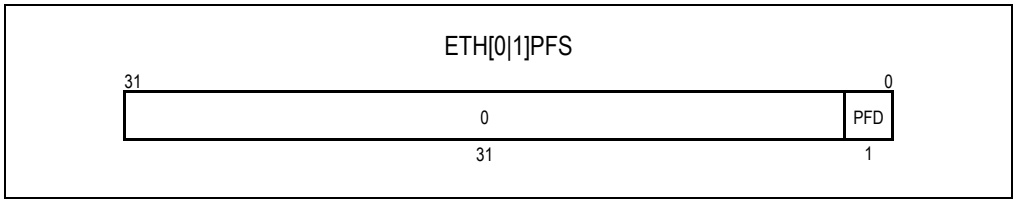


Figure 11.18 Ethernet Pause Frame Status Register (ETH[0|1]PFS)

Notes

PFD

Description: **Pause Frame Done.** This bit is set to 1 when the MAC completes PAUSE control frame transmission. The state of this bit is presented to the interrupt handler as an interrupt source.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Ethernet Control Frame Station Address 0 Register

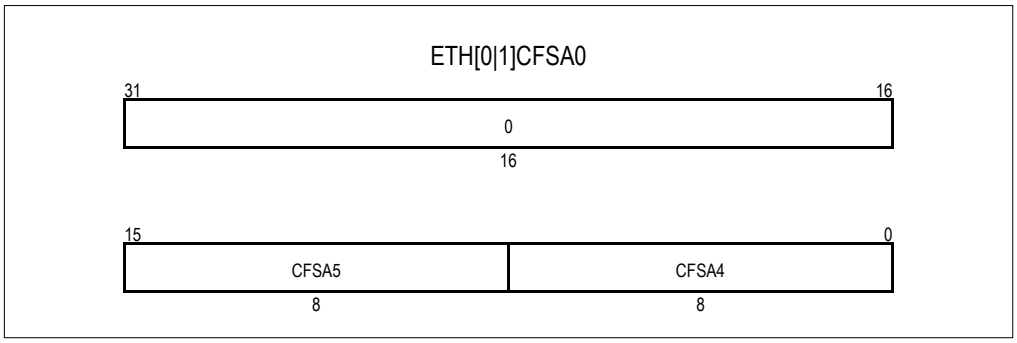


Figure 11.19 Ethernet Control Frame Station Address 0 (ETH[0|1]CFSA0)

CFSA4

Description: **Control Frame Station Address 4.** This field holds byte 4 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 00.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

CFSA5

Description: **Control Frame Station Address 5.** This field holds byte 5 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 80.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Ethernet Control Frame Station Address 1 Register

Figure 11.20 Ethernet Control Frame Station Address 1 (ETH[0|1]CFSA1)

CFSA2

Description: **Control Frame Station Address 2.** This field holds byte 2 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 48.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

CFSA3

Description: **Control Frame Station Address 3.** This field holds byte 3 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value 00.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Ethernet Control Frame Station Address 2 Register

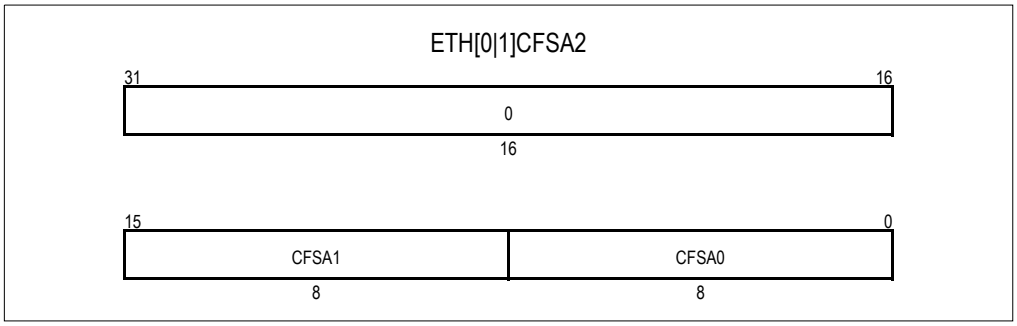


Figure 11.21 Ethernet Control Frame Station Address 2 (ETH[0|1]CFSA2)

CFSA0

Description: **Control Frame Station Address 0.** This field holds byte 0 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value AC.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

CFSA1

Description: **Control Frame Station Address 1.** This field holds byte 1 of the station address used for control frames. For example, for the MAC address AC-DE-48-00-00-80, this field holds the value DE.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Ethernet Medium Access Controller (MAC)

This section describes the configurable parameters for the Ethernet MAC. The function of the control bits in the MAC configuration registers are self-explanatory.

Ethernet MAC Configuration Register #1

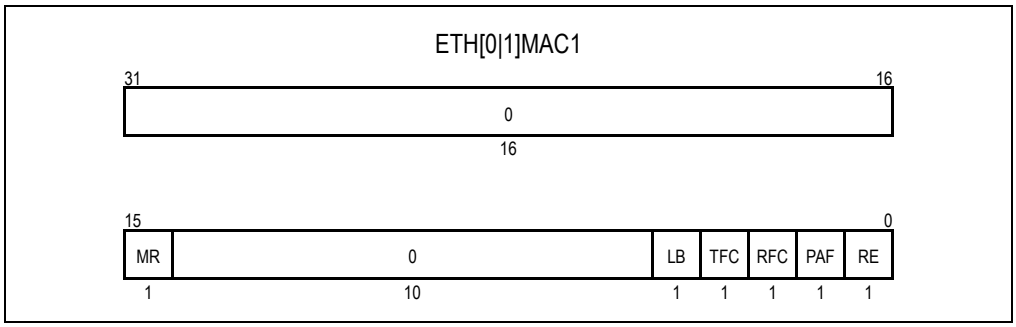


Figure 11.22 Ethernet MAC Configuration Register #1 (ETH[0|1]MAC1)

RE

Description: **Receive Enable.** When this bit is set to 1, the MAC is enabled to receive Ethernet frames. When this bit is set to 0, this function is disabled and all incoming traffic is discarded.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PAF

Description: **Pass All Frames.** When this bit is set to 1, the MAC passes all frames to the input FIFO regardless of the frame type (i.e., normal frame or control frame). When this bit is set to 0, control frames are discarded and only normal frames are written to the input FIFO.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RFC

Description: **Receive Flow Control.** When this bit is set to 1, the MAC will act upon received PAUSE flow control frames. When this bit is set to 0, PAUSE flow control frames are ignored.

Notes

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TFC

Description: **Transmit Flow Control.** When this bit is set to 1, the MAC will transmit PAUSE flow control frames. When this bit is set to 0, pause flow control frames are blocked.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

LB

Description: **Loopback.** When this bit is set to 1, the MAC transmit interface is looped back to the MAC receive interface. When this bit is set to 0, the MAC is in its normal operation mode.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MR

Description: **MAC Reset.** When this bit is set to 1, the MAC logic is reset. When this bit is set to 0, the MAC is in its normal operation mode.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Ethernet MAC Configuration Register #2

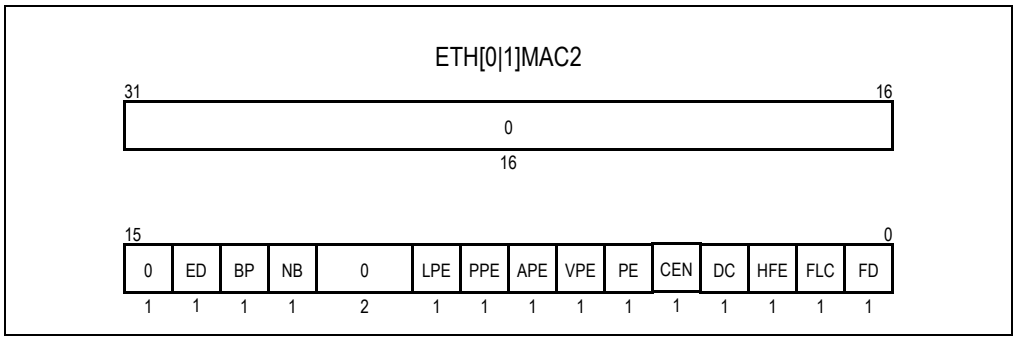


Figure 11.23 Ethernet MAC Configuration Register #2 (ETH[0|1]MAC2)

FD

Description: **Full Duplex.** When this bit is set to 1, the MAC is selected to operate in full-duplex mode. When this bit is set to 0, the MAC is selected to operate in half-duplex mode.

Initial Value: 0x0

Read Value: Status

Write Effect: Modify Value

Notes

FLC

Description: **Frame Length Checking.** When this bit is set to 1, both transmit and receive frame lengths are compared to the length/type field. If the length/type field represents a length, a check is performed. When this bit is set to 0, Frame Length Checking is disabled.

Initial Value: 0x0

Read Value: Status

Write Effect: Modify Value

HFE

Description: **Huge Frame Enable.** When this bit is set to 1, frames of any length may be transmitted and received. When this bit is set to 0, transmission is aborted after the length in ETH[0|1]MAXF has been reached and the remainder of the frame is discarded.

Initial Value: 0x0

Read Value: Status

Write Effect: Modify Value

DC

Description: **Delayed CRC.** When this bit is set to 1, a four byte proprietary header exists on the front of all IEEE 802.3 frames. CRCs are not computed over the proprietary header. Thus, when this bit is set to 1, CRC calculations are delayed by four bytes. When this bit is set to 0, Delayed CRC is disabled.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

CEN

Description: **CRC Enable.** When this bit is set to 1, the MAC pads all short frames and appends a CRC to every frame. When this bit is cleared to 0, frames passed to the MAC are assumed to have a valid length and CRC (that is, these operations are performed in software). Refer to Table 11.4.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PE

Description: **Pad Enable.** When this bit is set to 1, the MAC pads short transmit frames and computes and appends a CRC on all transmit frames. When this bit is set to 0, frames are padded prior to being passed to the MAC (i.e., padding operation is performed by software). Refer to Table 11.4.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

VPE

Description: **VLAN Pad Enable.** When this bit is set to 1 and padding is enabled, short transmit frames are padded to 64 bytes. If padding is enabled and this bit is cleared to 0, short transmit frames are padded to 60 bytes. Refer to Table 11.4.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

APE

Description: **Auto Pad Enable.** When this bit is set to 1 and padding is enabled, the MAC automatically detects the frame type, either tagged or untagged, by comparing the two bytes following the source address with 0x1800 (VLAN protocol ID) and pads accordingly. Untagged frames are padded to 60 bytes while tagged frames are padded to 64 bytes. When this bit is set to 0, the Auto Padding function is disabled. Refer to Table 11.4.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PPE

Description: **Pure Preamble Enforcement.** When this bit is set to 1, the MAC will verify the content of the preamble to ensure it contains 0x55 and is error-free. A frame with an error in the preamble is discarded. When this bit is cleared, no preamble checking is performed.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

LPE

Description: **Long Preamble Enforcement.** When this bit is set to 1, the MAC only allows receive frames which contain preamble fields less than 12 bytes in length. When this bit is cleared to 0, the MAC allows any length preamble.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

NB

Description: **No Backoff.** When this bit is set to 1, the MAC will immediately retransmit following a collision rather than using the Binary Exponential Backoff algorithm. When this bit is set to 0, the MAC will use the Binary Exponential Backoff algorithm.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

BP

Description: **Back Pressure / No Backoff.** When this bit is set to 1, after incidentally causing a collision during back pressure, the MAC will immediately retransmit without backoff. This reduces the chance of further collisions and ensures that transmit frames get sent.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

ED

Description: **Excess Defer.** When this bit is set to 1, the MAC will defer indefinitely. When this bit is set to 0, the MAC will abort when the excess deferral limit is reached.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

APE	VPE	PE	CEN	Result
0	0	0	0	No Pad or CRC appended.
0	0	0	1	CRC appended.
0	0	1	0	Pad to 60 bytes (if necessary), append CRC (min size = 64) with CRC Error.
0	0	1	1	Pad to 60 bytes (if necessary), append CRC (min size = 64).
0	1	0	0	No Pad or CRC appended.
0	1	0	1	CRC appended.
0	1	1	0	Pad to 64 bytes (if necessary), append CRC (min size = 68) with CRC Error.
0	1	1	1	Pad to 64 bytes (if necessary), append CRC (min size = 68).
1	0	0	0	No Pad or CRC appended.
1	0	0	1	CRC appended.
1	0	1	0	If untagged, pad to 60 bytes, add CRC with CRC Error. If tagged, pad to 64 bytes, add CRC with CRC Error.
1	0	1	1	If untagged, pad to 60 bytes, add CRC. If tagged, pad to 64 bytes, add CRC.
1	1	0	0	No Pad or CRC appended.
1	1	0	1	CRC appended.
1	1	1	0	If untagged, pad to 60 bytes, add CRC with CRC Error. If tagged, pad to 64 bytes, add CRC with CRC Error.
1	1	1	1	If untagged, pad to 60 bytes, add CRC. If tagged, pad to 64 bytes, add CRC.

Table 11.4 Padding Operation

Notes

Ethernet Back-to-Back Inter-Packet Gap Register

Figure 11.24 Ethernet Back-to-Back Inter-Packet Gap Register (ETH[0|1]IPGT)

IPGT

Description: **Inter-Packet Gap.** This is a programmable field representing the nibble time offset of the minimum possible period between the end of any transmitted packet to the beginning of the next. In Full-Duplex mode, the register value should be the desired period in nibble times minus 3. In Half-Duplex mode, the register value should be the desired period in nibble times minus 6. In Full-Duplex mode, the recommended setting is 0x15 (21d), which represents the minimum IPG of 0.96 μs (in 100 Mb/s) or 9.6 μs (in 10 Mb/s). In Half-Duplex the recommended setting is 0x12 (18d), which also represents the minimum IPG of 0.96 μs (in 100 Mb/s) or 9.6 μs (in 10 Mb/s).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Ethernet Non Back-to-Back Inter-Packet Gap Register

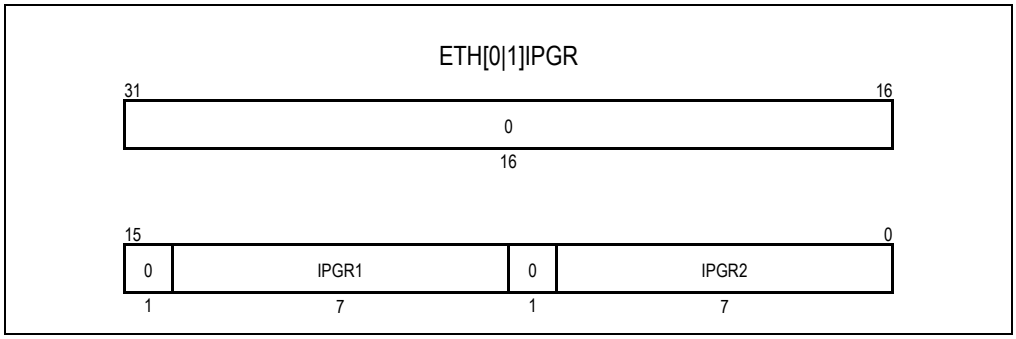


Figure 11.25 Ethernet Non Back-to-Back Inter-Packet Gap Register (ETH[0|1]IPGR)

IPGR2

Description: **Non Back-to-Back Inter-Packet Gap Part 2.** This field contains a field which represents the non back-to-back inter-packet gap. The default value of 0x12 represents a minimum value of 0.96 μs at 100 Mb/s or 9.6 μs at 10 Mb/s.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPGR1

Description: **Non Back-to-Back Inter-Packet Gap Part 1.** This field contains the field which represents the optional carrier sense window referenced in IEEE 802.3/4.2.3.2.1 “Carrier Deference.” If carrier is detected during the timing of IPGR1, the MAC defers to carrier. If carrier becomes active after IPGR1, the MAC continues timing IPGR2 and transmits, knowingly causing a collision, thus ensuring fair access to the medium. Its range of values are 0x0 to IPGR2.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Ethernet Collision Window and Retry Register

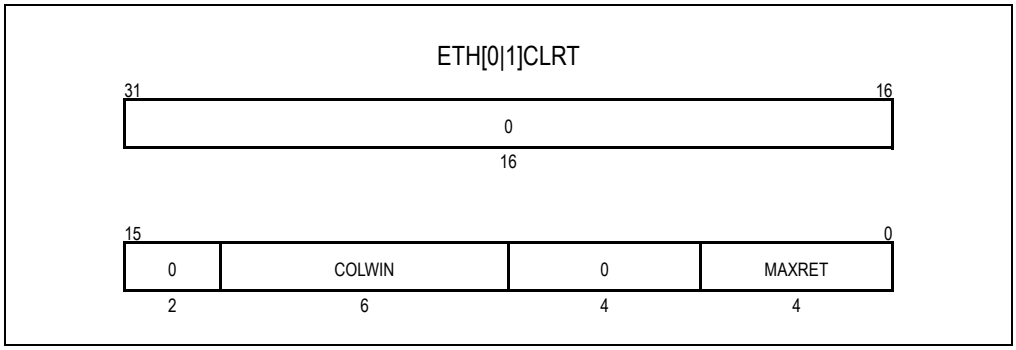


Figure 11.26 Ethernet Collision Window and Retry Register (ETH[0|1]CLRT)

MAXRET

Description: **Maximum Retransmissions.** This field specifies the number of retransmission attempts following a collision before transmission of the frame is aborted due to excessive collisions.

Initial Value: 0xF

Read Value: Previous value written

Write Effect: Modify value

COLWIN

Description: **Collision Window.** This field represents the slot time or collision window during which collisions occur in properly configured networks. Since the collision window starts at the beginning of transmission, the preamble and SFD are included. Its default value of 0x37 corresponds to the count of frame bytes at the end of the window.

Initial Value: 0x37

Read Value: Previous value written

Write Effect: Modify value

Notes

Ethernet Maximum Frame Length Register

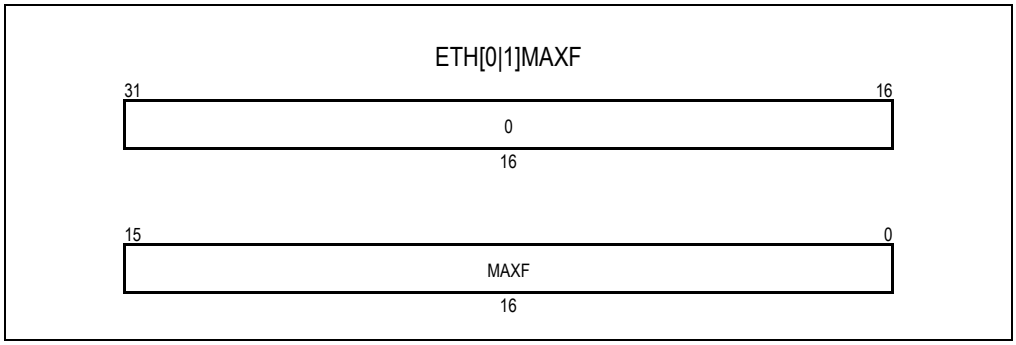


Figure 11.27 Ethernet Maximum Frame Length Register (ETH[0|1]MAXF)

MAXF

Description: **Maximum Frame Length.** This field contains the maximum frame length supported by the MAC. The default value 0x0600 represents a maximum receive frame of 1536 bytes. The maximum untagged Ethernet frame size is 1518 bytes. A tagged frame adds four bytes for a total of 1522 bytes.

Initial Value: 0x0600

Read Value: Previous value written

Write Effect: Modify value

Ethernet MAC Test Register

Figure 11.28 Ethernet MAC Test Register (ETH[0|1]MTEST)

TB

Description: **Test Back pressure.** When this bit is set to 1, the MAC asserts back pressure on the link. Back pressure causes the preamble to be transmitted, raising carrier sense. When this bit is set to 0, the Test Back pressure function is disabled.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Ethernet MII Management Interface

The MII management interface provides a simple serial interface for controlling PHYs and for gathering status from PHYs. Both Ethernet interfaces share a single MII management interface. The interface consists of two pins for reading and writing registers in a PHY:

Clock pin (MIIMDC)

Bidirectional data pin (MIIDIO)

The clock for the management interface is generated by the CPU core and driven on the MIIMDC pin. The clock frequency driven on this pin is based on the Ethernet management clock generated by the Ethernet clock prescalar. The Ethernet clock prescalar value should be selected such that the minimum high and low times for the MIIMDC pin are at least 160 ns, and the minimum period is 400 ns.

A PHY register is read by first writing the desired PHY address into the PHY address (PHYADDR) field of the MII management address (MIIMADDR) register and writing the desired register address in the register address (REGADDR) field of the MIIMADDR register. One of two operations can then be selected:

Setting the read (RD) bit in the MII management command (MIICMD) register causes a single read operation to be performed.

Setting the scan (SCN) bit in the MIICMD register causes repeated reads to be performed from the selected PHY register.

Once the read data not valid (NV) bit in the MII management indicators register (MIIMIND) is cleared to 0, the value read from the selected PHY register may be read from the MII management read data register (MIIMRDD) by the CPU core.

A PHY register may be written by writing the desired PHY address into the PHY address (PHYADDR) field of the MIIMADDR register, and then writing the data to the MII management write data (MIIWTD) register. A side effect of writing into the MIIWTD register is that a write is performed by the MII management interface to the selected PHY register. The PHY write operation is completed when the busy (BSY) bit in the MIIMIND register is cleared.

MII Management Configuration Register

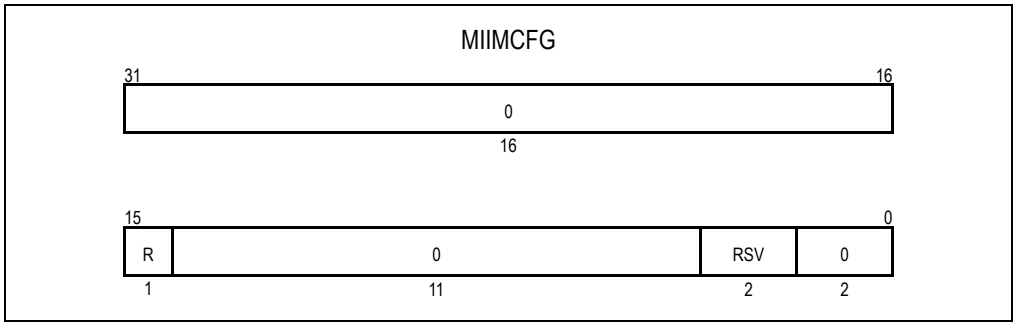


Figure 11.29 MII Management Configuration Register (MIIMCFG)

RSV

Description: **Reserved.** Any value may be written to this field.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Notes

R

Description: **Reset MII Management Logic.** When this bit is set to 1, the Ethernet MII management logic is reset. When this bit is set to 0, the Ethernet MII management logic is in normal operational mode.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

MII Management Command Register

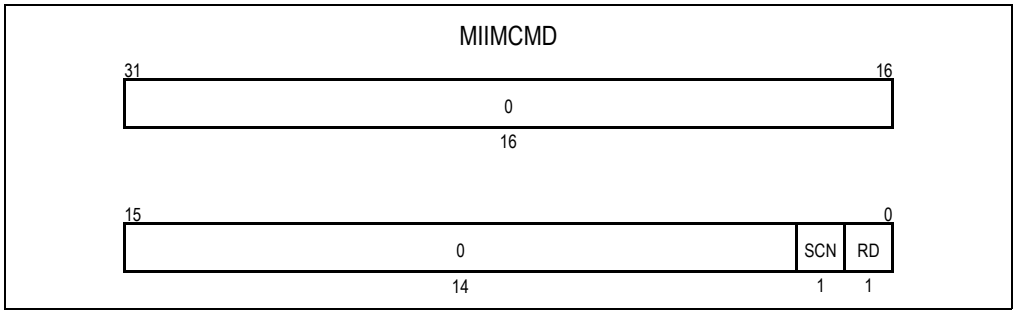


Figure 11.30 MII Management Command Register (MIIMCMD)

RD

Description: **Read.** When this bit is set to 1, the MII management interface performs a single read operation. The data read is returned in the MII management read data (MIIMRDD) register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SCN

Description: **Scan.** When this bit is set to 1, the MII management interface performs continuous read operations. This is useful for monitoring status.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

MII Management Address Register

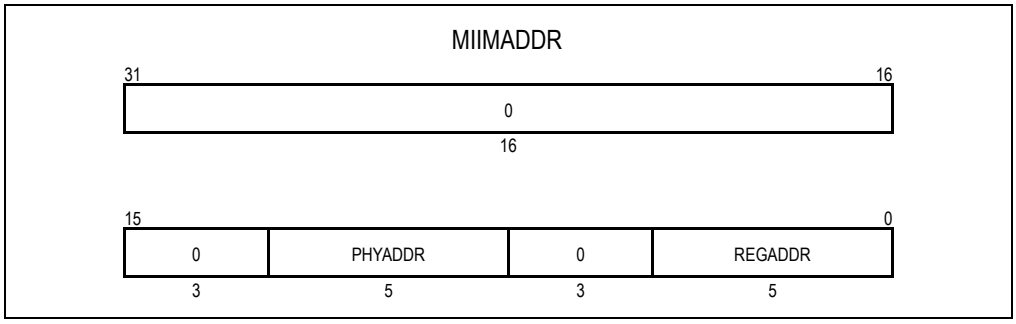


Figure 11.31 MII Management Address Register (MIIMADDR)

REGADDR

Description: **Register Address.** This field contains the 5-bit register address used for MII management operations.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PHYADDR

Description: **PHY Address.** This field contains the 5-bit PHY address used for MII management operations.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MII Management Write Data Register

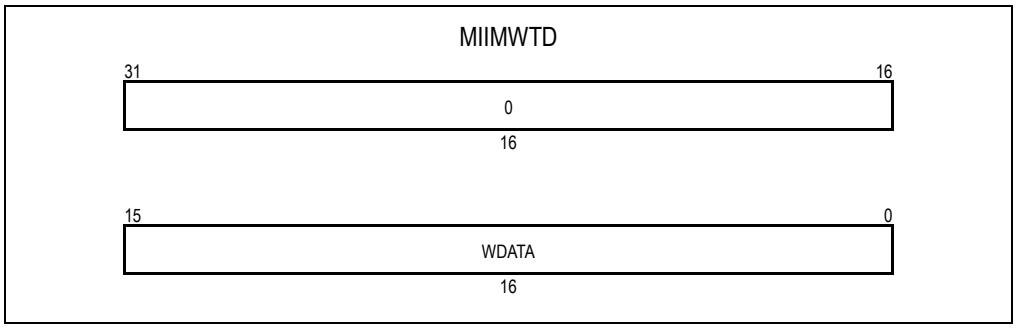


Figure 11.32 MII Management Write Data Register (MIIMWTD)

WDATA

Description: **Write Data.** When this field is written, a MII management write cycle is performed using the 16-bit data value written and the pre-configured PHY and register address from the MII management address (MIIMADDR) register.

Initial Value: 0x0000

Read Value: Previous value written

Write Effect: Modify value and initiate a MII management write cycle

Notes

MII Management Read Data Register

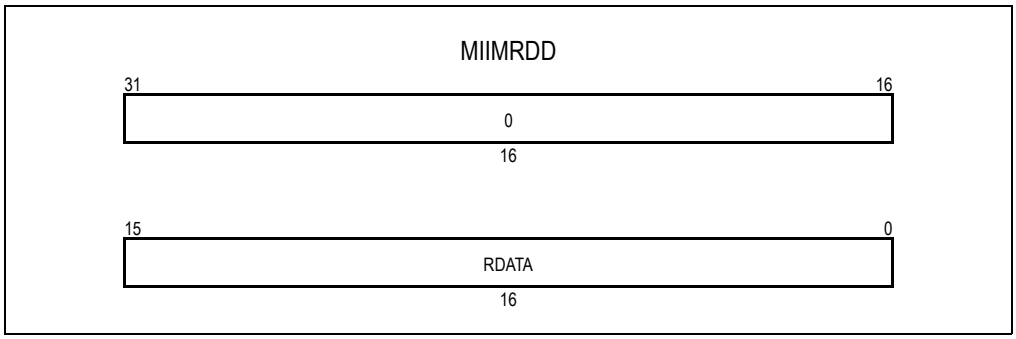


Figure 11.33 MII Management Read Data Register (MIIMRDD)

RDATA

Description: **Read Data.** Following a MII management read cycle, this field contains the data read. The NV bit is set to 0 when data is valid following the read operation.

Initial Value: 0x0000

Read Value: Data read from MII management interface

Write Effect: Read-only

MII Management Indicators Register

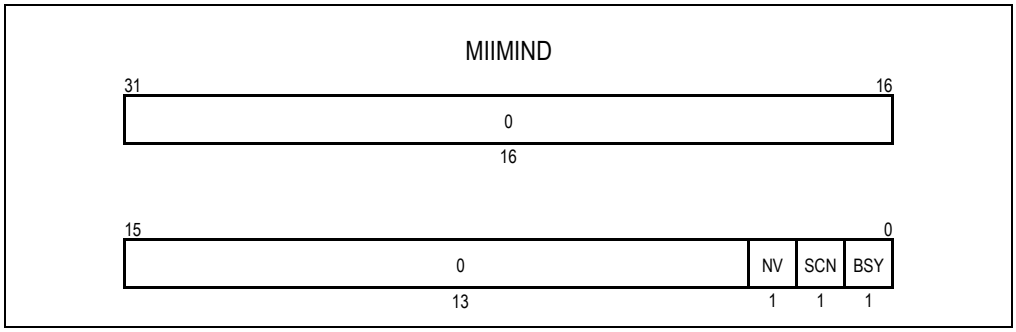


Figure 11.34 MII Management Indicators Register (MIIMIND)

BSY

Description: **Busy.** When this bit is set to 1, a MII management read cycle or write cycle is in progress and subsequent reads or writes are ignored until this bit is cleared to 0.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

SCN

Description: **SCAN.** When this bit is set to 1, a MII management scan operation is in progress.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Notes

NV

Description: **Read Data Not Valid.** When this bit is set to 1, a MII management read operation has not completed and the value in the MII management read data (MIIMRDD) register is not valid.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Ethernet Clock Prescalar

The Ethernet interfaces share an 8-bit clock prescalar which is used to generate the Ethernet management clock for shared MII management interface. The ethernet management clock is the media independent interface management data clock on the MIIMDC pin. The Ethernet management clock is equal to the IPBus clock (ICLK) frequency divided by the clock prescalar divisor (DIV) field in the Ethernet management clock prescalar register (ETHMCP).

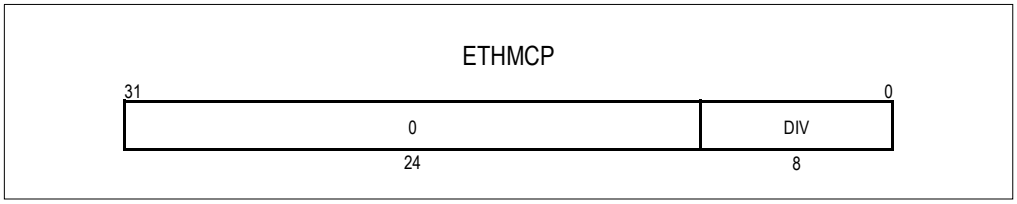


Figure 11.35 Ethernet Management Clock Prescalar Register (ETHMCP)

DIV

Description: **Clock Prescalar Divisor.** When the DIV field equals zero, one, two, or three, the internally generated ethernet management clock is equal to the system clock divided by four. For all other even values of the DIV field up to 255, the Ethernet management clock is equal to the system clock divided by the DIV field. Bit zero of the DIV field is always assumed to be zero.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Programming Example

Disclaimer: Code examples provided by IDT are for illustrative purposes only and should not be relied upon for developing applications. IDT does not assume liability for any loss or damage that may result from the use of this code.

```
*/

#define  ETHIPGT_HALF_DUPLEX      0x12
#define  ETHIPGT_FULL_DUPLEX      0x15

int reginit( void ) ;
int io_fifo( void ) ;
int addr_rec( void ) ;
int cpu_infc( void ) ;
int eth_mac( void ) ;
int eth_prescale( void ) ;
```

Notes

```
int eth_mii( void ) ;

int reginit( void )
{

  addr_rec();
  eth_mac();
  io_fifo();
  eth_prescale();
  reset_phy();

  return( 0 );
}

/* Set up the four physical station addresses for the MAC */

int addr_rec( void )
{
      /* Accept only packets destined for THIS Ethernet device address */
      ethernet.etharc = 0x0;
      /* Set all Ethernet address registers to the same initial values */
      /* set all four addresses to 66-88-aa-cc-dd-ee */

      ethernet.ethsal0 = 0xaaccddee;
      ethernet.ethsah0 = 0x00006688;
      ethernet.ethsal1 = 0xaaccddee;
      ethernet.ethsah1 = 0x00006688;
      ethernet.ethsal2 = 0xaaccddee;
      ethernet.ethsah2 = 0x00006688;
      ethernet.ethsal3 = 0xaaccddee;
      ethernet.ethsah3 = 0x00006688;
      return( 0 );
}

int eth_mac( void )
{
      /* Receive is ENABLED */
      ethernet.ethmac1 = ETHERMAC1_RE;
            /* enable full duplex */
      ethernet.ethmac2 = ETHERMAC2_FD;
      /* Back-to-back inter-packet-gap, full-duplex */
      ethernet.ethipgt = ETHIPGT_FULL_DUPLEX;
      /* None back-to-back inter-packet-gap, IPGR2 */
      ethernet.ethipgr = 0x12;
      return( 0 );
}

int eth_prescale( void )
```

Notes

```
{
    /* system clock divisor for MII bus */
    ethernet.ethmcp = 0x28;  /* 50 MHZ / 40 = 1.25 MHZ */
    return( 0 );
}

int io_fifo( void )
{
    unsigned int i, xthres;

    ethernet.ethintfc = 0; /* reset ethernet interfce */
    i = ethernet.ethintfc;
    printf("intfc = %x\n",i);
        for(i=0xffff;i>0;i--){
            if(!(ethernet.ethintfc & ETHERINTFC_RIP))
                break;
        }
    /* Enable Ethernet Interface */
    ethernet.ethintfc = ETHERINTFC_EN;

v   /* Fifo Tx Threshold Level */
    ethernet.ethfifott = 0x40;

    return( 0 );
}

        /* reset ethernet phy chip */
int reset_phy(void)
{
unsigned int tmp,i;

        ethernet.miimcfg = 0x8000; /* set mii reset bit */
        for(i=0;i<0xffff;i++);/* allow for slow mii clock */
        ethernet.miimcfg = 0;/* clear reset bit */

        /* PHY default is 10/100 full duplex mode */
        tmp = read_phy_reg(0);
        printf("read phy reg 0 = %x\n",tmp);
        tmp = read_phy_reg(0);
        printf("read phy reg 0 = %x\n",tmp);
        tmp = read_phy_reg(1);
        printf("read phy reg 1 = %x\n",tmp);
        while(!(tmp& 0x04))/* link is down */
            tmp = read_phy_reg(1);
        printf("read phy reg 1 = %x\n",tmp); /* link is up */
        return(0);
}
```

Notes

```
#define MII_TIMEOUT 0xf000

int write_phy_reg(int reg, int data)
{

        int i;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
            i--;
        if(i == 0){
            printf("write phy reg timed out waiting for mii busy\n");
            return (1);
            }
        ethernet.miimaddr = reg;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
            i--;
        if(i == 0){
            printf("write phy reg timed out waiting for mii busy\n");
            return (2);
            }
        ethernet.miimwtd = data;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
            i--;
        if(i == 0){
            printf("write phy reg timed out waiting for mii busy\n");
            return (3);
            }
        return(0);
}

int read_phy_reg(int reg)
{

        int i, data;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
            i--;
        if(i == 0){
            printf("read phy reg timed out waiting for mii busy\n");
            return (0x1);
            }
        ethernet.miimaddr = reg;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
```

Notes

```
                i--;
        if(i == 0){
                printf("read phy reg timed out waiting for mii busy\n");
                return (0x1);
                }
        ethernet.miimcmd = ETHERMIIMCMD_RD;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
                i--;
        if(i == 0){
                printf("read phy reg timed out waiting for mii busy\n");
                return (0x2);
                }
        if(ethernet.miimind & ETHERMIIMIND_NV){
                printf("read phy reg failed, data not valid\n");
                return(0x3);
                }
        data = ethernet.miimrdd;
        ethernet.miimcmd = 0;/* clear read bit */
        return(data);
}

int scan_phy_reg(int reg)
{

        int i, data;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
                i--;
        if(i == 0){
                printf("read phy reg timed out waiting for mii busy\n");
                return (0x1);
                }
        ethernet.miimaddr = reg;
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_BSY) && i)
                i--;
        if(i == 0){
                printf("read phy reg timed out waiting for mii busy\n");
                return (0x1);
                }
        ethernet.miimcmd = ETHERMIIMCMD_SCN;
        while(1){
        i=MII_TIMEOUT;
        while((ethernet.miimind & ETHERMIIMIND_NV) && i)
                i--;
```

Notes

```
        if(i == 0){
            printf("read phy reg timed out waiting for mii not vaild\n");
            return (0x2);
            }
        data = ethernet.miimrdd;
        printf("reg %d = %x\r",reg,data);
        if(data == 0x782d)
            break;
        }
        ethernet.miimcmd = 0;/* clear scan bit */
        return(data);
}
```

Notes

IDT interprise

General Purpose I/O Controller

Notes

Introduction

This chapter describes the operation of the General Purpose I/O (GPIO) Controller and the operation of the general purpose I/O pins. This chapter also describes how the GPIO Controller and pins are configured to operate as a general purpose I/O or as an alternate function.

Functional Overview

The general purpose I/O controller provides 32 general purpose I/O pins which may be individually configured as:

- *General purpose input*
- *General purpose output*
- *Alternate functions*

When configured as general purpose input, each pin can be used as an active high or active low level interrupt input.

As shown in Table 12.1, each general purpose I/O (GPIO) bit is shared with another on-chip function. The GPIO function (GPIOFUNC) field in the general purpose I/O function (GPIOFUNC) register controls whether a GPIO bit operates as a general purpose I/O or as the specified alternate function.

GPIO Pin	Alternate Function Pin Name	Alternate Function Description	Alternate Function Pin Type
0	U0SOUT	UART channel 0 serial output (see Chapter 13)	Output
1	U0SINP	UART channel 0 serial input (see Chapter 13)	Input
2	U0RIN	UART channel 0 ring indicator (see Chapter 13)	Input
3	U0DCDN	UART channel 0 data carrier detect (see Chapter 13)	Input
4	U0DTRN	UART channel 0 data terminal ready (see Chapter 13)	Output
5	U0DSRN	UART channel 0 data set ready (see Chapter 13)	Input
6	U0RTSN	UART channel 0 request to send (see Chapter 13)	Output
7	U0CTSN	UART channel 0 clear to send (see Chapter 13)	Input
8	U1SOUT	UART channel 1 serial output (see Chapter 13)	Output
9	U1SINP	UART channel 1 serial input (see Chapter 13)	Input
10	U1DTRN	UART channel 1 data terminal ready (see Chapter 13)	Output
11	U1DSRN	UART channel 1 data set ready (see Chapter 13)	Input
12	U1RTSN	UART channel 1 request to send (see Chapter 13)	Output
13	U1CTSN	UART channel 1 clear to send (see Chapter 13)	Input
14	DMAREQN0	External DMA channel 0 request (see Chapter 9)	Input
15	DMAREQN1	External DMA channel 1 request (see Chapter 9)	Input

Table 12.1 General Purpose I/O Pin Alternate Function (Part 1 of 2)

Notes

GPIO Pin	Alternate Function Pin Name	Alternate Function Description	Alternate Function Pin Type
16	DMADONEN0	External DMA channel 0 done (see Chapter 9)	Input
17	DMADONEN1	External DMA channel 1 done (see Chapter 9)	Input
18	DMAFINN0	External DMA channel 0 finished (see Chapter 9)	Output
19	DMAFINN1	External DMA channel 1 finished (see Chapter 9)	Output
20	MADDR[22]	Memory and peripheral bus address (see Chapter 6)	Output
21	MADDR[23]	Memory and peripheral bus address (see Chapter 6)	Output
22	MADDR[24]	Memory and peripheral bus address (see Chapter 6)	Output
23	MADDR[25]	Memory and peripheral bus address (see Chapter 6)	Output
24	PCIREQN[4]	PCI Request 4 (see Chapter 10)	Input
25	AFSPARE1	reserved	Input
26	PCIGNTN[4]	PCI Grant 4 (see Chapter 10)	Output
27	PCIREQN[5]	PCI Request 5 (see Chapter 10)	Input
28	PCIGNTN[5]	PCI Grant 5 (see Chapter 10)	Output
29-31	Reserved		

Table 12.1 General Purpose I/O Pin Alternate Function (Part 2 of 2)

Theory of Operation

After reset, all GPIO pins default to the GPIO input function. When a GPIO pin is configured for use as a GPIO pin, the alternate function associated with that pin is held in an inactive state by internal logic. Care should be exercised when configuring GPIO pins as outputs because an incorrect configuration (for example, mistakenly configuring an input pin as an output pin) could cause damage to external components as well as to the RC32438 device itself.

Each GPIO pin is controlled by its corresponding bit in each GPIO register. For example, GPIO bit [0] is controlled by GPIOFUNC[0], GPIOCFG[0], GPIOD[0], GPIOILEVEL[0], GPIOISTAT[0], and GPIONMIEN[0]. In another example, GPIO bit [2] is controlled by GPIOFUNC[2], GPIOCFG[2], GPIOD[2], GPIOILEVEL[2], GPIOISTAT[2], and GPIONMIEN[2].

All GPIO pins except GPIO[24] and GPIO[30:26] have LVTTL I/O buffers. GPIO pins 24 and 26 through 30 have PCI I/O buffers which allow these pins to be used for PCI interrupts.

GPIO Pin Configured As Input

When configured as an input in the GPIO configuration register (GPIOCFG) and as a GPIO function in the GPIO function register (GPIOFUNC), the GPIO pin value will be sampled and registered in the GPIO data register (GPIOD) each master clock cycle (after double registering to prevent metastability). The value of the input pin can be determined at any time by reading GPIOD.

GPIO Pin Configured As Output

When configured as an output in GPIOCFG and as a GPIO function in GPIOFUNC, the value written into GPIOD will be output at the pin. The value of the output pin can be determined at any time by reading GPIOD.

Notes

GPIO Pin Configured As an Alternate Function

When configured as an alternate function in GPIOFUNC register, the pin behaves as described in each chapter associated with that function. The value of the alternate function pin can be determined at any time by reading GPIOD.

GPIOFUNC	GPIOCFG	Pin Function
0	0	GPIO input
0	1	GPIO output
1	Don't care	Alternate 1 function

Table 12.2 Possible GPIO Configurations

GPIO Pins As Interrupt Sources

Each pin can also generate an interrupt to the Interrupt Controller, regardless of the configuration in GPIOFUNC or GPIOCFG. This allows an alternate function, a write to GPIOD, or a GPIO input from an external device, to generate an interrupt.

Interrupt generation is controlled using the GPIO interrupt level register (GPIOILEVEL) and GPIO interrupt status register (GPIOISTAT). GPIOILEVEL describes the interrupt level (either active high or low) of the signal that will cause the interrupt. When the value of a pin matches the level in GPIOILEVEL, the corresponding bit in the GPIO interrupt status register (GPIOISTAT) will be set high. Once set, the bit in GPIOISTAT will remain set even if the value of the GPIO pin changes. All GPIOISTAT bits are sent to the Interrupt Controller to request interrupt servicing.

To clear the interrupt, the source of the interrupt must be cleared or serviced. (This could be an alternate function service or clearing of GPIOD.) Then the bit in GPIOISTAT must also be cleared.

Note that if an interrupt is not wanted from a GPIO pin, it must be masked in the Interrupt Controller Interrupt Mask 6 Register (IMASK6). See Chapter 8, Interrupt Controller.

GPIO Pins As Non-maskable Interrupt Sources

Each GPIO pin can also be programmed to generate a non-maskable interrupt (NMI) to the CPU regardless of the configuration in GPIOFUNC or GPIOCFG. GPIOILEVEL and GPIOISTAT must be set up to generate an interrupt as described in the previous section. The GPIO Non-maskable Interrupt Enable Register (GPIONMIEN) enables the corresponding bit in the GPIOISTAT register to generate an NMI. All enabled NMI sources are logically combined to generate a single NMI to the CPU core. The GPIOSTAT register can be read to determine the cause of the NMI.

Note that in addition to the generation of the NMI, an interrupt is also generated unless masked in the Interrupt Controller.

General Purpose I/O Register Description

Register Offset[1]	Register Name	Register Function	Size
0x04_8000	GPIOFUNC	GPIO function	32-bit
0x04_8004	GPIOCFG	GPIO configuration	32-bit
0x04_8008	GPIOD	GPIO data	32-bit
0x04_800C	GPIOILEVEL	GPIO interrupt level	32-bit

Table 12.3 Ethernet Register Map (Part 1 of 2)

Notes

Register Offset[1]	Register Name	Register Function	Size
0x04_8010	GPIOISTAT	GPIO interrupt status	32-bit
0x04_8014	GPIONMIEN	GPIO nonmaskable interrupt enable	32-bit
0x04_8018 through 0x04_FFFF	Reserved		

Table 12.3 Ethernet Register Map (Part 2 of 2)

1. The address of the register is equal to the register offset added to the base value of 0x1800_0000.

GPIO Function Register

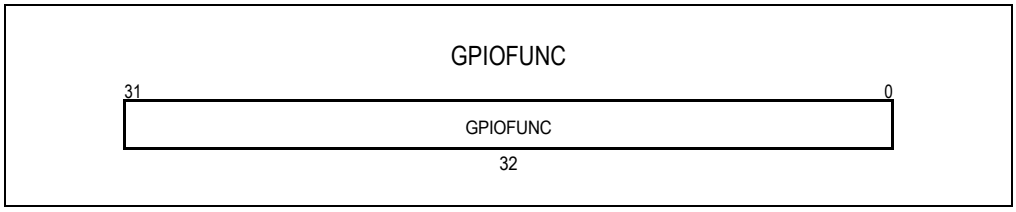


Figure 12.1 GPIO Function Register (GPIOFUNC)

GPIOFUNC

Description: **GPIO Function.** Each bit in this field controls its corresponding GPIO pin. When a bit is set to a one, the corresponding GPIO pin operates as the alternate 1 function as defined in Table 12.1. When a bit is set to a zero, the corresponding GPIO pin operates as a general purpose I/O pin.

Initial Value: 0x0

Read Value: Current value

Write Effect: Modify value

GPIO Configuration Register

Figure 12.2 GPIO Configuration Register (GPIOCFG)

GPIOCFG

Description: **GPIO Configuration.** Each bit in this field controls its corresponding GPIO pin. When a bit is configured as a general purpose I/O pin and the corresponding bit in this field is set, then the pin is configured as an output. When a bit is configured as a general purpose I/O pin and the corresponding bit in this field is a zero, the pin is configured as in input. When the pin is configured as an alternate function, the behavior of the pin is defined by the alternate 1 function.

Initial Value: 0x0

Read Value: Current value

Write Effect: Modify value

Notes

GPIO Data Register

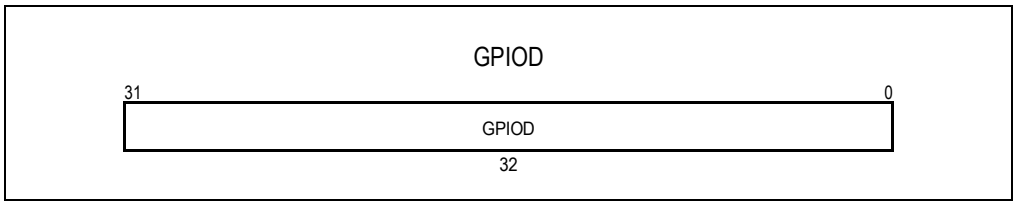


Figure 12.3 GPIO Data Register (GPIOD)

GPIOD

Description: **GPIO Data.** Each bit in this field controls its corresponding GPIO pin. Reading this field returns the current value of each GPIO pin. Writing a value to this field causes the corresponding pins which are configured as GPIO outputs to change state to the value written.

Initial Value: Undefined

Read Value: GPIO pin status

Write Effect: Modify GPIO output pin status

GPIO Interrupt Level Register

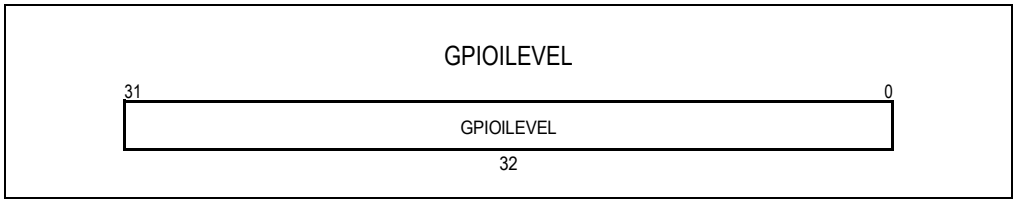


Figure 12.4 GPIO Interrupt Level Register (GPIOILEVEL)

GPIOILEVEL

Description: **GPIO Interrupt Level.** When the value of a GPIO pin matches the value of the corresponding bit in this field, then the corresponding bit is set in the GPIOISTAT field is set.

Initial Value: Undefined

Read Value: Current value

Write Effect: Modify value

GPIO Interrupt Status Register

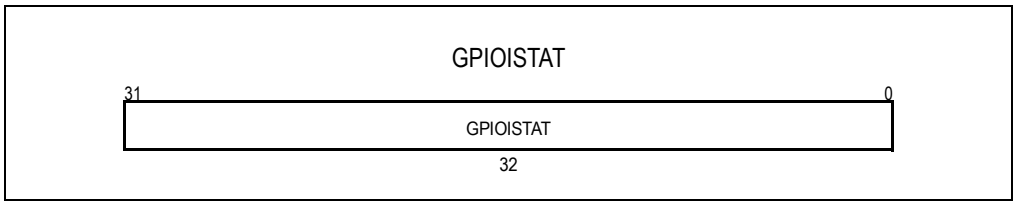


Figure 12.5 GPIO Interrupt Status Register (GPIOISTAT)

GPIOISTAT

Description: **GPIO Interrupt Status.** Each bit in this field controls its corresponding GPIO pin. When a bit in this field is set to 1, the GPIO pin value matches that of the corresponding bit in the GPIOILEVEL field. Each bit in this field is presented to the interrupt controller as an interrupt input. Bits in this field are typically cleared by an interrupt service routine.

Notes

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit[1]

1. A sticky bit is set by the hardware and can only be cleared by the CPU.

GPIO Non-maskable Interrupt Enable Register

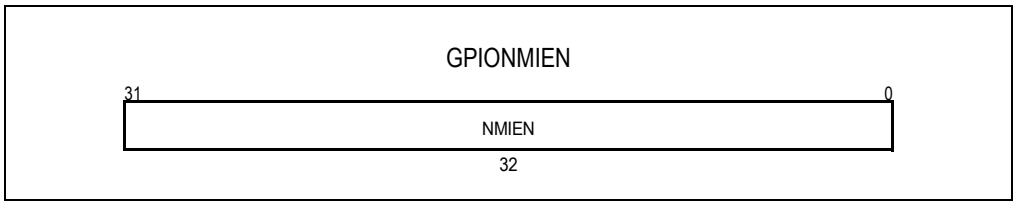


Figure 12.6 GPIO Non-maskable Interrupt Enable Register (GPIONMIEN)

NMIEN

Description: **GPIO Non-maskable Interrupt Enable.** When a bit in the GPIOISTAT register is set to 1 and the corresponding bit in the NMIEN field of the GPIONMIEN register is set to 1, a GPIO non-maskable interrupt request is generated. This results in the GPIO bit being set in the NMIPS register (see “Non-Maskable Interrupt Pin Status Register” on page 8-7) which causes a non-maskable interrupt exception.

Initial Value: 0x0000_0000

Read Value: Previous value written

Write Effect: Modify value

UART Controller

Notes

Introduction

The RC32438 contains two completely separate but identical serial channels (UARTs). Each UART is compatible with the industry standard 16550[1] UART. The two UARTs (referred to as channel 0 and channel 1) are functionally identical, except UART channel 1 does not use all the available modem control pins.

Features

- *Compatible with the 16550 and 16450 UARTs*
- *Two completely separate serial channels*
- *Modem control functions (CTS, RTS, DSR, DTR, RI, DCD)*
- *16-byte transmit and receive buffers*
- *Programmable baud rate generator derived from the system clock*
- *Fully programmable serial characteristics:*
- *5, 6, 7, or 8 bit characters*
- *Even, odd or no parity bit generation and detection*
- *1, 1-1/2, or 2 stop bit generation*
- *Line break generation and detection*
- *False start bit detection*
- *Internal loopback mode*

Functional Overview

The 16550 UART is an enhanced version of the 16450 UART. Upon power-up, each UART defaults to the 16450 mode. The 16550 contains two 16-byte buffers: one in the receive data path and one in the transmit data path. The buffers reduce the overhead on the CPU core in managing the data flow. The 16450 does not use the buffers in the data path.

The CPU core can read the status of either UART channel at any time during operation. Status information that is available includes the type and condition of the transfer operation, as well as any error condition (parity, overrun, framing, or break interrupt). The baud rate generator divides down the IPBus clock and provides a 16X clock for driving the transmitter and receiver logic.

The UART pins shown in Table 13.1 are multiplexed with the GPIO pins as shown in Table 12.1.

Signal	Description	Direction
U0SOUT	UART Channel 0 Serial Output	Output
U0SINP	UART Channel 0 Serial Input	Input
U0RIN	UART Channel 0 Ring Indicator	Input
U0DCRN	UART Channel 0 Data Carrier Detect	Input
U0DTRN	UART Channel 0 Data Terminal Ready	Output
U0DSRN	UART Channel 0 Data Set Ready	Input

Table 13.1 UART Input/Output Pins (Part 1 of 2)

1. *PC 16550D Dual Universal Asynchronous Receiver/Transmitter with FIFOs*, June 1995, National Semiconductor.

Notes

U0RTSN	UART Channel 0 Request to Send	Output
U0CTSN	UART Channel 0 Clear to Send	Input
U1SOUT	UART Channel 1 Serial Output	Output
U1SINP	UART Channel 1 Serial Input	Input
U1DTRN	UART Channel 1 Data Terminal Ready	Output
U1DSRN	UART Channel 1 Data Set Ready	Input
U1RTSN	UART Channel 1 Request to Send	Output
U1CTSN	UART Channel 1 Clear to Send	Input

Table 13.1 UART Input/Output Pins (Part 2 of 2)

The UART must be configured before operation may begin. To configure the UART:

1. Set up the transmit and receive parameters in the line control (UARTxLC) register.
2. Program the baud rate in the divisor latch low (UARTDLL) and divisor latch high (UARTDLH) registers.
3. Enable, if desired, the 16550 buffer mode in the FIFO control (UARTxFC) register.

The general purpose I/O controller must be configured to use the desired UART pins as alternate function GPIO pins. The UART contains a baud rate generator which is used to operate the transmit and receive logic at the baud rate determined by the divisor latches.

UART Register Description

In order to maintain full compatibility with the 16550, all registers in the UART are 8-bits in size and have the addressing architecture of the 16550. Despite the fact that the registers are 8-bits in size, they are word aligned. As in the 16550, the exact register which is selected when accessing the UART is dependent on the divisor latch access bit (DLAB) in the line control (UARTxLC) register and on whether a read or write operation is performed. Table 13.2 lists the UART registers.

Register Offset	Register Name		Register Function	Size
	DLAB = 0	DLAB = 1		
0x05_0000	UART0RB (read) UART0TH (write)	UART0DLL	UART 0 receive buffer / UART 0 transmit holding / UART 0 divisor latch low	32-bit
0x05_0004	UART0IE	UART0DLH	UART 0 interrupt enable / UART 0 divisor latch high	32-bit
0x05_0008	UART0II (read) UART0FC (write)	none	UART 0 interrupt identification / UART 0 FIFO control	32-bit
0x05_000C	UART0LC		UART 0 line control	32-bit
0x05_0010	UART0MC		UART 0 modem control	32-bit
0x05_0014	UART0LS		UART 0 line status	32-bit
0x05_0018	UART0MS		UART 0 modem status	32-bit
0x05_001C	UAART0S		UART 0 scratch	32-bit
0x05_0020	UART1RB (read) UART1TH (write)	UART1DLL	UART 1 receive buffer / UART 1 transmit holding / UART 1 divisor latch low	32-bit
0x05_0024	UART1IE	UART1DLH	UART 1 interrupt enable / UART 1 divisor latch high	32-bit

Table 13.2 UART Register Map (Part 1 of 2)

Notes

Register Offset	Register Name		Register Function	Size
	DLAB = 0	DLAB = 1		
0x05_0028	UART1II (read) UART1FC (write)	none	UART 1 interrupt identification / UART 1 FIFO control	32-bit
0x05_002C	UART1LC		UART 1 line control	32-bit
0x05_0030	UART1MC		UART 1 modem control	32-bit
0x05_0034	UART1LS		UART 1 line status	32-bit
0x05_0038	UART1MS		UART 1 modem status	32-bit
0x05_003C	UART1S		UART 1 scratch	32-bit
0x05_0040	UART0RR		UART 0 Reset	32-bit
0x05_0044	UART1RR		UART 1 Reset	32-bit
0x05_0048 through 0x05_7FFF	Reserved			

Table 13.2 UART Register Map (Part 2 of 2)

Baud Rate Selection

The baud rate is determined by a two-byte divisor that divides down the IPBus clock (ICLK). The divisor, in binary, is loaded into the UARTDLL and UARTDLH registers. A divisor value of zero or one is interpreted as a divisor of 32 decimal (0020 hex) by the baud rate generator.

To calculate the baud rate, use the following formula (the constant, 16, is used in the formula because the output frequency of the baud rate generator is 16 times the baud):

*Baud rate = (system frequency) / (divisor * 16)*

Or, to calculate the divisor to load into the Divisor Latches, use the following formula:

*Divisor = system frequency / (baud rate * 16)*

As an example, for a system frequency of 66 MHz and a baud rate of 9600 (values shown are decimal), calculate the divisor as follows:

*Divisor = 66,000,000 / (9600 * 16) = 429.6875*

Round off the ideal divisor to the nearest whole number, 430, to load into the divisor latches. Load 0000_0001_1010_1110 into the divisor latches: 0000_0001 into UARTDLH and 1010_1110 into UARTDLL. Some divisors and system frequencies will give a more accurate baud rate than others.

To **calculate the percent error** of the divisor, use this formula:

% error = ((difference of the whole divisor and the ideal fractional divisor) / ideal fractional divisor) * 100.

In this example, the error is ((430 - 429.6875) / 429.6875) * 100 = 0.073%. Divisor values for typical baud rates and system clock frequencies are provided in Table 13.3.

IPBus Clock Frequency	Baud Rate	Divisor (decimal)
133 MHz	19200	433
116.5 MHz	19200	379
100 MHz	9600	651
66 MHz	19200	214

Table 13.3 Divisor Values for Typical Baud Rates and IPBus Clock Frequencies (Part 1 of 2)

Notes

IPBus Clock Frequency	Baud Rate	Divisor (decimal)
66MHz	9600	430
66MHz	2400	1719
50MHz	9600	326
40MHz	9600	260
33MHz	9600	215
25MHz	9600	163

Table 13.3 Divisor Values for Typical Baud Rates and IPBus Clock Frequencies (Part 2 of 2)

UART Interrupts

The UART generates six interrupt requests to the interrupt controller:

- **General Interrupt 0**. Activated when one of the conditions in the UART0IE register is enabled and the necessary condition has occurred. This is bit (0) in the UART0II register, inverted, and sent to the interrupt controller.
- **TXRDY 0 Interrupt.** Activated depending on the DMA mode set in the FIFO Control Register for channel 0. An interrupt request is generated under the same conditions that the TXRDY pin for channel 0 would be asserted. (Refer to industry standard 16550 UART specification.)[1]
- **RXRDY 0 Interrupt**. Activated depending on the DMA mode set in the FIFO Control Register for channel 0. An interrupt request is generated under the same conditions that the RXRDY pin for channel 0 would be asserted. (Refer to industry standard 16550 UART specification.)[1]
- **General Interrupt 1**. Activated when one of the conditions in the UART1IE register is enabled and the necessary condition has occurred. This is bit (0) in the UART1II register, inverted, and sent to the interrupt controller.
- **TXRDY 1 Interrupt.** Activated depending on the DMA mode set in the FIFO Control Register for channel 1. An interrupt request is generated under the same conditions that the TXRDY pin for channel 1 would be asserted. (Refer to industry standard 16550 UART specification.)[1]
- **RXRDY 1 Interrupt**. Activated depending on the DMA mode set in the FIFO Control Register for channel 1. An interrupt request is generated under the same conditions that the RXRDY pin for channel 1 would be asserted. (Refer to industry standard 16550 UART specification.)[1]

UART Channel Reset

The UART provides two independent serial channels. When switching a UART channel between 16550 and 16450 modes, the internal UART FIFOs are not cleared. To support clean switching between modes, a UART Reset Register (UART[0|1]RR) is added to the standard 16550 UART register definition for each channel.

The standard 16550 UART registers are described in the Functional Overview section at the beginning of this chapter.

UART Registers

This section describes the UART registers. For additional information on configuring and operating the UART, see the 16550 data sheet[2].

1. *PC 16550D Dual Universal Asynchronous Receiver/Transmitter with FIFOs*, June 1995, National Semiconductor.

2. *PC 16550D Dual Universal Asynchronous Receiver/Transmitter with FIFOs*, June 1995, National Semiconductor.

Notes

Reset Register

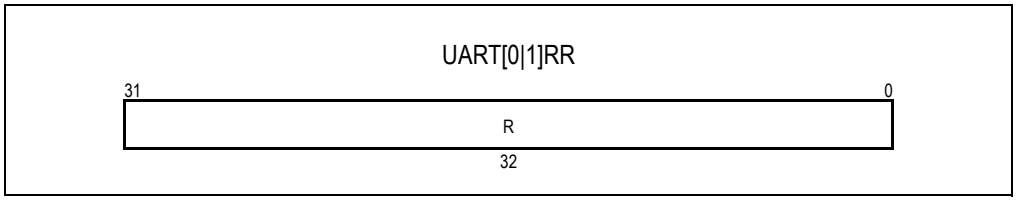


Figure 13.1 UART [0|1] Reset Register

R

Description: **Reset.** A write of any value to this register causes the corresponding UART channel to be reset.

Initial Value: Undefined

Read Value: Undefined

Write Effect: Write of any value causes UART channel reset

Receive Buffer Register

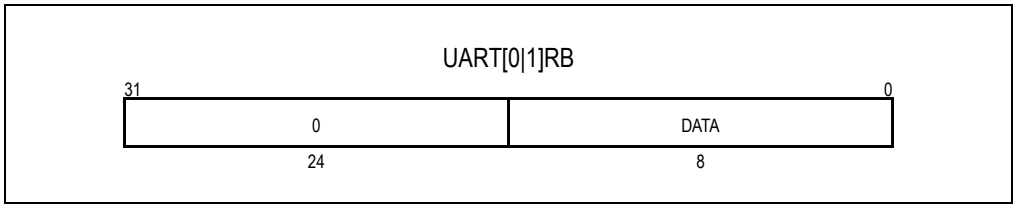


Figure 13.2 UART [0|1] Receive Buffer Register (UART[0|1]RB)

DATA

Description: **DATA.** Reading this field returns a byte from the UART receive buffer.

Initial Value: Undefined

Read Value: Byte from UART receive buffer

Write Effect: Read-only

Transmit Holding Register

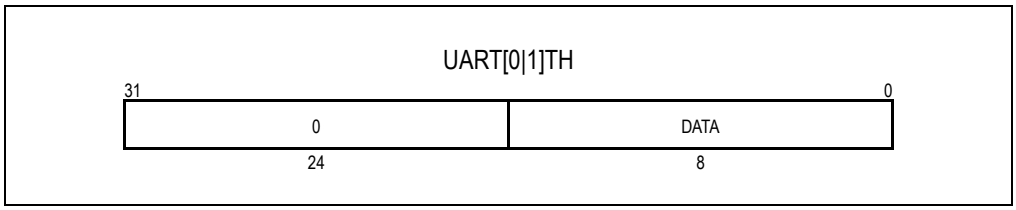


Figure 13.3 UART [0|1] Transmit Holding Register (UART[0|1]TH)

DATA

Description: **DATA.** Writing a byte to this field places the byte into the UART transmit buffer.

Initial Value: Undefined

Notes

Read Value: Write-only

Write Effect: Write byte into UART transmit buffer

Interrupt Enable Register

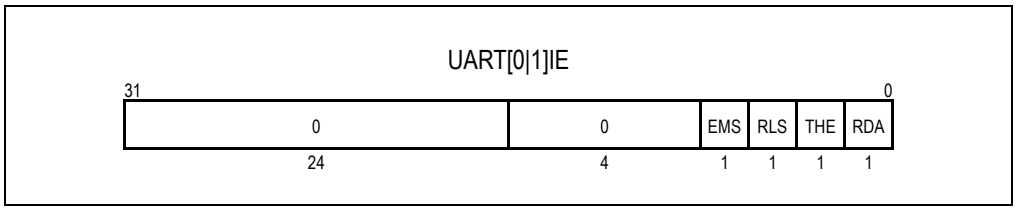


Figure 13.4 UART [0|1] Interrupt Enable Register (UART[0|1]IE)

RDA

Description: **Enable Receive Data Available Interrupt.** When set to 1, this bit enables receiver data available interrupts and time-out interrupts in FIFO mode.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

THE

Description: **Enable Transmitter Holding Register Empty Interrupt.** When set to 1, this bit enables transmitter holding register empty interrupts.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RLS

Description: **Enable Receiver Line Status Interrupt.** When set to 1, this bit enables receiver line status interrupts.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

EMS

Description: **Enable Modem Status Interrupt.** When set to 1, this bit enables modem status interrupts.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

Interrupt Identification Register

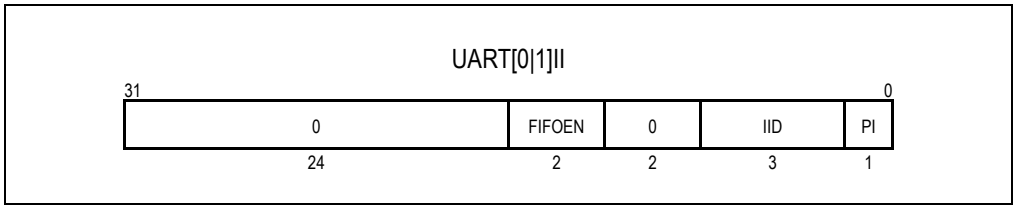


Figure 13.5 UART [0|1] Interrupt Identification Register (UART[0|1]II)

PI

Description: **Pending Interrupt.** When this bit is set to 1, no interrupt request is pending. When this bit is cleared, an interrupt request is pending.

Initial Value: 0x1

Read Value: Status

Write Effect: Read-only

IID

Description: **Interrupt ID.** These bits identify the highest priority pending interrupt.
0x0 **Modem Status**. Clear to send, data set ready, ring indicator or data carrier detect.
0x1 **Transmitter Holding Register Empty.** Writing to UARTxTH will reset this interrupt.
0x2 **Received Data Available.** RX data is available to read or the specified trigger level is reached. Reading either UARTxRB or if the buffer level drops below the trigger point resets the interrupt.
0x3 **Receiver Line Status**. Occurs during an overrun error, parity error, framing error or break interrupt. Reading UARTxLS resets the interrupt.
0x4 **Reserved**
0x5 **Reserved**
0x6 **Character Time-out Indication**. No characters have been removed from or input to the receiver buffer during the last four character times and there is at least 1 character in it during this time.
0x7 **Reserved**

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

FIFOEN

Description: **FIFO Enables.** These two bits are set when FIFO mode is enabled.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

Notes

FIFO Control Register

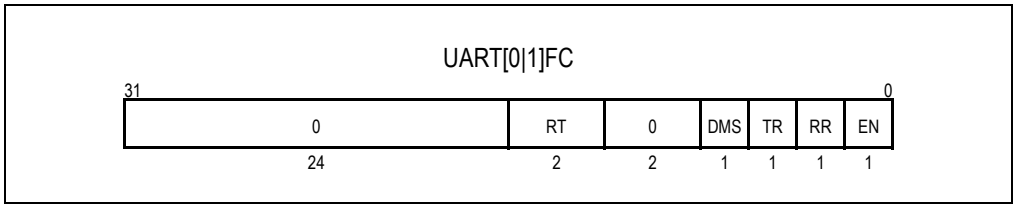


Figure 13.6 UART [0|1] FIFO Control Register (UART[0|1]FC)

EN

Description: **FIFO Enable.** When this bit is set, the transmit and receive FIFOs are enabled for 16550 mode. When switching between 16550 and 16450, always reset the buffers.

Initial Value: 0x0

Read Value: Write-only

Write Effect: Modify value

RR

Description: **Reset Receive FIFO.** Writing a 1 into this bit position resets the receive FIFO.

Initial Value: 0x0

Read Value: Write-only

Write Effect: Modify value

TR

Description: **Reset Transmit FIFO.** Writing a 1 into this bit position resets the transmit FIFO.

Initial Value: 0x0

Read Value: Write-only

Write Effect: Modify value

DMS

Description: **DMA Mode Select.** Writing a 1 into this bit position changes the DMA mode. The $\overline{\text{TXRDY}}$ and $\overline{\text{RXRDY}}$ signals of the 16550 go to the interrupt controller as an interrupt source. (Refer to industry standard 16550 UART specification.)[1]

Initial Value: 0x0

Read Value: Write-only

Write Effect: Modify value

RT

Description: **Receiver Trigger.** This field designates the interrupt trigger level. When the number of bytes in the receive FIFO equals the designated interrupt level, a receive data available interrupt is activated.
0x0 1-byte in the receive buffer
0x1 4-bytes in the receive buffer
0x2 8-bytes in the receive buffer
0x3 14-bytes in the receive buffer

Initial Value: 0x0

Notes

Read Value: Write-only

Write Effect: Modify value

1. *PC 16550D Dual Universal Asynchronous Receiver/Transmitter with FIFOs*, June 1995, National Semiconductor.

Line Control Register

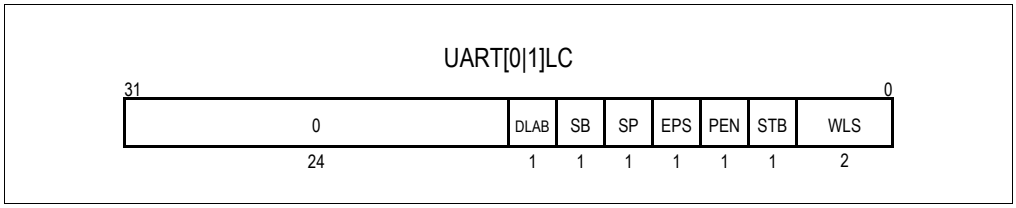


Figure 13.7 UART [0|1] Line Control Register (UART[0|1]LC)

WLS

Description: **Word Length Select.** This field specifies the number of data bits in transmit and receive serial characters.
0x0 5-bits
0x1 6-bits
0x2 7-bits
0x3 8-bits

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

STB

Description: **Number of Stop Bits.** This bit specifies the number of stop bits transmitted with each serial character.
0x0 One stop bit generated
0x1 5-bit word length: 1.5 stop bits generated. 6, 7 or 8-bit word length: 2 stop bits generated

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

PEN

Description: **Parity Enable.** When this bit is set to 1, parity is generated on transmit data and checked on receive data.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

EPS

Description: **Even Parity Select.** When parity is enabled and this bit is set to 1, an odd number of logic 1s is transmitted or checked. When parity is enabled and this bit is cleared, an even number of 1s is transmitted or checked.
0x1 even parity
0x0 odd parity

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

SP

Description: **Stick Parity.** When parity is enabled, this bit is used in conjunction with EPS to select Mark or Space parity.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SB

Description: **Set Break.** When this bit is set to 1, a break is transmitted.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DLAB

Description: **Divisor Latch Access Bit.** This bit must be set to access the divisor latches of the baud rate generator or the alternate functions register. When this bit is cleared, access to other registers is enabled.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Modem Control Register

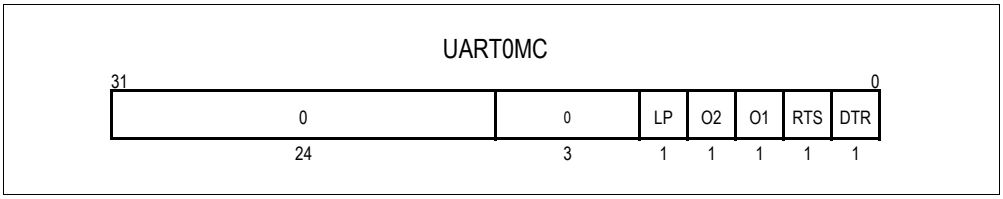


Figure 13.8 UART[0|1] Modem Control Register (UART0MC)

DTR

Description: **Data Terminal Ready.** When this bit is set to 1, the data terminal ready output (UxDTRN) is asserted.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RTS

Description: **Request To Send.** When this bit is set to 1, the request to send output (UxRTSN) is asserted.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

O1

Description: **Out 1.** In local loopback mode this bit controls bit 2 of the modem status register. No connection to pin.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

O2

Description: **Out 2.** In local loopback mode this bit controls bit 3 of the modem status register. No connection to pin.

Initial Value: 0x0

Read Value: Previous value written

LP

Description: **Loop.** This bit provides a local loopback feature for diagnostic testing of the associated serial channel.
0x0 loopback disabled
0x1 loopback enabled

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Line Status Register

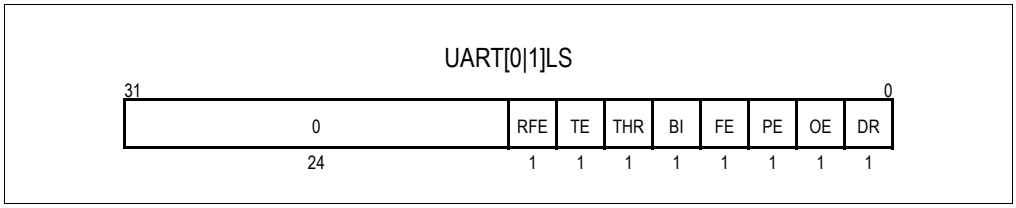


Figure 13.9 UART [0|1] Line Status Register (UART[0|1]LS)

DR

Description: **Data Ready.** This bit is set whenever a character has been received and may be read from the receive buffer.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

OE

Description: **Overrun Error.** This bit is set whenever a receiver overrun occurs.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

Notes

PE

Description: **Parity Error.** This bit is set when a character with incorrect parity is received.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

FE

Description: **Framing Error.** This bit is set whenever a received character does not have a valid stop bit.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

BI

Description: **Break Interrupt.** This bit is set when a break is received.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

THR

Description: **Transmitter Holding Register.** This bit is set to indicate that the serial channel is ready to accept a new character for transmission.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

TE

Description: **Transmitter Empty.** This bit is set when both the transmitter holding register and the transmitter shift register are empty.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

RFE

Description: **Receive FIFO Error.** This bit is set when there is a character with a parity error or a framing error, or there is a break indication in the FIFO.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

Notes

Modem Status Register

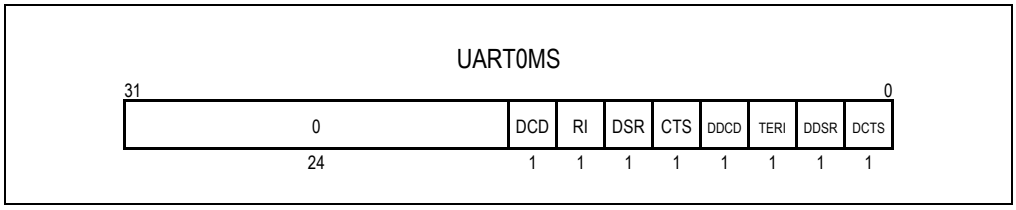


Figure 13.10 UART[0|1] Modem Status Register (UART0MS)

DCTS

Description: **Delta Clear to Send.** When this bit is set to 1, it indicates that the clear to send input has changed since the last time it was read by the CPU.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

DDSR

Description: **Delta Data Set Ready.** When this bit is set to 1, it indicates that the data set ready input has changed since the last time it was read by the CPU.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

TERI

Description: **Trailing Edge Ring Indicator.** This bit is set when the ring indicator input changes from a low to a high state.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

DDCD

Description: **Delta Data Carrier Detect.** When this bit is set to 1, it indicates that the data carrier detect input has changed since the last time it was read by the CPU.

Initial Value: Undefined

Read Value: Status

Write Effect: Modify value

CTS

Description: **Clear to Send.** This bit is the complement of the clear to send (UxCTSN) input.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

DSR

Description: **Data Set Ready.** This bit is the complement of the data set ready (UxDSRN) input.

Notes

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

RI

Description: **Ring Indicator.** The bit is the complement of the ring indicator (U0RIN) input for UART channel 0. UART channel 1 does not implement a ring indicator input. Thus, this field is undefined for UART channel 1.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

DCD

Description: **Data Carrier Detect.** This bit is the complement of the data carrier detect (U0DCRN) input for UART channel 0. UART channel 1 does not implement a data carrier detect input. Thus, this field is undefined for UART channel 1.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

Scratch Register

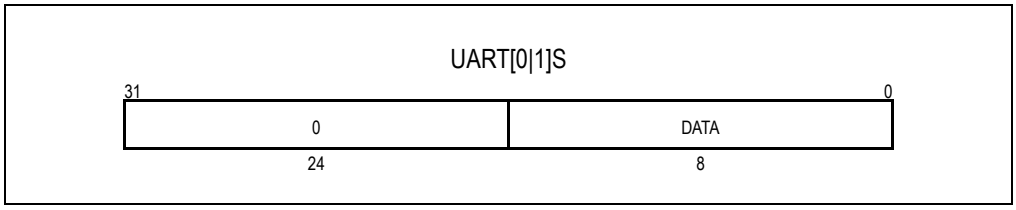


Figure 13.11 UART [0|1] Scratch Register (UART[0|1]S)

DATA

Description: **DATA.** This register may be used by the programmer to hold temporary data and does not control the serial channel in any way.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Divisor Latch Low Register

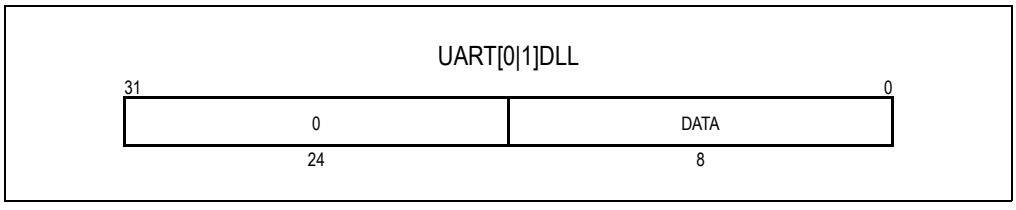


Figure 13.12 UART [0|1] Divisor Latch Low Register (UART[0|1]DLL)

Notes

DATA

Description: **DATA.** This field contains the lower 8-bits of the 16-bit baud rate divisor. See Table 13.3 for additional baud rate information.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Divisor Latch High Register

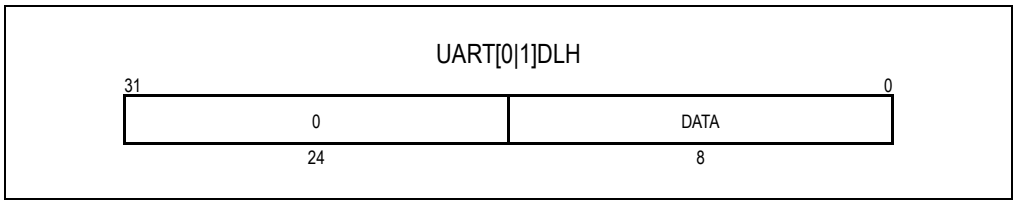


Figure 13.13 UART [0|1] Divisor Latch High Register (UART[0|1]DLH)

DATA

Description: **DATA.** This field contains the upper 8-bits of the 16-bit baud rate divisor. See Table 13.3 for additional baud rate information.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Notes

Counter/Timers

Notes

Functional Overview

The RC32438 contains three general purpose 32-bit counter/timers that operate at the IPBus clock (ICLK) frequency.

Each timer/counter is composed of three registers:

- The Count Register, which is a 32-bit register that holds the current value of timers. It is incremented on every clock ICLK clock cycle.
- The Compare Register, which is a 32-bit register that holds the value to which the count register is compared.
- The Control Register, which holds the status and control information of the counter.

Counter/Timers Register Description

Register Offset	Register Name	Register Function	Size
0x02_8000	COUNT0	Counter timer 0 count	32-bit
0x02_8004	COMPARE0	Counter timer 0 compare	32-bit
0x02_8008	CTC0	Counter timer 0 control	32-bit
0x02_800C	COUNT1	Counter timer 1 count	32-bit
0x02_8010	COMPARE1	Counter timer 1 compare	32-bit
0x02_8014	CTC1	Counter timer 1 control	32-bit
0x02_8018	COUNT2	Counter timer 2 count	32-bit
0x02_801C	COMPARE2	Counter timer 2 compare	32-bit
0x02_8020	CTC2	Counter timer 2 control	32-bit
0x02_8024	RCOUNT	Refresh timer count	32-bit
0x02_8028	RCOMPARE	Refresh timer compare	32-bit
0x02_802C	RTC	Refresh timer control	32-bit
0x02_8030 through 0x02_FFFF	Reserved		

Theory of Operation

A counter timer is enabled by setting the enable bit (EN) in the corresponding counter timer [0|1|2] control (CTC[0|1|2]) register. When this occurs, the counter timer begins incrementing its current counter timer count value with each IPBus (ICLK) clock cycle. The CPU may determine the current timer count value by reading the corresponding counter timer [0|1|2] count (COUNT[0|1|2]) register. Writing to this register modifies the counter timer count value. For normal operation, this register should be initialized to zero prior to enabling a counter timer.

Notes

When the counter timer count value matches the value in the corresponding counter timer [0|1|2] compare register (COMPARE[0|1|2]), the timer expires[1]. When this occurs: the time-out (TO) bit in CTCx register is set, the counter timer count value is reset to zero, and the counter begins incrementing at the master clock frequency. The TO bit is presented as an interrupt source to the interrupt controller. The operation of the timer/counter can be stopped at any time by writing 0 to the enable bit [EN].

Counter Timer [0|1|2] Count Register

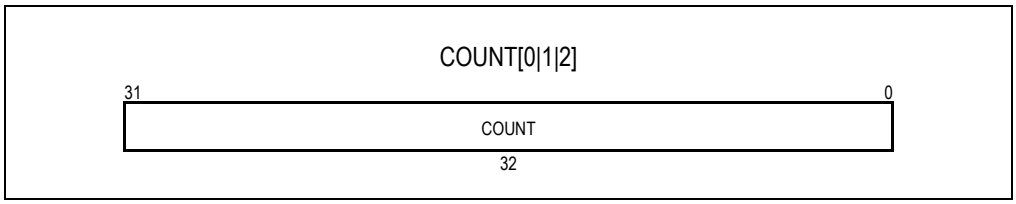


Figure 14.1 Counter Timer [0|1|2] Count Register (COUNT[0|1|2])

COUNT

Description: **Current Count.** This field contains the current counter timer count value.

Initial Value: 0x0000_0000

Read Value: Current counter timer count value

Write Effect: Set counter timer count value

Counter Timer [0|1|2] Compare Register

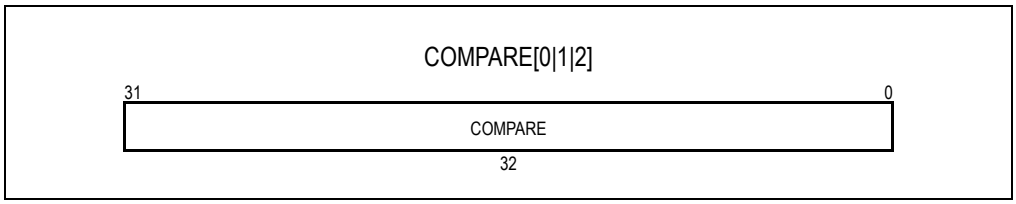


Figure 14.2 Counter Timer [0|1|2] Compare Register (COMPARE[0|1|2])

COMPARE

Description: **Compare Value.** This 32-bit field contains the maximum counter timer count value. When the value in the corresponding COUNTx register equals this value, the counter timer expires.

Initial Value: 0xFFFF_FFFF

Read Value: Previous value written

Write Effect: Modify value

[1] The counter timer expires at the point when the value in the COUNTx register first equals the value in the COMPAREx register (that is, COUNTx == COMPAREx) or when the counter timer is first enabled with COUNTx equal to COMPAREx.

Notes

Counter Timer [0|1|2] Control Register

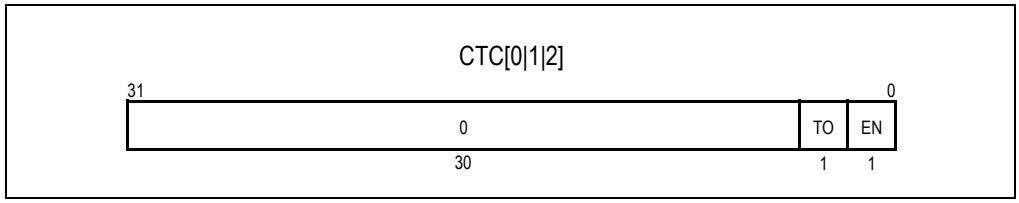


Figure 14.3 Counter Timer [0|1|2] Control Register (CTC[0|1|2])

EN

Description: **Enable.** When this bit is set the counter timer is enabled. Clearing this bit disables the counter timer. Neither enabling nor disabling the counter timer affects the counter timer count value.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TO

Description: **Time-out.** This bit is set to a one to indicate that the counter timer has expired. Once this bit is set, it will remain set until a zero is written into this field. Writing 0 to this value will to clear the source of the interrupt.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Notes

I²C Bus Interface

Notes

Introduction

This chapter describes the standard I²C bus interface that is implemented on the RC32438 device. The I²C bus interface allows the RC32438 device to connect to a number of standard external peripherals. The I²C implementation on the RC32438 device supports both master and slave operations, allowing it to be used in a variety of applications.

Features

- *Supports standard 100 kbps mode as well as 400 kbps fast mode*
- *Supports 7-bit and 10-bit addressing*
- *Supports four modes:*
  - *Master transmitter*
  - *Master receiver*
  - *Slave transmitter*
  - *Slave receiver*

Block Diagram

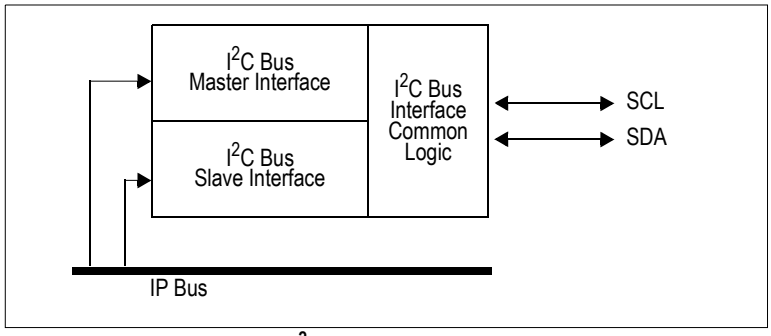


Figure 15.1 I²C Bus Interface Block Diagram

Functional Overview and Theory of Operation

The RC32438 contains an I²C bus interface and supports both master and slave modes.[1] Figure 15.1 shows a block diagram of the I²C bus interface. The interface has three major components:

- *I²C bus master interface*
- *I²C bus slave interface*
- *I²C bus interface common logic.*

The I²C bus interface connects to an external I²C bus using two pins: an I²C bus clock pin (SCL), and an I²C bus data pin (SDA). The I²C bus interface is controlled by the I²C bus control (I2CC) register. If the bus prescalar clock is running, setting the master enable (MEN) bit in this register enables the I²C bus master interface. Likewise, if the bus prescalar clock is running, setting the slave enable (SEN) bit enables the I²C bus slave interface.The I²C bus interface contains a 16-bit clock prescalar which is used to generate an

1. For a reference work on the I²C bus, see *The I²C-bus Specification, Version 2.0*, December 1998, Philips Semiconductor.

Notes

internal I^2C bus prescalar clock (I2CPCLK) that is used as a time base by the master and slave interfaces. The internally generated I^2C bus prescalar clock is equal to the IPBus clock input divided by the clock prescalar divisor (DIV) field in the I^2C bus clock prescalar (I2CCP) register.

The master and slave interfaces may be independently enabled and disabled at any point in time, allowing the interface to operate as an I^2C bus master, an I^2C bus slave, or concurrently as master and slave. When configured to operate concurrently as a master and slave, it is possible for the master interface to initiate transactions to the slave interface (that is, it is possible to perform loop-back operations).

A central part of the I^2C bus interface common logic is the I^2C bus data input (I2CDI) and I^2C bus data output (I2CDO) registers. The I2CDI register is used by both the master and slave interfaces to receive data from the I^2C bus. During the data phase of any I^2C bus operation, data present on the SDA pin is shifted into this register. Thus, at the end of each I^2C bus data transfer, this register contains the data byte present on the I^2C bus. Data to be driven onto the I^2C bus is written to I2CDO register by the CPU. During the data phase of an I^2C bus transmit operation, the contents of this register are shifted out a bit at a time on the SDA pin.

I^2C Register Description

Register Offset	Register Name	Register Function	Size
0x7_0000	I2CC	I^2C bus control	32-bit
0x7_0004	I2CDI	I^2C bus data input	32-bit
0x7_0008	I2CDO	I^2C bus data output	32-bit
0x7_000C	I2CCP	I^2C bus clock prescalar	32-bit
0x7_0010	I2CMCMD	I^2C bus master command	32-bit
0x7_0014	I2CMS	I^2C bus master status	32-bit
0x7_0018	I2CMSM	I^2C bus master status mask	32-bit
0x7_001C	I2CSS	I^2C bus slave status	32-bit
0x7_0020	I2CSSM	I^2C bus slave status mask	32-bit
0x7_0024	I2CSADDR	I^2C bus slave address	32-bit
0x7_0028	I2CSACK	I^2C bus slave acknowledge	32-bit
0x7_002C through 0x7_7FFF	Reserved		

Table 15.1 I2C Register Map

I^2C Bus Control Register

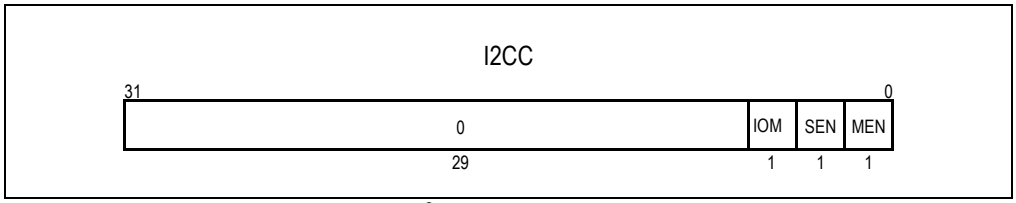


Figure 15.2 I^2C Bus Control Register (I2CC)

Notes

MEN

Description: **Master Enable.** When the bus prescalar clock is running and this bit is set, the I^2C bus master interface is enabled. When this bit is cleared, the I^2C bus master interface is disabled and all commands written to the I2CMCMD register are ignored. When disabled, the SLC and SDA pins are tri-stated by the I^2C bus master interface. Disabling and then enabling the master interface causes all logic associated with the master interface to be reset.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SEN

Description: **Slave Enable.** When the bus prescalar clock is running and this bit is set, the I^2C bus slave interface is enabled. When this bit is cleared, the slave is disabled. When disabled, the slave does not respond to any operations and the SLC and SDA pins are tri-stated. Disabling and then enabling the slave interface causes all logic associated with the slave interface to be reset.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IOM

Description: **Ignore Other Masters.** When this bit is set, the I^2C bus master interface will arbitrate for the I^2C bus but will assume that it always wins arbitration. This mode is used for testing and may be set in single master systems.
When this bit is cleared, the I^2C bus master will arbitrate for the I^2C bus, as outlined in *The I^2C-bus Specification, Version 2.0*, December 1998, Philips Semiconductor.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

I^2C Bus Data Input Register

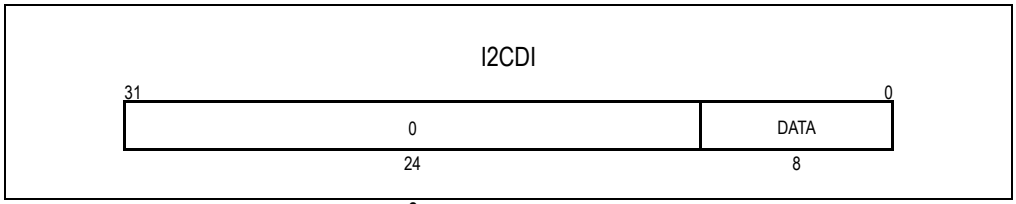


Figure 15.3 I^2C Bus Data Input Register (I2CDI)

DATA

Description: **Data.** This field is used to receive data from the I^2C bus and always contains the last byte present on the I^2C bus. The most significant bit of this field contains the first bit received from the I^2C bus.

Initial Value: Undefined

Notes

Read Value: Previous value received from I²C bus

Write Effect: Read-only

I²C Bus Data Output Register

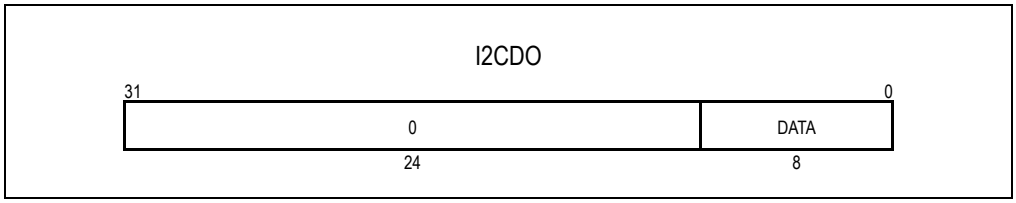


Figure 15.4 I²C Bus Data Output Register (I2CDO)

DATA

Description: **Data.** This field is used to transmit data onto the I²C bus. During I²C bus transmit operations the first bit to be transmitted is in the most significant bit of this field.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

I²C Bus Clock Prescalar

The I²C bus interface contains a 16-bit clock prescalar which is used to generate an internal I²C bus prescalar clock (I2CPCLK) that is used as a time base by the master and slave interfaces. The internally generated I²C bus prescalar clock is equal to the IPBus clock frequency (ICLK) divided by the clock prescalar divisor (DIV) field in the I²C bus clock prescalar (I2CCP) register. The generated clock may not be symmetric, but is guaranteed to meet I²C bus tolerances. The I²C bus prescalar clock is stopped and the master and slave interfaces are held in reset when the DIV field is set to zero or one.

The I²C bus interface operates at the I²C bus prescalar clock divided by eight. Therefore, the I²C data transfer rate may be calculated as follows:

I²C transfer rate = ICLK ÷ I2CCP ÷ 8

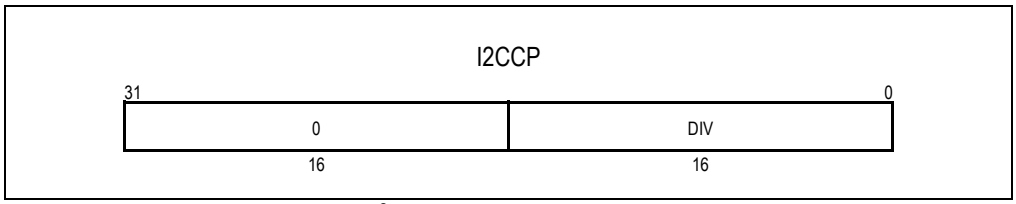


Figure 15.5 I²C Bus Clock Prescalar Register (I2CCP)

Notes

DIV

Description: **Clock Prescalar Divisor.** The internally generated I^2C bus prescalar clock is equal to the IPBus clock divided by the DIV field. The I^2C data transfer rate may be calculated as follows:

I2C transfer rate = IPBus clock frequency ÷ I2CCP ÷ 8

When the DIV field is equal to zero or one, the I^2C bus prescalar clock is stopped, and both the master and slave interfaces are held in reset. Starting or stopping the clock always occurs cleanly, but the clock may glitch when the period is modified. Therefore, the clock should be stopped before modifying the period.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

I^2C Bus Master Interface

The I^2C bus master interface operates by having the CPU issue commands to the I^2C bus master command (I2CMCMD) register and obtaining status from the I^2C bus master status register (I2CMS). All of the bits in the I2CMS register, which are not masked by the I^2C bus master status mask (I2CMSM) register, are ORed together and presented as the I^2C bus master interface interrupt. I^2C bus master commands are summarized in Table 15.2. Each command in this table consists of a simple action performed on the I^2C bus. Commands may be composed sequentially to perform complex I^2C bus transactions.

Command Encoding	Mnemonic	Description
0000	NOP	**No Operation**. Release I^2C bus and put master transmitter into idle state. When this command is issued the SDA and SCL signals are tri-stated. This command completes when a new command is written to the I2CMCMD register.
0001	START	**Start**. Wait for any alternate bus master transaction to complete, then generate a START condition on the I^2C bus. When this command completes the D bit is set. For more information on the D bit, refer to the I2C Bus Master Status Register section later in this chapter.
0010	STOP	**Stop**. Generate a STOP condition on the I^2C bus. When this command completes, the D bit is set. Unlike other commands which suspend the I^2C bus when the D bit is set, the completion of the STOP command sets the D bit but does not suspend the I^2C bus. The completion of the STOP command is automatically followed by a NOP command.
0011	Reserved	Same effect as NOP.
0100	RD	**Read Data**. Receive 8-bits of data from the I^2C bus and store it in the I2CDI register. When this command completes the D bit is set and the NA, LA, and ERR status bits are valid.
0101	RDACK	**Read Data and Acknowledge**. Receive 8-bits of data from the I^2C bus and store it in the I2CDI register. After data has been received, generate an acknowledge. When this command completes the D bit is set and the NA, LA, and ERR status bits are valid.

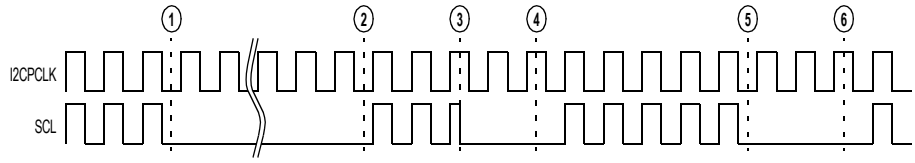
Table 15.2 I2C Bus Master Interface Commands (Part 1 of 2)

Notes

Command Encoding	Mnemonic	Description
0110	WD	**Write Data**. Transmit 8-bits of data from the I2CDO register onto the I^2C bus. When this command completes the D bit is set and the NA, LA, and ERR status bits are valid.
0111	WDACK	**Write Data and Acknowledge. (This command is for debug purposes only.)** Transmit 8-bits of data from the I2CDO register onto the I^2C bus. After the data has been transmitted, generate an acknowledge. When this command completes the D bit is set and the NA, LA, and ERR status bits are valid.
1000 through 1111	Reserved	Same effect as NOP.

Table 15.2 I2C Bus Master Interface Commands (Part 2 of 2)

The I^2C bus SCL and SDA signals are wired-AND, allowing the clock signal to be used as a synchronization mechanism. A device on the I^2C bus can slow down, or stop, the I^2C bus clock at any point by extending the low period of the clock. This can be done after each bit, or after a complete operation is performed. Thus, the speed of the master is automatically adapted to the operating rate of the slowest device. This is illustrated in Figure 15.6.



1. A slave becomes not-ready, so it pulls SCL low. Since SCL is wired-AND, it is held low as long as the slave is not-ready. The I^2C bus master is suspended.
2. Slave becomes ready and releases SCL. This allows the clock to progress.
3. A device may pull SCL low even before I2CPCLK (the internally generated I^2C bus prescalar clock) goes low. This may occur for example during I^2C bus arbitration when multiple masters drive the bus.
4. An external device can release SCL at any point. The master interface must make sure that "runt" clocks are not generated which have a period smaller than that programmed in the I2CCP register. This may mean that the master interface stretches the clock and waits for the next rising edge of I2CPCLK.
5. A slave becomes not-ready.
6. A slave becomes ready.

Figure 15.6 Using the I^2C Bus Clock (SCL) to Adapt the Operating Rate

When a command is written to the I2CMCMD register, the specified action is initiated on the I^2C bus. For commands other than NOP, this consists of generating the I^2C bus clock (SCL) and possibly driving the I^2C bus data pin (SDA). The completion of the command is signaled to the CPU by setting the done (D) bit in the I2CMS register. Depending on the command, other status bits in this register may also become valid. When the done bit is set, the master interface holds the SCL signal low, allowing the CPU core to respond to the received status information and issue the next command[1]. All of the status bits in the I2CMS register, including the done bit, are automatically cleared and SCL signal is released when a command is written to the I2CMCMD register.

The Read Data (RD), Read Data with Acknowledge (RDACK), Write Data (WD), and Write Data with Acknowledge (WDACK) commands all participate in I^2C bus arbitration. When one of these commands is issued, the master interface observes the state of SDA. Arbitration is lost when a master I^2C bus interfaces transmits a high value but observes a low value on the SDA signal. When this occurs the master I^2C bus

1. This is true for all commands except the STOP command. At the completion of the STOP command, the D bit is set, the I^2C bus is released by tri-stating the SDA and SCL signals, and the master goes into an idle state.

Notes

interface sets the lost arbitration (LA) and the done (D) bits in the I2CMS register and tri-states the SCL and SDA signals. The master interface does not automatically re-execute commands for which arbitration is lost; it is the responsibility of the software driver to notice that the LA bit is set and re-execute the command. Arbitration may be lost while executing the WD and WDACK commands when the 8-bit data quantity is driven on the bus, or during transmission of acknowledgment status. For the RD and RDACK commands, arbitration may only be lost during transmission of acknowledgment status. Arbitration is lost during the acknowledgment status phase of a command when the I^2C bus master reports not acknowledge (that is, a logic high) while another I^2C bus master reports an acknowledge (that is, a logic low).

At the completion of each RD, RDACK, WD, and WDACK command, the status of the acknowledgment is reported in the no acknowledge (NA) bit of the I2CMS register. The error (ERR) bit in the I2CMS register is set whenever an unexpected I^2C bus start or stop condition is detected during execution of a command by the I^2C bus master interface. When this occurs, the master interface immediately sets the D and ERR bits in the I2CMS register, and tri-states both the SCL and SDA signals.

Example I^2C Bus Transactions

This section illustrates how the I^2C bus master interface commands shown in Table 15.3 may be composed by the CPU to generate complete I^2C bus transactions. Table 15.3 shows abbreviations used by figures in this section.

Abbreviation	Explanation
S	Start condition
SLA7	7-bit slave address
SLA10	8-bits of 10-bit slave address
R	Read bit (high on SDA)
W	Write bit (low on SDA)
A	Acknowledge bit (low on SDA)
$\overline{A}$	Not acknowledge bit (high on SDA)
Data	8-bit data byte
P	Stop condition

Table 15.3 I^2C Bus Data Transfer Abbreviations

Figure 15.7 shows a master transmitter transaction to a slave with a 7-bit slave address. At the completion of the previous transaction issued by the master interface, or immediately following the enabling of the master interface, a NOP command was issued. This caused the master interface to tri-state the SCL and SDA signals. To begin a transaction, the CPU writes the START command to the I2CMCMD register. This causes the I^2C bus master interface to wait for any transaction in progress by an alternate bus master to complete, and for a start condition to be driven on the I^2C bus. Once the start condition has been generated, the command stops causing the D bit in the I2CMS register to be set and stops causing the master interface to suspend the I^2C bus by holding the SCL signal low until the next command is written to the I2CMCMD register.

Notes

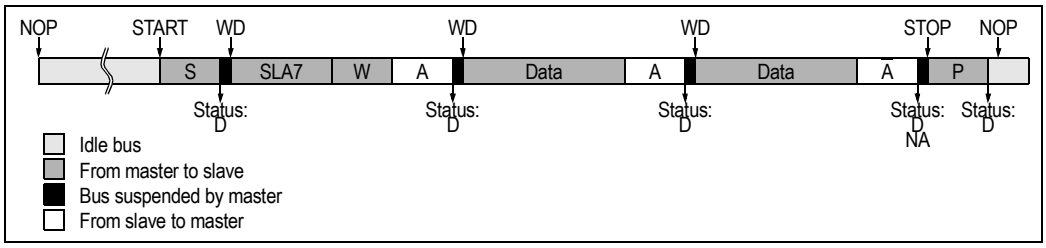


Figure 15.7 Master Operation: Master Transmitter Addressing a Slave Receiver (7-bit Address)

At the completion of the start command, the CPU initializes the I2CDO register with an 8-bit data quantity which consists of the 7-bit slave address and a read/write bit set to write. The CPU then writes the transfer data (WD) command to the I2CMCMD register. This causes the master interface to release the I^2C bus and drive the slave address and write bit onto the I^2C bus. The addressed slave device indicates that it can accept data by generating an acknowledge. At the completion of the WD command, the D bit is set in the I2CMS register and the master interface suspends the I^2C bus. In addition to the D bit being set, the I2CMS register contains additional status information. The NA bit is cleared if a slave generated an acknowledge. The LA bit is set if the master interface lost an arbitration with an alternate bus master. Finally, the ERR bit is set if an unexpected start or stop condition was detected on the I^2C bus during execution of the command.

Continuing the example shown in Figure 15.7, the CPU transmits data to the addressed slave by writing the 8-bit data quantity to be transmitted to the I2CDO register and issuing a WD command. At the completion of each command, the status bits in the I2CMS register become valid and the I^2C bus is suspended until the next command is issued. When the CPU wishes to end the transaction because it has no more data to transmit, or because no acknowledgment was observed, it issues a STOP command. This causes a stop condition to be driven on the I^2C bus. When the command completes, the done bit in the I2CMS register is set. At this point, the CPU may begin a new transaction.

Figure 15.8 shows a master receiver transaction to a slave with a 7-bit slave address. The transaction is similar to the master transmitter transaction shown in Figure 15.7 except that data is driven by the slave. To transfer data the CPU issues an RDACK command. This causes the master interface to issue clock pulses on the SCL signal and the slave transmitter to drive data on the SDA signal. The data driven by the slave transmitter is shifted into the I2CDI register. After the data has been transferred, the master interface generates an acknowledge. This completes the command, causing the D bit to be set, status information in the I2CS register to be valid, and the master interface to suspend the I^2C bus. The RDACK command will always cause the NA status bit to be cleared. The master interface signals the end of data to the slave transmitter by not generating an acknowledge. This is done by issuing an RD command rather than an RDACK command.

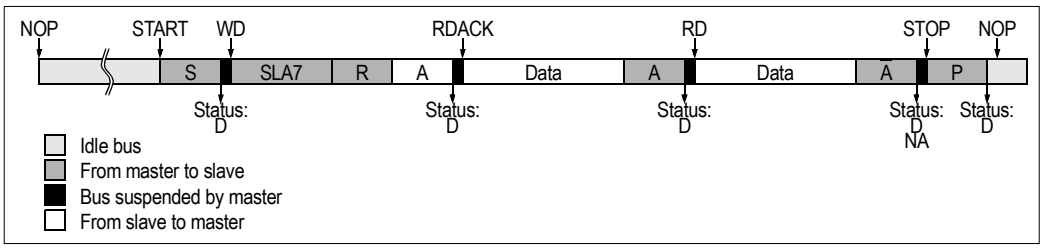


Figure 15.8 Master Operation: Master Receiver Addressing a Slave Transmitter (7-bit Address)

Notes

A repeated start condition allows a master to begin a new transaction on the I^2C bus without relinquishing control of the bus. Thus, rather than generating a stop condition at the end of a transaction, the master generates a start condition and addresses a slave. As shown in Figure 15.9, master interface commands may be composed to generate a repeated start condition.

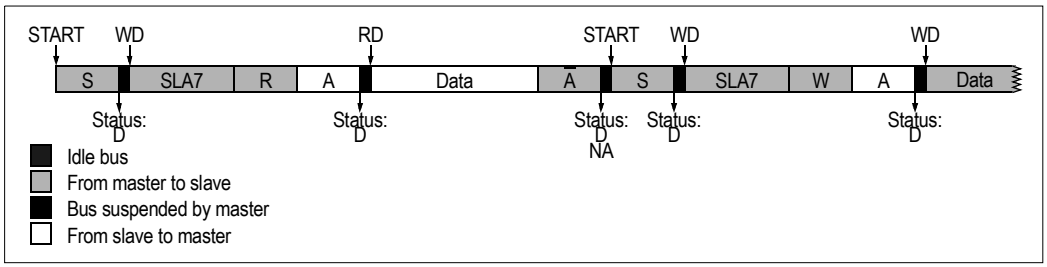


Figure 15.9 Master Operation: Master Interface Initiated Repeated Start Condition

The I^2C bus has been extended to support 10-bit slave addressing. As shown in Figure 15.10, the master interface commands listed in Table 15.2 may be used to address 10-bit slave devices. Following an initial START command, the CPU issues a WD command with the I2CDO register initialized with the bit address 0b11110XX and the read/write bit set to write. The X's in the address 0b11110XX represent the two high order bits of the 10-bit slave address. More than one slave may match this address, and may thus acknowledge the address. The CPU next issues a WD command, with the low order 8-bits of the 10-bit slave address. Only one slave will find a match and generate an acknowledge. At this point the CPU can write data to the addressed slave receiver. If the CPU wants to read data from a 10-bit slave receiver, it must issue a repeated START condition followed by a WD command with the slave address equal to 0b11110XX as before, but this time with the read/write bit set to read. The matching slave remembers that it was addressed before. This slave checks if the address after the repeated start condition is the same as in the previous transaction and tests if the read/write bit is set to read. If there is a match, the slave declares that it has been addressed as a 10-bit slave transmitter and generates an acknowledge. The CPU is then free to read from the slave using RDACK and RD commands as shown in Figure 15.8.

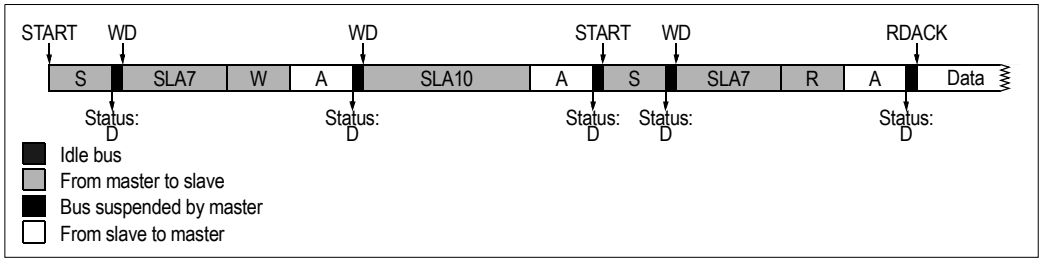


Figure 15.10 Master Operation: Addressing a 10-bit Slave as a Slave Transmitter

I^2C Bus Master Command Register

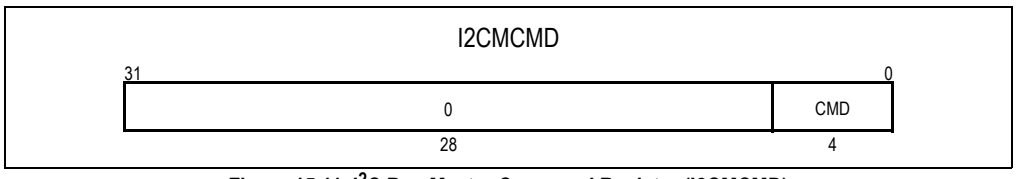


Figure 15.11 I^2C Bus Master Command Register (I2CMCMD)

Notes

CMD

Description: **Command.** When a value is written into this field, the corresponding command is initiated on the I^2C bus. Completion of the command is signalled when the done (D) bit in the I2CMS register is set.

Initial Value: 0x0 (NOP)

Read Value: Previous command

Write Effect: Initiate command on I^2C bus

I^2C Bus Master Status Register

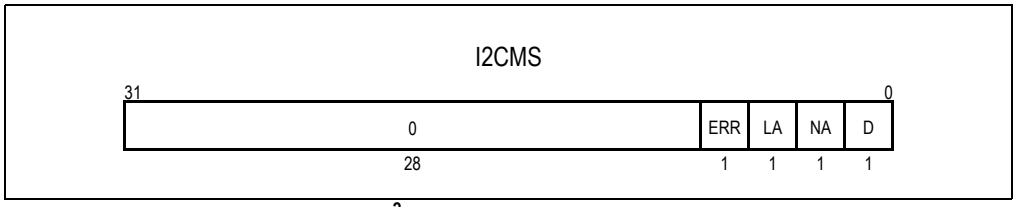


Figure 15.12 I^2C Bus Master Status Register (I2CMS)

D

Description: **Done.** This bit is set when the command written to the I2CMCMD register has been completed and the remaining status bits in this register are valid. At the completion of each command except stop, the I^2C bus SCL signal is held in a low state. This bit is automatically cleared when a command is written to the I2CMCMD register.

Initial Value: 0x0

Read Value: Status

Write Effect: Read-only

NA

Description: **No Acknowledge.** At the completion of each data transfer initiated by the I^2C bus master interface, if there was a “no acknowledge” signal, this bit is set to one. If there was an “acknowledge” signal, this bit is cleared to zero. The absence or presence of the acknowledge signal is recorded in this bit whether the acknowledge signal comes from the I^2C bus master interface or an external slave. This bit is automatically cleared when a command is written to the I2CMCMD register.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

LA

Description: **Lost Arbitration.** Arbitration takes place during each byte transmitted by the I^2C bus master interface. If the I^2C bus master interface transmits a HIGH level during a bit period while another master transmits a LOW level, then the I^2C bus master interface has lost arbitration. When this occurs, this bit is set and the I^2C bus master interface tri-states the SLC pin for the remainder of the byte transfer. This bit is automatically cleared when a command is written to the I2CMCMD register.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

Notes

ERR

Description: **Error.** This bit is set if a misplaced START or STOP condition is detected during execution of a command by the I^2C bus master interface. This bit is automatically cleared when a command is written to the I2CMCMD register.

Initial Value: Undefined

Read Value: Status

Write Effect: Read-only

I^2C Bus Master Status Mask Register

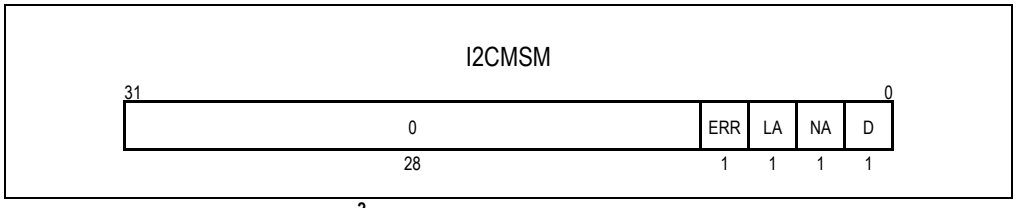


Figure 15.13 I^2C Bus Master Status Mask Register (I2CMSM)

D

Description: **Done.** When this bit is set, the D bit in the I2CMS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

NA

Description: **No Acknowledge.** When this bit is set, the NA bit in the I2CMS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

LA

Description: **Lost Arbitration.** When this bit is set, the LA bit in the I2CMS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

ERR

Description: **Error.** When this bit is set, the ERR bit in the I2CMS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

Notes

I²C Bus Slave Interface

The I²C bus slave interface operates by monitoring the state of the I²C bus and suspending the I²C bus clock at points where CPU intervention is required. Status is reported in the I²C bus slave status (I2CSS) register. All of the bits in this register which are not masked by the I²C bus slave status mask (I2CSSM) register are ORed together and presented to the interrupt controller as the I²C bus slave interface interrupt. The I²C bus is suspended by the slave interface when any of the following bits: read request (RR), write request (WR), or slave addressed (SA) bits in the I2CSS register are set. The slave interface releases the I²C bus when the these bits are cleared by the CPU.

The I²C bus slave acknowledge (I2CSACK) register controls how the slave interface responds during acknowledgment phases on the I²C bus. If the acknowledge (ACK) bit is set in this register and the slave is addressed, then the slave responds with an acknowledge during I²C bus acknowledgment phases. Otherwise, the slave tri-states the SDA pin during acknowledgment phases (that is, it issues a “no acknowledge”).

The I²C bus slave interface may be configured to operate with either a 7-bit or a 10-bit slave address. When the A10 bit is set in the I²C bus slave address (I2CSADDR) register, the slave interface operates using the 10-bit slave address in the address (ADDR) field of the I2CSADDR register. When the A10 bit is cleared, the slave interface operates using the address in the bottom 7-bits of the ADDR field. The general call enable (GCE) bit in the I2CSADDR register controls whether the slave interface responds to the I²C bus general call address. If the GCE bit is set, the slave interface responds to both the address in the ADDR field and the general call address. A general call address is one in which the 7-bit I²C bus address is bit address 0b0000000 and the read/write bit is set to write (that is, low). A general call transaction is similar to a master transmitter transaction in its operation.

An I²C bus master may generate start byte transactions to allow a microcontroller sampling at a slow sampling rate to detect a start condition A start byte transaction consists of a start condition followed by a 7-bit address equal to 0b0000000 and with the read/write bit set to read (that is, high). This is then followed by another start condition and a transaction with the address of the actual slave to be addressed. The I²C bus slave interface ignores all start byte transactions.

Example of I²C Bus Transaction

Figure 15.14 shows a master transmitter transaction with a 7-bit slave address issued to the slave interface. The master transmitter generates a start condition followed by the 7-bit address of the slave and the read/write bit set to write. The slave interface compares the address to the value in its ADDR field. If the address matches the bottom seven bits of this field and the A10 bit is cleared, then the slave interface is addressed. When this occurs, the slave interface suspends the I²C bus and sets the slave addressed (SA) bit in the I2CSS register. If the address on the I²C bus was the general call address and the GCE bit was set, then in addition to suspending the I²C bus and setting the SA bit, the slave interface sets the general call (GC) bit in the I2CSS register. The setting of the SA bit indicates to the CPU the beginning of an I²C bus transaction addressed to the slave interface. The CPU may examine the address and read/write bit driven by the master by reading the I2CDI register. If the CPU wishes to acknowledge that it has been addressed, it sets the ACK bit in the I2CSACK register. When the CPU clears the SA bit it releases the I²C bus and allows the transaction to progress.

Notes

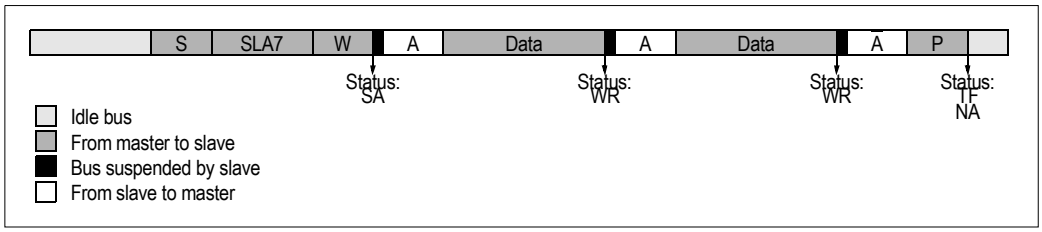


Figure 15.14 Slave Operation: Master Transmitter Addressing a Slave Receiver (7-bit Address)

The master transmitter then drives the 8-bit data quantity to be transmitted on the I^2C bus. At the completion of the data transfer, the write request (WR) bit in the I2CSS is set and the slave interface once again suspends the I^2C bus. The NA bit will be cleared to indicate that an acknowledge was observed in the previous acknowledgment phase in which the slave interface was addressed. The CPU may read the value transmitted by the master by reading the I2CDI register. If the CPU wishes to acknowledge the data transfer, it sets the ACK bit in the I2CSACK register. When the CPU clears the WR bit it releases the I^2C bus and allows the transaction to progress.

The master transmitter completes a transaction by generating a stop or repeated start condition. When this occurs while the slave is addressed, the transaction finished (TF) bit in the I2CSS register is set. This indicates to the CPU that the current transaction has completed. If an unexpected start or stop condition is detected by the slave interface while it is addressed, then the error (ERR) bit in the I2CSS register is set along with the TF bit thus aborting the current transaction.

Figure 15.15 shows a master receiver transaction with a 7-bit slave address issued to the slave interface. After acknowledgment of the save address, the slave interface suspends the I^2C bus and sets the read request (RR) bit in the I2CSS register. In response to this bit being set, the CPU writes the 8-bit quantity to be transmitted to the master into the I2CDO register and clears the RR bit. This releases the I^2C bus and allows the data transfer to progress. At the completion of the data transfer the I^2C bus is once again suspended and the RR bit is set. The acknowledgment status from the master transmitter during the previous data transfer is reported in the NA bit. If the NA bit is cleared and RR bit is set, the CPU writes the next 8-bit quantity to be transmitted into the I2CDO register and clears the RR bit allowing the transfer to progress. Otherwise, if the NA bit is set, the master receiver did not acknowledge the previous data transfer. This indicates the end of data transfer to the slave. The CPU clears the NA and RR bits allowing the master receiver to generate a stop or repeated start condition. After the stop or repeated start condition, the TF bit is set. This indicates to the CPU that the transaction has completed.

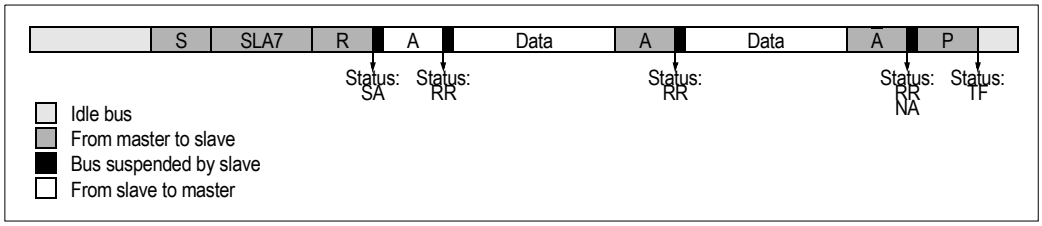


Figure 15.15 Slave Operation: Master Receiver Addressing a Slave Transmitter (7-bit Address)

Figure 15.16 shows a master receiver transaction to the slave interface using a 10-bit slave address. The master first generates a start condition followed by a bit address of 0b11110XX and the read/write bit set to write. The X's in the bit address 0b11110XX represent the high order two bits of the 10-bit slave address. If the A10 bit is set, the slave interface compares the value in the X's to the high order two bits of the ADDR field. If they match, the slave interface automatically generates an acknowledge. The master

Notes

then transmits the remaining 8-bits of the 10-bit slave address. If these 8-bits match the bottom 8-bits of the ADDR field, then the slave interface suspends the I^2C bus and sets the SA bit. At this point the slave is addressed as a slave receiver and the master may write data to the slave interface using the same mechanism as shown in Figure 15.14 for slaves with 7-bit addresses. If the master wishes to read data from a 10-bit slave, it must issue a repeated start condition followed by the same address 0b11110XX as before, but this time with the read/write bit set to read. The slave interface remembers that it was addressed in the previous transaction. It checks if the address after the repeated start condition is the same as it was in the previous transaction and tests if the read/write bit is set to read. If there is a match, the slave interface is addressed as a slave transmitter. It suspends the I^2C bus and set the SA bit. From this point on the transaction is the same as that shown in Figure 15.15 for a slave transmitter with a 7-bit address.

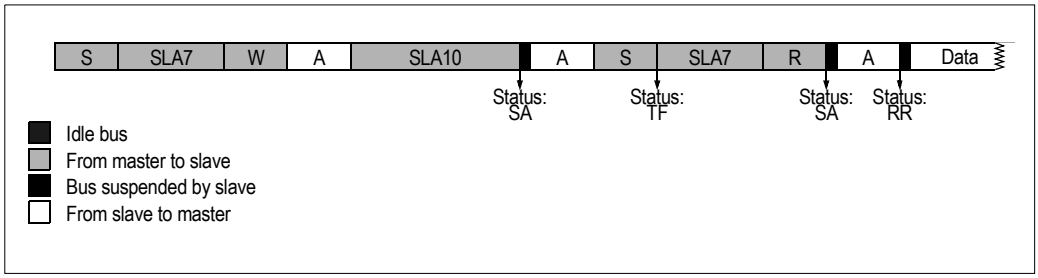


Figure 15.16 Slave Operation: Addressing a 10-bit Slave as a Slave Transmitter

I^2C Bus Slave Status Register

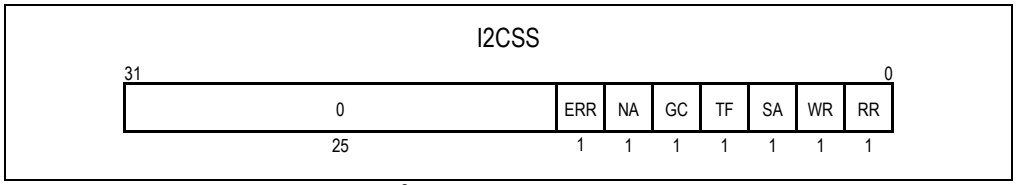


Figure 15.17 I^2C Bus Slave Status Register (I2CSS)

RR

Description: **Read Request.** This bit is set when a master initiates a read request of an 8-bit data quantity from the slave interface. The value to be returned to the master is written to the I2CDO register and this bit cleared. Clearing the RR bit causes the slave interface to release the I^2C bus.

Initial Value: Undefined

Read Value: Status

Write Effect: Clear to release I^2C bus

WR

Description: **Write Request.** This bit is set when a master initiates a write request of an 8-bit data quantity to the slave interface. The value transmitted by the master is written to the I2CDI register. Once the value has been read by the CPU the WR bit is cleared. Clearing this bit causes the slave interface to release the I^2C bus.

Initial Value: Undefined

Read Value: Status

Write Effect: Clear to release I^2C bus

Notes

SA

Description: **Slave Addressed.** This bit is set when the slave interface determines that it has been addressed by an I^2C bus master. This occurs when an address on the I^2C bus matches that in the I2CSADDR register, or when the general call address (zero) is observed and the GCE bit is set in the I2CSADDR register. Clearing this bit causes the slave interface to release the I^2C bus.

Initial Value: Undefined

Read Value: Status

Write Effect: Clear to release I^2C bus

TF

Description: **Transaction Finished.** This bit is set when the slave interface determines that it is no longer addressed by an I^2C bus master. This occurs as the result of a stop or repeated start condition.

Initial Value: Undefined

Read Value: Status

Write Effect: Clear to release I^2C bus

GC

Description: **General Call.** This bit is set when the slave interface observes a general call address on the I^2C bus and the GCE bit in the I2CSADDR register is set.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

NA

Description: **No Acknowledge.** This bit reflects the state of the acknowledgment signal driven during the previous I^2C bus acknowledge phase in which the slave interface was addressed (that is, it reflects the value of the ACK on the wire).

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

ERR

Description: **Error.** This bit is set when a start or stop condition is detected in an illegal position during a I^2C bus transaction in which the slave interface is addressed.

Initial Value: Undefined

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

I^2C Bus Slave Status Mask Register

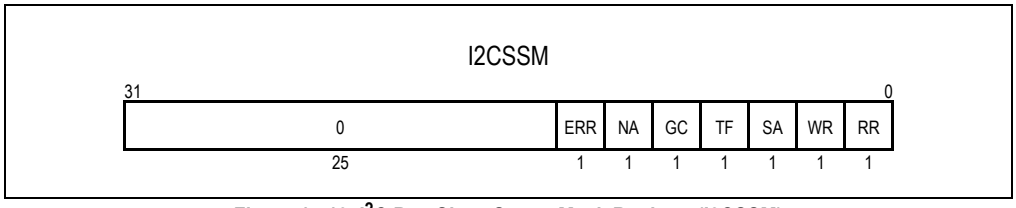


Figure 15.18 I^2C Bus Slave Status Mask Register (I2CSSM)

Notes

RR

Description: **Read Request.** When this bit is set to 1, the RR bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

WR

Description: **Write Request.** When this bit is set to 1, the WR bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

SA

Description: **Slave Addressed.** When this bit is set to 1, the SA bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

TF

Description: **Transaction Finished.** When this bit is set to 1, the TF bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

GC

Description: **General Call.** When this bit is set to 1, the GC bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

NA

Description: **No Acknowledge.** When this bit is set to 1, the NA bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

Notes

ERR

Description: **Error.** When this bit is set to 1, the ERR bit in the I2CSS register is masked from generating an interrupt.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

I²C Bus Slave Address Register

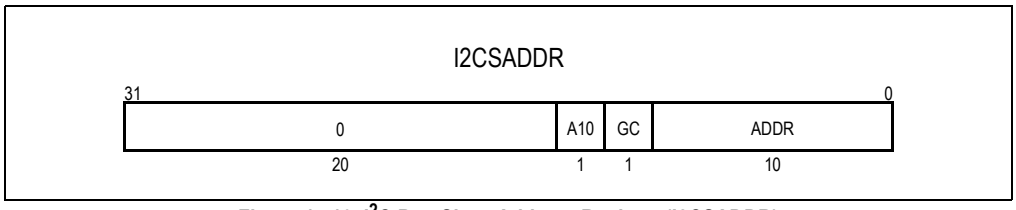


Figure 15.19 I²C Bus Slave Address Register (I2CSADDR)

ADDR

Description: **Slave Address.** This field contains the address of the I²C bus slave interface. When the A10 bit is set to 1, the slave interface is configured for a 10-bit address equal to the value in this field. When the A10 bit is cleared, the slave interface is configured for a 7-bit address equal to the value in the bottom seven bits of this field.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

GC

Description: **General Call.** When this bit is set to 1, the general call address (0x00) is recognized by the slave; otherwise it is ignored.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

A10

Description: **10-bit Slave Address.** When this bit is set to 1, the slave interface is configured to use 10-bit addressing. In this mode, the ten bit ADDR field contains the address of the slave. When this bit is cleared, the slave interface is configured to use 7-bit addressing. In this mode, the bottom seven bits of the ADDR field contains the address of the slave.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Notes

I²C Bus Slave Acknowledge Register

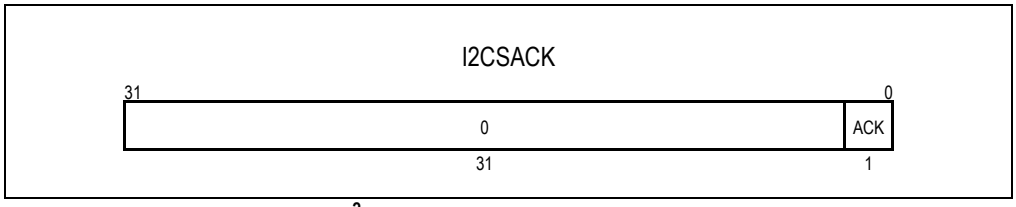


Figure 15.20 I²C Bus Slave Acknowledge Register (I2CSACK)

ACK

Description: **Acknowledge.** When this bit is set to 1, the slave interface returns an acknowledge during the next I²C bus acknowledge phase in which the slave interface is addressed. When this bit is cleared, the slave interface returns a not acknowledge during the next I2C bus acknowledge phase in which the slave interface is addressed.

Initial Value: Undefined

Read Value: Previous value written

Write Effect: Modify value

Programming Example

Disclaimer: Code examples provided by IDT are for illustrative purposes only and should not be relied upon for developing applications. IDT does not assume liability for any loss or damage that may result from the use of this code.

```
/*
** This is an example to read/write an I2C EEPROM
** using the RC32438 as a master and I2C EEPROM as
** a slave.(MICROCHIP 24AA64/24LC64)
**
** NOTE: Every single variable used is not defined
** here. The emphasis is to get the hardware bit
** setting and the program flow across, and not the
** programming language syntax. The hardware register
** address and values are defined in the following
** header files as are the used C data structures. These
** header files can be obtained from IDT.
*/
#include "s364-355.h"
#include "i2c.h"

unsigned int master_done;
unsigned int slave_done;

unsigned int num_master_data_bytes_txd;
unsigned int num_master_data_bytes_rxd;
```

Notes

```
unsigned int num_master_done_ints;
unsigned int num_master_lost_arb_ints;
unsigned int num_master_err_ints;
unsigned int num_acks;
unsigned int num_naks;

void i2c_master_isr(void);

//////////////////////////////////////////////////////////////////////
//
// Handler for Master ISR
//
//////////////////////////////////////////////////////////////////////

void i2c_master_isr (void)
{
  unsigned int master_status;
  volatile unsigned char temp;
  printf("\nM ISR - \n");

  // Read the Master Status Regs
  master_status = i2c.i2cms;

  if (master_status & I2CMS_ERR) {
    num_master_err_ints++;
    printf("\nI2C Master ERR Detected!\n");
  }

  if (master_status & I2CMS_D) {
    num_master_done_ints++;
  }
  if (master_status & I2CMS_LA) {
    num_master_lost_arb_ints++;
    printf ("\nI2C Master LA Detected!\n");
  }

  // Master is done with the current operation.
  switch (master.state) {
  case MASTER_IDLE:
    // No need to do anything...
    break;

  case MASTER_START:
    // DONE sending START, begin sending address
```

Notes

```
  printf (" START DONE");
  i2c.i2cdo = master.dest_addr[0];
  i2c.i2cmcmd = I2CMCMD_CMD(WD);
  master.state = MASTER_ADDR;
  break;

 case MASTER_ADDR:
  printf (" ADDR DONE");
  // Count ACKs & NAKs - note, an ACK occurs when the ACK bit is cleared
  // (Because SDA is driven low)
  if (!(master_status & I2CMS_ACK))
    num_acks++;
  else
    num_naks++;

  if (master_status & I2CMS_ACK) {
    // No Slave Acknowledged the Address byte, so generate STOP if desired
    if (master.stop_when_done) {
      i2c.i2cmcmd = I2CMCMD_CMD(STOP);
      master.state = MASTER_STOP;
    }
    else {
      // No STOP desired, so go to IDLE and set global variable
      master.state = MASTER_IDLE;
      master_done = TRUE;
      // Mask ALL Master Interrupts
      i2c.i2cmsm = 0xFFFFFFFF;
    }
    break;
  }
  if (master.data_len == 0) {
    // Data Length is zero, so skip Write / Read Stage
    if (master.stop_when_done) {
      i2c.i2cmcmd = I2CMCMD_CMD(STOP);
      master.state = MASTER_STOP;
    }
    else {
      // No STOP desired, so go to IDLE and set global variable
      master.state = MASTER_IDLE;
      master_done = TRUE;
```

Notes

```
        // Mask ALL Master Interrupts
        i2c.i2cmsm = 0xFFFFFFFF;
      }
      break;
    }
    if (master.transfer_type == MASTER_WRITE) {
      // DONE sending address, now send data
      master.state = MASTER_WRITE_DATA;
      num_master_data_bytes_txd++;
      i2c.i2cdo =  *master.data_ptr++;
      i2c.i2cmcmd = I2CMCMD_CMD(WD);
    }
    else {
      // DONE sending address, now read data
      master.state = MASTER_READ_DATA;
      if (num_master_data_bytes_rxd == (master.data_len - 1)) {
        // Almost done reading data, now send RD (not RDACK!)
        i2c.i2cmcmd = I2CMCMD_CMD(RD);
      }

      else {
        // Read Another Data Byte (And ACK)
        i2c.i2cmcmd = I2CMCMD_CMD(RDACK);
      }
      num_master_data_bytes_rxd++;
    }

    break;
  case MASTER_WRITE_DATA:
    printf(" WD DONE");
    // Count ACKs & NAKs - note, an ACK occurs when the ACK bit is cleared
    // (Because SDA is driven low)
    if (!(master_status & I2CMS_ACK))
      num_acks++;
    else
      num_naks++;
    if (num_master_data_bytes_txd >= master.data_len) {

      // done sending data, now send STOP if desired.
      if (master.stop_when_done) {
        i2c.i2cmcmd = I2CMCMD_CMD(STOP);
```

Notes

```
        master.state = MASTER_STOP;
      }
      else {
        // No STOP desired, so go to IDLE and set global variable
        master.state = MASTER_IDLE;
        master_done = TRUE;
        // Mask ALL Master Interrupts
        i2c.i2cmsm = 0xFFFFFFFF;
      }
    }
    else {
      // Send next data byte
      i2c.i2cdo = *master.data_ptr++;
      i2c.i2cmcmd = I2CMCMD_CMD(WD);
      num_master_data_bytes_txd++;
    }
    break;

  case MASTER_READ_DATA:
    // Write Incoming Read data to buffer
    printf(" RD DONE");

    *master.data_ptr = (unsigned char)i2c.i2cdi;

    master.data_ptr++;
    // Count ACKs & NAKs - note, an ACK occurs when the ACK bit is cleared
    // (Because SDA is driven low)
    if (!(master_status & I2CMS_ACK))
      num_acks++;
    else
      num_naks++;

    if (num_master_data_bytes_rxd >= master.data_len) {
      // done sending data, now send STOP if desired.
      if (master.stop_when_done) {
        i2c.i2cmcmd = I2CMCMD_CMD(STOP);
        master.state = MASTER_STOP;
      }
      else {
        // No STOP desired, so go to IDLE and set global variable
        master.state = MASTER_IDLE;
```

Notes

```
        master_done = TRUE;
        // Mask ALL Master Interrupts
        i2c.i2cmsm = 0xFFFFFFFF;
       }

     }
     else      // Almost done reading data, now send RD (not RDACK!)
      if (num_master_data_bytes_rxd == (master.data_len - 1)) {
        // Almost done reading data, now send RD (not RDACK!)
        i2c.i2cmcmd = I2CMCMD_CMD(RD);
       }
       else {
        // Read Another Data Byte (And ACK)
        i2c.i2cmcmd = I2CMCMD_CMD(RDACK);
       }

     num_master_data_bytes_rxd++;
     break;
   case MASTER_STOP:
     // Done with packet, set global variable, write NOP command, and go to idle
     printf(" STOP DONE");
     // Mask ALL Master Interrupts
     i2c.i2cmsm = 0xFFFFFFFF;
     master.state = MASTER_IDLE;
     master_done = TRUE;
     i2c.i2cmcmd = I2CMCMD_CMD(NOP);
     break;

   default:
     printf ("\nErr in Default\n");
     break;
   }
}

void perform_rd_wr_eeprom (unsigned int transfer_type,
   unsigned int num_data_bytes,
   unsigned int dest_addr,
   unsigned int stop_when_done,
   )
{
  master.stop_when_done = stop_when_done;
```

Notes

```
num_master_data_bytes_txd = 0;
num_master_data_bytes_rxd = 0;
master.data_len = num_data_bytes;
master_done = FALSE;
master.transfer_type = transfer_type;
master.state = MASTER_IDLE;
master_done = FALSE;
if (transfer_type == MASTER_WRITE)
  // Master Write
  master.dest_addr[0] = (unsigned char)((dest_addr & 0x7F) << 1);
else
  // Master Read

  master.dest_addr[0] = (unsigned char)(((dest_addr & 0x7F) << 1) | 0x1);
// Initialize Slave Address / Slave Control Bits
i2c.i2csaddr = 0x30;
// Initialize Slave Ack Register
i2c.i2csack = I2CSACK_ACK;
// Update Master State
master.state = MASTER_START;

// Kickoff Master Operation by Writing Command START to command reg.
i2c.i2cmcmd = I2CMCMD_CMD(START);
printf("Start read I2C ");
while (1) {
  if (master_done)
    break;

  // using polling!

  if((i2c.i2cms &~I2CMS_ACK) != 0)

    i2c_master_isr();
 }
}

//////////////////////////////////////////////////////////////////////////
//
//      START
//
//////////////////////////////////////////////////////////////////////////

main()
```

Notes

```
{
  unsigned int i;
  unsigned int slave_addr;
  unsigned int dest_addr;
  unsigned int divisor;
  unsigned int num_data_bytes;
  unsigned char data[1024];
  unsigned int prescaler_value;

  // Enable Master & Slave interfaces
  i2c.i2cc = I2CC_MEN;

  // Make sure to mask all unused bits.
  // Prescalar value is programmed for 800KHz clock.
  prescaler_value = 84;
  i2c.i2ccp = prescaler_value;
  //I2C Bus Master status Mask register is masked
  //from generating an interrrupt.
  i2c.i2cmsm = 0xF;

  //slave address is set here.
  slave_addr = 0x30;
  //I2C bus slave is masked from generating interrupt.
  i2c.i2cssm = 0x7F;
  num_data_bytes = 8;
  // The 1st and 2nd data byte is set to the address
  // where data is located within the I2C NVRAM.
  data[0] = 0;
  data[1] = 0;
  for (i = 2; i<8; i++)
    {
      data[i] = 0x33;
    }

  master.data_ptr = data;
  printf("\nWrite:");
  perform_rd_wr_eeprom (MASTER_WRITE,
// Trans. Type
num_data_bytes,
// # Data Bytes
slave_addr,
```

Notes

```
// Dest. Addr.
TRUE,
// Gen. STOP when done ?
);

  //  This write is performed to set the address
  //  within I2C NVRAM TO DO RANDOM READ.
  //  The 1st and 2nd byte is the address from where you
  //  want to read within the I2c EEPROM.

  data[0] = 0;
  data[1] = 0;
  master.data_ptr = data;
  num_data_bytes = 2;
  printf("\nWrite:");
  perform_rd_wr_eeprom (MASTER_WRITE,
// Trans. Type
num_data_bytes,
// # Data Bytes
slave_addr,
// Dest. Addr.
FALSE,
// Gen. STOP when done ?
);

  // Initialize Data
  for (i = 0; i<8; i++)
    {
      data[i] = 0x0;
    }

  master.data_ptr = data;
  num_data_bytes = 6;
  printf("\nRead /RDACK:");
  perform_rd_wr_eeprom (MASTER_READ,
// Trans. Type
num_data_bytes,
// # Data Bytes
slave_addr,
// Dest. Addr.
TRUE,
```

Notes

```
);
  for (i=0; i<6; i++){
    if (data[i] != 0x33){
      printf("\nDATA FAILED  location is %d data is %x\n", i, data[i]);
    }
  }
}
```

Notes

Serial Peripheral Interface

Notes

Introduction

The Serial Peripheral Interface (SPI) included on the RC32438 device supports an SPI master interface allowing it to interface to low-cost SPI peripherals and memory. The SPI interface connects to an external SPI device using three signals:

- *SDO (Serial Data Output)*
- *SDI (Serial Data Input)*
- *SCK (Serial clock)*

Additional SPI functions, such as chip select and write protect, must be implemented by allocating a GPIO pin for this purpose and managing the GPIO pin's behavior in software.

Block Diagram

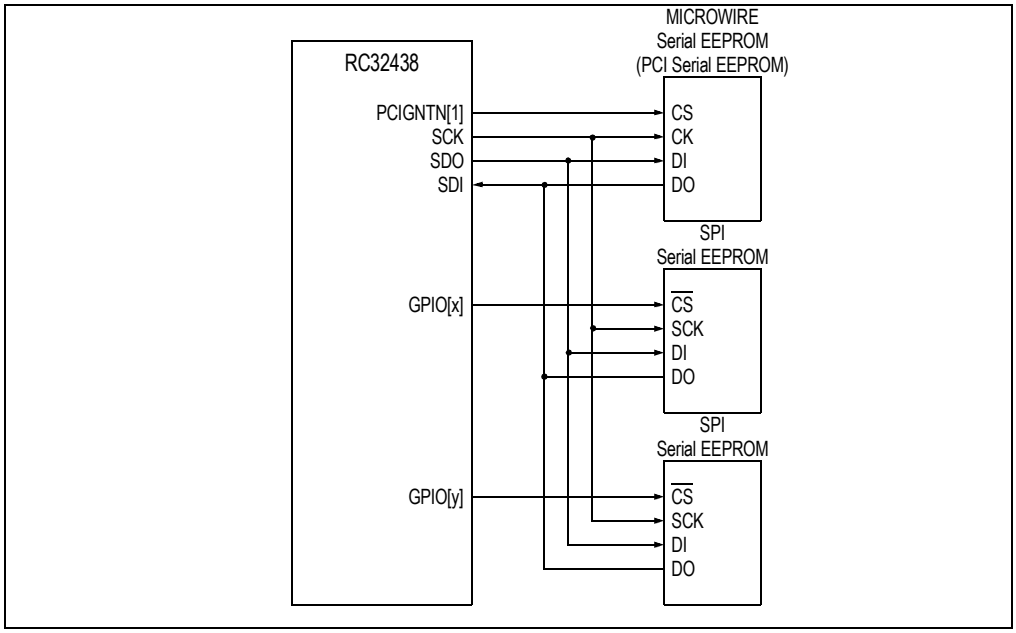


Figure 16.1 SPI and PCI Serial EEPROMs Interfacing

Notes

SPI Register Description

Register Offset	Register Name	Register Function	Size
0x07_8000	SPCP	SPI clock prescalar	32-bit
0x07_8004	SPC	SPI control	32-bit
0x07_8008	SPS	SPI status	32-bit
0x07_800C	SPD	SPI data	32-bit
0x07_8010	SIOFUNC	Serial I/O function	32-bit
0x07_8014	SIOCFG	Serial I/O configuration	32-bit
0x07_8018	SIOD	Serial I/O data	32-bit
0x07_801C through 0x07_FFFF	Reserved		

Table 16.1 SPI Register Map

Functional Overview

PCI serial EEPROM and SPI interface share common clock (SCK), data input (SDI), and data output (SDO) pins. The behavior of these pins is different depending on the mode of operation. In addition to operating in its own mode, the SPI interface can also operate in PCI serial EEPROM mode. When the PCI block is not in use, a PCI input clock must be provided for the SPI interface to work correctly. The PCI serial EEPROM and SPI interface share the same pins, and the pins default to the PCI serial EEPROM mode. For the SPI to function, the PCI block must release these pins but cannot if there is no PCI input clock. If the PCI is not in use, it is acceptable to clock the PCI interface with the same clock being used for the CPU, the Ethernet clock, or any other clock in the system, provided that such a clock is operating at a frequency of 66MHz or less.

PCI Serial EEPROM Mode (Microwire)

When the PCI interface is configured to operate in PCI satellite mode with suspended CPU execution, the PCI interface drives the SCK and the SDO pins using the National Semiconductor MICROWIRE™ serial protocol to read PCI configuration information from the PCI serial EEPROM. Data is read in on the SDI pin.

In this mode, the interface only supports 93C46-compatible MICROWIRE™ serial EEPROMs. The PCI Serial EEPROM done bit (EED) in the PCIS register is set when the loading of configuration information has been completed and the Serial I/O signals have been released. Only EEPROMs which are 2048-bits in size should be used.

The chip select signal for the PCI serial EEPROM is active high. PCIGNTN[1] behaves as the PCI serial EEPROM chip select when the PCI interface operates in PCI satellite mode with suspended CPU execution. Initially, the PCIGNTN[1] signal is driven low following a reset. The signal is driven high when the PCI interface begins reading configuration information.

When the PCI interface completes reading configuration information from the PCI serial EEPROM, it tri-states the SCK and SDO pins and drives PCIGNTN[1] low (i.e., it negates the chip select). This allows the SCK, SDO, and SDI pins to be used by the SPI Interface.

After a reset, the SPI interface is initially disabled. When the PCI interface completes reading configuration information from the PCI serial EEPROM, the SPI interface may be enabled by setting the SPE bit in the SPI control register. The SPI interface may not be enabled before the PCI serial EEPROM has completed reading configuration information (i.e., before the PCI Serial EEPROM Done (EED) bit is set in the PCIS register). Attempting to enable the SPI interface while the interface is in use by the PCI interface does not damage the RC32438 (i.e., no dual sourcing), but it does produce unpredictable results. When the PCI mode is not PCI satellite mode with suspended CPU execution, the SPI interface may be enabled at any time since the PCI interface will not read the PCI serial EEPROM.

Notes

PCI Satellite Mode	PCI Serial EEPROM Loading Complete[1]	SPI Interface Enabled	Corresponding SPIOFUNC Bit (1=bit I/O)	Corresponding SIOCFG Bit (1=Output)	Serial I/O Pins			
					SCK	SDO	SDI	PCIGNTN[1]
No	X[2]	No	0	X	Z[3]	Z	Z	O[4]
No	X	Yes	0	Z	O[5]	O	I[6]	O[4]
No	X	X	1	0	I	I	I	O[4]
Yes	Yes	X	1	0	I	I	I	I
No	X	X	1	1	O	O	O	O[4]
Yes	Yes	X	1	1	O	O	O	O
Yes	No	X	X	X	O	O	I	O
Yes	Yes	No	0	X	Z	Z	Z	O[7]
Yes	Yes	Yes	0	X	O	O	I	O[7]

Table 16.2 Serial I/O Pin Configuration

1. PCI Serial EEPROM loading only occurs in PCI satellite mode with suspended execution. In PCI satellite mode with PCI target not ready, the PCI serial EEPROM loading is effectively always completed.
2. Don't care
3. Tri-stated
4. State determined by PCI function in corresponding PCI mode
5. Output
6. Input
7. This signal is driven low (MICROWIRE chip select is negated).

SPI Interface Mode

When the SPI interface is enabled, it drives the SC and SDO pins. When an SPI transaction is initiated by writing to the SPI Data Register (SPD), the SCK, SDO, and SDI signals are used to transfer data. A general purpose I/O pin must be used as the SPI chip select, and this pin must be managed by software. In systems where multiple SPI devices are required, multiple general purpose I/O pins may be used as SPI chip selects. In these scenarios, the GPIO pins used as chip selects must be managed by software.

In cases where the SPI interface is not enabled, the serial I/O pins are not used as bit I/O ports and the SCK, SDO, and SDI pins are tri-stated after the loading of configuration information is complete. Pull-ups or pull-downs are necessary on the board. (Refer to the second to the last row in Table 16.2.) When the SPIE bit is set in the SPC register, the SPI interrupts are enabled. An SPI interrupt is generated when the MODF or SPIF bits are set in the SPS register.

SPI Clock Prescalar

The SPI contains an 8-bit clock prescalar which is used to generate an internal SPI prescalar clock. This clock is further divided by the value in the SPI Clock Rate Divisor (SPR) field of the SPI Control Register (SPC) before being used by the SPI interface as the time base for all transfers. The internally generated SPI prescalar clock is equal to the IPBus clock (ICLK) frequency divided by twice the clock prescalar divisor (DIV) field value in the SPI clock prescalar (SPCP) register plus one. The generated clock may not be symmetric.

The clock used by the SPI interface is equal to: $\text{SPI Clock} = \frac{\text{ICLK}}{2 \times (\text{DIV} + 1) \times \text{SPR}}$

Notes

Clock Prescalar Register

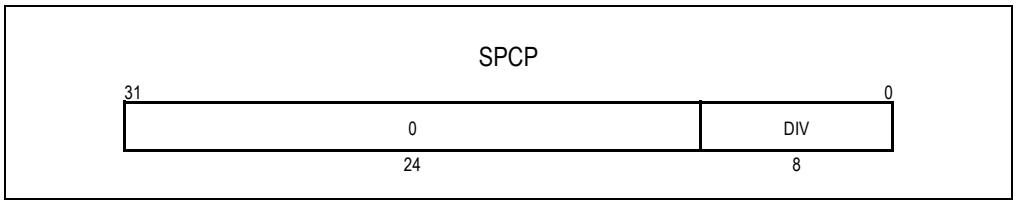


Figure 16.2 SPI Clock Prescalar Register (SPCP)

DIV

Description: **Clock Prescalar Divisor.** The internally generated SPI prescalar clock is equal to the master clock divided by twice the DIV field plus one.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SPI Control Register

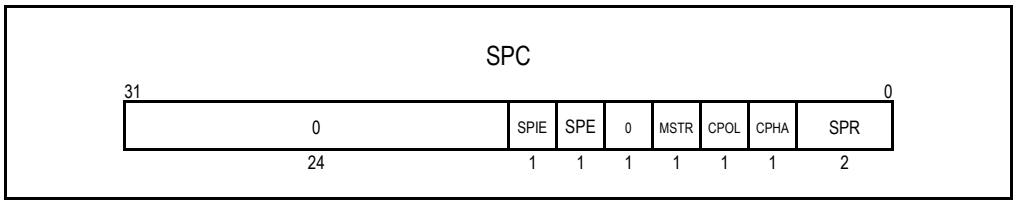


Figure 16.3 SPI Control Register (SPC)

SPR

Description: **Clock Divisor.** This two bit field specifies the value by which the SPI prescalar clock is divided. The resulting clock is used as the time base for all SPI operations.
0x0 - Divide by 2
0x1 - Divide by 4
0x2 - Divide by 16
0x3 - Divide by 32

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

CPHA

Description: **Clock Phase.** This bit together with the CPOL bit control the clock and data relationship for serial data clocked out on the SDO pin and clocked in on the SDI pin.
0x0 - Data is clocked out/in on the first edge of the clock
0x1 - Data is clocked out/in on the second edge of the clock

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

CPOL

Description: **Clock Polarity**. This bit specifies the polarity of the clock. When this bit is set to zero (cleared), the SPI clock (SPCLK) is held in a low state during SPI idle periods (i.e., between transactions when the bus is idle). When this bit is set to one, the SPI clock is held in a high state during SPI idle periods.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MSTR

Description: **Master/Slave Mode**. Since the SPI interface only supports master mode, this bit should always be set. It is provided for software compatibility only.

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

SPE

Description: **Enable**. When this bit is set to one, the serial peripheral interface is enabled. When this bit is set to zero (cleared), the serial peripheral interface is disabled and held in a low power state. Disabling and then re-enabling the SPI initializes all SPI interface logic to a known state.
When the SPI is disabled, writes to the SPD register will produce undefined results.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SPIE

Description: **SPI Interrupt Enable**. When this bit is set to zero (cleared), SPI Transfer Complete (SPIF) and Master Error Flag (MODF) bits in the SPS register are masked from generating an interrupt.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

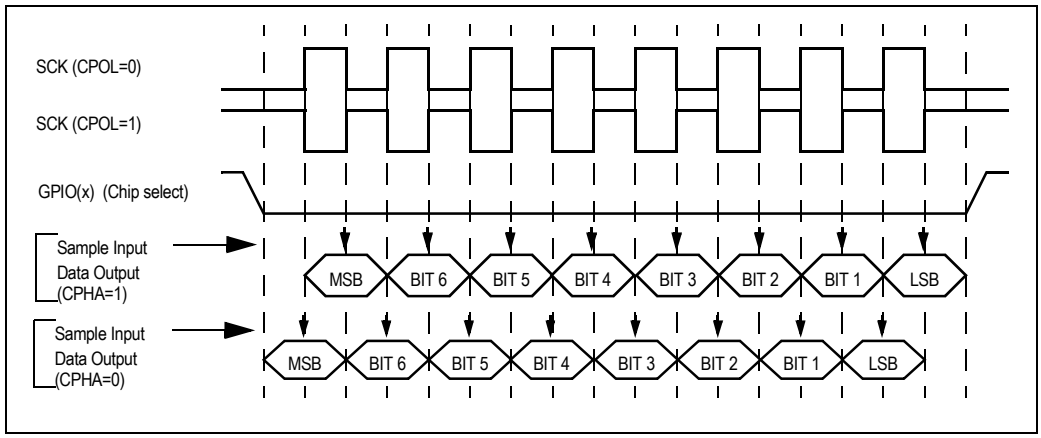


Figure 16.4 Serial Peripheral Interface (SPI) Clock/Data Timing

SPI Status Register

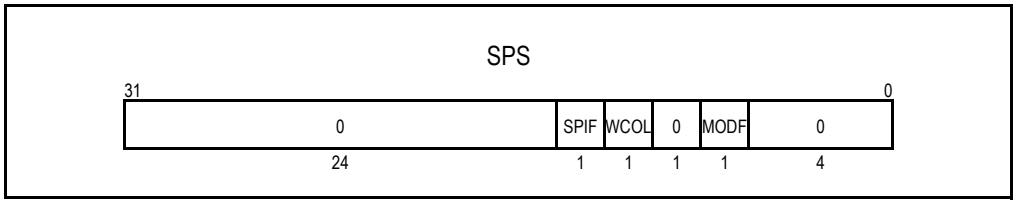


Figure 16.5 SPI Status Register (SPS)

MODF

Description: **Master Error Flag.** This bit is asserted if a write is performed to the SPD register while the SPI interface is in non-master mode (i.e., slave mode). This bit is provided for software compatibility.

Initial Value: 0x0

Read Value: Status

Write Effect: No effect. This bit is automatically set to zero when the SPS register is read and then a write is performed to the SPC register with the MSTR bit set.

WCOL

Description: **Write Collision.** This bit is set if a write collision occurs (i.e., the CPU writes to the SPD register during an SPI transaction).

Initial Value: 0x0

Read Value: Status

Write Effect: No effect. This bit is automatically set to zero when the SPS register is read and then the SPD register is written.

SPIF

Description: **SPI Transfer Complete.** This bit is set when an SPI transaction completes.

Initial Value: 0x1

Notes

Read Value: Status

Write Effect: No effect. This bit is automatically set to zero when the SPS register is read and then the SPD register is read.

SPI Data Register

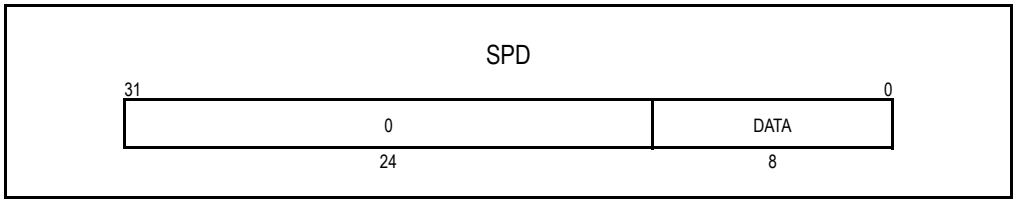


Figure 16.6 SPI Data Register (SPD)

DATA

Description: **DATA.** A write to this field results in an SPI transaction in which the value written to this register is shifted out on the SDO pin while data is simultaneously shifted into this field from the SDI pin. At the completion of the transaction, the SPIF bit in the SPS register is set to one and this field contains the 8-bit quantity read from the SDI pin.

Initial Value: 0x0

Read Value: Value shifted in from SDI pin during the previous transaction

Write Effect: Initiate an SPI transaction. After an initial transaction, subsequent SPI transactions can only be initiated when the SPIF bit is set in the SPS register and a read of the register is performed before a write to the SPD register.

SPI Setup

The following describes the typical setup of the SPI interface which occurs during boot time:

1. As the SPI interface shares data and clock pins with the PCI EEPROM, the SPI module must first poll the PCI EEPROM EED bit in the PCI Status register of the PCI Controller to determine if the PCI module has finished loading data from the PCI EEPROM. The RC32438 device automatically switches the functionality of the pins for use as an SPI interface when the loading of configuration data from the PCI EEPROM is completed.
2. As the SPI signal functions are routed via the PIO Controller, the PIO Controller will generally be initialized to the Effect Mode and establish the correct direction for each SPI pin. At reset time, the default Effect Mode and Direction are set up for the PCI EEPROM and also for the SPI.
3. The SPI Clock Prescalar Register, SPCP, is programmed.
4. The SPI Control Register (SPC), including the SPE Enable Bit, is programmed.
5. The data being sent to the SPI Slave is written into the SPI Data Register (SPD).
6. The SPI Controller will initiate the hardware protocol on the SPI pins. The RC32438 device will receive data from the Slave at the same time it is sending data to the Slave.
7. System either with:
   - *Wait for an SPI Interrupt. After receiving an SPI Interrupt via the Interrupt Controller, the SPI Status Register SPIF and MODF Flags can be read.*
   - *Poll the SPI Status Register SPIF and MODF Flags.*

Notes

8. If the SPIF Flag is set, indicating the transaction is complete, reading the SPI Status Register resets the SPIF Flag.
9. Read the data from the SPI Data Register.
10. Repeat Steps 5 through 10, as needed.

Serial Bit I/O Pins

The serial I/O signals SCK, SDO, SDI, and PCIGNTN[1] may be used as bit I/O ports that operate in basically the same way as GPIO pins. For additional information on the GPIO pins, refer to Chapter 12, General Purpose I/O Controller.

The PCI serial EEPROM may be read to and written from when loading to the PCI Configuration registers has completed. This is achieved by disabling the SPI interface and synthesizing (via software) MICROWIRE transactions on the serial I/O pins.

When the PCI interface operates in PCI satellite mode, the state of the PCIGNTN pin may be controlled by writing the desired pin state value into the Serial I/O Data (SIOD) register.

Serial I/O Function Register

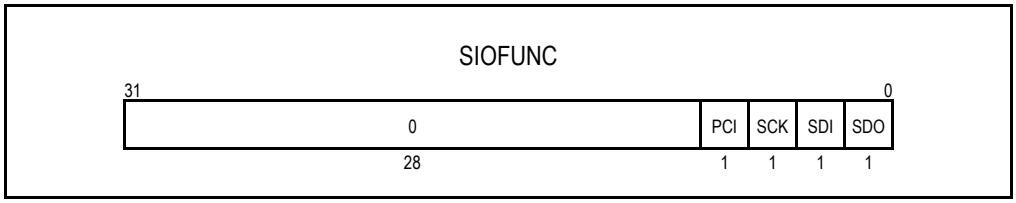


Figure 16.7 Serial I/O Function Register (SIOFUNC)

SDO

Description: **Serial Data Output.** When this bit is set to one, the SDO pin operates as a bit I/O port regardless of the state of the SPI or PCI interfaces.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SDI

Description: **Serial Data Input.** When this bit is set to one, the SDI pin operates as a bit I/O port regardless of the state of the SPI or PCI interfaces.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SCK

Description: **Serial Clock.** When this bit is set to one, the SCK pin operates as a bit I/O port regardless of the state of the SPI or PCI interfaces.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

PCI

Description: **PCI Chip Select.** When this bit is set to one, the PCIGNTN[1] pin operates as a bit I/O port regardless of the state of the PCI interface if the PCI interface is in PCI satellite mode. If the PCI interface is in host mode, the state of this bit has no effect, and the operating mode of this pin is determined by the PCI pin function in that mode.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Serial I/O Configuration Register

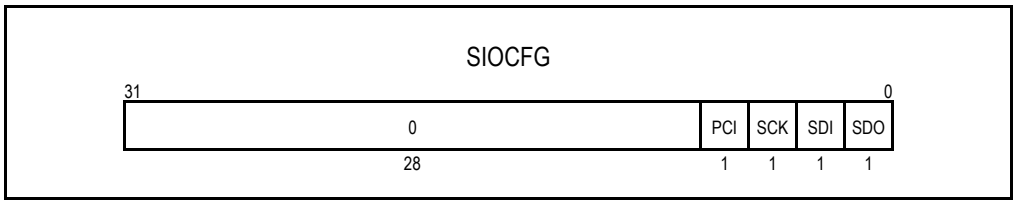


Figure 16.8 Serial I/O Configuration Register (SIOCFG)

SDO

Description: **Serial Data Output.** When this bit is set to one and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an output. Otherwise, if this bit is reset and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an input. If the pin is not configured as a bit I/O port, the bit in this register has no effect.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SDI

Description: **Serial Data Input.** When this bit is set to one and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an output. Otherwise, if this bit is reset and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an input. If the pin is not configured as a bit I/O port, the bit in this register has no effect.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SCK

Description: **Serial Clock.** When this bit is set to one and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an output. Otherwise, if this bit is reset and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an input. If the pin is not configured as a bit I/O port, the bit in this register has no effect.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

PCI

Description: **PCI Chip Select.** When this bit is set to one and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an output. Otherwise, if this bit is reset and the corresponding pin is configured as a bit I/O port in the SIOFUNC register, the pin is configured as an input. If the pin is not configured as a bit I/O port, the bit in this register has no effect.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Serial I/O Data Register

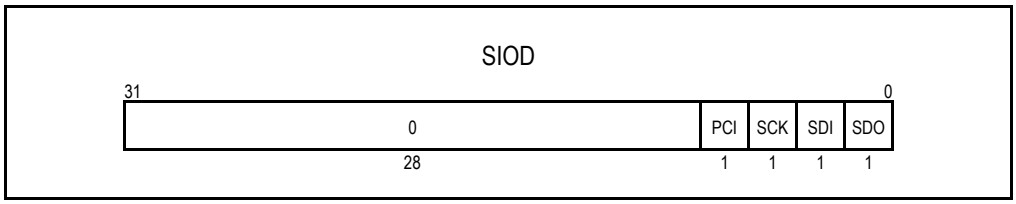


Figure 16.9 Serial I/O Data Register (SIOD)

SDO

Description: **Serial Data Output.** Reading this bit returns the state of the SDO pin. Writing a value to this bit causes the SDO pin to take on the corresponding value if it is configured to be a bit I/O output port in the SIOFUNC and SIOCFG registers.

Initial Value: SDO pin value

Read Value: Previous value written

Write Effect: Modify value

SDI

Description: **Serial Data Input.** Reading this bit returns the state of the SDI pin. Writing a value to this bit causes the SDI pin to take on the corresponding value if it is configured to be a bit I/O output port in the SIOFUNC and SIOCFG registers.

Initial Value: SDI pin value

Read Value: Previous value written

Write Effect: Modify value

SCK

Description: **Serial Clock.** Reading this bit returns the state of the SCK pin. Writing a value to this bit causes the SCK pin to take on the corresponding value if it is configured to be a bit I/O output port in the SIOFUNC and SIOCFG registers.

Initial Value: SCK pin value

Notes

Read Value: Previous value written

Write Effect: Modify value

PCI

Description: **PCI Chip Select.** Reading this bit returns the state of the PCIGNTN[1] pin. Writing a value to this bit causes the PCIGNTN[1] pin to take on the corresponding value if it is configured to be a bit I/O output port in the SIOFUNC and SIOCFG registers and the PCI interface is operating in PCI satellite mode.

Initial Value: PCIGNTN[1] pin value

Read Value: Previous value written

Write Effect: Modify value

Master Programming Example

SPI Initialization

1. If the PCI interface is configured to operate in PCI satellite mode with suspended CPU execution, wait until PCI Serial EEPROM Done (EED) bit is set in the PCIS register.
2. Based on operating IPBus clock frequency and desired SPI clock frequency, write SPCP register (i.e., 0x0C for 100 MHz IPBus clock, 2 MHz SPI clock and SPR = 0 in SPC).
3. Write SPIC register with 0x0000_00D0. SPIE = 1 - Interrupt enable, SPE = 1 - Enable interface, MSTR = 1 - Master mode, SPOL = 0 - Idle clock polarity low, CPHA = 0 - Data clocked on first edge, SPR = 0 - Clock divisor is 2.
4. Write IMASK6 register to disable GPIO Interrupt, GPIOx = 0, where "x" is used GPIO pin for SPI chip select. If you have more than one device, disable all interrupts for used GPIO pins.
5. Write GPIOFUNC register to set GPIOx = 0 — not alternate function.
6. Write GPIOCFG register to set GPIOx = 1 — output.
7. Write GPIOD register to de-assert chip select(s) GPIOx = 1.
8. Read SPS and then SPD to clear SPIF bit.
9. Write IMASK5 register SPI = 0 — enable SPI interrupts.
10. Write GPIOD register to assert chip select GPIOx = 0 for the device to be accessed.
11. Write SPID register with data to transmit over SPI interface to start the transmission process.
12. Wait until the SPI interrupt occurs. The interrupt routine will perform the following steps:
    - *· Read SPS register and check for errors.*
    - *· Mandatory read SPD register, to get input data and clear SPIF bit in SPS register.*
    - *· If finished with (multi-)byte command sequence (i.e., a read sequence: command; address byte 1; address byte 2; 4 data bytes) de-assert chip select writing GPIOD register with GPIOx = 1.*
13. Repeat steps 10 - 12 as needed.

Notes

On-Chip Memory

Notes

Introduction

This chapter describes the on-chip memory features and functions of the RC32438.

Theory of Operation

The RC32438 device includes 4KB of high speed SRAM organized as 1K x 32 bits of on-chip memory. On-chip memory supports byte, halfword, triple-byte, and word memory read and write operations. On-chip memory accesses are restricted to CPU accesses. DMA or PCI transfers to or from on-chip memory are not supported. The contents of on-chip memory is preserved across warm and cold resets.

Address decoding for on-chip memory is controlled by the On-Chip Memory Base (OCMBASE) and On-Chip Memory Mask (OCMMASK) registers. The mask register is used to select which bits are used for address decoding. When a bit in this register is a one, the corresponding address bit is active in address comparisons. If a bit in this register is a zero, the corresponding address bit does not participate in address comparisons. All of the active address bits not masked by the mask register are compared to the value in the base register. If they all match, then on-chip memory is selected.

On-chip Memory Base Register

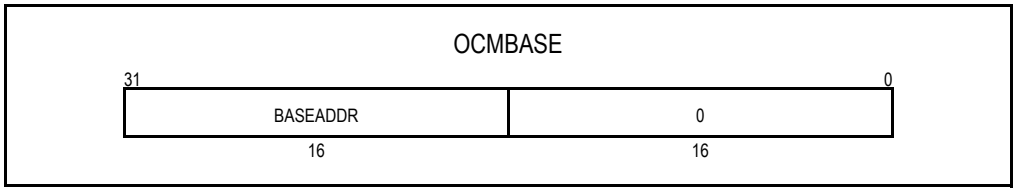


Figure 17.1 On-chip Memory Base Register (OCMBASE)

BASEADDR

Description: **Base Address.** This field specifies the upper 16-bits of the on-chip memory base address.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

On-chip Memory Mask Register

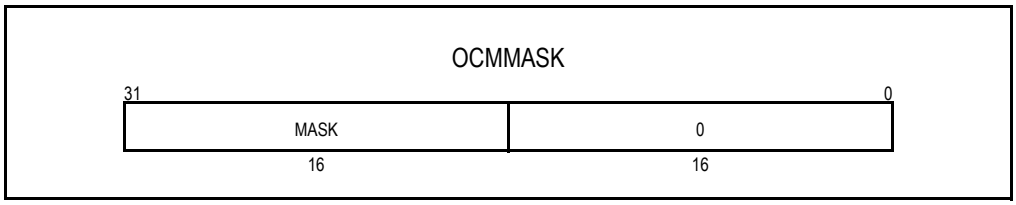


Figure 17.2 On-chip Memory Mask Register (OCMMASK)

Notes

MASK

Description: **Address Mask.** This field determines which bits of the upper 16-bits of the address participate in address comparisons. When a bit is set to one in this field, then the corresponding address bit participates in address comparisons. When a bit is set to zero in this field, then the corresponding address bit is masked and does not participate in address comparisons.
When the MASK field is zero, the on-chip memory does not appear in the memory map.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Debugging and Performance Monitoring

Notes

Introduction

This chapter discusses the three different debugging features available on the RC32438: IPBus Monitor, Event Monitor, and Debug Pins. These features can be used together or independently to aid in system optimization or system debugging.

Features

- *IPBus Monitor provides an on-chip "logic analyzer" for hardware and software debugging*
- *Eight 24-bit statistics counters*
- *External debug support pins provide external visibility to internal operation*

Debug and Performance Register Description

Register Offset	Register Name	Register Function	Size
0x09_0000	IPBMTCFG	IPBus Monitor Trigger Configuration	32-bit
0x09_0004	IPBMTS	IPBus Monitor Trigger Select	32-bit
0x09_0008	IPBMMT	IPBus Monitor Manual Trigger	32-bit
0x09_000C	IPBMTC0	IPBus Monitor Trigger Condition 0	32-bit
0x09_0010	IPBMTC1	IPBus Monitor Trigger Condition 1	32-bit
0x09_0014	IPBMTC2	IPBus Monitor Trigger Condition 2	32-bit
0x09_0018	IPBMTC3	IPBus Monitor Trigger Condition 3	32-bit
0x09_001C	IPBMFS	IPBus Monitor Filter Select	32-bit
0x09_0020	IPBMFC0	IPBus Monitor Filter Control 0	32-bit
0x09_0024	IPBMFC1	IPBus Monitor Filter Control 1	32-bit
0x09_0028	IPBMFC2	IPBus Monitor Filter Control 2	32-bit
0x09_002C	IPBMRC	IPBus Monitor Record Control	32-bit
0x09_0030	IPBMTT	IPBus Monitor Trigger Time	32-bit
0x09_0034	IPBMTP	IPBus Monitor Trigger Position	32-bit
0x09_0038	EMC	Event Monitor Control	32-bit
0x09_003C	EM0COMPARE	Event Monitor 0 Compare	32-bit
0x09_0040	EM0COUNT	Event Monitor 0 Count	32-bit
0x09_0044	EM1COUNT	Event Monitor 1 Count	32-bit
0x09_0048	EM2COUNT	Event Monitor 2 Count	32-bit
0x09_004C	EM3COUNT	Event Monitor 3 Count	32-bit
0x09_0050	EM4COUNT	Event Monitor 4 Count	32-bit
0x09_0054	EM5COUNT	Event Monitor 5 Count	32-bit

Table 18.1 Debug and Performance Register Map (Part 1 of 2)

Notes

Register Offset	Register Name	Register Function	Size
0x09_0058	EM6COUNT	Event Monitor 6 Count	32-bit
0x09_005C	EM7COUNT	Event Monitor 7 Count	32-bit
0x09_0060 through 0x09_7FFF	Reserved		

Table 18.1 Debug and Performance Register Map (Part 2 of 2)

IPBus Monitor

The IPBus monitor provides on-chip "logic analyzer" functionality for debugging hardware and software. It provides sophisticated support for debugging transactions on the internal IPBus that would otherwise not be available to the user. Unlike most other blocks in the RC32438, the IPBus Monitor is **not reset** during a warm reset. This allows the IPBus monitor to be used to debug across a warm reset.

The IPBus monitor allows IPBus transaction information to be recorded in on-chip memory for later analysis (for additional information, refer to Chapter 17, On-Chip Memory). The on-chip memory region used by the IPBus monitor is determined by the IPBMBASE field of the IPBMRC register. As shown in Figure 18.1, the IPBus monitor uses memory starting at IPBMBASE to the end of on-chip memory to record transactions. Memory below IPBMBASE is available for other uses.

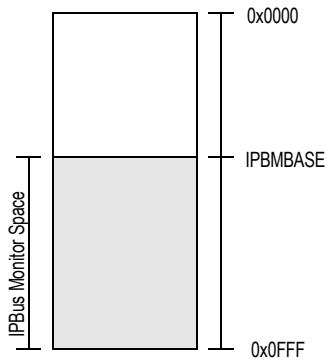


Figure 18.1 IPBus Monitor On-Chip Memory Usage

Transaction information is stored using two types of double word (i.e., 64-bit) records. A clock cycle record is stored in on-chip memory during each clock cycle of a transaction. A transaction summary record is stored in on-chip memory at the end of each transaction (refer to the IPBus Monitor Trigger Time section later in this chapter). Records are stored in on-chip memory in a circular fashion. When the end of on-chip memory is reached, recording continues starting at IPBMBASE.

When the IPBus monitor is enabled (i.e., the EN bit is set in the IPBMTCFG register), it begins recording each IPBus transaction in on-chip memory. Recording stops shortly after a final trigger event occurs. Once a final trigger event occurs the IPBus monitor continues storing transactions records in on-chip memory until the space allocated by the Final Trigger Record Length (FTRL) field in the IPBMRC register is exhausted. The FTRL field provides control over how many transactions are recorded before and after a final trigger event. When a final trigger event occurs the FT bit is set in the IPBMTCFG register. This bit is presented to the interrupt controller as an interrupt source.

When the EJTAG Debug Interrupt Enable (DIE) bit is set in the IPBMTCFG register, an EJTAG debug interrupt request is generated to the CPU core whenever the FT bit is set in the IPBMTCFG register. This allows synchronization between the IPBus monitor and an external EJTAG ICE. When the IPBus monitor completes storing transaction records in on-chip memory (i.e., the space allocated by the FTRL field is exhausted) the Recording Completed (RC) bit is set in the IPBMTCFG register. This bit is presented to the interrupt controller as an interrupt source.

Notes

The Trigger Condition (TC) bit in the IPBMTCFG allows the AND or OR of trigger conditions selected in the IPBMTS register to result in a trigger event. Trigger conditions are defined by system events, such as a warm reset, or by conditions specified in the IPBus Monitor Trigger Condition [0..3] registers (IPBMTC[0..3]). Each time a trigger event occurs, the value in the TCOUNT field of IPBMTCFG is decremented. When TCOUNT reaches zero, a final trigger event occurs.

The IPBus monitor uses two external pins. One of these is an alternate function input of GPIO[29] (IPBMTRIGINP) whose level can be selected as a trigger condition. The other is an output pin (IPBMTRIGOUTP) that is toggled or pulsed when a trigger event occurs. The TIP and TOM fields of IPBMTCFG control the behavior of these signals. There is a delay of 4 ICLK cycles between a transition on the IPBMTRIGOUTP signal and a final trigger event. There is a delay of 5 ICLK cycles between assertion of the IPBMTRIGINP input (a GPIO alternate function) and detection of this event by the IPBus monitor.

The IPBus monitor allows transactions to be filtered “in” or “out” depending on conditions specified in the IPBus Monitor Filter Control [0..2] (IPBMFC[0..2]) registers. If a transaction has been filtered “out,” then none of the clock cycle records or the transaction summary record for that transaction are recorded in on-chip memory. If a transaction is filtered “in,” then all clock cycle and transaction summary records for that transaction are recorded in on-chip memory. When the EN bit in IPBus Monitor Filter Select (IPBMFS) register is set, filtering is enabled. The Filter Condition (FC) field controls which transactions are recorded. The remaining bits in this register allow one to select which filter conditions are enabled.

The IPBus monitor contains a free running counter that is incremented on each rising edge of ICLK. The time stamp (TS) field in each transaction summary record contains the value of this counter. If the number of ICLK clock cycles between the previous and current transaction summary records is greater than or equal to 2^{23}, the overflow (OVR) bit is set in the transaction summary record and the value of the TS field should be disregarded.

The IPBus Monitor Trigger Time (IPBMTT) register contains the value of the free running counter when a final trigger condition occurs.

After a final trigger condition is recorded, the address of the first transaction summary record that was recorded in on-chip memory is saved in the ADDR field of the IPBus Monitor Trigger Position (IPBMTP) register. For example, if the final trigger condition occurs due to a data transfer on the IPBus and a clock cycle record format transaction is recorded in on-chip memory for this data transfer, then IPBMTP points to the transactions summary record for that transaction. IPBMTP may not actually point to the transaction summary record that generated the final trigger condition since the clock cycle record and even the transaction summary record may have been filtered “out.” In these cases, IPBMTP points to the first transaction summary record stored in on-chip memory after a final trigger condition.

The bus master index referred to in this section corresponds to the IPBus master indices listed in Table 5.1 of Chapter 5, Bus Arbitration.

Note: A warm reset does not modify the state of IPBus monitor registers or on-chip memory. A cold reset does not modify the state of on-chip memory but does modify the state of IPBus monitor registers.

IPBus Monitor Registers

IPBus Monitor Trigger Configuration Register

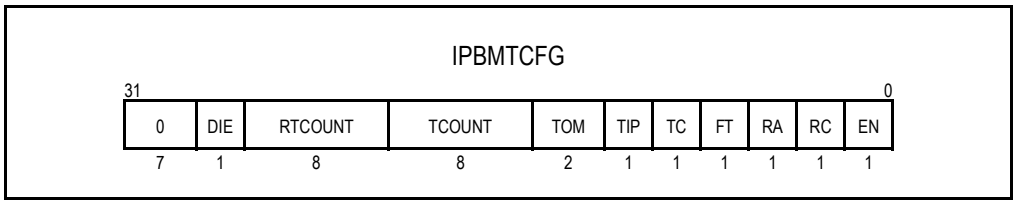


Figure 18.2 IPBus Monitor Trigger Configuration Register (IPBMTCFG)

Notes

EN

Description: **Enable.** When this bit is set to one, the IPBus monitor is armed. Each time the trigger condition specified by the TC field and the IPBus Monitor Trigger Select (IPBMTS) register are satisfied the Trigger Count (TCOUNT) field is decremented. When the TCOUNT field reaches zero, the enable bit is set to zero (cleared) and a final trigger event occurs.
Note: When this bit is set, the IPBus records transactions until a final trigger event occurs or until this bit is cleared by software.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RC

Description: **Recording Completed.** When the IPBus monitor completes storing transaction records in on-chip memory (i.e., the space allocated by the FTRL field is exhausted) this bit is set.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

RA

Description: **Rearm.** When this bit is set to one, the IPBus monitor is automatically rearmed (i.e., the enable bit is set) after a final trigger event occurs. When the IPBus monitor is rearmed, the value in the RTCOUNT field is loaded into the TCOUNT field.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

FT

Description: **Final Trigger.** This bit is set to one when a final trigger event occurs.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

TC

Description: **Trigger Condition.** When this bit is set to one, the IPBus monitor triggers when all of the selected trigger conditions selected in the IPBMTS register are satisfied (i.e., AND of all enabled trigger conditions). When this bit is cleared, the IPBus monitor triggers when any of the selected trigger conditions are satisfied (i.e., OR of all enabled trigger conditions).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

TIP

Description: **IPBus Monitor Trigger Input Polarity.** This bit selects the active polarity of the IPBus Monitor Trigger Input (IPBMTRIGINP). IPBMTRIGINP is a GPIO alternate function and is sampled by EXTCLK.
0 - IPBMTRIGINP is active low (trigger when signal transitions from 1 to 0)
1 - IPBMTRIGINP is active high (trigger when signal transitions from 0 to 1)

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TOM

Description: **IPBus Monitor Trigger Output Mode.** This bit selects the operating mode of the IPBus Monitor Trigger Output (IPBMTRIGOUT).
0 - IPBMTRIGOUT is driven low for one EXTCLK clock cycle when final trigger occurs
1 - IPBMTRIGOUT is driven high for one EXTCLK clock cycle when final trigger occurs
2 - IPBMTRIGOUT is inverted (i.e., toggled) when final trigger event occurs
3 - reserved

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TCOUNT

Description: **Trigger Count.** This field contains a trigger count which is decremented each time a trigger event occurs.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RTCOUNT

Description: **Rearm Trigger Count.** This field contains the rearm trigger count value which is loaded into the TCOUNT field whenever the IPBus monitor is automatically rearmed (i.e., when the RA bit is set and the final trigger event occurs).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DIE

Description: **Debug Interrupt Enable.** When this bit is set in the IPBMTCFG register, an EJTAG debug interrupt request is generated to the CPU core whenever the FT bit is set. This allows synchronization between the IPBus monitor and an external EJTAG ICE.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPBus Monitor Trigger Select Register

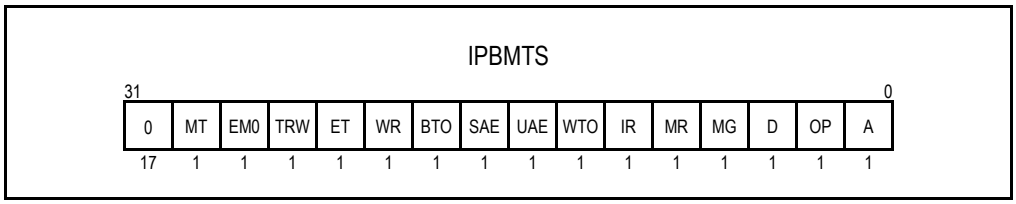


Figure 18.3 IPBus Monitor Trigger Select Register (IPBMTS)

A

Description: **Address.** This bit selects the address trigger condition in the IPBMTC0 register. A trigger condition occurs when a transaction address matches the address bits in the address (A) field of the IPBMTC0 register which are not masked by the address mask (AM) field in the IPBMTC1 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

OP

Description: **Operation.** This bit selects the read or write operation select trigger (RW) condition in the IPBMTC3 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

D

Description: **Data.** This bit selects the data trigger condition in the IPBMTC2 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MG

Description: **IPBus Master Grant.** This bit selects the IPBus master grant trigger condition in the IPBMTC3 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MR

Description: **IPBus Master Bus Requests.** This bit selects the IPBus master bus requests trigger condition in the IPBMTC3 register. The trigger condition is determined by the masters selected in the MR field and the state of the MRM field.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

IR

Description: **Interrupt Request.** This bit selects the interrupt request trigger condition in the IPBMTC3 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

WTO

Description: **Watchdog Timer Time-out.** This bit selects the watchdog timer time-out trigger condition (see the Functional Overview section in Chapter 4, System Integrity Functions).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

UAE

Description: **Undecoded Address Error.** This bit selects the undecoded address error trigger condition which is reported by the address space monitor (see the Functional Overview section in Chapter 4, System Integrity Functions).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

SAE

Description: **IPBus Slave Acknowledge Error.** This bit selects the IPBus slave acknowledge error trigger condition (see the Functional Overview section in Chapter 4, System Integrity Functions).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

BTO

Description: **Bus Transaction Timer Time-out.** This bit selects the transaction timer time-out trigger condition which is reported by the memory and peripheral bus transaction timer (see the Theory of Operation section in Chapter 6, Device Controller).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

WR

Description: **Warm Reset.** This bit selects the warm reset trigger condition.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

ET

Description: **External Trigger.** This bit selects the IPBMTRIGINP input trigger condition. A trigger event occurs when the state of the IPBMTRIGINP input is asserted (as specified by the TIP field in IPBMTCFG). The IPBMTRIGINP input is a GPIO alternate function.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TRW

Description: **Trigger Register Write.** This bit selects writes to the IPBus monitor manual trigger register as a trigger condition.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

EM0

Description: **Event Monitor 0 Trigger Event.** This bit selects an event monitor 0 trigger condition (i.e, when T bit is set in the EM0COMPARE register).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MT

Description: **Merged Transaction Trigger Event.** This bit selects IPBus merged transactions as a trigger condition. This event occurs with the DMA controller merges two transactions on the IPBus. Merged transactions eliminate the bus overhead associated with consecutive IPBus transactions to the same peripheral.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Manual Trigger Register

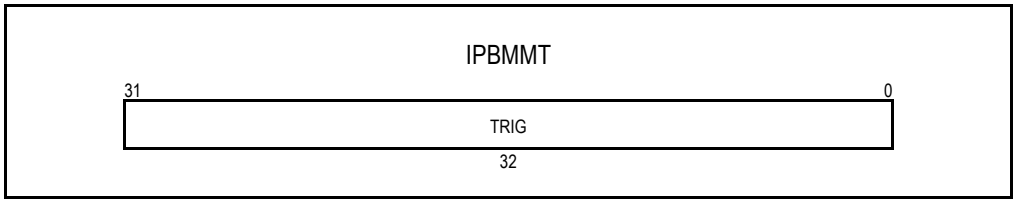


Figure 18.4 IPBus Monitor Manual Trigger Register (IPBMMT)

Notes

TRIG

Description: **Trigger.** A write to this field results in a "trigger register write" event which may be selected as an IPBus monitor trigger condition by the TRW bit in the IPBMTS register.

Initial Value: 0x0

Read Value: 0x0

Write Effect: Cause a trigger register write event

IPBus Monitor Trigger Condition 0 Register

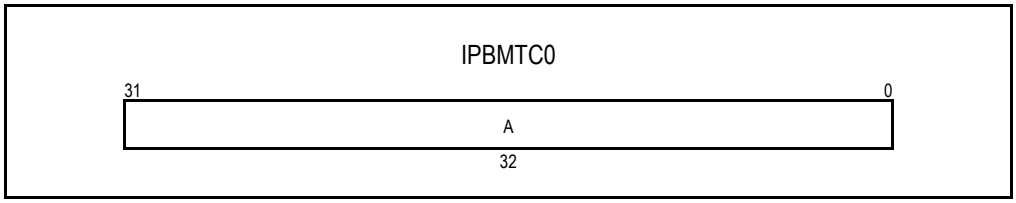


Figure 18.5 IPBus Monitor Trigger Condition 0 Register (IPBMTC0)

A

Description: **Address.** This field contains the trigger address.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Trigger Condition 1 Register

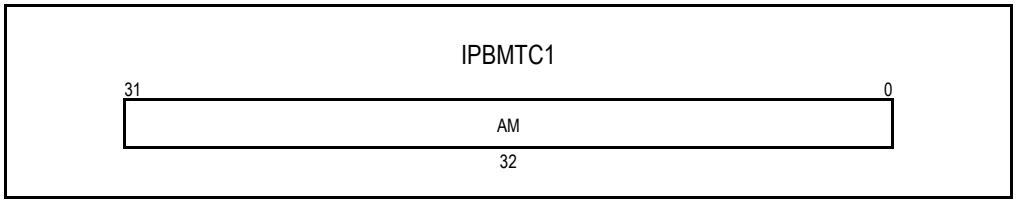


Figure 18.6 IPBus Monitor Trigger Condition 1 Register (IPBMTC1)

AM

Description: **Address Mask.** Each bit in this field corresponds to an address bit in the Address (A) field of the IPBMTC0 register. When a bit in this field is set, the state of the corresponding address bit in the A field is ignored (i.e., masked) in making trigger decisions.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPBus Monitor Trigger Condition 2 Register

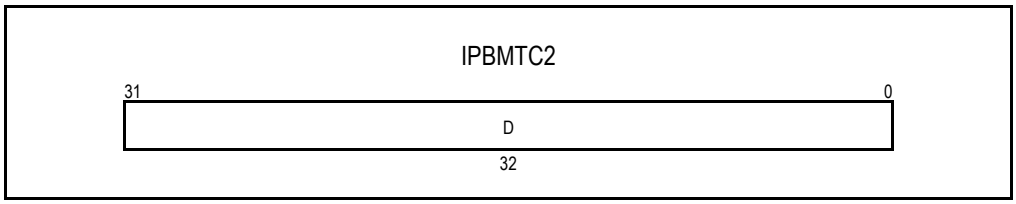


Figure 18.7 IPBus Monitor Trigger Condition 2 Register (IPBMTC2)

D

Description: **D.** This field contains the 32-bit trigger data value. During each data transfer on the IPBus only the data value(s) of active byte lanes are compared to the corresponding byte value(s) in this field. For example, if only byte zero is active in an IPBus data transfer, then only the least significant byte of this register would be compared.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Trigger Condition 3 Register

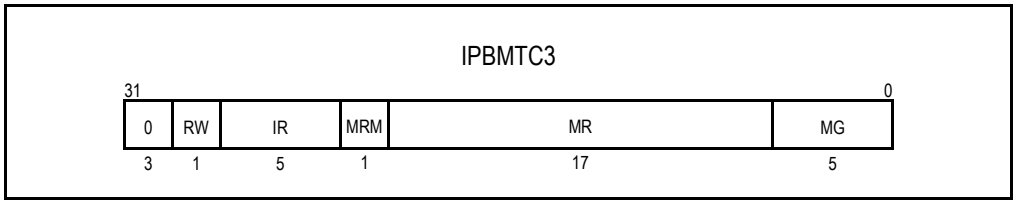


Figure 18.8 IPBus Monitor Trigger Condition 3 Register (IPBMTC3)

MG

Description: **IPBus Master Grant.** This field contains the IPBus master trigger index (i.e., the index of the bus master granted the bus).

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

MR

Description: **IPBus Master Requests**. Each bit in this field corresponds to an IPBus master index. A trigger condition occurs when the MRM bit is set and all of the masters whose corresponding bit is set in this field are requesting service or when the MRM bit is cleared and any of the masters whose corresponding bit is set in this field are requesting service.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

MRM

Description: **IPBus Master Request Mode**. This field controls the interpretation of the IPBus Master Request (MR) field in generating a trigger condition.
0 - Trigger when all of the masters selected in the MR field are requesting service (i.e. AND)
1 - Trigger when any of the masters selected in the MR field are requesting service (i.e., OR)

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IR

Description: **Interrupt Request**. This field encodes the index of IPEND interrupt request presented to the CPU (bit 0 corresponds to IPEND2, bit one to IPEND3, and so on). A trigger condition occurs when an interrupt request is presented to the CPU and the corresponding bit in the IR field is set.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

RW

Description: **Read or Write Operation Select**. This field specifies the trigger transaction operation.
0 - read transaction
1 - write transaction

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Filter Select Register

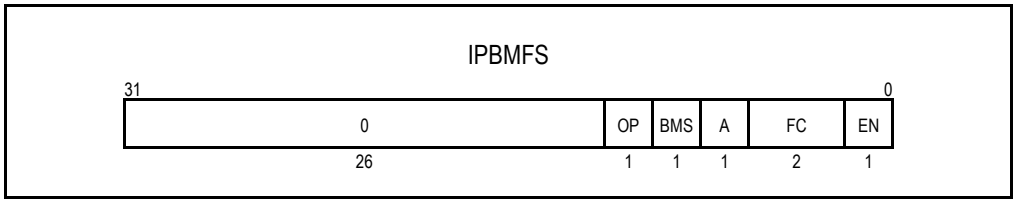


Figure 18.9 IPBus Monitor Filter Select Register (IPBMFS)

EN

Description: **Enable.** When this bit is set to one, filtering is enabled. When filtering is disabled, all data is recorded.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

FC

Description: **Filter Condition.** This field controls which transactions are recorded using filtering.
0 - Record transactions that match all of the conditions selected in the IPBMFS register (i.e filter in AND of conditions)
1 - Record transactions that match any of the conditions selected in the IPBMFS register (i.e., filter in OR of conditions)
2 - Record transactions that do not match all of the conditions selected in the IPBMFS register (i.e., filter out AND of conditions)
3 - Record transactions that do not match any of the conditions selected in the IPBMFS register (i.e., filter out OR of conditions)

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

A

Description: **Address.** This bit selects the address filter condition in the IPBMFC0 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

BMS

Description: **Bus Master Select.** This bit selects the bus master select filter condition in the IPBMFC2 register.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

OP

Description: **Operation.** When this bit is set to one, transactions of the type selected by the RW field in the IPBMFC2 register are selected as a filter condition.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Filter Control 0 Register

Figure 18.10 IPBus Monitor Filter Control 0 Register (IPBMFC0)

Notes

A

Description: **Address.** This field contains the filter address. A transaction is considered to match the filter condition if its starting address matches unmasked bits (i.e., bits not masked by the AM field in the IPBMFC1 register) in this field.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Filter Control 1 Register

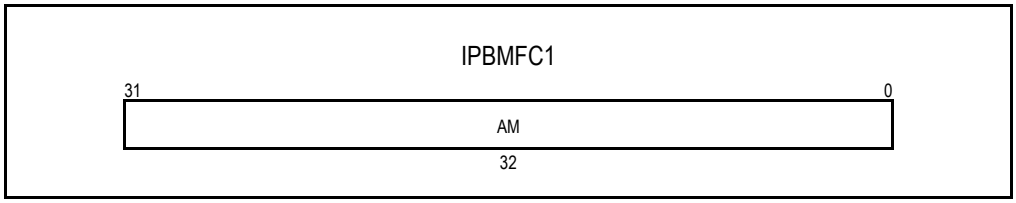


Figure 18.11 IPBus Monitor Filter Control 1 Register (IPBMFC1

AM

Description: **Address Mask.** Each bit in this field corresponds to an address bit in the address (A) field of the IPBMFC0 register. When a bit in this field is set to one, the state of the corresponding address bit in the A field is ignored in making filtering decisions.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Filter Control 2 Register

r

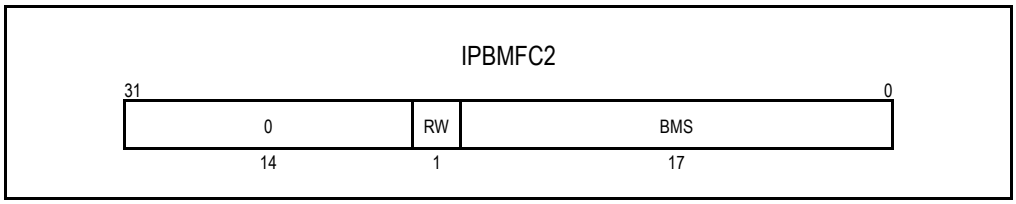


Figure 18.12 IPBus Monitor Filter Control 2 Register (IPBMFC2)

BMS

Description: **Bus Master Select.** Each bit in this field corresponds to a bus master index. When a transaction is generated (i.e., the bus has been granted) from a bus master whose corresponding bit is set in this field, then the transaction is considered to match the filter.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

RW

Description: **Read or Write Operation Select.** This field selects the type of transactions that are recorded.
0 - write transactions
1 - read transactions

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Record Control

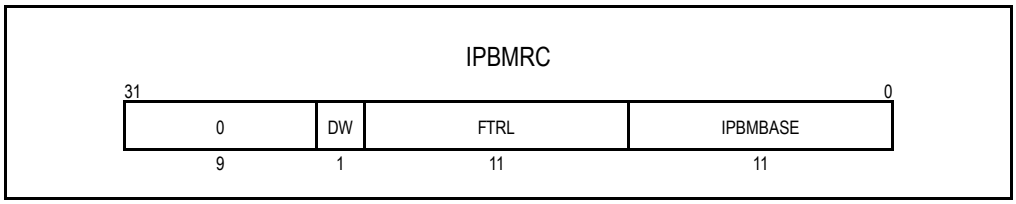


Figure 18.13 IPBus Monitor Record Control Register (IPBMRC)

IPBMBASE

Description: **IPBus Monitor Base Recording Address.** This field contains the on-chip memory double word (i.e., 64-bit) base address used to record transactions. This address corresponds to an offset into on-chip memory and is not a complete local address space address.
Unused address bits are stored in this field but are ignored by hardware.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

FTRL

Description: **Final Trigger Record Limit.** This field contains the number of double words written to on-chip memory after a final trigger event.
Unused address bits are stored in this field but are ignored by hardware.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

DW

Description: **Discard Wait Records.** Do not write clock cycle records into memory that have the wait (W) bit set.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPBus Monitor Trigger Position

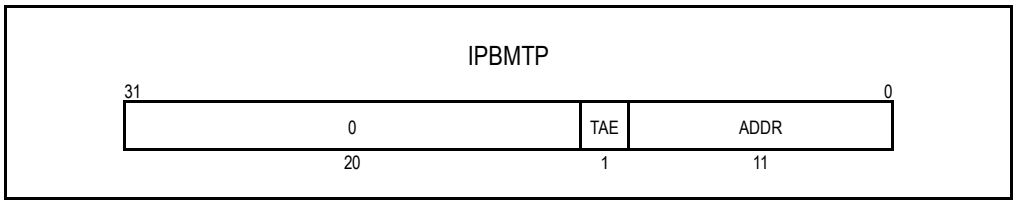


Figure 18.14 IPBus Monitor Trigger Position Register (IPBMTP)

ADDR

Description: **Trigger Address.** This field contains the on-chip memory double word address of the first IPBus monitor transaction summary record stored in on-chip memory after a final trigger. Unused address bits are stored in this field but are ignored by hardware.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

TAE

Description: **Trigger Address Error.** This bit is set if the ADDR field is invalid following a final trigger. This occurs when the IPBus monitor is unable to write a transaction summary record following a final trigger due to miscommunication of the FRTL field in the IPBMRC register..

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

IPBus Monitor Trigger Time

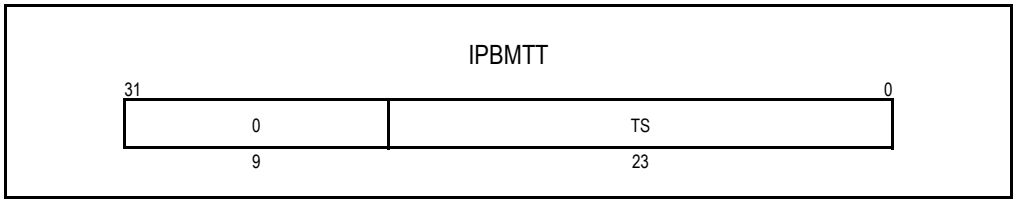


Figure 18.15 IPBus Monitor Trigger Time Register (IPBMTT)

TS

Description: **Time Stamp.** This field contains the value of the free running counter that is incremented at the ICLK clock frequency when the final trigger event occurred.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Notes

IPBus Monitor Record Formats

The IPBus Monitor stores data in the On-chip RAM using two record formats. Both formats consist of double words (i.e., 64-bits or two 32-bit words).

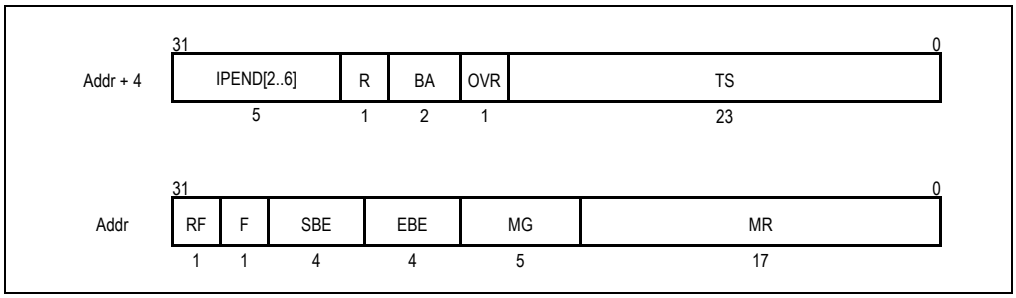


Figure 18.16 IPBus Monitor Transaction Summary Record Format

RF — **Record Format.** This bit indicates the format of the record. If this bit is set, then the record has a transaction summary format. If the bit is cleared, then the record has a clock cycle format.

F — **Filtered.** This bit is set if any transactions were filtered between the previously recorded transaction and this one.

SBE — **Starting Byte Enables.** This field represents the state of the byte enables in the first data transfer of the transaction. Bit 0 corresponds to data bits 0 through 7, bit 1 corresponds to data bits 8 through 15, and so on. A bit is set if the byte lane is enabled.

EBE — **Ending Byte Enables.** This field represents the state of the byte enables during last first data transfer of the transaction. Bit 0 corresponds to data bits 0 through 7, bit 1 corresponds to data bits 8 through 15, and so on. A bit is set if the byte lane is enabled.

MG — **IPBus Master Grant.** This field contains the IPBus master index corresponding to the bus master that generated the transaction.

MR — **IPBus Master Bus Requests.** Each bit in this field corresponds to an IPBus master index. A bit is set if the corresponding bus master requested ownership of the IPBus at any point after the previously recorded IPBus transaction and this one.
In general, the bus master that has been granted the bus for the current transaction will not have its MR bit set (because in order to have been granted the bus, the current master has to have previously requested the bus). However, there are two exceptions to this condition. First, if the bus master generates a request after it has already been granted the bus for the current transaction (this action is called a pre-request) and the current transaction is not yet completed, its MR bit will be set. Second, if the bus master requested and performed a transaction that was filtered out after the previously recorded transaction, its MR bit will be set.

IPEND[2..6] — **Interrupt Requests.** Each bit in this field corresponds to an interrupt request to the CPU. If an interrupt request was generated at any time during the current transaction or since the last transaction, then the corresponding bit in this field is set.

R — **Read.** This bit is set if the transaction was an IPBus read transaction (i.e., either an IPBus master read or an IPBus fly-by read). This bit is cleared if the transaction was an IPBus write transaction.

BA — **Byte Address.** This two bit field contains the bottom two bits of the IPBus transaction starting address. The complete address of each transfer in a transaction may be determined by concatenating this field with the ADDR field in the IPBus monitor clock cycle record (i.e., 32-bit address equals ((ADDR << 2) | BA)).

OVR — **Overflow.** This bit is set if the number of clock cycles between the previously recorded IPBus monitor transaction summary record and this one is greater than or equal to 2^{23}.

TS — **Time Stamp.** This field contains the value of the free running counter incremented at the ICLK clock frequency when the transaction summary record was recorded. This value is equivalent to that of the last clock cycle in the transaction (i.e., the last clock cycle of the transaction before the IPBus goes idle or starts a new transaction).

Notes

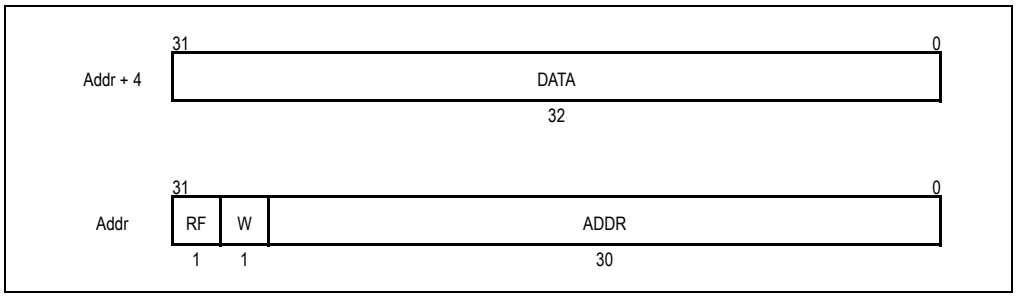


Figure 18.17 IPBus Monitor Clock Cycle Record Format

RF	**Record Format.** This bit indicates the format of the record. If this bit is set to 1, then the record has a transaction summary format. If the bit is cleared, then the record has a clock cycle format.
W	**Wait.** This bit is set if a wait state was generated in the clock cycle represented by the current data transfer record or a data transfer occurred in which all the byte lanes were disabled.
ADDR	**Address.** This field contains the value of the upper 30 bits of the IPBus address in the clock cycle represented by the current data transfer record.
DATA	**Data.** This field contains the 32-bit IPBus data value in the clock cycle represented by the current data transfer record. When the wait (W) bit is set, this field may be used to distinguish between a true wait state and a data transfer in which all byte lanes were disabled. 0x0000_0000 - wait state 0x1111_1111 - data transfer with all byte lanes disabled 0x2222_2222 - null data associated with transactions that generate an undecoded address error.

Event Monitor

The event monitor provides a means of gathering performance statistics. Unlike most other blocks in the RC32438, the Event Monitor is not reset during a warm reset. The statistics monitor consists of eight 24-bit counters. The COUNT value for each counter may be read or written at any time. A counter's COUNT value is incremented each time a selected event occurs if the Freeze (FRZ) bit is not set in the Event Monitor Control (EMC) register. Setting the FRZ bit freezes the value of all event monitor counters. The COUNT field may be read or written but is never incremented when the FRZ bit is set to 1.

Writing a one to the CLR bit in the EMC register clears the value of all event monitor counters to zero. This occurs regardless of the state of the FRZ bit. Each event monitor counter contains a 6-bit Select (SEL) field that maps one of 64 events to the event counter.

Event Index	Event Description
0	CPU instruction executed
1	CPU instruction cache miss
2	CPU data cache hit
3	CPU data cache miss
4	CPU joint TLB miss
5	CPU instruction TLB miss
6	CPU data TLB miss
7	Maximum number of wait states in a single IPBus transaction[1]
8	Rising edge of IPBus clock (ICLK)

Table 18.2 Event Monitor Sources (Part 1 of 3)

Notes

Event Index	Event Description
9	Event monitor trigger event (i.e., T bit in EM0COMPARE register transition from 0 to 1)
10	IPBus monitor final trigger event
11	PMBus transaction
12	PMBus CPU transaction
13	PMBus IPBus transaction
14	PMBus sneak transaction
15	PMBus delay (each ICLK cycle in which an IPBus transaction is delayed due to a sneak transaction)
16	DDR read transaction
17	DDR write transaction
18	IPBus arbiter grants bus to a bus master with a CMTC equal to zero (uses round robin arbitration)
19	Number of double words written to on-chip memory by IPBus monitor
20	IPBus transaction (an event is generated for each transaction even if the transaction is merged with another transaction)
21	IPBus idle cycle
22	IPBus master index 0 bytes transferred
23	IPBus master index 1 bytes transferred
24	IPBus master index 2 bytes transferred
25	IPBus master index 3 bytes transferred
26	IPBus master index 4 bytes transferred
27	IPBus master index 5 bytes transferred
28	IPBus master index 6 bytes transferred
29	IPBus master index 7 bytes transferred
30	IPBus master index 8 bytes transferred
31	IPBus master index 9 bytes transferred
32	IPBus master index 10 bytes transferred
33	IPBus master index 11 bytes transferred
34	IPBus master index 12 bytes transferred
35	IPBus master index 14 bytes transferred
36	IPBus master index 15 bytes transferred
37	IPBus master index 16 bytes transferred
38	Maximum number of idle cycles between IPBus transactions[1]
39	IPBus read transaction
40	IPBus write transaction
41	IPBus transaction that transferred between 1 and 16 bytes
42	IPBus transaction that transferred between 17 and 32 bytes

Table 18.2 Event Monitor Sources (Part 2 of 3)

Notes

Event Index	Event Description
43	IPBus transaction that transferred between 33 and 48 bytes
44	IPBus transaction that transferred between 49 and 64 bytes
45	IPBus unaligned transfer transaction (i.e., a transaction starting on a non-word boundary)
46	Number of IPBus transaction merges (each merge is countered within a transaction)
47	IPBus master index 0 transaction
48	IPBus master index 1 transaction
49	IPBus master index 2 transaction
50	IPBus master index 3 transaction
51	IPBus master index 4 transaction
52	IPBus master index 5 transaction
53	IPBus master index 6 transaction
54	IPBus master index 7 transaction
55	IPBus master index 8 transaction
56	IPBus master index 9 transaction
57	IPBus master index 10 transaction
58	IPBus master index 11 transaction
59	IPBus master index 12 transaction
60	External memory and peripheral bus master granted bus
61	IPBus master index 14 transaction
62	IPBus master index 15 transaction
63	IPBus master index 16 transaction

Table 18.2 Event Monitor Sources (Part 3 of 3)

[1.] This field records a maximum count. A shadow counter is maintained that records the actual count, and this counter is incremented only when a shadow count exceeds the value in an actual counter that selects this event.

The event monitor 0 count register has a corresponding compare register. When the value of the COUNT field in EM0COUNT equals or is greater than the value in the COMPARE field of EM0COMPARE, then the Triggered (T) bit in the EM0COMPARE register is set. The T bit in the EM0COMPARE register is presented to the interrupt controller as an interrupt source.

When the EJTAG Debug Interrupt Enable (DIE) bit is set in the EM0COMPARE register, an EJTAG debug interrupt request is generated to the CPU core whenever the T bit is set in the EM0COMPARE register. This allows synchronization between the event monitor and an external EJTAG ICE.

Note: The state of event monitor registers is **not** modified due to a warm reset (i.e., they are not reset).

Note: When an event that occurs at the PCLK clock frequency is selected as an event monitor event source (e.g., CPU instruction executed), the event counter value may be overstated by up to 12 cycles due to synchronization delays (the counter is updated every 12 CPU cycles).

Notes

Event Monitor Control Register

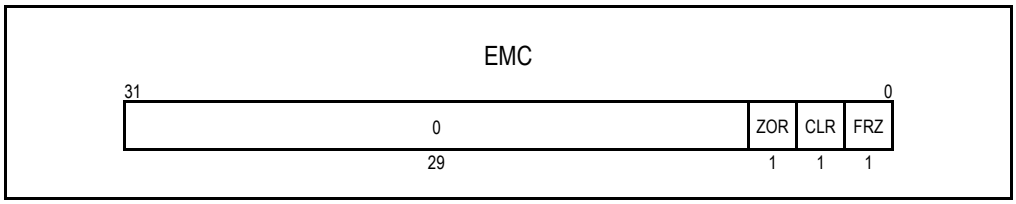


Figure 18.18 Event Monitor Control Register (EMC)

FRZ

Description: **Freeze.** When this bit is set to zero (cleared), event monitor count registers are incremented when the selected event occurs. When this bit is set to one, events are ignored and the event monitor count registers remain "frozen."

Initial Value: 0x1

Read Value: Previous value written

Write Effect: Modify value

CLR

Description: **Clear Counters.** Writing a one to this bit causes the COUNT field in all Event Monitor [0..7] Count (EM[0..7]COUNT) registers to be set to zero (cleared).

Initial Value: 0x0

Read Value: 0x0

Write Effect: Writing a one clears all event monitor counters, writing a zero has no effect

ZOR

Description: **Zero On Read.** When this bit is set to one, reading an event monitor count (EMxCOUNT) register causes it to be automatically cleared as a side effect of the read. **Note**: zero on read works only when the FRZ bit is not set to 1.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Event Monitor [0..7] Count Register

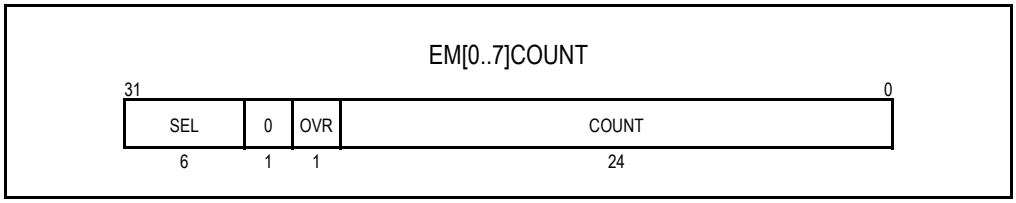


Figure 18.19 Event Monitor [0..7] Count Register (EM[0..7]COUNT)

Notes

COUNT

Description: **Count.** This field contains the current event monitor count.

Initial Value: 0x0

Read Value: Current event count

Write Effect: Modify value

OVR

Description: **Overflow.** This bit is set when the event monitor count register overflows (i.e., when COUNT rolls over from 0xFFFFFF to 0x000000).

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

SEL

Description: **Event Select.** This field selects the event monitor counter event source.

Initial Value: 0x0

Read Value: Previous value written

Write Effect: Modify value

Event Monitor 0 Compare Register

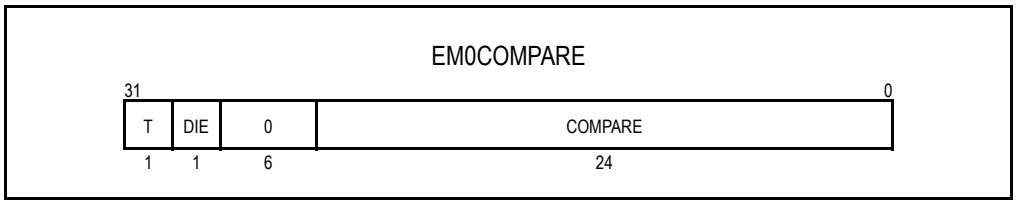


Figure 18.20 Event Monitor 0 Compare Register (EM0COMPARE)

COMPARE

Description: **Event Compare.** When the COUNT field in the Event Monitor 0 Count (EM0COUNT) register is equal to or greater than the value in this field, an event monitor 0 trigger event occurs and the T bit in this register is set.

Initial Value: 0xFF_FFFF

Read Value: Current event count

Write Effect: Modify value

DIE

Description: **Debug Interrupt Enable.** When this bit is set to 1, an EJTAG debug interrupt request is generated to the CPU core whenever the T bit is set. This allows synchronization between the event monitor and an external EJTAG ICE.

Initial Value: 0x0

Notes

Read Value: Previous value written

Write Effect: Modify value

T

Description: **Triggered.** This bit is set when the COUNT value in the EM0COUNT register equals or is greater than the COMPARE value in this register. A subsequent trigger can occur only when the COUNT value becomes less than the COMPARE value (i.e., the counter rolls over or software resets the counter).
Note: The T bit is not set under the following conditions:
(a) when any of the following event indices are selected by event monitor zero: 20 IPBus transaction, 40 IPBus write transaction, 45 IPBus unaligned transfer transaction, or 46 IPBus merged transaction
AND
(b) an IPBus master accesses the on-chip memory when the COUNT value in the EM0COUNT register is equal to or greater than the COMPARE value in that same register.

Initial Value: 0x0

Read Value: Status

Write Effect: Sticky bit (a sticky bit is set by the hardware and can only be cleared by the CPU)

Debug Pins

The RC32438 provides external debug pins to aid in system debugging. The CPU pin is asserted during all DDR and memory and peripheral bus transactions caused by the CPU. During CPU transactions, the INST pin is asserted if the transaction is due to an instruction fetch. The INST and CPU pins are valid whenever a memory and peripheral bus chip select is asserted or when a DDR chip select is asserted during a read or write transaction.

Table 18.3 describes the operation of these pins.

CSNx	DDR-CSNx	CPU	INST	Description
0	1[1]	0	X	DMA read or write from memory and peripheral bus.
0	1	1	0	CPU data read or write from memory and peripheral bus.
0	1	1	1	CPU instruction fetch from memory and peripheral bus.
1	0	0	X	DMA read or write from DDR.
1	0	1	0	CPU data read or write from DDR.
1	0	1	1	CPU instruction fetch from DDR.
0	0	X	0	CPU data read or write from DDR with an external DMA operation to the memory and peripheral bus.
0	0	X	1	CPU instruction fetch from DDR with an external DMA operation to the memory and peripheral bus.

Table 18.3 Debug Pin Operation

1. Don't care.

JTAG Boundary Scan

Notes

Introduction

The RC32438 is a general-purpose integrated processor that incorporates a high performance CPU core and a number of on-chip peripherals. There are 2 TAP controllers on the RC32438, one for the CPU core (referred to as the MIPS32 CPU Core TAP Controller), described in the next chapter (Chapter 20), and one for System Logic controller, described in this chapter.

The System Logic TAP Controller is used to provide conventional standard JTAG Boundary Scan access to the RC32438 pin interface. The MIPS32 CPU Core TAP Controller is used to provide access to the EJTAG interface on the CPU Core.

The two TAP Controllers are connected in parallel as shown in Figure 19.1 and share the JTAG control pins, except for separate JTAG_TMS and EJTAG_TMS pins. Thus, at least one of the two TAP Controllers must be in Test-Logic-Reset at any given time, so that the JTAG_TDO pin is only actively being driven from no more than one of the TAP Controllers. For example, if neither TAP Controller is in use, they both can be reset by asserting JTAG_TRST_N or by asserting both JTAG_TMS and EJTAG_TMS high for 5 consecutive JTAG_TCK clocks. If the MIPS32 CPU Core TAP Controller is to be used, then the System Controller TAP Controller must be reset by asserting JTAG_TMS high for 5 consecutive JTAG_TCK clocks. If the System Controller TAP Controller is to be used, then the MIPS32 CPU Core TAP Controller must be reset by asserting EJTAG_TMS high for 5 consecutive JTAG_TCK clocks.

The MIPS32 CPU Core TAP Controller is used primarily for EJTAG support, since many EJTAG functions are accessed via the MIPS32 CPU Core TAP Controller JTAG port. **Note that the Boundary Scan Register for the internal CPU Core is not used, as it would access internally connected CPU Core ports/pins.** Instead, the System Controller TAP Controller Boundary Scan Register is provided for RC32438 conventional JTAG pin access, control, and boundary scan.

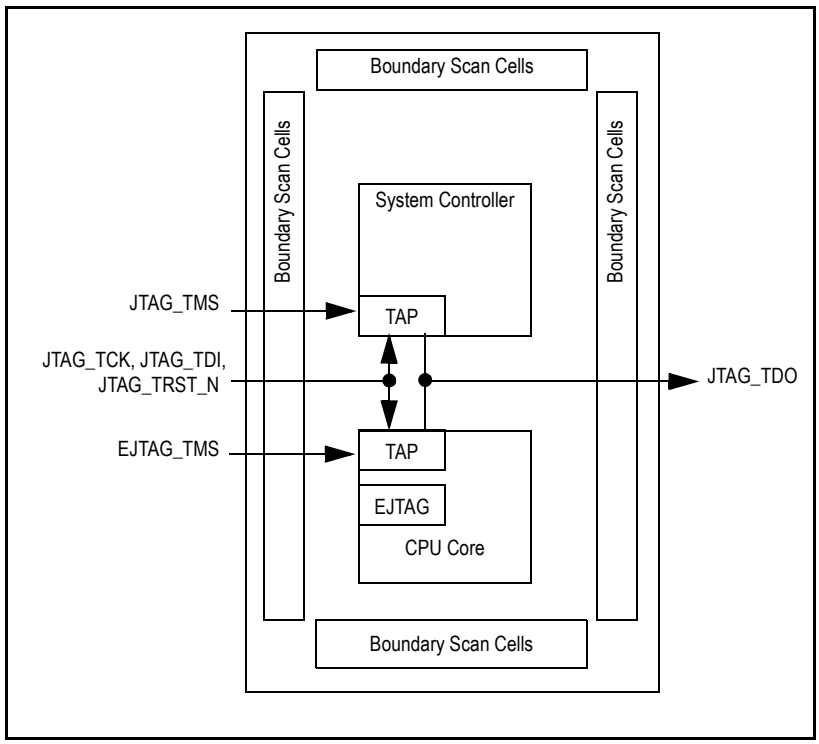


Figure 19.1 Dual TAP Controller Block Diagram

Notes

System Logic TAP Controller Overview

The system logic utilizes a 16-state, six-bit TAP controller, a four-bit instruction register, and five dedicated pins to perform a variety of functions. The primary use of the JTAG TAP Controller state machine is to allow the five external JTAG control pins to control and access the RC32438's many external signal pins. The JTAG TAP Controller can also be used for identifying the device part number. The JTAG logic of the RC32438 is depicted in Figure 19.2.

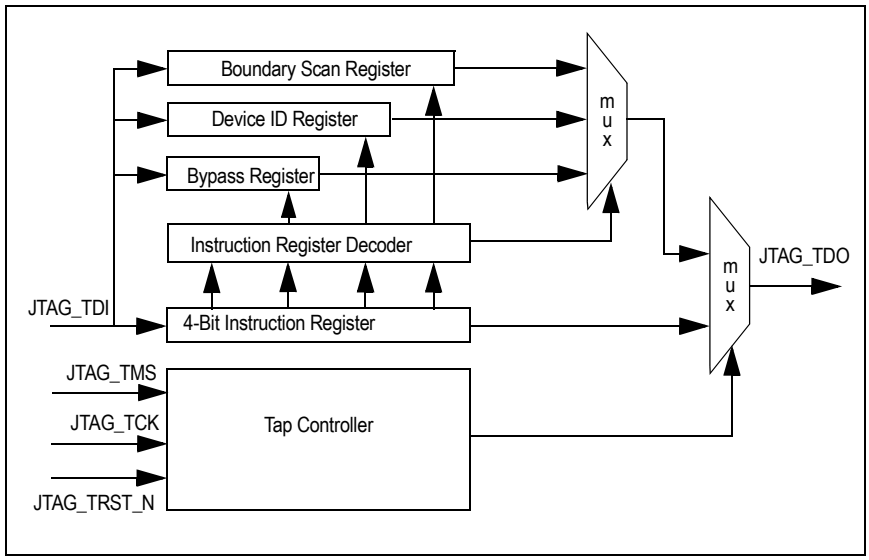


Figure 19.2 Diagram of the JTAG Logic

Signal Definitions

JTAG operations such as Reset, State-transition control and Clock sampling are handled through the signals listed in Table 19.1. A functional overview of the TAP Controller and Boundary Scan registers is provided in the sections following the table.

Pin Name	Type	Description
JTAG_TRST_N	Input	JTAG RESET Asynchronous reset for JTAG TAP controller (internal pull-up)
JTAG_TCK	Input	JTAG Clock Test logic clock. JTAG_TMS and JTAG_TDI are sampled on the rising edge. JTAG_TDO is output on the falling edge.
JTAG_TMS	Input	JTAG Mode Select Requires an external pull-up. Controls the state transitions for the TAP controller state machine (internal pull-up)
JTAG_TDI	Input	JTAG Input Serial data input for BSC chain, Instruction Register, IDCODE register, and BYPASS register (internal pull-up)
JTAG_TDO	Output	JTAG Output Serial data out. Tri-stated except when shifting while in Shift-DR and SHIFT-IR TAP controller states.

Table 19.1 JTAG Pin Descriptions

The system logic TAP controller transitions from state to state, according to the value present on JTAG_TMS, as sampled on the rising edge of JTAG_TCK. The Test-Logic Reset state can be reached either by asserting JTAG_TRST_N or by applying a 1 to JTAG_TMS for five consecutive cycles of

Notes

JTAG_TCK. A state diagram for the TAP controller appears in Figure 19.3. The value next to state represent the value that must be applied to JTAG_TMS on the next rising edge of JTAG_TCK, to transition in the direction of the associated arrow.

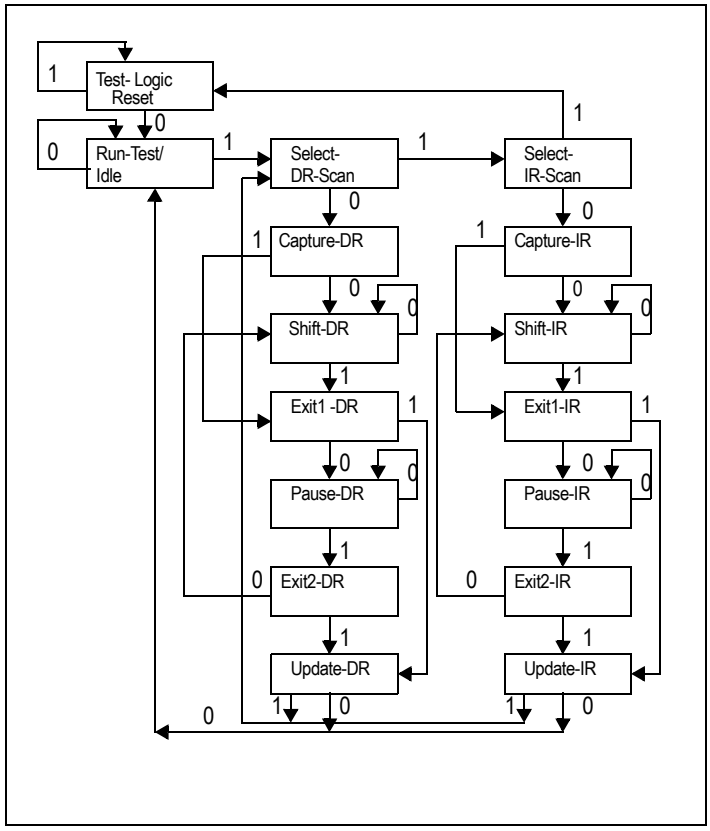


Figure 19.3 State Diagram of RC32438's TAP Controller

Test Data Register (DR)

The Test Data register contains the following:

- *The Bypass register*
- *The Boundary Scan registers*
- *The Device ID register*

These registers are connected in parallel between a common serial input and a common serial data output, and are described in the following sections. For more detailed descriptions, refer to IEEE Standard Test Access port (IEEE Std. 1149.1-1990).

Boundary Scan Registers

The RC32438 scan chain is 489 bits long and comprises 259 logical elements — where each logical element represents a signal pin. The five JTAG pins do not have scan elements associated with them, nor does the EJTAG EJTAG_TMS pin. In addition, DDRVREF does not have scan elements associated with it. Of the 259 logical elements, 141 are two-bit bidirectional cells, 89 are two-bit tri-statable outputs, and 29 are one-bit dedicated inputs.

This boundary scan chain is connected between JTAG_TDI and JTAG_TDO when the EXTEST or SAMPLE/PRELOAD instructions are selected. Once EXTEST is selected and the TAP controller passes through the UPDATE-IR state, whatever value is currently held in the boundary scan register's output latches is immediately transferred to the corresponding outputs or output enables.

Notes

Therefore, the SAMPLE/PRELOAD instruction must first be used to load suitable values into the boundary scan cells, so that inappropriate values are not driven out onto the system pins. All of the boundary scan cells feature a negative edge latch, which guarantees that clock skew cannot cause incorrect data to be latched into a cell. The input cells are sample-only cells. The simplified logic configuration is shown in Figure 19.4.

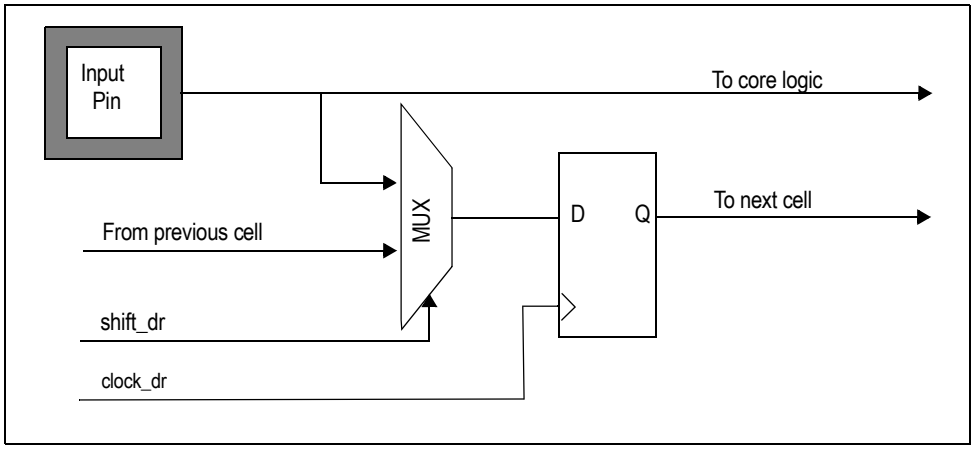


Figure 19.4 Diagram of Observe-only Input Cell

The simplified logic configuration of the output cells is shown in Figure 19.5.

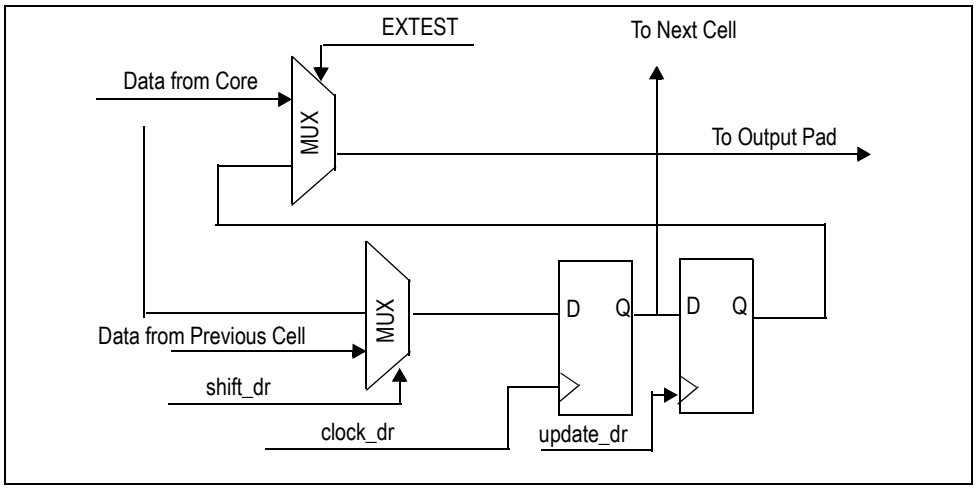


Figure 19.5 Diagram of Output Cell

The output enable cells are also basically output cells. The simplified logic appears in Figure 19.6.

Notes

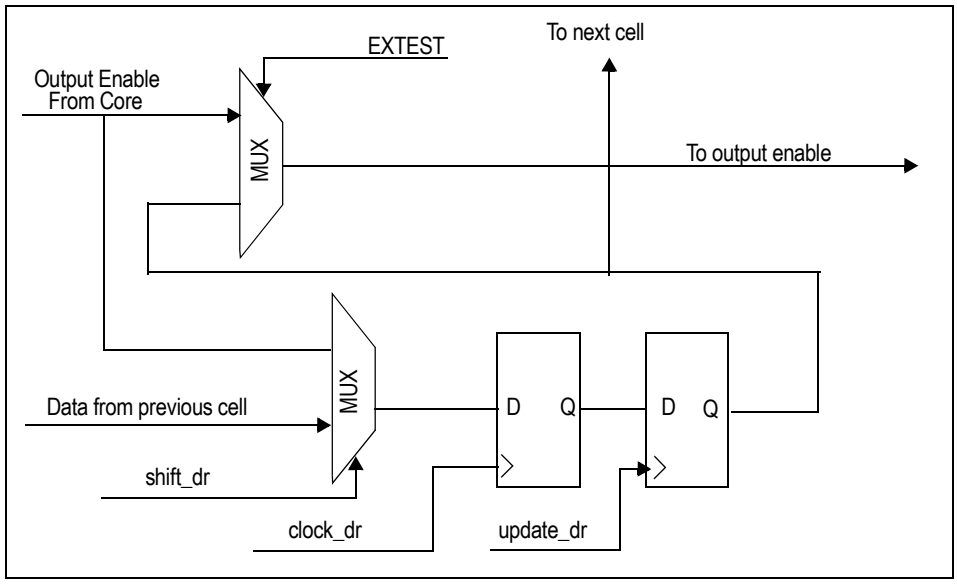


Figure 19.6 Diagram of Output Enable Cell

The bidirectional cells are composed of only two boundary scan cells. They contain one output enable cell and one capture cell, which contains only one register. The input to this single register is selected via a mux that is driven selected by the output enable cell when EXTEST is disabled. When the output enable cell is driving a high out to the pad (which enables the pad for output) and EXTEST is disabled, the single capture register will be configured to capture from the output signal from the core to the pad.

However, in the case where the Output Enable is low (signifying a tri-state condition at the pad) or EXTEST is enabled, then the Capture Register will capture from the input from the pad. The configuration is shown graphically in Figure 19.7.

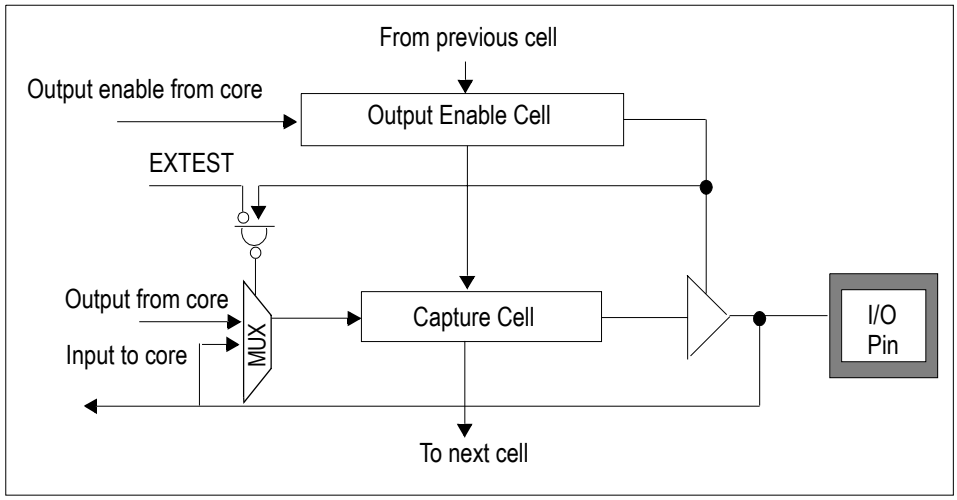


Figure 19.7 Diagram of Bidirectional Cell

Instruction Register (IR)

The Instruction register allows an instruction to be shifted serially into the processor at the rising edge of JTAG_TCK. The instruction is then used to select the test to be performed or the test register to be accessed, or both. The instruction shifted into the register is latched at the completion of the shifting process, when the TAP controller is at the Update-IR state.

Notes

The Instruction register contains six shift-register-based cells that can hold instruction data. This register is decoded to perform the following functions:

- *To select test data registers that may operate while the instruction is current. The other test data registers should not interfere with chip operation and selected data registers.*
- *To define the serial test data register path used to shift data between JTAG_TDI and JTAG_TDO during data register scanning.*

The Instruction Register is comprised of 6 bits to decode instructions, as shown in Table 19.2.

Instruction	Definition	Opcode
EXTEST	Mandatory instruction allowing the testing of board level interconnections. Data is typically loaded onto the latched parallel outputs of the boundary scan shift register using the SAMPLE/PRELOAD instruction prior to use of the EXTEST instruction. EXTEST will then hold these values on the outputs while being executed. Also see the CLAMP instruction for similar capability.	000000
SAMPLE/ PRELOAD	Mandatory instruction that allows data values to be loaded onto the latched parallel output of the boundary-scan shift register prior to selection of the other boundary-scan test instruction. The Sample instruction allows a snapshot of data flowing from the system pins to the on-chip logic or vice versa.	000001
DEVICE_ID	Provided to select Device Identification to read out manufacturer's identity, part, and version number.	000010
HIGHZ	Tri-states all output and bidirectional boundary scan cells.	000011
RESERVED	Behaviorally equivalent to the BYPASS instruction as per the IEEE std. 1149.1 specification. However, the user is advised to use the explicit BYPASS instruction.	000100 — 100011
UNUSED	The unused instructions are behaviorally equivalent to the BYPASS instruction as per the IEEE Std. 1149.1 specification. However, the user is advised to use the explicit BYPASS instruction, as the internal usage of these currently unused instructions could possibly vary in future implementations of the device.	100100 — 101100
VALIDATE	Automatically loaded into the instruction register whenever the TAP controller passes through the CAPTURE-IR state. The lower two bits '01' are mandated by the IEEE std. 1149.1 specification.	101101
UNUSED	Same as other UNUSED instructions above.	101110 — 111100
RESERVED	Behaviorally equivalent to the BYPASS instruction as per the IEEE std. 1149.1 specification. However, the user is advised to use the explicit BYPASS instruction.	111101
CLAMP	Provides JTAG user the option to bypass the part's JTAG controller while keeping the part outputs controlled similar to EXTEST.	111110
BYPASS	The BYPASS instruction is used to truncate the boundary scan register as a single bit in length.	111111

Table 19.2 Instructions Supported By RC32438's JTAG Boundary Scan

EXTEST

The external test (EXTEST) instruction is used to control the boundary scan register, once it has been initialized using the SAMPLE/PRELOAD instruction. Using EXTEST, the user can then sample inputs from or load values onto the external pins of the RC32438. Once this instruction is selected, the user then uses the SHIFT-DR TAP controller state to shift values into the boundary scan chain. When the TAP controller passes through the UPDATE-DR state, these values will be latched onto the output pins or into the output enables.

Notes

SAMPLE/PRELOAD

The sample/preload instruction has a dual use. The primary use of this instruction is for preloading the boundary scan register prior to enabling the EXTEST instruction. Failure to preload will result in unknown random data being driven onto the output pins when EXTEST is selected. The secondary function of SAMPLE/PRELOAD is for sampling the system state at a particular moment. Using the SAMPLE function, the user can halt the device at a certain state and shift out the status of all of the pins and output enables at that time.

BYPASS

The BYPASS instruction is used to truncate the boundary scan register to a single bit in length. During system level use of the JTAG, the boundary scan chains of all the devices on the board are connected in series. In order to facilitate rapid testing of a given device, all other devices are put into BYPASS mode. Therefore, instead of having to shift 499 times to get a value through the RC32438, the user only needs to shift one time to get the value from JTAG_TDI to JTAG_TDO. When the TAP controller passes through the CAPTURE-DR state, the value in the BYPASS register is updated to be 0.

If the device being used does not have a DEVICE_ID register, then the BYPASS instruction will automatically be selected into the instruction register whenever the TAP controller is reset. Therefore, the first value that will be shifted out of a device without a DEVICE_ID register is always 0. Devices such as the RC32438 that include a DEVICE_ID register will automatically load the DEVICE_ID instruction when the TAP controller is reset, and they will shift out an initial value of 1. This is done to allow the user to easily distinguish between devices having DEVICE_ID registers and those that do not.

CLAMP

This instruction, listed as optional in the IEEE 1149.1 JTAG Specifications, allows the boundary scan chain outputs to be clamped to fixed values. When the clamp instruction is issued, the scan chain will bypass the RC32438 and pass through to devices further down the scan chain.

DEVICEID

The DEVICEID instruction is automatically loaded when the TAP controller state machine is reset either by the use of the JTAG_TRST_N signal or by the application of a '1' on JTAG_TMS for five or more cycles of JTAG_TCK as per the IEEE Std 1149.1 specification. The least significant bit of this value must always be 1. Therefore, if a device has a DEVICE_ID register, it will shift out a 1 on the first shift if it is brought directly to the SHIFT-DR TAP controller state after the TAP controller is reset. The board- level tester can then examine this bit and determine if the device contains a DEVICE_ID register (the first bit is a 1), or if the device only contains a BYPASS register (the first bit is 0).

However, even if the device contains a DEVICE_ID register, it must also contain a BYPASS register. The only difference is that the BYPASS register will not be the default register selected during the TAP controller reset. When the DEVICE_ID instruction is active and the TAP controller is in the Shift-DR state, the thirty-two bit value that will be shifted out of the device-ID register is `0x00022067`.

Bit(s)	Mnemonic	Description	R/W	Reset
0	reserved	reserved 0x1	R	1
11:1	Manuf_ID	**Manufacturer Identity** (11 bits) IDT 0x33	R	0x33
27:12	Part_number	**Part Number** (16 bits) This field identifies the part number of the processor derivative. For the RC32438 this value is: 0x0022	R	impl. dep.
31:28	Version	**Version** (4 bits) This field identifies the version number of the processor derivative. For the RC32438, this value is 0x0	R	impl. dep.

Table 19.3 System Controller Device Identification Register

Notes

Version	Part Number	Vendor ID	LSB
0000	0000|0000|0010|0010	0000|0110|011	1

Figure 19.8 System Controller Device ID Instruction Format

VALIDATE

The VALIDATE instruction is automatically loaded into the instruction register whenever the TAP controller passes through the CAPTURE-IR state. The lower two bits '01' are mandated by the IEEE Std. 1149.1 specification.

RESERVED

Reserved instructions implement various test modes used in the device manufacturing process. The user should not enable these instructions.

UNUSED[1]

The unused instructions are behaviorally equivalent to the BYPASS instruction as per the IEEE Std. 1149.1 specification. However, the user is advised to use the explicit BYPASS instruction as the internal usage of these currently unused instructions could possibly vary in future implementations of the device.

Usage Considerations

As previously stated, there are internal pull-ups on JTAG_TRST_N, JTAG_TMS, and JTAG_TDI. However, JTAG_TCK also needs to be driven to a known value. It is best to either drive a zero on the JTAG_TCK pin when it is not being used or to use an external pull-down resistor. In order to guarantee that the JTAG does not interfere with normal system operation, the TAP controller should be forced into the Test-Logic-Reset controller state by continuously holding JTAG_TRST_N low and/or JTAG_TMS high when the chip is in normal operation. If JTAG will not be used, externally pull-down JTAG_TRST_N low to disable it.

1. Any unused instruction is defaulted to the BYPASS instruction

EJTAG System

Notes

Introduction

This chapter describes the behavior and organization of on-chip EJTAG hardware resources on the RC32438 device. EJTAG is a hardware/software subsystem that provides comprehensive debugging and performance tuning capabilities to system-on-a-chip components that include a MIPS CPU core. It exploits the infrastructure provided by the IEEE 1149.1 JTAG Test Access Port (TAP) standard to provide an external interface, and it extends the MIPS instruction set and privileged resource architectures to provide a standard software architecture for integrated system debugging.

The EJTAG probe consists of third party hardware and software that connects to the standard JTAG port. The probe will provide software drivers to handle breakpoints, single step, register inquiries, etc.

Functional Description

EJTAG provides a standard debug I/O interface, enabling the use of traditional MIPS debug facilities on system-on-a-chip components. In addition, EJTAG provides the following new capabilities for software and system debug:

- *Off-board EJTAG Memory*

  EJTAG allows the RC32438 device, when in Debug Mode, to reference instructions or data that are not resident on the system. This EJTAG memory is mapped to the processor as if it were physical memory, and references to it are converted into transactions on the TAP interface. Both instructions and data can be accessed in EJTAG memory, which allows debugging of systems without requiring the presence of a ROM monitor or debugger scratchpad RAM. It also provides a communications channel between debug software executing on the processor and an external debugging agent.

- *Hardware Breakpoints*

  EJTAG introduces two types of hardware breakpoints, which can be configured to cause a debug exception on:

  – *an instruction fetch from a specific virtual address*
  – *a memory reference from a specific virtual address, which additionally can be qualified by a data value.*

  These breakpoints can be used to implement watchpoints and breakpoints in programs executing out of ROM or RAM.

- *Single-Step Execution*

  EJTAG provides support for single-step execution of programs and operating systems, without requiring that the code reside in RAM.

- *System Access via the EJTAG TAP*

  EJTAG allows an external debugging agent connected to the EJTAG TAP to obtain information about the configuration and state of the processor under test and to force processor entry into Debug Mode. Debug software can then provide further system access via EJTAG memory.

- *Debug Breakpoint Instruction*

  EJTAG introduces a new breakpoint instruction, SDBBP, which differs from the MIPS32 and MIPS64 BREAK instruction in that the resulting exception, like the single-step and hardware breakpoint debug exceptions described above, places the processor in Debug Mode and can fetch its associated handler code from EJTAG memory.

Notes

EJTAG Components

EJTAG hardware support consists of several distinct components: extensions to the MIPS processor core, the EJTAG Test Access Port, the Debug Control Register, and the Hardware Breakpoint Unit. Figure 20.1 shows the relationship between these components on the RC32438 device.

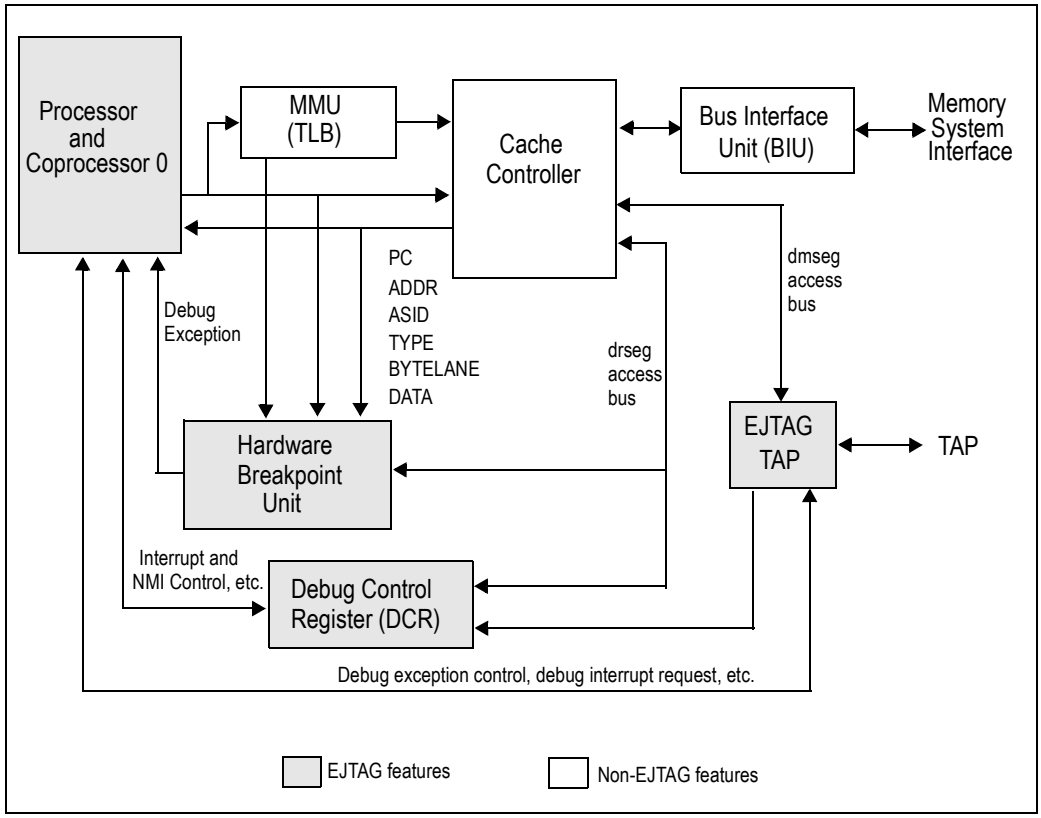


Figure 20.1 Simplified EJTAG Block Diagram

Debug Control Register

The Debug Control Register (DCR) is a memory-mapped register that is implemented as part of the processor core and indicates the availability and status of EJTAG features. The memory-mapped region containing the DCR is available to software only in Debug Mode.

Hardware Breakpoint Unit

The Hardware Breakpoint Unit implements memory-mapped registers that control the instruction and data hardware breakpoints. The memory-mapped region containing the hardware breakpoint registers is accessible to software only in Debug Mode.

EJTAG hardware breakpoint support is implemented with the following functionality:

- *Supports 4 instructions*
- *Supports 2 data hardware breakpoints*
- *Breakpoint address comparisons for instruction and data hardware breakpoints optionally qualified with a comparison of the MMU ASID*
- *Data hardware breakpoints optionally qualified with a data value comparison*

The presence or absence of hardware breakpoint capability is indicated to debug software in the DCR. The number of breakpoints and the availability of optional qualifiers is indicated to debug software in the instruction and data breakpoint status registers.

Notes

Register and Memory Map Overview

This section summarizes the registers and special memory that are used for the EJTAG debug solution.

Coprocessor 0 Register

Table Table 20.1 summarizes the Coprocessor 0 (CP0) registers. These registers are accessible by the debug software executed on the processor; they provide debug control and status information. General information about the debug CP0 registers is found in section “EJTAG Coprocessor 0 Registers” on page 20-24.

Register Name	Register Mnemonic	Functional Description	Reference
Debug	Debug	Debug indications and controls for the processor, including information about recent debug exception.	Refer to section “Debug Register (CP0 Register 23, Select 0)” on page 20-25.
Debug Exception Program Counter	DEPC	Program counter at last debug exception or exception in Debug Mode.	Refer to section “Debug Exception Program Counter Register (CP0 Register 24, Select 0)” on page 20-29.
Debug Exception Save	DESAVE	Scratchpad register available for the debug handler.	Refer to section “Debug Exception Save Register (CP0 Register 31, Select 0)” on page 20-30.

Table 20.1 Overview of Coprocessor 0 Registers for EJTAG

Memory Mapped EJTAG Register

The memory-mapped EJTAG registers are located in the debug register segment (drseg), which is a subsegment of the debug segment (dseg). They are accessible by the debug software when the processor is executing in Debug Mode. These registers provide both miscellaneous debug control and control of hardware breakpoints. General information about the debug segment and registers is found in section “Debug Mode Address Space” on page 20-7.

Debug Control Register

Table 20.2 summarizes the Debug Control Register (DCR) which provides miscellaneous debug control.

Register Name	Register Mnemonic	Functional Description	Reference
Debug Control Register	DCR	Indicates available EJTAG memory, and controls enable of interrupts and NMI in Non-Debug Mode.	Refer to section “Debug Control Register” on page 20-30.

Table 20.2 Overview of Debug Control Register as Memory-mapped Register for EJTAG

Instruction Hardware Breakpoint Register

Table 20.3 summarizes the instruction hardware breakpoint registers, which are controlled through a number of memory-mapped registers. Certain registers are provided for each implemented instruction hardware breakpoint, as indicated with an “n”. General information about the instruction hardware breakpoint registers is found in section “Instruction Breakpoint Registers” on page 20-43.

Notes

Register Name	Register Mnemonic	Functional Description	Reference
Instruction Breakpoint Status	IBS	Indicates number of instruction hardware breakpoints and status on a previous match.	See section “Instruction Breakpoint Status (IBS) Register” on page 20-43.
Instruction Breakpoint Address n	IBAn	Address to compare for breakpoint n.	See section “Instruction Breakpoint Address n (IBAn) Register” on page 20-44.
Instruction Breakpoint Address Mask n	IBMn	Mask for address comparison for breakpoint n.	See section “Instruction Breakpoint Address Mask n (IBMn) Register” on page 20-45.
Instruction Breakpoint ASID n	IBASIDn	ASID value to compare for breakpoint n.	See section “Instruction Breakpoint ASID n (IBASIDn) Register” on page 20-45.
Instruction Breakpoint Control n	IBCn	Control of breakpoint n comparison of ASID and generated event on match.	See section “Instruction Breakpoint Control n (IBCn) Register” on page 20-46.

Table 20.3 Overview of Instruction Hardware Breakpoint Registers

Data Hardware Breakpoint Register

Table 20.4 summarizes the data hardware breakpoints, which are controlled through a number of memory-mapped registers. Certain registers are provided for each implemented data hardware breakpoint, as indicated with an “n”. General information about the data hardware breakpoint registers is found in section “Data Breakpoint Registers” on page 20-47.

Register Name	Register Mnemonic	Functional Description	Reference
Data Breakpoint Status	DBS	Indicates number of data hardware breakpoints and status on a previous match.	See section “Data Breakpoint Status (DBS) Register” on page 20-47.
Data Breakpoint Address n	DBAn	Address to compare for breakpoint n.	See section “Data Breakpoint Address n (DBAn) Register” on page 20-48.
Data Breakpoint Address Mask n	DBMn	Mask for address comparison for breakpoint n.	See section “Data Breakpoint Address Mask n (DBMn) Register” on page 20-49.

Table 20.4 Overview of Data Hardware Breakpoint Registers (Part 1 of 2)

Notes

Register Name	Register Mnemonic	Functional Description	Reference
Data Breakpoint ASID n	DBASIDn	ASID value to compare for breakpoint n.	See section “Data Breakpoint ASID n (DBASIDn) Register” on page 20-49.
Data Breakpoint Control n	DBCn	Control of breakpoint n match on load/store, data bytes, access to data bytes, comparison of ASID, and generated event on match.	See section “Data Breakpoint Control n (DBCn) Register” on page 20-49.
Data Breakpoint Value n	DBVn	Data value to match for breakpoint n.	See section “Data Breakpoint Value n (DBVn) Register” on page 20-51.

Table 20.4 Overview of Data Hardware Breakpoint Registers (Part 2 of 2)

Memory-mapped EJTAG Memory

The memory-mapped EJTAG memory is located in the debug memory segment (dmseg), which is a subsegment of the debug segment (dseg). It is accessible by the debug software when the processor is executing in Debug Mode. The EJTAG probe handles all accesses to this segment through the Test Access Port (TAP), whereby the processor has access to dedicated debug memory even if no debug memory was originally located in the system. General information about the debug segment and memory is found in section “Debug Mode Address Space” on page 20-7.

EJTAG Test Access Port Registers

The probe accesses EJTAG TAP registers (shown in Table 20.5) through the TAP, so the processor can not access these registers. These registers allow specific control of the target processor through the TAP. General information about the TAP registers is found in section “TAP Data Registers” on page 20-59.

Register Name	Register Mnemonic	Functional Description	Reference
Device ID	none	Identifies device and accessed processor in the device.	See section “Device Identification (ID) Register (TAP Instruction IDCODE)” on page 20-61.
Implementation	none	Identifies main debug features implemented and accessible through the TAP.	See section “Implementation Register (TAP Instruction IMPCODE)” on page 20-61.
Data	none	Data register for processor accesses used to support the EJTAG memory.	See section “Data Register (TAP Instruction DATA, ALL, or FASTDATA)” on page 20-62.

Table 20.5 Overview of Test Access Port Registers (Part 1 of 2)

Notes

Register Name	Register Mnemonic	Functional Description	Reference
Address	none	Address register for processor access used to support the EJTAG memory.	See section “Address Register (TAP Instruction ADDRESS or ALL)” on page 20-63.
EJTAG Control	ECR	Control register for most EJTAG features used through the TAP.	See section “EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)” on page 20-64.
Bypass	none	Provides a one-bit shift path through the TAP.	See section “Bypass Register (TAP Instruction BYPASS, (EJTAG/NORMAL) BOOT, or Unused)” on page 20-68.

Table 20.5 Overview of Test Access Port Registers (Part 2 of 2)

Pin Description

Signal	Type	Name/Description
EJTAG_TMS	I	**EJTAG Mode**. The value on this signal controls the test mode select of the EJTAG Controller. When using the JTAG boundary scan, this pin should be left disconnected (since there is an internal pull-up) or driven high.
JTAG_TCK	I	**JTAG Clock**. This is an input test clock, used to clock the shifting of data into or out of the boundary scan logic, JTAG Controller or the EJTAG Controller. JTAG_TCK is independent of the system and the processor clock with nominal 50% duty cycle.
JTAG_TDI	I	**JTAG Data Input**. This is the serial data input to the boundary scan logic, JTAG Controller, or the EJTAG Controller.
JTAG_TDO	O	**JTAG Data Output**. This is the serial data shifted out from the boundary scan logic, JTAG Controller, or the EJTAG Controller. When no data is being shifted out, this signal is tri-stated.
JTAG_TMS	I	**JTAG Mode**. The value on this signal controls the test mode select of the boundary scan logic or JTAG Controller. When using the EJTAG debug interface, this pin should be left disconnected (since there is an internal pull-up) or driven high.
JTAG_TRST_N	I	**JTAG Reset**. This active low signal asynchronously resets the boundary scan logic, JTAG TAP Controller, and the EJTAG Debug TAP Controller. An external pull-up on the board is recommended to meet the JTAG specification in cases where the tester can access this signal, however, specific systems when running in functional mode ordinarily should either: 1) actively drive this signal low with control logic 2) statically drive this signal low with an external pull-down on the board 3) clock JTAG_TCK while holding EJTAG_TMS and/or JTAG_TMS high.

Table 20.6 JTAG / EJTAG Pin Description

EJTAG Processor Core Extensions

Overview

The extensions for EJTAG provide the following major features:

Notes

- *Debug Mode, associated exceptions and dedicated debug vector*
- *Instruction set extensions: SDBBP (Software Debug Breakpoint) and DERET (Debug Exception Return)*
- *CP0 registers: Debug, DEPC and DESAVE*
- *Memory-mapped debug segment (dseg)*
- *Interrupt and NMI control*
- *Single step*
- *Debug interrupt request signal*

Debug Mode Execution

Debug Mode is entered only through a debug exception. It is exited as a result of either execution of a DERET instruction or application of a reset or soft reset.

When the processor is operating in Debug Mode it has access to the same resources, instructions, and CP0 registers as in Kernel Mode. Restrictions on Kernel Mode access (non-zero coprocessor references, access to extended addressing controlled by UX, SX, KX, etc.) apply equally to Debug Mode, but Debug Mode provides some additional capabilities as described in this chapter.

Other processor modes (Kernel Mode, Supervisor Mode, User Mode) are collectively considered as Non-Debug Mode. Debug software can determine if the processor is in Non-Debug Mode or Debug Mode through the DM bit in the Debug register.

Debug Mode Instruction Set

The full native ISA of the processor is accessible in Debug Mode. Coprocessor loads and stores to the dseg segment are not supported. The operation of the processor is UNDEFINED if a coprocessor load or store to dseg is executed in Debug Mode. Refer to section “Debug Mode Address Space” on page 20-7 for more information on the dseg address space.

Debug Mode Address Space

Debug Mode access to unmapped address space is identical to that of Kernel Mode. Mapped areas are accessible as in Kernel Mode, but only if a valid translation is possible immediately by the MMU. The reason is that a memory accesses that would cause an TLB-type exception if tried from Kernel Mode will cause re-entry into Debug Mode (see section “Debug Mode Exceptions” on page 20-19) through an exception if the memory access is tried while in Debug Mode. Memory accesses usually causing TLB-type exception are therefore not handled by the usual memory management routines if these memory accesses are made while in Debug Mode. Updating and handling of cached areas is the same as that in Kernel Mode.

In addition, an uncached and unmapped debug segment dseg (EJTAG area) appears in the address range 0xFF20 0000 to 0xFF3F FFFF. The dseg thereby appears in the kseg part of the compatibility segment, and access to kseg is possible with dseg provided as described in section “Debug Mode Address Space” on page 20-7. Coprocessor loads and stores to dseg are not allowed.

The dseg area is implemented only if the Debug Control Register (DCR) is included in the implementation. Refer to “Debug Control Register” on page 20-30 for additional information on the DCR. The implementation-dependent value of the NoDCR bit in the Debug register (see section “Debug Register (CP0 Register 23, Select 0)” on page 20-25) indicates the presence of the dseg segment as shown in Table 20.7. If dseg is not present, then all transactions from the processor in Debug Mode go to the Kernel Mode address space. Debug software must check the DebugNoDCR bit before trying to access the dseg segment.

Notes

NoDCR bit in Debug Register	dseg Presence
0	dseg present
1	no dseg

Table 20.7 Overview of Test Access Port Registers

Conditions for access to dseg are described in section “Access to dmseg (EJTAG memory) Address Range” on page 20-9 and section “Access to drseg (EJTAG Registers) Address Range” on page 20-10. Figure 2-1 shows the layout of the virtual address space.

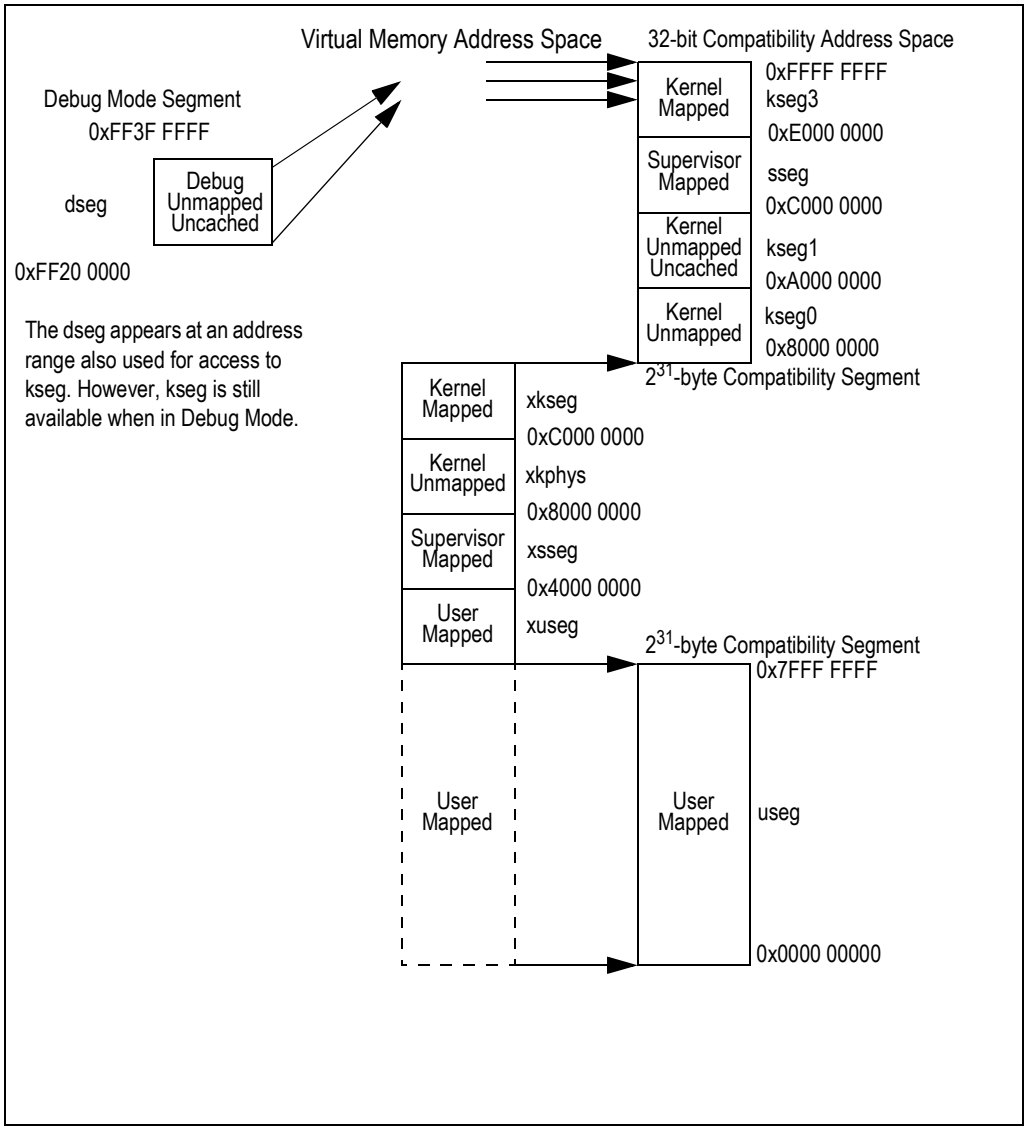


Figure 20.2 Virtual Address Spaces with Debug Mode Segments

Notes

The dseg segment is subdivided into dmseg (EJTAG memory) segment and the drseg (EJTAG registers) segment. The dmseg segment is used when the probe services the memory segment. The drseg segment is used when the memory-mapped debug registers are accessed. Table 20.8 shows the subdivision and attributes for the segments.

Segment Name	Subsegment Name	Virtual Address	Reference Address	Cache Attribute
dseg	dmsg	0xFF20 0000 to 0xFF2F FFFF	Because the dseg address range is serviced exclusively by the EJTAG features, there are no physical address per se. Instead the lower 21 bits of the virtual address select the appropriate reference in either EJTAG memory or registers. References are not mapped through the TLB, nor do the accesses appear on the external system memory interface.	Uncached
	dreg	0xFF30 0000 to 0xFF3F FFFF		

Table 20.8 Physical Address and Cache Attribute for dseg's dmsg and drseg

The SYNC instruction, followed by appropriate spacing (as described in section "SYNC Instruction Behavior" on page 20-11 and section "CP0 and dseg Hazards" on page 20-12) must be executed to ensure that an access to dseg is committed (for example, after writing to dseg and before leaving Debug Mode). This procedure ensures that locations in dseg are fully updated for Non-Debug Mode, otherwise behavior of the processor is UNDEFINED.

Access to dmseg (EJTAG memory) Address Range

Table 20.9 shows the behavior of processor accesses in Debug Mode to the dmseg address range from 0xFF20 0000 to 0xFF2F FFFF.

NoDCR bit in Debug Register	Transaction	ProbEn bit in DCR Register	LSNM bit in Debug Register	Access
1	x[1]	(Not present)	0 (read only)	Kernel Mode address space
0	Fetch	1	x	dmseg
		0	x	See note below table on ProbEn behavior
	Load/Store	1	0	dmseg
			1	Kernel Mode address space
		0	1	Kernel Mode address space
			0	See note below table on ProbEn behavior

Table 20.9 Access to dmseg Address Range

1. x = don't care

Notes

Note: When ProbEn equals 0 for dmseg accesses, debug software accessed dmseg when the ProbEn bit was 0, indicating that there is no probe available to service the request. Debug software must read the state of the ProbEn bit in the DCR register before attempting to reference dmseg. However, accessing dmseg while ProbEn is 0 can occur because there is an inherent race between the debug software sampling the ProbEn bit as 1 and the probe clearing it to 0. The probe can therefore not assume that a reference to dmseg never occurs if the ProbEn bit is dynamically cleared to 0. If debug software references dmseg when ProbEn is 0, the reference hangs until it is satisfied by the probe.

There are no timing requirements with respect to transactions to dmseg, which the probe services. Therefore, a system watchdog must be disabled during dseg transactions, so accesses can take any amount of time without being terminated. The protocol for accesses to dmseg does not allow a transaction to be aborted once started, except by a reset or soft reset. Transactions of all sizes are allowed to dmseg.

Merging is allowed for accesses to dmseg, whereby for example two byte accesses can be merged to one halfword access, and debug software is thus required to allow merging. However, merging must only occur for accesses which can be combined into legal processors accesses, since processor access can only indicate accesses which can occur due to a single load/store, thus not for example accesses to only first and last bytes of a word. The SYNC instruction, followed by appropriate spacing, can be executed to ensure that earlier accesses to dmseg are committed thus will not be merged with later accesses.

The processor can do speculative fetching from dmseg whereby it can fetch doublewords even if an instruction that is not required in the execution flow is thereby fetched. For example, if the DERET instruction is fetched as the first word of a doubleword, the instruction in the second word is not executed. For details, refer to architecture description covering speculative fetching from uncached area in general.

If the TAP is not present in the implementation, the operation of the processor is UNDEFINED if the dmseg is accessed.

Access to drseg (EJTAG Registers) Address Range

NoDCR bit in Debug Register	Trans-action	LSNM bit in Debug Register	Access
1	x[1]	0 (read only)	Kernel Mode address space
	Fetch	x	Operation of the processor is UNDEFINED at fetch.
	Load/Store	0	drseg
		1	Kernel Mode address space

Table 20.10 Access to drseg Address Range

1. x = don't care

Note: Instruction fetches from drseg are not allowed. The operation of the processor is UNDEFINED if the processor tries to fetch from drseg.

When the NoDCR bit is 0 in the Debug register, it indicates that the processor is allowed to access the entire drseg segment and can therefore respond to all transactions to drseg.

The DCR register, at offset 0x0000 in drseg, is always available if dseg is present. Debug software is expected to read the DCR register to determine what other memory-mapped registers exist in drseg. The value returned in response to a read of any un-implemented memory-mapped register is UNPREDICTABLE, and writes are ignored to any un-implemented register in drseg. The allowed transaction size is limited for drseg. Only word size transactions are allowed for 32-bit processors, and only doubleword size transactions are allowed for 64-bit processors. Operation of the processor is UNDEFINED for other transaction sizes.

Notes

Debug Mode Handling of Processor Resources

Unless otherwise specified, the processor resources in Debug Mode are handled identically to those in Kernel Mode. Some identical cases are described in the following sections for emphasis. In addition, see the following related sections for more information:

"Debug Mode Exceptions" on page 20-19 covering exception handling in Debug Mode.

"Interrupts and NMIs" on page 20-21 for handling in both Debug and Non-Debug Modes.

"Reset and Soft Reset of Processor" on page 20-22 for handling in both Debug and Non-Debug Modes.

Coprocessors

A Debug Mode Coprocessor Unusable exception is raised under the same conditions as for a Coprocessor Unusable exception in Kernel Mode (see section "Exceptions Taken in Debug Mode" on page 20-19). Therefore, Debug Mode software cannot reference Coprocessors 1 through 2 without first setting the respective enable in the Status register.

Random Register

The Random register (CP0 register 1, select 0) can be frozen in Debug Mode, whereby execution with and without debug exceptions are identical with respect to TLB exception handling. If the values that the Random register provides cannot be identical in behavior to the case where debug exceptions do not occur, then freezing the Random register has no effect, because execution with and without debug exceptions will not be identical. Stalls when entering Debug Mode (for example, due to pending scheduled loads resolved at context save in the debug handler) can make it impossible in some implementations to ensure that the Random register will provide the same set of values when running with and without debug exceptions.

There is no bit to indicate or control if the Random register is frozen in Debug Mode, so the user must consult system documentation.

Counter Register

The Count register (CP0 register 9) operation in Debug Mode depends on the state of the CountDM bit in the Debug register (see section "Debug Register (CP0 Register 23, Select 0)" on page 20-25). The Count Register has three possible configurations, depending on the implementation:

- *Count register runs in Debug Mode the same as in Non-Debug Mode*
- *Count register is stopped in Debug Mode but is running in Non-Debug Mode*
- *The CountDM bit controls the Count register behavior in Debug Mode whereby it can be either running or stopped.*

Stopping of the Count register in Debug Mode is allowed in order to prevent generation of an interrupt at every return to Non-Debug Mode, if the debug handler takes so long to execute that the Count/Compare registers request an interrupt. In this case, system timing behavior might not be the same as if no debug exception occurred.

WatchLo/WatchHi Registers

The WatchLo/WatchHi registers (CP0 Registers 18 and 19) are inhibited from matching any instruction executed in Debug Mode.

Load Linked (LL/LLD) and Store Conditional (SC/SCD) Instruction Pair

A DERET instruction does not clear the LLbit (see section "DERET Instruction" on page 20-24), neither does the occurrence of a debug exception. Loads and stores to uncacheable locations that do not match the physical address of the previous LL instruction do not affect the result of SC instruction. The value of the LLbit is not directly visible by software.

SYNC Instruction Behavior

The SYNC instruction is used to request the hardware to commit certain operations before proceeding. For example, a SYNC is required to remove memory hazards on reference to dseg. Also, the SYNC instruction ensures that status bits in the Debug register and the hardware breakpoint registers are fully updated

Notes

before the debug handler accesses them and before Debug Mode is exited. Similarly, a SYNC combined with appropriate spacing is used to remove Coprocessor 0 (CP0) hazards (see the next section, CP0 and dseg Hazards). The SYNC instruction must provide specific behavior as described in Table 20.11.

Behavior	References
Commit accesses to dseg	See section “Debug Mode Address Space” on page 20-7.
Update the DDBLImpr and DDBSImpr bits in the Debug register	See section “Debug Data Break Load/Store Imprecise Exception” on page 20-17 and section “Debug Register (CP0 Register 23, Select 0)” on page 20-25.
Update the BS bits in the IBS and DBS registers in drseg	See section “Debug Exception by Data Breakpoint” on page 20-40.
Update the IBusEP, DBusEP, CacheEP, and MCheckP bits in the Debug register	See section “Exceptions on Imprecise Errors” on page 20-20 and section “Debug Register (CP0 Register 23, Select 0)” on page 20-25.

Table 20.11 SYNC Instruction References

The SYNC instruction must be executed before leaving Debug Mode in order to commit all accesses to dseg, such as accesses to set up hardware breakpoints. It may be necessary to remove hazards in relation to the SYNC instruction. Other requirements of the SYNC instruction is described in the MIPS32 and MIPS64 specifications.

CP0 and dseg Hazards

Because resources controlled via Coprocessor 0 and EJTAG memory and registers in dseg affect the operation of various pipeline stages of the processor, manipulation of these resources may produce results that are not detectable by subsequent instructions for some number of execution cycles. When no hardware interlock exists between one instruction that causes an effect that is visible to a second instruction, a CP0 or dseg hazard exists.

Implementations can place the entire burden on the debug software to pad the instruction stream in such a way that the second instruction is spaced far enough from the first that the effects of the first are seen by the second. Otherwise, the implementations can add full hardware interlocks such that the debug software need not pad. The trade-off is between debug software changes for each new processor vs. more complex hardware interlocks required in the processor. The EJTAG Architecture does not dictate the solution that is required for a compatible implementation. The choice of implementation ranges from full hardware interlocks to full dependence on debug software padding, to some combination of the two. For an implementation choice that relies on debug software padding, see Table 20.12 which lists the “typical” spacing required to allow the consumer to eliminate the hazard. The “required” values shown in this table represent spacing that is required to be used by debug software. An implementation which requires less spacing to clear the hazard (including one which has full hardware interlocking) should operate correctly with the debug software that uses this hazard table. An implementation which requires more spacing to clear the hazard incurs the burden of validating debug software against the new hazard requirements.

Notes

Producer	→	Consumer	Hazard On	"Required" spacing (cycles)
SYNC	→	DERET	dseg memory locations	2
SYNC	→	Load/Store	BS bits in the IBS and DBS registers in drseg	2
SYNC	→	MFCO Debug	$Debug_{DDBSImpr}$ $Debug_{DDBLImpr}$ $Debug_{IBusEP}$ $Debug_{DBusEP}$ $Debug_{CacheEP}$ $Debug_{MCheckP}$	2
MTCO DEPC	→		DEPC	2
MTCO Debug	→	DERET	Debug	2
MTCO Debug[LSNM]	→	lOAD/sTORE IN DSEG	Debug[LSNM]	3
MTCO Debug[IEXI]	→	Instructions that can cause an imprecise exception	Debug[IEXI]	3

Table 20.12 "Required" CP0 and dseg Hazard Spacing

Dependencies from the SYNC instruction as producer takes effect since specific updates of dseg memory and resolving of pending imprecise exception indications are triggered by the SYNC instruction. This is described in the SYNC Instruction Behavior section. Note that, for superscalar MIPS implementations, the number of instructions issued per cycle may be greater than one, and thus that the duration of the hazard in instructions may be greater than the duration in cycles. For this reason, the SSNOP instruction is defined to convert instruction issues to cycles in a superscalar design.

SSNOP Instruction Behavior

The SSNOP instruction ensures that instructions are executed and not eliminated by processors during optimization. The SSNOP instruction can be used, for example, with execution of the SYNC and MTC0/DMTC0 instruction to remove CP0 and dseg hazards.

Debug Exceptions

Debug exceptions bring the processor from Non-Debug Mode into Debug Mode. Implementations need only support those debug exceptions that are applicable to that implementation. Exceptions can occur in Debug Mode, and these are denoted as debug mode exceptions. These exceptions are handled differently from exceptions that occur in Non-Debug Mode, as described in section "Debug Mode Exceptions" on page 20-19.

Debug Exception Priorities

Table 20.13 lists the exceptions that can occur in Non-Debug Mode in order of priority, from highest to lowest. The table also categorizes each exception with respect to type (debug or non-debug). Each debug exception has an associated status bit in the Debug register (indicated in the table in parentheses). For additional information, refer to section "Debug Register (CP0 Register 23, Select 0)" on page 20-25.

Notes

Priority	Exception	Exception Type
Highest	Reset	Non-Debug
	Soft Reset	
	Debug Single Step	Debug
	Debug Interrupt; by external signal (DINT), from EjtagBrk in TAP, or through use of EJTAG Boot.	
	Debug Data Break Load/Store Imprecise (DDBLImpr/DDBSImpr).	
	Nonmaskable Interrupt (NMI)	Non-Debug
	Machine Check	
	Interrupt	
	Deferred Watch	
	Debug Instruction Break	Debug
	Watch on instruction fetch	Non-Debug
	Address error on instruction fetch	
	TLB refill on instruction Ifetch	
	TLB Invalid on instruction Ifetch	
	Cache error on instruction Ifetch	
	Bus error on instruction Ifetch	
	Debug Breakpoint; execution of SDBBP instruction	Debug
	Other execution-based exceptions	Non-Debug
	Debug Data Break on Load/Store address match only or Debug Data Break on Store address+data value match	Debug
	Watch on data access	Non-Debug
	Address error on data access	
	TLB Refill on data access	
	TLB Invalid on data access	
	TLB Modified on data access	
	Cache error on data access	
	Bus error on data access	
Lowest	Debug Data Break on Load address+data match	Debug

Table 20.13 Priority of Non-Debug and Debug Exceptions

The specific implementation determines which exceptions can occur and the priority of asynchronous exceptions, such as interrupts.

Debug Exception Vector Location

The same debug exception vector location is used for all debug exceptions. The ProbTrap bit in the EJTAG Control Register (ECR) in the optional Test Access Port (TAP) determines the vector location.

Notes

ProbTrap bit in ECR Register	Debug Exception Vector Address
0	0xBFC0 0480
1	0xFF20 0200 in dmseg

Table 20.14 Debug Exception Vector Location

General Debug Exception Processing

All debug exceptions have the same basic processing flow:

- *The DEPC register is loaded with the PC at which execution can be restarted, and the DBD bit is set to indicate whether the last debug exception occurred in a branch delay slot. The value loaded into the DEPC register is either the current PC (if the instruction is not in the delay slot of a branch) or the PC of the branch or jump (if the instruction is in the delay slot of a branch or jump).*
- *The DSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr, and DDBSImpr bits in the Debug register are updated appropriately depending on the debug exception.*
- *DExcCode field in the Debug register is undefined.*
- *Halt and Doze bits in the Debug register are updated appropriately.*
- *IEXI bit is set to inhibit imprecise exceptions in the start of the debug handler.*
- *DM bit in the Debug register is set to 1.*
- *The processor begins fetching instructions from the debug exception vector.*

The value loaded into the DEPC register represents the restart address from the debug exception and does not need to be modified by the debug exception handler software. Debug software need only look at the DBD bit in the Debug register if it wishes to identify the address of the instruction that actually caused a precise debug exception.

The DSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr, and DDBSImpr bits in the Debug register indicate the occurrence of distinct debug exceptions, except when a Debug Data Break Load/Store Imprecise exception occurs (see section “Debug Data Break Load/Store Imprecise Exception” on page 20-17). Note that occurrence of an exception while in Debug mode will clear these bits. The handler can thereby determine whether an debug exception or an exception in Debug Mode occurred. No other CP0 registers or fields are changed due to the debug exception, thus no additional state is saved. The overall exception processing flow is shown below:

Operation:

```
if (InstructionInBranchDelaySlot) then
    DEPC ¨ BranchInstructionPC
    DebugDBD ¨ 1
else
    DEPC ¨ PC
    DebugDBD ¨ 0
endif
DebugDSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr and DDBSImpr ¨ DebugExceptionType
DebugDExcCode ¨ UNPREDICTABLE
DebugHalt ¨ HaltStatusAtDebugException
DebugDoze ¨ DozeStatusAtDebugException
DebugIEXI ¨ 1
```

Notes

DebugDM ¨ 1

if ECRProbTrap = 1 then

PC ¨ 0xFF20 0200

else

PC ¨ 0xBFC0 0480

endif

Debug Breakpoint Exception

A Debug Breakpoint exception occurs when an SDBBP instruction is executed. The contents of the DEPC register and the DBD bit in the Debug register indicate that the SDBBP instruction caused the debug exception.

Debug Register Debug Status Bit Set

DBp

Additional State Saved

None

Entry Vector Used

Debug exception vector

Debug Instruction Break Exception

A Debug Instruction Break exception occurs when an instruction hardware breakpoint matches an executed instruction. The DEPC register and DBD bit in the Debug register indicate the instruction that caused the instruction hardware breakpoint match.

Debug Register Debug Status Bit Set

DIB

Additional State Saved

None

Entry Vector Used

Debug exception vector

Debug Data Break Load/Store Exception

A Debug Data Break Load/Store exception occurs when a data hardware breakpoint matches the load/store address of an executed load/store instruction. The DEPC register and DBD bit in the Debug register indicate the load/store instruction that caused the data hardware breakpoint to match, as this is a precise debug exception. The load/store instruction that caused the debug exception has not completed (it has not updated the destination register or memory location), and the instruction therefore is executed on return from the debug handler.

Debug Register Debug Status Bit Set

DDBL for a load instruction or DDBS for a store instruction

Additional State Saved

None

Entry Vector Used

Debug exception vector

Notes

Debug Data Break Load/Store Imprecise Exception

A Debug Data Break Load/Store Imprecise exception occurs when a data hardware breakpoint matches a load/store access of an executed load/store instruction, if it is not possible to take a precise debug exception on the instruction. This case occurs when a data hardware breakpoint was set up with a value compare, and a load access did not return data until after the load instruction had left the pipeline as for non-blocking loads. The DEPC register and the DBD bit in the Debug register indicate an instruction later in the execution flow instead of the load/store instruction that caused the data hardware breakpoint to match. The DDBLImpr/DDBSImpr bits in the Debug register indicate that a Debug Data Break Load/Store Imprecise exception occurred. The instruction that caused the Debug Data Break Load/Store Imprecise exception will have completed. It updates its destination register, and is not executed on return from the debug handler.

Imprecise debug exceptions from data hardware breakpoints are indicated together with another debug exception if the load/store transaction that made the data hardware breakpoint match did not complete until after another debug exception occurred. In this case, the other debug exception was the cause of entering Debug Mode, so the DEPC register and the DBD bit in Debug register point to this instruction. DDBLImpr/DDBSImpr are set concurrently with the status bit for that debug exception.

The SYNC instruction, followed by appropriate spacing (as described in section “SYNC Instruction Behavior” on page 20-11 and section “CP0 and dseg Hazards” on page 20-12), must be executed in Debug Mode before the DDBLImpr and DDBSImpr bits in the Debug register and the BS bits for the data hardware breakpoint are read in order to ensure that all imprecise breaks are resolved and the bits are fully updated. A match of the data hardware breakpoint is indicated in DDBLImpr/DDBSImpr so the debug handler can handle this together with the debug exception.

This scheme ensures that all breakpoints matching due to code executed before the debug exception are indicated by the DDBLImpr, DDBSImpr, and BS bits for the following debug handler. Matches are neither queued nor do they cause debug exceptions at a later point. A debug exception occurring later than the debug exception handler is therefor caused by code executed in Non-Debug Mode after the debug exception handler.

Debug Register Debug Status Bit Set

DDBLImpr for a load instruction or DDBSImpr for a store instruction

Additional State Saved

None

Entry Vector Used

Debug exception vector

Debug Single Step Exception

When single-step mode is enabled, a Debug Single Step exception occurs each time the processor has taken a single execution step in Non-Debug Mode. An execution step is a single instruction, or an instruction pair consisting of a jump/branch instruction and the instruction in the associated delay slot. The SSt bit in the Debug register enables Debug Single Step exceptions. They are disabled on the first execution step after a DERET.

The DEPC register points to the instruction on which the Debug Single Step exception occurred, which is also the next instruction to execute when returning from Debug Mode. The debug software can examine the system state before this instruction is executed. Thus, the DEPC will not point to the instruction(s) that have just executed in the execution step, but rather the instruction following the execution step. The Debug Single Step exception never occurs on an instruction in a jump/branch delay slot, because the jump/branch and the instruction in the delay slot are always executed in one execution step; thus the DBD bit in the Debug register is never set for a Debug Single Step exception.

Notes

Exceptions occurring on the instruction(s) in the execution step are taken regardless, so if a non-debug exception occurs (other than reset or soft reset), a Debug Single Step exception is taken on the first instruction in the non-debug exception handler. The non-debug exception occurs during the execution step, and the instruction(s) that received a non-debug exception counts as the execution step.

Debug exceptions are unaffected by single-step mode; returning to an SDBBP instruction with single step enabled causes a Debug Breakpoint exception with the DEPC register pointing to the SDBBP instruction. Also, returning to an instruction (not jump/branch) just before the SDBBP instruction causes a Debug Single Step exception with the DEPC register pointing to the SDBBP instruction.

To ensure proper functionality of single-step execution, the Debug Single Step exception has priority over all exceptions, except resets and soft resets.

Debug Single Step exception is only possible when the NoSSt bit in the Debug register is 0 (see section "Debug Register (CP0 Register 23, Select 0)" on page 20-25).

Debug Register Debug Status Bit Set

DSS

Additional State Saved

None

Entry Vector Used

Debug exception vector

Debug Interrupt Exception

The Debug Interrupt exception is an asynchronous debug exception that is taken as soon as possible, but with no specific relation to the executed instructions. The DEPC register and the DBD bit in the Debug register reference the instruction at which execution can be resumed after Debug Interrupt exception service.

Debug interrupt requests are ignored when the processor is in Debug Mode, and pending requests are cleared when the processor takes any debug exception, including debug exceptions other than Debug Interrupt exceptions.

A debug interrupt restarts the pipeline if stopped by a WAIT instruction and the processor clock is restarted if it was stopped due to a low-power mode.

Debug Register Debug Status Bit Set

DINT

Additional State Saved

None

Entry Vector Used

Debug exception vector

The possible sources for debug interrupts depend on the implementation. The following sources can cause Debug Interrupt exceptions:

- *The DINT signal from the probe*

  Note: This signal is not connected on the RC32438.

- *The EjtagBrk Bit in the EJTAG Control Register*

  The EjtagBrk bit in the EJTAG Control register requests a Debug Interrupt exception when set (see section "EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)" on page 20-64).

- *A debug boot by EJTAGBOOT*

  The EJTAGBOOT feature allows a debug interrupt to be requested immediately after a reset or soft reset has occurred (see section "EJTAGBOOT Feature" on page 20-22 and section "EJTAGBOOT and NORMALBOOT Instructions" on page 20-59).

Notes

- *An implementation-specific debug interrupt signal to the processor*

  Through the availability of an optional debug interrupt request signal to the processor system, an external device can request a Debug Interrupt exception, for example, when a signal goes from deasserted to asserted.

Debug Mode Exceptions

The handling of exceptions generated in Debug Mode, other than through resets and soft resets, differs from those exceptions generated in Non-Debug Mode in that only the Debug and DEPC registers are updated. All other CP0 registers are unchanged by an exception taken in Debug Mode. The exception vector is equal to the debug exception vector (see section “Debug Exception Vector Location” on page 20-14), and the processor stays in Debug Mode.

Reset and soft reset are handled as when occurring in Non-Debug Mode (see section “Reset and Soft Reset of Processor” on page 20-22).

Exceptions Taken in Debug Mode

Only some Non-Debug Mode exception events cause exceptions while in Debug Mode. Remaining events are blocked. Exceptions occurring in Debug Mode have the same relative priorities as the Non-Debug Mode exceptions for the same exception event. These exceptions are called Debug Mode <Non-Debug Mode exception name>. For example, a Debug Mode Breakpoint exception is caused by execution of a BREAK instruction in Debug Mode, and a Debug Mode Address Error exception is caused by an address error due to an instruction executed in Debug Mode.

Table 20.15 lists all the Debug Mode exceptions with their corresponding non-debug exception event names, priorities, and handling.

Priority	Event in Debug Mode	Debug Mode Handling
Highest	Reset	Reset and soft reset handled as for Non-Debug Mode, see section “Reset and Soft Reset of Processor” on page 20-22.
	Soft Reset	
	Debug Single Step	Blocked
	Debug Interrupt	
	Debug Data Break Load/Store Imprecise	
	NMI	
	Machine Check	Re-enter Debug Mode
	Interrupt	Blocked
	Deferred Watch	
	Debug Instruction Break, DIB	
	Watch on instruction fetch	
	Address error on instruction Ifetch	Re-enter Debug Mode
	TLB refill on instruction Ifetch	
	TLB Invalid on instruction Ifetch	
	Cache error on instruction Ifetch	
	Bus error on instruction Ifetch	

Table 20.15 Priority of Non-Debug and Debug Exceptions (Part 1 of 2)

Notes

Priority	Event in Debug Mode	Debug Mode Handling
	Debug Breakpoint; execution of SDBBP instruction	Re-enter Debug Mode as for execution of the BREAK instruction
	Other execution-based exceptions	Re-enter Debug Mode
	Debug Data Break Load/Store address match only or Debug Data Break Store address+data value match	Blocked
	Watch on data access	
	Address error on data access	Re-enter Debug Mode
	TLB Refill on data access	
	TLB Invalid on data access	
	TLB Modified on data access	
	Cache error on data access	
	Bus error on data access	
Lowest	Debug Data Break on Load address+data match	Blocked

Table 20.15 Priority of Non-Debug and Debug Exceptions (Part 2 of 2)

The specific implementation determines which exceptions can occur. Exceptions that are blocked in Debug Mode are simply ignored, not causing updates in any state.

Handling of the exceptions causing Debug Mode re-enter are described below.

Exceptions on Imprecise Errors

Exceptions on imprecise errors are possible in Debug Mode due to a bus error on an instruction fetch or data access, cache error, or machine check.

The IEXI bit in the Debug register blocks imprecise error exceptions on entry or re-entry into Debug Mode. They can be re-enabled by the debug exception handler once sufficient context has been saved to allow a safe re-entry into Debug Mode and the debug handler.

Pending exceptions due to instruction fetch bus errors, data access bus errors, cache errors, and machine checks are indicated and controlled by the IBusEP, DBusEP, CacheEP and MCheckP bit in the Debug register.

The SYNC instruction, followed by appropriate spacing, must be executed in Debug Mode before the IBusEP, DBusEP, CacheEP, and MCheckP bits are read in order to ensure that all pending causes for imprecise errors are resolved and all bits are fully updated.

Those bits required to handle the possible imprecise errors in an implementation are implemented as R/W, otherwise they are read only.

Debug Mode Exception Processing

All exceptions that are allowed in Debug Mode (except for reset and soft reset) have the same basic processing flow:

- *The DEPC register is loaded with the PC at which execution will be restarted and the DBD bit is set appropriately in the Debug register. The value loaded into the DEPC register is either the current PC (if the instruction is not in the delay slot of a branch or jump) or the PC of the branch or jump if the instruction is in the delay slot of a branch or jump).*
- *The DSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr, and DDBSImpr bits in the Debug register are all cleared to differentiate from debug exceptions where at least one of the bits are set.*
- *The DExcCode field in the Debug register is updated to indicate the type of exception that occurred.*

Notes

- *The Halt and Doze bits in the Debug register are UNPREDICTABLE.*
- *The IEXI bit is set to inhibit imprecise exceptions at the start of the debug handler.*
- *The DM bit in the Debug register is unchanged, leaving the processor in Debug Mode.*
- *The processor is started at the debug exception vector, specified in section "Debug Exception Vector Location" on page 20-14.*

The value loaded into the DEPC register represents the restart address for the exception. Typically, debug software does not need to modify this value at the location of the debug exception. Debug software need not look at the DBD bit in the Debug register unless it wishes to identify the address of the instruction that actually caused the exception in Debug Mode.

It is the responsibility of the debug handler to save the contents of the Debug, DEPC, and DESAVE registers before nested entries into the handler at the debug exception vector can occur. The handler returns to the debug exception handler by a jump instruction, not a DERET, in order to kept the processor in Debug Mode.

The cause of the exception in Debug Mode is indicated through the DExcCode field in the Debug register, and the same codes are used for the exceptions as those for the ExcCode field in the Cause register when the exceptions with the same names occur in Non-Debug Mode, with addition of the code 30 (decimal) with the mnemonic CacheErr for cache errors.

No other CP0 registers or fields are changed due to the exception in Debug Mode. The overall processing flow for exceptions in Debug Mode is shown below:

```
Operation:
        if (InstructionInBranchDelaySlot) then
            DEPC ¨ BranchInstructionPC
            DebugDBD ¨ 1
        else
            DEPC ¨ PC
            DebugDBD ¨ 0
        endif
    DebugDSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr and DDBSImpr ¨ 0
DebugDExcCode ¨ DebugExceptionType
DebugHalt ¨ UNPREDICTABLE
DebugDoze ¨ UNPREDICTABLE
DebugIEXI ¨ 1
if ECRProbTrap = 1 then
        PC ¨ 0xFF20 0200
else
        PC ¨ 0xBFC0 0480
endif
```

Interrupts and NMIs

Interrupts

Interrupts are requested through either asserted external hardware signals or internal software-controllable bits. Interrupt exceptions are disabled when any of the following conditions are true:

- *The processor is operating in Debug Mode*
- *The Interrupt Enable (IntE) bit in the Debug Control Register (DCR) is cleared (see section "Debug*

Notes

Control Register" on page 20-30)

- *A non-EJTAG related mechanism disables the interrupt exception.*

A pending interrupt is indicated through the Cause register, even if Interrupt exceptions are disabled.

NMIs

An NMI is requested on the asserting edge of the NMI signal to the processor, and an internal indicator holds the NMI request until the NMI exception is actually taken. NMI exceptions are disabled when either of the following is true:

- *The Processor is operating in Debug Mode*
- *The NMI Enable (NMIE) bit in the Debug Control Register (DCR) is cleared (see section "Debug Control Register" on page 20-30).*

If an asserting edge on the NMI signal to the processor is detected while NMI exception is disabled, then the NMI request is held pending and is deferred until NMI exceptions are no longer disabled. A pending NMI is indicated in the NMIpend bit in the DCR even if NMI exceptions are disabled.

Reset and Soft Reset of Processor

For EJTAG features, there are no differences between a reset and a soft reset occurring to the CPU core; they behave identically in both Debug Mode and Non-Debug Mode. In this section, references to reset include both reset (hard reset) and soft reset,

EJTAGBOOT Feature

The EJTAGBOOT feature allows a debug interrupt to be requested as a result of a reset, whereby a Debug Interrupt exception is taken right after reset, and before any of the instructions from the Reset exception handler are executed. The debug exception handler is, in this case, provided by the probe through dmseg, even if no instructions can be fetched from the Reset exception handler. Control and details of EJTAGBOOT are described in section "EJTAGBOOT and NORMALBOOT Instructions" on page 20-59.

Reset from Probe

While asserted, the RST* signal from the probe is required to generate a cold (hard) reset or soft (warm) reset to the system. The SRstE bit in the Debug Control Register does not mask this source. For more information on connecting RST*, see section "Using the EJTAG Probe" on page 20-74.

Processor Reset by Probe through Test Access Port

The PrRst bit in the EJTAG Control register causes a soft (warm) reset to the entire RC32438 device.

Reset Occurred Indication through Test Access Port

The Rocc bit in the EJTAG Control register is set at both reset and soft reset in order to indicate the event to the probe. Refer to section "EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)" on page 20-64 for more information on the EJTAG Control Register.

Soft Reset Enable

The optional Soft Reset Enable (SRstE) bit in the Debug Control Register (DCR) can mask the soft reset signal outside the processor. Because SRstE masks the soft reset signal before it arrives at the processor, there is no masking of soft reset within the processor itself.

Reset of Other Debug Features

The operation of processor resets and soft resets also apply to resets of the following:

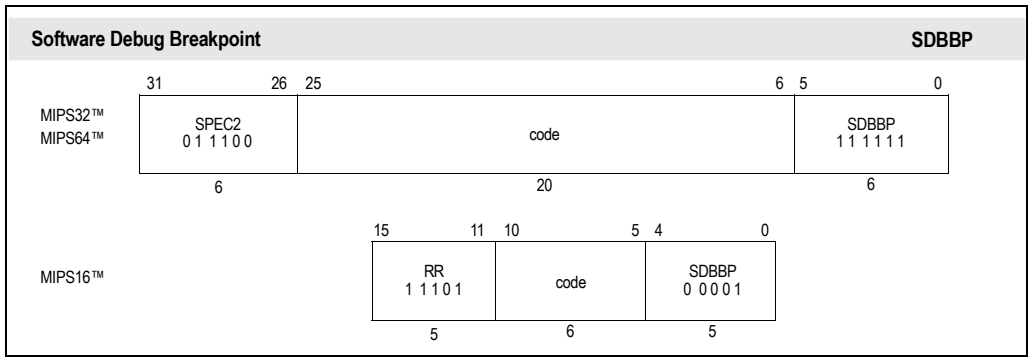
- *Debug Control Register (DCR)*
- *Hardware Breakpoint*
- *Test Access Port (TAP) EJTAG Control Register, (see "EJTAG Test Access Port" on page 20-54.)*

Notes

EJTAG Instructions

The SDBBP and DERET instructions are added to the CPU core's instruction set as part of the required EJTAG features.

SDBBP Instruction



Format:

SDBBP code MIPS16 / MIPS32 / MIPS64

Purpose:

To cause a Debug Breakpoint exception

Description:

If the processor is operating in Non-Debug Mode, then a Debug Breakpoint exception occurs, immediately and unconditionally transferring control to the debug exception handler. If the processor is operating in Debug Mode, then a Debug Mode exception occurs, resulting in an immediate and unconditional re-entry into the debug exception handler with the DebugDExcCode field indicating Bp. The code field is available as a software parameter. The debug exception handler retrieves it only by loading the contents of the memory containing the instruction.

Restrictions:

None.

Operation:

```
if (DebugDM = 0) then
        InitiateDebugBreakpointException()
else
        InitiateDebugModeBreakpointException()
endif
```

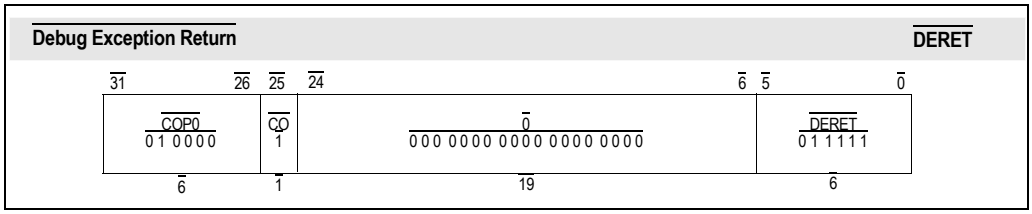
Exceptions:

Debug Breakpoint exception

Debug Mode Breakpoint exception

Notes

DERET Instruction



Format:

DERET MIPS32 / MIPS64

Purpose:

Return from debug exception

Description:

The DERET instruction returns from Debug Mode and resumes non-debug execution at the instruction pointed to by the DEPC register. DERET does not execute the next instruction (it has no delay slot).

Restrictions:

This instruction is legal only if the processor is executing in Debug Mode, and the DERET instruction is not placed in a delay slot of a branch or a jump instruction. If the DERET instruction is executed in User Mode when the StatusCU0 bit is cleared, then a Coprocessor Unusable exception occurs. If the DERET instruction is executed in other circumstances including if placed in the delay slot of a branch or a jump instruction when the processor is executing in Debug Mode, then operation of the processor is UNDEFINED.

If the DEPC register with the return address for DERET was modified by an MTC0/DMTC0 instruction, then it must be followed by an appropriate spacing (refer to section “CP0 and dseg Hazards” on page 20-12) before a DERET instruction in order to remove CP0 hazards. DERET implements a software barrier for all changes in the CP0 state that could affect the fetch and decode of the instruction at the PC to which the DERET returns, such as changes to the effective ASID, user-mode state, and addressing mode.

Operation:

```
if (DebugDM = 1) then
                    DebugDM ¨ 0
                    DebugIEXI ¨ 0
                    PC ¨ DEPC
elseif (in User Mode) and (SRCU0 = 0) then
                    InitiateCoprocessorUnusableException(0)
else
                    UNDEFINED
endif
```

Exceptions:

Coprocessor Unusable exception.

EJTAG Coprocessor 0 Registers

The Coprocessor 0 registers for EJTAG are shown in Table 20.16. Each register is described in more detail in the following subsections.

Notes

Register Number	SEL	Register Name	Function	Reference
23	0	Debug	Debug indications and controls for the processor.	See section "Debug Register (CP0 Register 23, Select 0)" on page 20-25.
24	0	DEPC	Program counter at last debug exception or exception in Debug Mode.	See section "Debug Exception Program Counter Register (CP0 Register 24, Select 0)" on page 20-29.
31	0	DESAVE	Debug exception save register.	See section "Debug Exception Save Register (CP0 Register 31, Select 0)" on page 20-30.

Table 20.16 Coprocessor 0 Registers for EJTAG

The CP0 instructions MTC0, MFC0, DMTC0, and DMFC0 work with the three EJTAG CP0 registers. Operation of the processor is UNDEFINED if the Debug, DEPC, or DESAVE registers are written from Non-Debug Mode. The value of the Debug, DEPC, or DESAVE registers is UNPREDICTABLE when read from Non-Debug Mode, unless otherwise explicitly stated in the individual register description. However, for test purposes, the implementations can allow writes to and reads from the registers from Non-Debug Mode.

To avoid pipeline hazards, there must be an appropriate spacing (refer to section "CP0 and dseg Hazards" on page 20-12) between the update of the Debug and DEPC registers by MTC0/DMTC0 and use of the new value. This applies for example to modification of the LSNM bit of the Debug register and a load/store affected by that bit.

Debug Register (CP0 Register 23, Select 0)

Compliance Level: Required for EJTAG debug support.

The Debug register contains the cause of the most recent debug exception and exception in Debug Mode. It also controls single stepping. This register indicates low-power and clock states on debug exceptions, debug resources, and other internal states. Only the DM bit and the EJTAGver field are valid when read from the Debug register in Non-Debug Mode; the value of all other bits and fields is UNPREDICTABLE. The following bits and fields are only updated on debug exceptions and/or exceptions in Debug Mode:

- *DSS, DBp, DDBL, DDBS, DIB, DINT, DDBLImpr, and DDBSImpr are updated on both debug exceptions and on exceptions in Debug Modes*
- *DExcCode is updated on exceptions in Debug Mode, and is undefined after a debug exception*
- *Halt and Doze are updated on a debug exception, and are undefined after an exception in Debug Mode*
- *DBD is updated on both debug and on exceptions in Debug Modes*

The SYNC instruction, followed by appropriate spacing, (as described in section "SYNC Instruction Behavior" on page 20-11 and section "CP0 and dseg Hazards" on page 20-12) must be executed to ensure that the DDBLImpr, DDBSImpr, IBusEP, DBusEP, CacheEP, and MCheckP bits are fully updated. This

Notes

instruction sequence must be used both in the beginning of the debug handler before pending imprecise errors are detected from Non-Debug Mode, and at the end of the debug handler before pending imprecise errors are detected from Debug Mode. The IEXI bit controls enable/disable of imprecise error exceptions.

Figure 20.3 shows the format of the Debug register and Table 20.17 describes the Debug register fields.

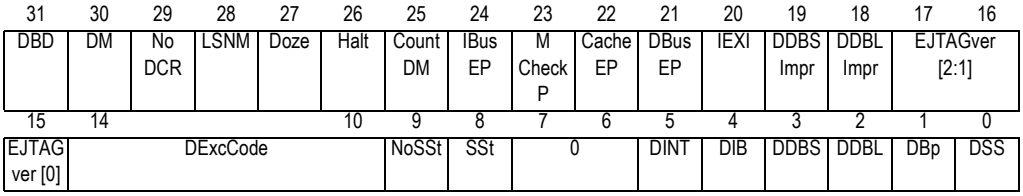


Figure 20.3 Debug Register Format

Fields Name	Bits	Description	Read/ Write	Reset State
DBD	31	Indicates whether the last debug exception or exception in Debug Mode occurred in a branch or jump delay slot: 0: Not in delay slot 1: In delay slot	R	Undefined
DM	30	Indicates that the processor is operating in Debug Mode: 0: Processor is operating in Non-Debug Mode 1: Processor is operating in Debug Mode	R	0
NoDCR	29	Indicates whether the dseg memory segment is present: 0: dseg is present 1: No dseg present	R	Preset
LSNM	28	Controls access of loads/stores between dseg and remaining memory when dseg is present: 0: Loads/stores in dseg address range go to dseg 1: Loads/stores in dseg address range go to system memory See section Debug Mode Address Space. This bit is read-only (R) and reads as zero if not implemented.	R/W	0
Doze	27	Indicates that the processor was in a low-power mode when a debug exception occurred: 0: Processor not in low-power mode when debug exception occurred 1: Processor in low-power mode when debug exception occurred The Doze bit indicates Reduced Power (RP) and WAIT, and other implementation-dependent low-power modes.	R	Undefined
Halt	26	Indicates that the internal processor system bus clock was stopped when the debug exception occurred: 0: Internal system bus clock running 1: Internal system bus clock stopped Halt indicates WAIT, and other implementation-dependent events that stop the system bus clock.	R	Undefined

Table 20.17 Debug Register Field Descriptions (Part 1 of 4)

Notes

Fields Name	Bits	Description	Read/ Write	Reset State
CountDM	25	Controls or indicates the Count register behavior in Debug Mode. Implementations can have fixed behavior, in which case this bit is read-only (R), or the implementation can allow this bit to control the behavior, in which case this bit is read/write (R/W). The reset value of this bit indicates the behavior after reset, and depends on the implementation.	R	1 **Note:** This value is always 1.
IBusEP	24	Indicates if a Bus Error exception is pending from an instruction fetch. Set when an instruction fetch bus error event occurs or a 1 is written to the bit by software. Cleared when a Bus Error exception on an instruction fetch is taken by the processor. If IBusEP is set when IEXI is cleared, a Bus Error exception on an instruction fetch is taken by the processor, and IBusEP is cleared. In Debug Mode, a Bus Error exception applies to a Debug Mode Bus Error exception.	R/W1	0
MCheckP	23	Indicates if a Machine Check exception is pending. Set when a machine check event occurs or a 1 is written to the bit by software. Cleared when a Machine Check exception is taken by the processor. If MCheckP is set when IEXI is cleared, a Machine Check exception is taken by the processor, and MCheckP is cleared. In Debug Mode, a Machine Check exception applies to a Debug Mode Machine Check exception.	R/W	0 **Note:** This value is always 0.
CacheEP	22	Indicates if a Cache Error is pending. Set when a cache error event occurs or a 1 is written to the bit by software. Cleared when a Cache Error exception is taken by the processor. If CacheEP is set when IEXI is cleared, a Cache Error exception is taken by the processor, and CacheEP is cleared. In Debug Mode, a Cache Error exception applies to a Debug Mode Cache Error exception.	R/W1	0 **Note:** This value is always 0.
DBusEP	21	Indicates if a Data Access Bus Error exception is pending. Set when a data access bus error event occurs or a 1 is written to the bit by software. Cleared when a Bus Error exception on data access is taken by the processor. If DBusEP is set when IEXI is cleared, a Bus Error exception on data access is taken by the processor, and DBusEP is cleared. In Debug Mode, a Bus Error exception applies to a Debug Mode Bus Error exception.	R/W1	0
IEXI	20	An Imprecise Error eXception Inhibit (IEXI) controls exceptions taken due to imprecise error indications. Set when the processor takes a debug exception or an exception in Debug Mode occurs. Cleared by execution of the DERET instruction. Otherwise modifiable by Debug Mode software. When IEXI is set, then the imprecise error exceptions from bus errors on instruction fetches or data accesses, cache errors, or machine checks are inhibited and deferred until the bit is cleared.	R/W	0

Table 20.17 Debug Register Field Descriptions (Part 2 of 4)

Notes

Fields Name	Bits	Description	Read/ Write	Reset State
DDBSImpr	19	Indicates that a Debug Data Break Store Imprecise exception due to a store was the cause of the debug exception, or that an imprecise data hardware break due to a store was indicated after another debug exception occurred. Cleared on exception in Debug Mode. 0: No match of an imprecise data hardware breakpoint on store 1: Match of imprecise data hardware breakpoint on store	R	0 **Note:** This value is always 0.
DDBLImpr	18	Indicates that a Debug Data Break Load Imprecise exception due to a load was the cause of the debug exception, or that an imprecise data hardware break due to a load was indicated after another debug exception occurred. Cleared on exception in Debug Mode. 0: No match of an imprecise data hardware breakpoint on load 1: Match of imprecise data hardware breakpoint on load	R	0 **Note:** This value is always 0.
EJTAGver	17:15	Provides the EJTAG version. 0: Version 1 and 2.0 1: Version 2.5 2-7: Reserved	R	1 **Note:** This value is always 1.
DExcCode	14:10	Indicates the cause of the latest exception in Debug Mode. The field is encoded as the ExcCode field in the Cause register for those exceptions that can occur in Debug Mode (the encoding is shown in MIPS32 and MIPS64 specifications), with addition of code 30 with the mnemonic CacheErr for cache errors.	R	Undefined
NoSSt	9	Indicates whether the single-step feature controllable by the SSt bit is available in this implementation: 0: Single-step feature available 1: No single-step feature available A minimum number of hardware instruction breakpoints must be available if no single-step feature is implemented in hardware. Refer to section “Number of Instruction Breakpoints Without Single Stepping” on page 20-52 for more information.	R	0 **Note:** This value is always 0.
SSt	8	Controls whether single-step feature is enabled: 0: No enable of single-step feature 1: Single-step feature enabled	R/W	0
0	7:6	Must be written as zeros; return zeros on reads.	0	0
DINT	5	Indicates that a Debug Interrupt exception occurred. Cleared on exception in Debug Mode. 0: No Debug Interrupt exception 1: Debug Interrupt exception	R	Undefined
DIB	4	Indicates that a Debug Instruction Break exception occurred. Cleared on exception in Debug Mode. 0: No Debug Instruction Break exception 1: Debug Instruction Break exception	R	Undefined

Table 20.17 Debug Register Field Descriptions (Part 3 of 4)

Notes

Fields Name	Bits	Description	Read/ Write	Reset State
DDBS	3	Indicates that a Debug Data Break Store exception occurred on a store due to a precise data hardware break. Cleared on exception in Debug Mode. 0: No Debug Data Break Store Exception 1: Debug Data Break Store Exception	R	Undefined
DDBL	2	Indicates that a Debug Data Break Load exception occurred on a load due to a precise data hardware break. Cleared on exception in Debug Mode. 0: No Debug Data Break Store Exception 1: Debug Data Break Store Exception	R	Undefined
DBp	1	Indicates that a Debug Breakpoint exception occurred. Cleared on exception in Debug Mode. 0: No Debug Breakpoint exception 1: Debug Breakpoint exception	R	Undefined
DSS	0	Indicates that a Debug Single Step exception occurred. Cleared on exception in Debug Mode. 0: No debug single-step exception 1: Debug single-step exception	R	Undefined

Table 20.17 Debug Register Field Descriptions (Part 4 of 4)

Debug Exception Program Counter Register (CP0 Register 24, Select 0)

The Debug Exception Program Counter (DEPC) register is a read/write register that contains the address at which processing resumes after the exception has been serviced. The size of this register is 32 bits for 32-bit processors and 64 bits for 64-bit processors, even with only 32-bit virtual addressing enabled. All bits of the DEPC register are significant and writable. A DMFC0 from the DEPC register returns the full 64-bit DEPC on 64-bit processors. Hardware updates this register on debug exceptions and exceptions in Debug Mode.

For precise debug exceptions and precise exceptions in Debug Mode, the DEPC register contains either:

- *The virtual address of the instruction that was the direct cause of the exception, or*
- *The virtual address of the immediately preceding branch or jump instruction, when the exception-causing instruction is in a branch delay slot, and the Debug Branch Delay (BDB) bit in the Debug register is set.*

For imprecise debug exceptions and imprecise exceptions in Debug Mode, the DEPC register contains the address at which execution is resumed when returning to Non-Debug Mode. Figure 20.4 shows the format of the DEPC register and Table 20.18 describes the DEPC register field.

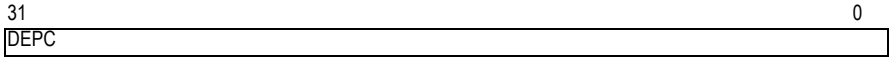


Figure 20.4 DEPC Register Forma

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bits				
DEPC	MSB:0	Debug Exception Program Counter	R/W	Undefined	Required

Table 20.18 DEPC Register Field Description

Debug Exception Save Register (CP0 Register 31, Select 0)

The Debug Exception Save (DESAVE) register is a read/write register that functions as a simple scratchpad register. The size of this register is 32 bits for 32-bit processors and 64 bits for 64-bit processor.

The debug exception handler uses this to save one of the GPRs, which is then used to save the rest of the context to a pre-determined memory area, for example, in the dmseg. This register allows the safe debugging of exception handlers and other types of code where the existence of a valid stack for context saving cannot be assumed.

Figure 2-4 shows the format of the DESAVE register; Table 2-13 describes the DESAVE register field.

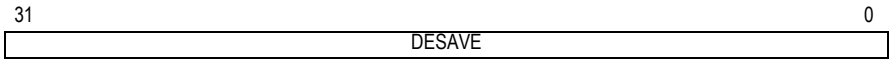


Figure 20.5 DESAVE Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bits				
DESAVE	MSB:0	Debug Exception Save contents	R/W	Undefined	Required

Table 20.19 DESAVE Register Field Description

Debug Control Register

The Debug Control Register (DCR) controls and provides information about debug issues. The width of the register is 32 bits for 32-bit processors, and 64 bits for 64-bit processors. The DCR is located in the drseg at offset 0x0000. The Debug Control Register (DCR) provides the following key features:

- *Interrupt and NMI control when in Non-Debug Mode*
- *NMI pending indication*
- *Availability indicator of instruction and data hardware breakpoints.*

For EJTAG features, there are no difference between a reset and a soft reset occurring to the processor; they behave identically in both Debug Mode and Non-Debug Mode. References to reset in the following therefore refers to both reset (hard reset) and soft reset. The DataBrk and InstBrk bits within the DCR indicate the types of hardware breakpoints implemented. Debug software is expected to read hardware breakpoint registers for additional information on the number of implemented breakpoints. Refer to section “Hardware Breakpoints” on page 20-32 for a description of the hardware breakpoint registers.

Hardware and software interrupts can be disabled in Non-Debug Mode using the DCR’s IntE bit. This bit is a global interrupt enable used along with several other interrupt enables that enable specific mechanisms. The NMI interrupt can be disabled in Non-Debug Mode using the DCR’s NMIE bit; a pending NMI is indicated through the NMIpend bit. Pending interrupts are indicated in the Cause register, and pending

Notes

NMIs are indicated in the DCR register NMIpend bit, even when disabled. Hardware and software interrupts and NMIs are always disabled in Debug Mode (refer to section “Interrupts and NMIs” on page 20-21 for more information).

The ProbEn bit reflects the state of the ProbEn bit from the EJTAG Control register (ECR). Through this bit, the probe can indicate to the debug software running on the CPU if it expects to service dmseg accesses. For more information, see section “EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)” on page 20-64.

Figure 20.6 shows the format of the DCR register; Table 20.20 describes the DCR register fields. The reset values in Table 20.20 take effect on both hard resets and soft resets.

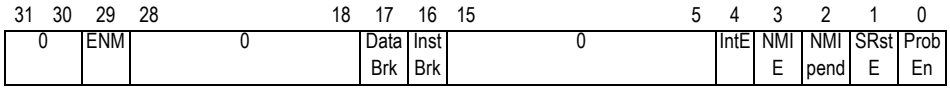


Figure 20.6 DCR Register Format

Fields Name	Bits	Description	Read/ Write	Reset State	Compliance
ENM	29	Endianess in which the processor is running in kernel and Debug Mode: 0: Little endian 1: Big endian	R	Preset	Required
DataBrk	17	Indicates if data hardware breakpoint is implemented: 0: No data hardware breakpoint implemented 1: Data hardware breakpoint implemented	R	Preset	Required
InstBrk	16	Indicates if instruction hardware breakpoint is implemented: 0: No instruction hardware breakpoint implemented 1: Instruction hardware breakpoint implemented	R	Preset	Required
IntE	4	Hardware and software interrupt enable for Non-Debug Mode, in conjunction with other disable mechanisms: 0: Interrupt disabled 1: Interrupt enabled depending on other enabling mechanisms	R/W	1	Required
NMIE	3	Non-Maskable Interrupt (NMI) enable for Non-Debug Mode: 0: NMI disabled 1: NMI enabled	R/W	1	Required
NMIpend	2	Indication for pending NMI: 0: No NMI pending 1: NMI pending	R	0	Required

Table 20.20 DCR Register Field Descriptions (Part 1 of 2)

Notes

Fields Name	Bits	Description	Read/ Write	Reset State	Compliance
SRstE	1	Controls soft reset enable: Not used. All soft (warm) resets are always enabled.	R/W	1	Optional
ProbEn	0	Indicates value of the ProbEn value in the ECR register: 0: No access should occur to dmseg 1: Probe services accesses to dmseg	R	Same value as ProbEn in ECR	Required of EJTAG TAP is present, otherwise not implemented
0	MSB:30, 28:18, 15:5	Must be written as zeros; return zeros on reads.	0	0	Reserved

Table 20.20 DCR Register Field Descriptions (Part 2 of 2)

Hardware Breakpoints

Hardware breakpoints compare addresses and data of executed instructions, including data load/store accesses. Instruction breakpoints can be set even on addresses in ROM areas, and data breakpoints can cause debug exceptions on specific data accesses. Instruction and data hardware breakpoints are alike in many aspects, and are described in parallel in the following sections. When the term “breakpoint” is used in this chapter, then the reference is to a “hardware breakpoint”, unless otherwise explicitly noted.

The breakpoints provide the following key features:

- *From zero to 15 instruction breakpoints can be implemented to cause debug exceptions on executed instructions, both in ROM and RAM. Bit masking is provided for virtual address compares, and masking of compares with ASID (optional) is also provided.*
- *From zero to 15 data breakpoints can be implemented to cause debug exceptions on data accesses. Bit masking is provided for virtual address compares, masking of compares with ASID (optional) is provided, optional data value compares allows masking at byte level, and qualification on byte access and access type is possible.*
- *Registers for setup and control are memory mapped in drseg, accessible in Debug Mode only.*
- *Breakpoints have several implementation options to ease integration with various microarchitectures.*

Hardware breakpoints require the implementation of the Debug Control Register (DCR). Several additional options are possible for breakpoints, as described in the following subsections. For EJTAG features, there are no difference between a reset and a soft reset occurring to the processor; they behave identically in both Debug Mode and Non-Debug Mode. References to reset in the following therefore refers to both reset (hard reset) and soft reset.

Instruction Breakpoint Features

Figure 20.7 shows an overview of the instruction breakpoint feature. The feature compares the virtual address (PC) and the ASID of the executed instructions with each instruction breakpoint, applying masking on address and ASID. When an enabled instruction breakpoint matches the PC and ASID, a debug exception and/or a trigger is generated, and an internal bit in an instruction breakpoint register is set to indicate that a match occurred.

Notes

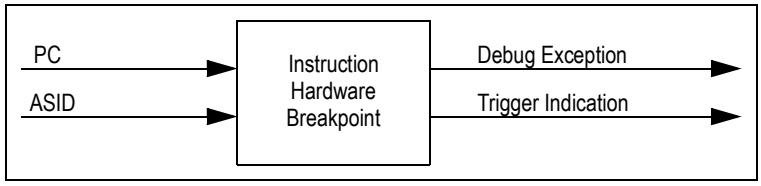


Figure 20.7 Instruction Breakpoint Overview

Data Breakpoint Features

Figure 20.8 shows an overview of the data breakpoint feature. The feature compares the load or store access type (TYPE), the virtual address of the access (ADDR), the ASID, the accessed bytes (BYTELANE), and data value (DATA) with each data breakpoint, applying masks and/or qualifications on the access properties.

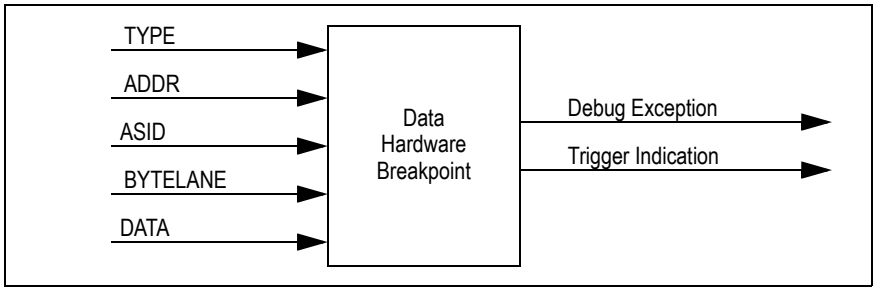


Figure 20.8 Data Breakpoint Overview

When an enabled data breakpoint matches, a debug exception and/or a trigger is generated, and an internal bit in a data breakpoint register is set to indicate that a match occurred. The match is either precise (the debug exception or trigger occurs on the instruction that caused the breakpoint to match) or imprecise (the debug exception or trigger occurs later in the program flow).

Overview of Instruction and Data Breakpoint Registers

From zero to 15 instruction and data breakpoints can be implemented independently. Implementation of any breakpoint implies that the Debug Control Register (DCR) is implemented. The InstBrk and DataBrk bits in the DCR register indicate whether there are zero or 1 to 15 implementations of a breakpoint type. If no breakpoints of a specific type are implemented, then none of the registers associated with this breakpoint type are implemented. If any (1 to 15) breakpoints of a specific type are implemented, then the breakpoint status register associated with that breakpoint type is implemented. The instruction and data break status registers indicate the number of breakpoints for each corresponding type. The number of additional registers depends on the number of implemented breakpoints for the respective breakpoint type. Registers for ASID compares are only implemented if indicated in the corresponding breakpoint status register.

The next two sections, Overview of Instruction Breakpoint Registers and Overview of Data Breakpoint Registers, provide overviews of the instruction and data breakpoint registers, respectively. All registers are memory mapped in the drseg segment. All registers are 32 bits wide for 32-bit processors.

Overview of Instruction Breakpoint Registers

Table 20.21 lists the Instruction Breakpoint registers. The Instruction Breakpoint Status register provides implementation indication and status for instruction breakpoints in general. The 1 to 15 implemented breakpoints are numbered 0 to 14, respectively, for registers and breakpoints. The specific breakpoint number is indicated by “n”.

Notes

Register Mnemonic	Register Name and Description	Reference	Compliance Level
IBS	Instruction Breakpoint Status	See section “Instruction Breakpoint Status (IBS) Register” on page 20-43.	Required if any instruction breakpoints are implemented, optional otherwise.
IBAn	Instruction Breakpoint Address n	See section “Instruction Breakpoint Address n (IBAn) Register” on page 20-44.	Required with instruction breakpoint n, optional otherwise.
IBMn	Instruction Breakpoint Address Mask n	See section “Instruction Breakpoint Address Mask n (IBMn) Register” on page 20-45.	
IBASIDn	Instruction Breakpoint ASID n	See section “Instruction Breakpoint ASID n (IBASIDn) Register” on page 20-45.	Required with instruction breakpoint n, optional otherwise. Not implemented if ASIDsup bit in IBS is 0 (zero).
IBCn	Instruction Breakpoint Control n	See section “Instruction Breakpoint Control n (IBCn) Register” on page 20-46.	Required with instruction breakpoint n, optional otherwise.

Table 20.21 Instruction Breakpoint Register Summary

Register addresses are shown in section “Instruction Breakpoint Registers” on page 20-43.

Overview of Data Breakpoint Registers

Table 4-2 lists the Data Breakpoint Registers. The Data Breakpoint Status register provides implementation indication and status for data breakpoints in general. The 1 to 15 implemented breakpoints are numbered 0 to 14, respectively, for registers and breakpoints. The specific breakpoint number is indicated by “n”. The registers for data value compares are only implemented if the value compares for the data breakpoints are implemented, which occurs when either the NoLVmatch bit or the NoSVmatch bit in the DBS is 0.

Register Mnemonic	Register Name and Description	Reference	Compliance
DBS	Data Breakpoint Status	See section “Data Breakpoint Status (DBS) Register” on page 20-47.	Required if any data breakpoints are implemented, optional otherwise.
DBAn	Data Breakpoint Address n	See section “Data Breakpoint Address n (DBAn) Register” on page 20-48.	Required with data breakpoint n, optional otherwise.

Table 20.22 Data Breakpoint Register Description (Part 1 of 2)

Notes

Register Mnemonic	Register Name and Description	Reference	Compliance
DBMn	Data Breakpoint Address Mask n	See section “Data Breakpoint Address Mask n (DBMn) Register” on page 20-49.	
DBASIDn	Data Breakpoint ASID n	See section “Data Breakpoint ASID n (DBASIDn) Register” on page 20-49.	Required with data breakpoint n, optional otherwise. Not implemented if ASIDsup bit in DBS is 0 (zero).
DBCn	Data Breakpoint Control n	See section “Data Breakpoint Control n (DBCn) Register” on page 20-49.	Required with data breakpoint n, optional otherwise.
DBVn	Data Breakpoint Value n	See section “Data Breakpoint Value n (DBVn) Register” on page 20-51.	Required with data breakpoint n, optional otherwise. Only implemented with value compares, shown in DBS.

Table 20.22 Data Breakpoint Register Description (Part 2 of 2)

Conditions for Matching Breakpoints

A number of conditions must be fulfilled in order for a breakpoint to match on an executed instruction or a data access. These conditions are described in the following subsections. A breakpoint only matches for instructions executed in Non-Debug Mode, never due to instructions executed in Debug Mode.

The match of an enabled breakpoint generates a debug exception as described in section “Debug Exceptions from Breakpoints” on page 20-40 and/or a trigger indication as described in section “Breakpoints Used as Triggerpoints” on page 20-42. The BE and/or TE bits in the IBCn or DBCn registers enable the breakpoints for breaks and triggers, respectively.

It is implementation dependent whether or not a breakpoint stalls the processor in order to evaluate the match expression; for example, if required for timing reasons or in order to wait on a scheduled load to return for evaluation of a data breakpoint with a data value compare. In some cases, stalling is avoided with imprecise data breakpoints, as described in section “Debug Exception by Data Breakpoint” on page 20-40.

Conditions for Matching Instruction Breakpoints

When an instruction breakpoint is enabled, that breakpoint is evaluated in Non-Debug Mode with the instruction boundary address (the lowest address of a byte in the instruction) of every executed instruction. The instruction breakpoint is also evaluated on addresses usually causing an Address Error exception, a TLB exception, or other exceptions. It is thereby possible to cause a Debug Instruction Break exception on the destination address of a jump, even if a jump to that address would cause an Address Error exception. The breakpoint is not evaluated on instructions from speculative fetches or execution.

A match of an instruction breakpoint depends on a number of parameters, shown in Table 20.23. The fields in the instruction breakpoint registers are in the form REG_{FIELD}.

Notes

Parameter	Description	Width
ASID	ASID field in EntryHi CP0 register.	8 bits
$IBCn_{ASIDuse}$	Use ASID value in compare for instruction breakpoint n: 0: Do not use ASID value in compare 1: Use ASID value in compare	1 bit
$IBASIDn_{ASID}$	Conditional Instruction breakpoint n ASID value for comparing.	8 bits
PC	Virtual address of instruction boundary or target for jump/branch.	32 / 64 bits
ISAmode	Used only when MIPS16 ISA support is implemented. It indicates the ISA mode for the executed instruction or the mode at the target of a jump/branch: 0: 32-bit MIPS instruction 1: MIPS16 instruction	1 bit
$IBAn_{IBA}$	Instruction breakpoint n address for compare with conditions.	32 / 64 bits
$IBMn_{IBM}$	Instruction breakpoint n address mask condition: 0: Corresponding address bit compared 1: Corresponding address bit masked	32 / 64 bits

Table 20.23 Instruction Breakpoint Condition Parameters

The PC, IBAnIBA, and IBMnIBM fields are 32 bits wide for 32-bit processors and 64 bits wide for 64-bit processors.

The equation that determines the match is shown below with “C”-like operators. In the equation, 0 means all bits are 0’s, and ~0 means all bits are 1’s. The widths are similar to the widths of the parameters. The match equation is IB_match, and is dependent on whether MIPS16 is supported or not.

If there is no support for MIPS16 then the IB_match equation is:

IB_match =

(! $IBCn_{ASIDuse}$ || (ASID = = $IBASIDn_{ASID}$)) &&

(($IBMn_{IBM}$ | ~ (PC ^ $IBAn_{IBA}$)) = = ~0)

If MIPS16 is supported then the IB_match equation is shown below, in which case the ISAmode bit is compared with bit 0 of $IBAn_{IBA}$ instead of compare with bit 0 in PC:

IB_match =

(! $IBCn_{ASIDuse}$ || (ASID = = $IBASIDn_{ASID}$)) &&

(($IBMn_{IBM}$ | ~ (((PC[MSB:1] << 1) + ISAmode) ^ $IBAn_{IBA}$)) = = ~0)

The IB_match equation also applies to 64-bit processors running in 32-bit addressing mode, in which case all 64 bits are compared between the PC and the $IBAn_{IBA}$ register. The match indication for instruction breakpoints is always precise; that is, it is indicated on the instruction causing the IB_match to be true. It is implementation dependent for an instruction breakpoint to match when the memory system does not ever respond to the fetch or generates a bus error from a system watchdog. If no match occurs, then the processor hangs without the instruction breakpoint generating either a debug exception or a trigger.

Notes

Conditions for Matching Data Breakpoints

When a data breakpoint is enabled, that breakpoint is evaluated in Non-Debug Mode with both the access address of every data access due to load/store instructions (including loads/stores of coprocessor registers) and the address causing address errors upon data access. Data breakpoints are not evaluated with addresses from PREF (prefetch) or CACHE instructions.

The concept “data bus” is used in the following to denote the bytes accessed and the data value transferred in a load/store operation. In this notation data bus referees to the naturally-aligned memory word (for 32-bit processors) or doubleword (for 64-bit processors) containing the accessed address referred to as ADDR. This notation is independent of the actual width of the processor bus, e.g., the “data bus” width of a 64-bit processor is 64, even if that processor has a 32-bit processor bus. A match of the data breakpoint depends on a number of parameters, shown in Table 20.24. The fields in the data breakpoint registers are in the form REG_{FIELD}.

Reference	Description	Width
TYPE	Data access type is either load or store.	No width
$DBCn_{NoSB}$	Controls whether condition for data breakpoint is fulfilled on a store access: 0: Condition can be fulfilled on store access 1: Condition is never fulfilled on store access	1 bit
$DBCn_{NoLB}$	Controls whether condition for data breakpoint is fulfilled on a load access: 0: Condition can be fulfilled on load access 1: Condition is never fulfilled on load access	1 bit
ASID	ASID field in EntryHi CP0 register.	8 bits
$DBCn_{ASIDuse}$	ASID value used in compare for data breakpoint n: 0: Do not use ASID value in compare 1: Use ASID value in compare	1 bit
$DBASIDn_{ASID}$	Conditional Data breakpoint n ASID value for comparison.	8 bits
ADDR	Virtual address of data access, effective address.	32 / 64 bits
$DBAn_{DBA}$	Data breakpoint n address for compare with conditions.	32 / 64 bits
$DBMn_{DBM}$	Conditional Data breakpoint n address mask: 0: Corresponding address bit compared 1: Corresponding address bit masked	32 / 64 bits
BYTELANE	Byte lane access indication, where BYTELANE[0] is 1 only if the byte at bits [7:0] of the data bus is accessed, BYTELANE[1] is 1 only if the byte at bits [15:8] of the data bus is accessed, etc.	4 / 8 bits
$DBCn_{BAI}$	Determines whether access is ignored to specific bytes. BAI[0] controls ignore of access to the byte at bits [7:0] of the data bus, BAI[1] ignores access to byte at bits [15:8] of the data bus, etc.: 0: Condition depends on access to corresponding byte 1: Access for corresponding byte is ignored	4 / 8 bits

Table 20.24 Data Breakpoint Condition Parameters (Part 1 of 2)

Notes

Reference	Description	Width
DATA	Data value from the data bus.	32 / 64 bits
$DBVn_{DBV}$	Conditional Data breakpoint n data value for compare.	32 / 64 bits
$DBCn_{BLM}$	Conditional Byte lane mask for value compare on data breakpoint. BLM[0] masks byte at bits [7:0] of the data bus, BLM[1] masks byte at bits [15:8], etc.: 0: Compare corresponding byte lane 1: Mask corresponding byte lane	4 / 8 bits

Table 20.24 Data Breakpoint Condition Parameters (Part 2 of 2)

The ADDR, DBAnDBA, DBMnDBM, DATA, and DBVnDBV fields are 32 bits wide for 32-bit processors and 64 bits wide for 64-bit processors. The BYTELANE, DBCnBLM, and DBCnBAI fields are four bits wide for 32-bit processors and eight bits wide for 64-bit processors. The width is indicated as "N" in the equations below. The match equations are shown below with "C"-like operators. In the equation, 0 means all bits are 0's, and ~0 means all bits are 1's. The bit widths are similar to the widths of the parameters. DB_match is the overall match equation (the DB_addr_match, DB_no_value_compare, and DB_value_match equations in the DB_match equation are defined below):

DB_match =

(((TYPE = = load) && ! $DBCn_{NoLB}$) || ((TYPE = = store) && ! $DBCn_{NoSB}$)) &&

DB_addr_match && (DB_no_value_compare || DB_value_match)

DB_addr_match is defined as:

DB_addr_match =

(! $DBCn_{ASIDuse}$ || (ASID = = $DBASIDn_{ASID}$)) &&

(($DBMn_{DBM}$ | ~ (ADDR ^ $DBAn_{DBA}$)) = = ~0) &&

((~ $DBCn_{BAI}$ & BYTELANE) != 0)

The DB_addr_match equation also applies to 64-bit processors running in 32-bit addressing mode, in which case all 64 bits are compared between the ADDR and the $DBAn_{DBA}$ field.

DB_no_value_compare is defined as:

DB_no_value_compare =

(($DBCn_{BLM}$ | $DBCn_{BAI}$ | ~ BYTELANE) = = ~0)

If a data value compare is indicated on a breakpoint, then DB_no_value_compare is false, and if there is no data value compare then DB_no_value_compare is true. Note that a data value compare is a run-time property of the breakpoint if ($DBCn_{BLM}$ | $DBCn_{BAI}$) is not ~0, because DB_no_value_compare then depends on BYTELANE provided by the load/store instructions.

If a data value compare is required, then the data value from the data bus is compared and masked with the registers for the data breakpoint, as shown in the DB_value_match equation:

DB_value_match =

((DATA[7:0] = = $DBVn_{DBV[7:0]}$) || ! BYTELANE[0] || $DBCn_{BLM[0]}$ || $DBCn_{BAI[0]}$) &&

((DATA[15:8] = = $DBVn_{DBV[15:8]}$) || ! BYTELANE[1] || $DBCn_{BLM[1]}$ || $DBCn_{BAI[1]}$) &&

.....

((DATA[8*N-1:8*N-8] = = $DBVn_{DBV[8*N-1:8*N-8]}$) ||

! BYTELANE[N-1] || $DBCn_{BLM[N-1]}$ || $DBCn_{BAI[N-1]}$)

Notes

Data breakpoints depend on endianess, because values on the byte lanes are used in the equations. Thus it is required that the debug software programs the breakpoints accordingly to endianess. It is implementation dependent for a data breakpoint to match when the memory system does not ever respond to the data access or generates a bus error from a system watchdog. If no match occurs, then the processor hangs without the data breakpoint generating a debug exception or trigger.

Data Breakpoints in case of Unaligned Address

Unaligned addresses can result from explicit halfword, word, and doubleword accesses (for example, if an effective address of 0x01 is used as source of a Load Halfword (LH) instruction). The ADDR used in the comparison is the effective address. The BYTELANE value is defined according to Table 20.25 for a 32-bit processor.

Size	ADDR			BYTELANE[3:0]	
	[2]	[1]	[0]	Little Endian	Big Endian
Halfword	x[1]	0	x	0011_2	1100v
	x	1	x	1100_2	0011_2
Word	x	x	x	1111_2	

Table 20.25 BYTELANE at Unaligned Address for 32-bit Processors

1. x = Don't care

With the above well-defined values of BYTELANE, the behavior is well-defined for data breakpoints without value compares on operations with unaligned addresses. The BLM field in the DBCn register can be used to avoid value compares if all BLM bits are set to 1. If the data breakpoint depends on a value compare, then loads will cause an Address Error exception, and for stores the data value (DATA) is UNPREDICTABLE. This UNPREDICTABLE data can cause match of a data breakpoint on a store, but an implementation can choose never to indicate a match on data breakpoints depending on value compare if having unaligned address.

If a debug exception is taken on the store then the debug handler can investigate the processor state and thereby determine if the address was unaligned and UNPREDICTABLE store data for the memory access thereby caused the debug exception. If a debug exception is not taken for the store, then an Address Error exception is taken. So, in both cases it is possible for debug software to detect the bug. The BLM field in the DBCn register can be used to avoid compare on UNPREDICTABLE data, in case all of the BLM bits are set to 1.

If the data breakpoint is used as a triggerpoint, a BS bit might be set after a compare with UNPREDICTABLE data; however, an Address Error exception occurs in this case thereby making it possible to detect the bug.

Match for Data Breakpoint with Value Compare on Bus or Cache Error

If a data value compare is required to evaluate a data breakpoint, the DB_no_value_compare equation is false (see section "Conditions for Matching Data Breakpoints" on page 20-37). However, if a bus or cache error occurs on the load, then there is no valid data to use in the compare. This case has two possibilities:

- *The match will fail.*
- *The match will compare on invalid data, and then indicate a pending bus or cache error through the DBusEP or CacheEP bits in the Debug register, if a debug exception is taken. This occurrence might cause a trigger indication to be set on the compare with invalid data.*

A bus or cache error on a store does not affect the data breakpoint compare.

Refer to section "Data Breakpoint Compare on Invalid Data" on page 20-52for recommendations on implementing data breakpoint compares on invalid data.

Notes

Precise Match for Data Breakpoints

A precise match for a data breakpoint occurs when the match equation can be fully evaluated at the time the load/store instruction is executed. A true DB_match can thereby be indicated on the very same instruction causing the DB_match equation to be true. Matches on data breakpoints without data value compares are always precise. Accesses using data value compares are either imprecise or precise depending on the implementation and specific access.

Imprecise Match for Data Breakpoints

An imprecise match for a data breakpoint occurs when the match equation cannot be fully evaluated at the time the load/store instruction is executed. This case occurs when the processor is not stalled on a scheduled load and a data breakpoint must compare on the data value returned by the load. If the breakpoint matches, then the DB_match equation is true later in the execution flow rather than at the same time as load/store instruction that caused the load/store access to match. Only data breakpoints with value compares can be imprecise, in which case the breakpoints can be imprecise for all or some of those accesses depending on the implementation.

Debug Exceptions from Breakpoints

This section describes how to set up instruction and data breakpoints to generate debug exceptions when the match conditions are true.

Debug Exception Caused by Instruction Breakpoint

The BE bit in the IBCn register must be set for an instruction breakpoint to be enabled. A Debug Instruction Break exception occurs when the IB_match equation is true (see section“Conditions for Matching Instruction Breakpoints” on page 20-35). The corresponding BS bit in the IBS register is set when the breakpoint generates the debug exception. The Debug Instruction Break exception is precise, so the DEPC register and DBD bit in the Debug register point to the instruction that caused the IB_match equation to be true. The instruction receiving the debug exception only updates the debug related registers. That instruction will not cause any loads/stores to occur. Thus a debug exception from a data breakpoint cannot occur at the same time an instruction receives a Debug Instruction Break exception.

The debug handler usually returns to the instruction causing the Debug Instruction Break exception, whereby the instruction is executed. Debug software must disable the breakpoint when returning to the instruction, otherwise the Debug Instruction Break exception will reoccur. An alternative is for debug software to emulate the instruction(s) in software and change the DEPC accordingly.

Debug Exception by Data Breakpoint

The BE bit in the DBCn register must be set for a data breakpoint to be enabled. A debug exception occurs when the DB_match condition is true. A matching data breakpoint generates either a precise or an imprecise debug exception (see section “Precise / Imprecise Debug Exceptions on Data Breakpoints with Data Value Compares” on page 20-52).

Debug Data Break Load/Store Exception as a Precise Debug Exception

A Debug Data Break Load/Store exception occurs when a data breakpoint indicates a precise match. In this case, the DEPC register and DBD bit in the Debug register point to the load/store instruction that caused the DB_match equation to be true, and the corresponding BS bit in the DBS register is set. Details about behavior of the instruction causing the debug exception is shown in Table 20.26.

Notes

Instruction and Data Breakpoint	Load/Store Instruction Execution	Destination Register	External Memory System Access
Store with/without value match	Not completed	Not updated[1]	Store to memory is not committed
Load without value match		Not updated[2]	Load from memory does not occur
Loan with value match			Load from memory does occur

Table 20.26 Behavior on Precise Exceptions from Data Breakpoints

1. This applies to the Store Conditional Word/Doubleword (SC/SCD instructions.

2. This includes side effects like Load Linked Word/Doubleword (LL/LLD) instructions.

Thus, in the case a data breakpoint with data value compare is set up on a load instruction, the load does occur from the external memory, since the data value is required to evaluate the match condition, but the destination register is not updated, so the loaded value is simply discarded. The rules shown in Table 20.27 describe update of the BS bits when several data breakpoints match the same access and generate a debug exception

Instruction	Breakpoints that Match		Update of BS Bits Matching Data Breakpoints	
	Without Value Compare	With Value Compare	Without Value Compare	With Value Compare
Load / Store	One or more	None	BS bits set for all	No matching break-points
Load	One or more	One or more	BS bits set for all	Unchanged BS bits since load of data value does not occur, so match of the breakpoint cant be determined
Load	None	One or more	No matching break-points	BS bits set for all
Store	One or more	One or more	BS bits set for all	Optional to either set BS bits for all, or change none of the BS bits
Store	None	One or more	No matching break-points	BS bits set for all

Table 20.27 Behavior on Precise Exceptions from Data Breakpoints

Any BS bit set prior to the match and debug exception is kept set, since only debug software can clear the BS bits.

The debug handler usually returns to the instruction that caused the Debug Data Break Load/Store exception, whereby the instruction is re-executed. This re-execution results in a repeated load from system memory after a data breakpoint with a data value compare on a load, because the load occurred previously in order to allow evaluation of the breakpoint as described above. Memory-mapped devices with side

Notes

effects on loads must allow such reloads, or debug software should alternatively avoid setting data breakpoints with data value compares on the address of such devices. Debug software must disable breakpoints when returning to the instruction, otherwise the Debug Data Break Load/Store exception will reoccur. An alternative is for debug software to emulate the instruction in software and change the DEPC accordingly.

Debug Data Break Load/Store Exception as an Imprecise Debug Exception

A Debug Data Break Load/Store Imprecise exception occurs when a data breakpoint indicates an imprecise match. In this case, the DEPC register and DBD bit in the Debug register point to an instruction later in the execution flow rather than at the load/store instruction that caused the DB_match equation to be true. The load/store instruction causing the Debug Data Break Load/Store Imprecise exception always updates the destination register and completes the access to the external memory system. Therefore this load/store instruction is not re-executed on return from the debug handler, because the DEPC register and DBD bit do not point to that instruction.

Several imprecise data breakpoints can be pending at a given time, if the bus system supports multiple outstanding data accesses. The breakpoints are evaluated as the accesses finalize, and a Debug Data Break Load/Store Imprecise exception is generated only for the first one matching. Both the first and succeeding matches cause corresponding BS bits and DDBLImpr/DDBSImpr to be set, but no debug exception is generated for succeeding matches because the processor is already in Debug Mode. Similarly, if a debug exception had already occurred at the time of the first match (for example, due to a precise debug exception), then all matches cause the corresponding BS bits and DDBLImpr/DDBSImpr to be set, but no debug exception is generated because the processor is already in Debug Mode.

The SYNC instruction, followed by appropriate spacing must be executed before the BS bits and DDBLImpr/DDBSImpr bits are accessed for read or write. This delay ensures that these bits are fully updated. Any BS bit set prior to the match and debug exception are kept set, because only debug software can clear the BS bits.

Breakpoints Used as Triggerpoints

Software can set up both instruction and data breakpoints such that a matching breakpoint does not generate a debug exception, but sends an indication through the BS bit only. The TE bit in the IBCn or DBCn register controls whether an instruction or data breakpoint, respectively, is used as a triggerpoint. Triggerpoints are evaluated for matches under the same criteria as breakpoints. The BS bit in the IBS or DBS register is set for a triggerpoint when the respective IB_match condition (see section “Conditions for Matching Instruction Breakpoints” on page 20-35) or DB_match condition (see section “Conditions for Matching Data Breakpoints” on page 20-37) is true. For the BS bit to be set for an instruction triggerpoint, either the instruction must be fully executed or an exception must occur on the instruction.

The BS bit for a data triggerpoint can only be set if no exception with higher priority than the Debug Data Break Load/Store exception with address match only occurred on the load/store instruction. For exceptions with equal or lower priority than the Debug Data Break Load/Store exception with address match only, the BS bits are still set for a matching triggerpoint. For example, the BS bit is set even if a TLB or Bus Error exception occurred on the load/store instruction. Data triggerpoints with value compares require the data value to be valid for the BS bit to be set, which is not the case if, for example, a TLB or Bus Error exception occurs on a load instruction. However, for stores, the trigger may compare on UNPREDICTABLE data as described in section “Data Breakpoints in case of Unaligned Address” on page 20-39. The rules for update of the BS bits are shown in Table 20.28.

Notes

Instruction	With/Without Value Compare	BS Bits Update for Triggerpoint
Load / Store	Without value compare	BS bit set if no exception with higher priority than the Debug Data Break Load/Store exception, with address match only, occurred on the instruction.
Load	With value compare	BS bit set if no exception with higher priority than the Debug Data Break Load exception, with address and data value match, occurred on the instruction.
Store	With value compare	BS bit is set if no exception occurred on the instruction, and is optional to be if an exception with equal or lower priority than the Debug Data Break Store exception, with address match only, occurred on the instruction, with the requirement that either all the relevant BS bits are set, or none are changed.

Table 20.28 Rules for Update of BS Bits on Data Triggerpoints

Data breakpoints with imprecise matches generate imprecise triggers when enabled by the TE bit. Note that trigger indications by BS may be set based on compare with UNPREDICTABLE data. A triggerpoint match can be indicated on an optional internal signal or chip pin.

Instruction Breakpoint Registers

This section describes the instruction breakpoint registers for MIPS32 and MIPS64 processors, and other R4k privileged environment implementations of 32-bit and 64-bit processors. These registers provide status and control for the instruction breakpoints. All registers are in drseg. The 1 to 15 implemented breakpoints are numbered 0 to 14, respectively, for registers and breakpoints. The specific breakpoint number is indicated by “n”. The registers and their respective addresses offsets are shown in Table 20.29.

Offset in drseg	Register Mnemonic	Register Name and Description
0x1000	IBS	Instruction Breakpoint Status
0x1100 + 0x100*n	IBAn	Instruction Breakpoint Address n
0x1108 + 0x100*n	IBMn	Instruction Breakpoint Address Mask n
0x1110 + 0x100*n	IBASIDn	Instruction Breakpoint ASID n
0x1118 + 0x100*n	IBCn	Instruction Breakpoint Control n

Table 20.29 Instruction Breakpoint Register Mapping

Instruction Breakpoint Status (IBS) Register

Compliance Level: Required if any instruction breakpoints are implemented, optional otherwise.

The Instruction Breakpoint Status (IBS) register holds implementation and status information about the instruction breakpoints. It is located at drseg offset 0x1000. The ASIDsup bit applies to all instruction breakpoints. Figure 20.9 shows the format of the IBS register and Table 20.30 describes the IBS register fields.

Notes

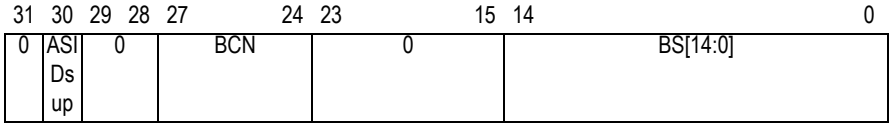


Figure 20.9 IBS Register Format

Fields		Description	Read/ Write	Reset State	Compliance
Name	Bit				
ASIDsup	30	Indicates if ASID compare is supported in instruction breakpoints: 0: No ASID compare 1: ASID compare (IBASIDn register implemented) ASID support indication does not guarantee a TLB-type MMU, because the same breakpoint implementation can be used with processors having all different types of MMUs.	R	Preset	Required
BCN	27:24	Number of instruction breakpoints implemented: 0: Reserved 1-15: Number of instructions breakpoints	R	Preset	Required
BS[14:0]	14:0	Break Status (BS) bit for breakpoint n is at BS[n], where n is 0 to 14. A bit is set to 1 when the condition for its corresponding breakpoint has matched. The number of BS bits implemented corresponds to the number of breakpoints indicated by the BCN field. Debug software is expected to clear the bits before use, because reset does not clear these bits. Bits not implemented are read-only (R) and read as zeros.	R/W0	Undefined	Required for bits at implemented breakpoints, other bits not implemented
0	MSB:31, 29:28, 23:15	Must be written as zeros on read.	0	0	Reserved

Table 20.30 IBS Register Field Description

Instruction Breakpoint Address n (IBAn) Register

Compliance Level: Required with instruction breakpoint n, optional otherwise. The Instruction Breakpoint Address n (IBAn) register has the address used in the condition for instruction breakpoint n. It is located at drseg offset 0x1100 + 0x100 * n. Figure 20.10 shows the format of the IBAn register and Table 20.31 describes the IBAn register field.

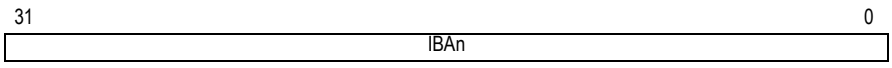


Figure 20.10 IBAn Register Format

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
IBA	MSB:0	Instruction breakpoint address for condi-tion.	R/W	Undefined	Required

Table 20.31 IBAn Register Field Description

Instruction Breakpoint Address Mask n (IBMn) Register

Compliance Level: Required with instruction breakpoint n, optional otherwise.

The Instruction Breakpoint Address Mask n (IBMn) register has the address compare mask used in the condition for instruction breakpoint n. The address that is masked is in the IBAn register. The IBMn register is located at drseg offset 0x1108 + 0x100 * n. Figure 20.11 shows the format of the IBMn register and Table 20.32 describes the IBMn register field.

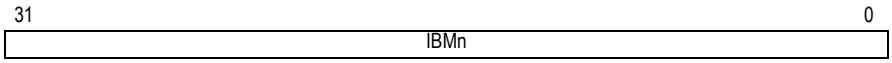


Figure 20.11 IBMn Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
IBM	MSB:0	Instruction breakpoint address mask for condition: 0: Corresponding address bit compared 1: Corresponding address bit masked.	R/W	Undefined	Required

Table 20.32 IBMn Register Field Description

Instruction Breakpoint ASID n (IBASIDn) Register

Compliance Level: Required with instruction breakpoint n if the ASIDsup bit in the IBS register is 1, optional otherwise.

The Instruction Breakpoint ASID n (IBASIDn) register has the ASID value used in the compare for instruction breakpoint n. It is located at drseg offset 0x1110 + 0x100 * n. Figure 20.12 shows the format of the IBASIDn register and Table 20.33 describes the IBASIDn register fields. The width of the ASID field for the compare is 8 bits. It is identical to the width of the ASID field in the EntryHi register used with the TLB-type MMU.

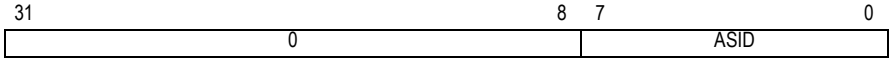


Figure 20.12 IBASIDn Register Format

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
ASID	7:0	Instruction breakpoint ASID value for com-pare.	R/W	Undefined	Required
0	MSB:8	Must be written as zeros; return zeros on read.	0	0	Reserved

Table 20.33 IBASIDn Register Field Description

Instruction Breakpoint Control n (IBCn) Register

Compliance Level: Required with instruction breakpoint n, optional otherwise.

The Instruction Breakpoint Control n (IBCn) register determines what constitutes instruction breakpoint n: triggerpoint, breakpoint, ASID value inclusion. This register is located at drseg offset 0x1118 + 0x100 * n. Figure 20.13 shows the format of the IBCn register and Table 20.34 describes the IBCn register fields.

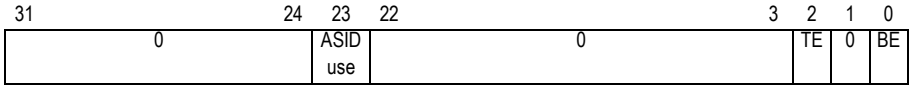


Figure 20.13 IBCn Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
ASIDuse	23	Use ASID value in compare for instruction breakpoint n: 0: Do not use ASID value in compare 1: Use ASID value in compare Debug software should only set the ASI-Duse if a TLB in the implementation is used by the application software. This bit is read-only and reads as zero, if not implemented.	R/W	Undefined	Required if ASIDsup in IBS register is 1, otherwise not imple-mented
TE	2	Use instruction breakpoint n as trigger-point: 0: Do not use it as triggerpoint 1: Use it as triggerpoint	R/W	0	Required
BE	0	Use instruction breakpoint n as breakpoint: 0: Do not use it as breakpoint 1: Use it as breakpoint	R/W	0	Required
0	MSB:24, 22:3, 1	Must be written as zeros; return zeros on read	0	0	Required

Table 20.34 IBCn Register Field Description

Notes

Data Breakpoint Registers

This section describes the data breakpoint registers for MIPS32 and MIPS64 processors, and other R4k privileged environment implementations of 32-bit and 64-bit processors. These registers provide status and control for the data breakpoints. All registers are in drseg. The 1 to 15 implemented breakpoints are numbered 0 to 14, respectively, for registers and breakpoints. The specific breakpoint number is indicated by “n”. The registers and their respective addresses offsets are shown in Table 20.35.

Offset in drseg	Register Mnemonic	Register Name and Description
0x2000	DBS	Data Breakpoint Status
0x2100 + 0x100*n	DBAn	Data Breakpoint Address n
0x2108 + 0x100*n	DBMn	Data Breakpoint Address Mask n
0x2110 + 0x100*n	DBASIDn	Data Breakpoint ASID n
0x2118 + 0x100*n	DBCn	Data Breakpoint Control n
0x2120 + 0x100*n	DBVn	Data Breakpoint Value n

Table 20.35 Data Breakpoint Register Mapping

Data Breakpoint Status (DBS) Register

Compliance Level: Required if any data breakpoints are implemented, optional otherwise.

The Data Breakpoint Status (DBS) register holds implementation and status information about the data breakpoints. It is located at drseg offset 0x2000. The ASIDsup, NoSVmatch, and NoLVmatch fields apply to all data breakpoints. Figure 20.14 shows the format of the DBS register and Table 20.36 describes the DBS register fields

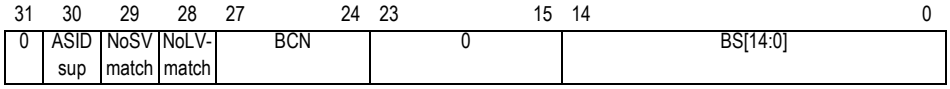


Figure 20.14 DBS Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
ASIDsup	30	Indicates if ASID compare is supported in data breakpoints: 0: No ASID compare 1: ASID compare (DBASIDn register implemented) ASID support indication does not guarantee a TLB-type MMU, because the same breakpoint implementation can be used with processors having all different types of MMUs.	R	Preset	Required

Table 20.36 DBS Register Field Description (Part 1 of 2)

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
NoSV-match	29	Indicates if a value compare on a store is supported in data breakpoints: 0: Data value and address in condition on store 1: Address compare only in condition on store	R	Preset	Required
NoLVmatch	28	Indicates if a value compare on a load is supported in data breakpoints: 0: Data value and address in condition on load 1: Address compare only in condition on load	R	Preset	Required
BCN	27:24	Number of data breakpoints implemented: 0: Reserved 1-15:Number of data breakpoints	R	Preset	Required
BS[14:0]	14:0	Break Status (BS) bit for breakpoint n is at BS[n], where n is 0 to 14. The bit is set to 1 when the condition for its corresponding breakpoint has matched. The number of BS bits implemented corresponds to the number of breakpoints indicated by the BCN bit. Debug software is expected to clear the bits before use, since these are not cleared by reset. Bits not implemented are read-only (R) and read as zeros.	R/W0	Undefined	Required for bits at implemented breakpoints, other bits not implemented
0	MSB:31, 23:15	Must be written as zeros; return zeros on read.	0	0	Reserved

Table 20.36 DBS Register Field Description (Part 2 of 2)

Data Breakpoint Address n (DBAn) Register

Compliance Level: Required with data breakpoint n, optional otherwise.

The Data Breakpoint Address n (DBAn) register has the address used in the condition for data breakpoint n. This register is located at drseg offset 0x2100 + 0x100 * n. Figure 20.15 shows the format of the DBAn register and Table 20.37 describes the DBAn register field.

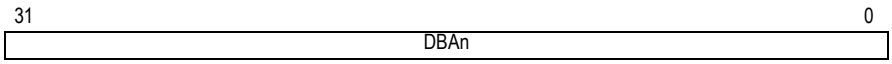


Figure 20.15 DBAn Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
DBA	MSB:0	Data breakpoint address for condition.	R/W	Undefined	Required

Table 20.37 DBAn Register Field Description

Notes

Data Breakpoint Address Mask n (DBMn) Register

Compliance Level: Required with data breakpoint n, optional otherwise.

The Data Breakpoint Address Mask n (IBMn) register has the address compare mask used in the condition for data breakpoint n. The address that is masked is in the DBAn register. The DBMn register is located at drseg offset 0x2108 + 0x100 * n. Figure 20.16 shows the format of the DBMn register and Table 20.38 describes the DBMn register field.

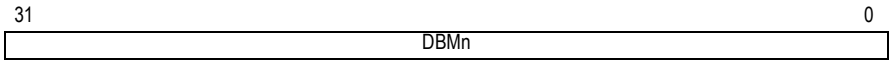


Figure 20.16 DBMn Register Format

Fields		Description	Read/ Write	Reset State	Compliance
Name	Bit				
DBMn	MSB:0	Data breakpoint address mask for condition: 0: Corresponding address bit compared 1: Corresponding address bit masked	R/W	Undefined	Required

Table 20.38 DBMn Register Field Description

Data Breakpoint ASID n (DBASIDn) Register

Compliance Level: Required with data breakpoint n if the ASIDsup bit in the DBS register is 1, optional otherwise.

The Data Breakpoint ASID n (DBASIDn) register has the ASID value used in the compare for data breakpoint n. It is located at drseg offset 0x2110 + 0x100 * n. Figure 20.17 shows the format of the DBASIDn register and Table 20.39 describes the DBASIDn register fields. The width of the ASID field for the compare is 8 bits. It is identical to the width of the ASID field in the EntryHi register used with the TLB-type MMU.

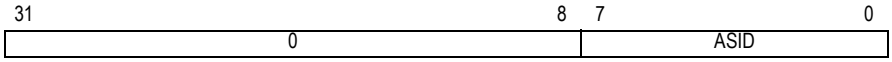


Figure 20.17 DBASIDn Register Format

Fields		Description	Read/ Write	Reset State	Compliance
Name	Bit				
ASID	7:0	Data breakpoint ASID value for compare.	R/W	Undefined	Required
0	MSB:0	Must be written as zeros; return zeros on read.	0	0	Reserved

Table 20.39 DBASIDn Register Field Description

Data Breakpoint Control n (DBCn) Register

Compliance Level: Required with data breakpoint n, optional otherwise.

Notes

The Data Breakpoint Control n (DBCn) register what constitutes data breakpoint n: triggerpoint, breakpoint, ASID value inclusion, load/store access fulfillment, ignore byte access, byte lane mask. This register is located at drseg offset 0x2118 + 0x100 * n. The “data bus” is described in section “Conditions for Matching Data Breakpoints” on page 20-37. Figure 20.18 shows the format of the DBCn register and Table 20.40 describes the DBCn register fields.

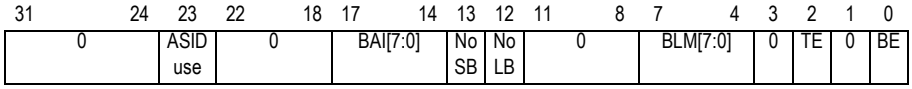


Figure 20.18 DBCn Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
ASIDuse	23	Use ASID value in compare for data breakpoint n: 0: Do not use ASID value in compare 1: Use ASID value in compare Debug software should only set the ASIDuse if a TLB in the implementation is used by the application software. This bit is read-only and reads as zero, if not implemented.	R/W	Undefined	Required if ASIDsup in DBS reg. is 1, otherwise not implemented
BAI[7:0]	21:14	Byte access ignore. Controls ignore of access to specific bytes. BAI[0] ignores access to byte at bits [7:0] of the data bus, BAI[1] ignores access to byte at bits [15:8], etc.: 0: Condition depends on access to corresponding byte 1: Access for corresponding byte is ignored. Debug software must adjust for endianess when programming this field. BAI[7:4] are read-only (R) and read as zeros for 32-bit processors.	R/W	Undefined	Required for byte lanes in implementation, otherwise not implemented.
NoSB	13	Controls whether condition for data breakpoint is ever fulfilled on a store access: 0: Condition can be fulfilled on store access 1: Condition is never fulfilled on store access	R/W	Undefined	Required
NoLB	12	Controls whether condition for data breakpoint is ever fulfilled on a load access: 0: Condition can be fulfilled on load access 1: Condition is never fulfilled on load access	R/W	Undefined	Required

Table 20.40 DBCn Register Field Description (Part 1 of 2)

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
BLM[7:0]	11:4	Byte lane mask for value compare on data breakpoint. BLM[0] masks byte at bits [7:0] of the data bus, BLM[1] masks byte at bits [15:8], etc.: 0: Compare corresponding byte lane 1: Mask corresponding byte lane Debug software must adjust for endianess when programming this field. BLM[7:4] are un-implemented for 32-bit processors. BLM[7:0] are un-implemented if value compare is not implemented, which is the case when NoSVmatch and NoLV-match bits in DBS are both 1. Bits are read-only (R) and read as zeros if not implemented.	R/W	Undefined	Required for byte lanes in implementa-tion and if value com-pare, other-wise not implemented
TE	2	Use data breakpoint n as triggerpoint: 0: Do not use it as triggerpoint 1: Use it as triggerpoint	R/W	0	Required
BE	0	Use data breakpoint n as breakpoint: 0: Do not use it as breakpoint 1: Use it as breakpoint	R/W	0	Required
0	MSB:24, 22, 3, 1	Must be written as zeros; return zeros on read.	0	0	Reserved

Table 20.40 DBCn Register Field Description (Part 2 of 2)

Data Breakpoint Value n (DBVn) Register

Compliance Level: Required with data breakpoint n if data value compare is supported (indicated by either NoSVmatch or NoLVmatch bits in DBS being 0), optional otherwise.

The Data Breakpoint Value n (DBVn) register has the value used in the condition for data breakpoint n. It is located at drseg offset 0x2120 + 0x100 * n. Figure 20.19 shows the format of the DBVn register and Table 20.41 describes the DBVn register field.

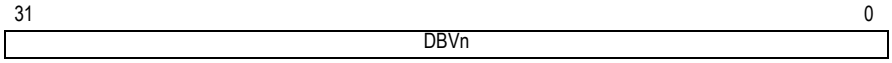


Figure 20.19 DBVn Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
DBV	MSB:0	Data breakpoint data value for condition. Debug software must adjust for endianess when programming this field.	R/W	Undefined	Required

Table 20.41 DBVn Register Field Description

Recommendations for Implementing Hardware Breakpoints

This section provides useful information for implementing instruction and data breakpoints.

Notes

Number of Instruction Breakpoints Without Single Stepping

If hardware single stepping is not implemented, then at least two instruction breakpoints are required. Four instruction hardware breakpoints are recommended.

Data Breakpoints with Data Value Compares

Data breakpoints should be implemented with data value compares. Also, data value compares should be implemented even if it is not possible to break on loads with precise data value compares. For more information on precise exceptions, refer to section “Precise / Imprecise Debug Exceptions on Data Breakpoints with Data Value Compares” on page 20-52.

Data Breakpoint Compare on Invalid Data

Data breakpoints should only compare on valid data, meaning they only generate debug exceptions based on valid data in the compare. This does also apply to compare on store data for a store to an unaligned address. For example, no debug exception should be generated for a bus error on a load that has a pending data breakpoint to compare on the data returned by the load. However, in some cases, the indication of invalid data is late relative to the data, for example, for a cache error as a result of a complex error detection. In this case, data breakpoints can indicate a debug exception because the data was believed to be valid at the time of the compare, and the pending error is then indicated to the debug handler through the DBusEP or CacheEP bit in the Debug register, because the error occurred after the debug exception. Note that for bus errors due to external events, the bus error indication usually is available when the compare in the data breakpoint would take place. Thus, it is possible to avoid a debug exception.

Precise / Imprecise Debug Exceptions on Data Breakpoints with Data Value Compares

Data breakpoints are recommended to generate precise debug exceptions, if possible in the implementation. Thus the DEPC register and DBD bit in the Debug register point to the load/store that caused the debug exception to occur. This instruction can then be re-executed when execution resumes after the debug handler. However, data breakpoints are allowed to cause imprecise debug exceptions when the breakpoint is set up with data value compares; for example, if data breakpoints with compares on loaded data values cannot be made precise due to a non-blocking load. In this case, the DEPC register and DBD bit in the Debug register point to an instruction in the execution flow after the load/store that caused the imprecise debug exception. The BS bit can be updated when the match is detected, even though a debug exception is not taken until later due to internal stalls (for example, a nulled instruction in the pipeline at the time the match is detected). It is implementation specific as to which cases a data breakpoint can cause an imprecise debug exception. It is recommended that the data breakpoints cause imprecise matches in as few cases as possible.

Implementations can require imprecise debug exceptions from data breakpoints on loads with value compares in a specific address range, if re-execution of a load in this range is not acceptable. This case is possible if the load has side effects such as removing an entry on a queue. Imprecise debug exceptions for value compares ensure that the destination register is properly updated with the loaded value, whereby re-execution of the load is avoided.

Breakpoint Examples

Instruction Breakpoint Examples

This section provides examples that illustrate using an instruction break.

Instruction Break in Small Range of Instructions with ASID

This example shows how to set up an instruction breakpoint to break on the fetch of any one of the four instructions in the virtual address range shown below:

```
0x0000 0010    J L1          // ASID = 0x5
0x0000 0014    NOP
0x0000 0018    J L2
0x0000 001C    NOP
```

Notes

The break registers must be set up as follows:

- *IBA0 = 0x0000 0010*
- *IBM0 = 0x0000 000C*
- *IBC0: BE=1, ASIDuse=1, ASID = 0x5, other bits zero.*

Note that IBA0 has the starting address, and IBM0 has the address mask.

Instruction Break on 32-bit MIPS16™ Instruction

In this example, instruction breakpoint 0 needs to be set up to break on the range 0x0000 0030 to 0x0000 0036, which starts with the second part of an extended MIPS16 instruction:

```
0x0000 002e    EXT     // (1st part of MIPS16 inst.)
0x0000 0030    ADD     // (2nd part)
0x0000 0032    SUB
0x0000 0034    SUB
0x0000 0036    SUB
```

The break registers must be set up as follows:

- *IBA0 = 0x0000 0031*
- *IBM0 = 0x0000 0006*
- *IBC0: BE = 1, ASIDuse = 0, other bits zero*

The CPU does not take a debug exception when fetching the second part of the ADD instruction, because it does not constitute a whole instruction. The first break is on the SUB instruction at 0x0000 0032.

Data Breakpoint

This section provides three examples of data breakpoints.

Data Break on Load Access with ASID

This example shows how to perform a break on data breakpoint 0 when the CPU loads data 0xAAAA 0000 from memory location 0x0000 0100 in ASID=0x7:

```
LW $2, 0x100($0)   // ASID = 0x7
```

The break registers must be set up as follows:

- *DBA0 = 0x0000 0100*
- *DBM0 = 0x0*
- *DBV0 = 0xAAAA 0000*
- *DBC0: BE = 1, NoLB = 0, NoSB = 1, BLM = 0, BAI = 0, ASIDuse = 1, ASID = 0x7, other bits zero*

In this example, DBA0 contains the breakpoint address; DBM0 has the address mask; DBV0 has the data value; and DBC0 indicates a breakpoint condition might be fulfilled on a load but not on a store, there is a value compare for a corresponding byte, and an ASID is used.

Data Break on Store(s) to Halfword in Memory

This example shows a break on data breakpoint 0 when the CPU stores data in a specific halfword in memory. Stores to the other halfword at the same address can be ignored. The data word is illustrated in Figure 20.20; the halfword for bits 31:16 is shaded. The store instructions shown in Figure 20.20 alter the shaded halfword and cause a break if the breakpoint registers are set up as shown below.

Notes

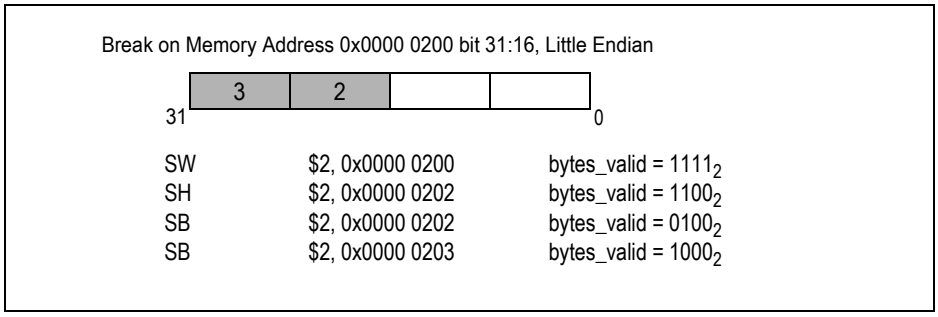


Figure 20.20 Data Break on Store with Value Compare

In this example, the data breakpoint registers are set up as follows:

– *DBA0 = 0x0000 0200*
– *DBM0 = 0*
– *DBC0: BE = 1, NoLB = 1, NoSB = 0, BLM = 11112, BAI = 00112, ASIDuse = 0, other bits zero*

Data Break on Store(s) to Halfword Range in Memory with Certain Value

In this example, the most significant halfword in a given memory range is altered, and the most significant part of the halfword is written a certain value. The data word is illustrated below; the halfword for bits 31:16 is shaded. The store instructions shown in Figure 20.21 alter the shaded halfword and cause a break if the breakpoint registers are set up as shown below.

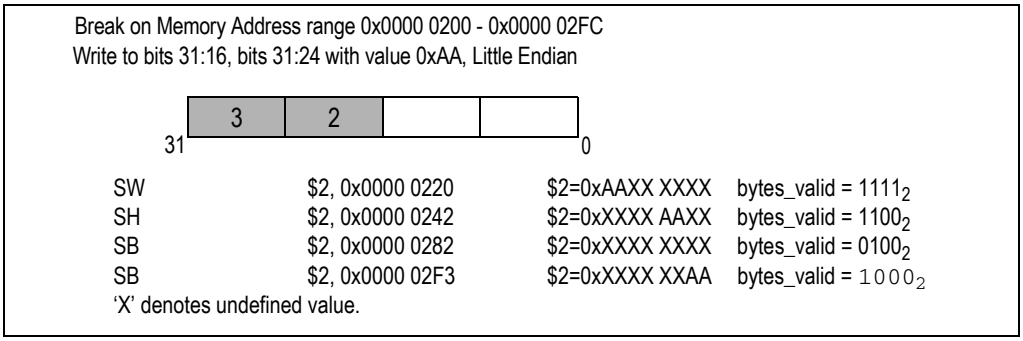


Figure 20.21 Data Break on Store with Value Compare

In this example, the data breakpoint registers are set up as follows:

– *DBA0 = 0x0000 0200*
– *DBM0 = 0x0000 00FC*
– *DBV0 = 0xAA00 0000*

DBC0: BE = 1, NoLB = 1, NoSB = 0, BLM = 01112, BAI = 00112, ASIDuse = 0, other bits zero

EJTAG Test Access Port

The overall features of the EJTAG Test Access Port (TAP) are:

- *Identification of device and EJTAG debug features accessed through the TAP*
- *dmseg memory "emulation" (mapping dmseg processor accesses into probe transactions).*
- *Reset handling allows debug exception immediately after reset*
- *Low-power mode indications*
- *Implementation-dependent processor and peripheral reset.*

Notes

If the TAP is not implemented then other features depending on register values and indications from the TAP should behave as if these register values and indications have the power-up and reset value. Figure Figure 20.22 shows an overview of the elements in the TAP.

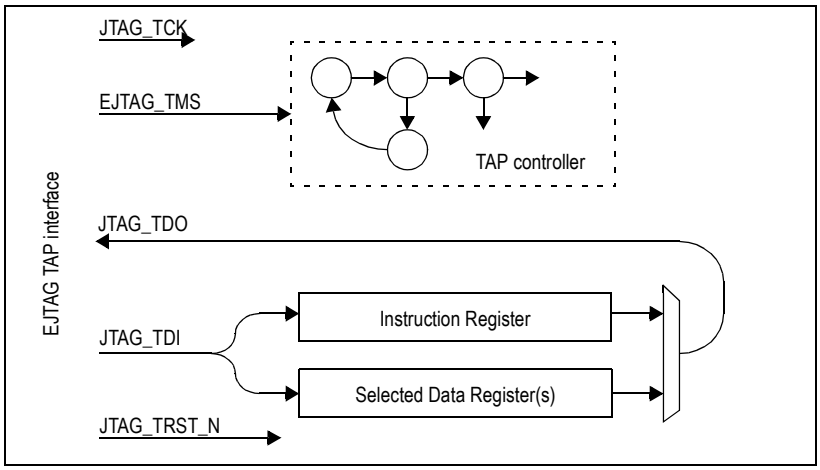


Figure 20.22 Test Access Port (TAP) Overview

The TAP consists of the following signals: Test Clock (JTAG_TCK), Test Mode (EJTAG_TMS), Test Data In (JTAG_TDI), Test Data Out (JTAG_TDO), and Test Reset (JTAG_TRST_N). JTAG_TCK and EJTAG_TMS control the state of the TAP controller, which controls access to the Instruction or selected data register(s). The Instruction register controls selection of data registers. Access to the Instruction and data register(s) occurs serially through JTAG_TDI and JTAG_TDO. JTAG_TRST_N is an asynchronous reset signal to the TAP. Access through the TAP does not interfere with the operation of the processor, unless features specifically described to do so are used.

The description of the EJTAG TAP in this chapter is intended only to cover EJTAG issues related to use of a TAP. Consult the “IEEE Std 1149.1-1990, IEEE Standard Test Access Port and Boundary-Scan Architecture” and also Chapter 19 of this manual for detailed information about the use of the JTAG boundary scan. For EJTAG features, there is no difference between a reset and a soft reset occurring to the processor; they behave identically in both Debug Mode and Non-Debug Mode. References to reset in the following sections refer to both reset (hard reset) and soft (warm) reset.

TAP Signals

The signals JTAG_TCK, EJTAG_TMS, JTAG_TDI, JTAG_TDO, and JTAG_TRST_N make up the interface for the EJTAG TAP. These signals are described in detail below. Figure 20.40 shows the connection of the signals to chip pins.

Test Clock Input (JTAG_TCK)

JTAG_TCK is the clock that controls the updating of the TAP controller and the shifting of data through the Instruction or selected data register(s). JTAG_TCK is independent of the processor clock, with respect to both frequency and phase.

Test Mode Select Input (EJTAG_TMS)

EJTAG_TMS is the control signal for the EJTAG TAP controller. This signal is sampled on the rising edge of JTAG_TCK. When EJTAG is in use, JTAG_TMS should be left disconnected (since there is an internal pull-up) or driven high.

Test Data Input (JTAG_TDI)

JTAG_TDI is the test data input to the Instruction or selected data register(s). This signal is sampled on the rising edge of JTAG_TCK for some EJTAG TAP controller states.

Notes

Test Data Output (JTAG_TDO)

JTAG_TDO is the test data output from the Instruction or data register(s). This signal changes on the falling edge of JTAG_TCK, or becomes tri-stated asynchronously when JTAG_TRST_N is driven low. The off-chip JTAG_TDO is only driven when data is shifted out, otherwise the off-chip JTAG_TDO is tri-stated. The tri-state notation indicates that the JTAG_TDO off-chip signal is undriven.

Test Reset Input (JTAG_TRST_N)

JTAG_TRST_N is the test reset input that asynchronously resets the EJTAG TAP, with the following immediate effects:

- *The TAP controller is put into the Test-Logic-Reset state*
- *The Instruction register is loaded with the IDCODE instruction*
- *Any EJTAGBOOT indication is cleared*
- *The JTAG_TDO output is tri-stated.*

JTAG_TRST_N does not reset any other part of the EJTAG TAP or processor. Thus this type of reset does not affect the processor, and the processor reset is not allowed to have any effect on the above parts of the EJTAG TAP.

TAP Controller

The TAP controller is a state machine whose active state controls TAP reset and access to Instruction and data registers. The state transitions in the EJTAG TAP controller occur on the rising edge of JTAG_TCK or when JTAG_TRST_N goes low. The JTAG_TMS signal determines the transition at the rising edge of JTAG_TCK. Figure 20.23 shows the state diagram for the TAP controller.

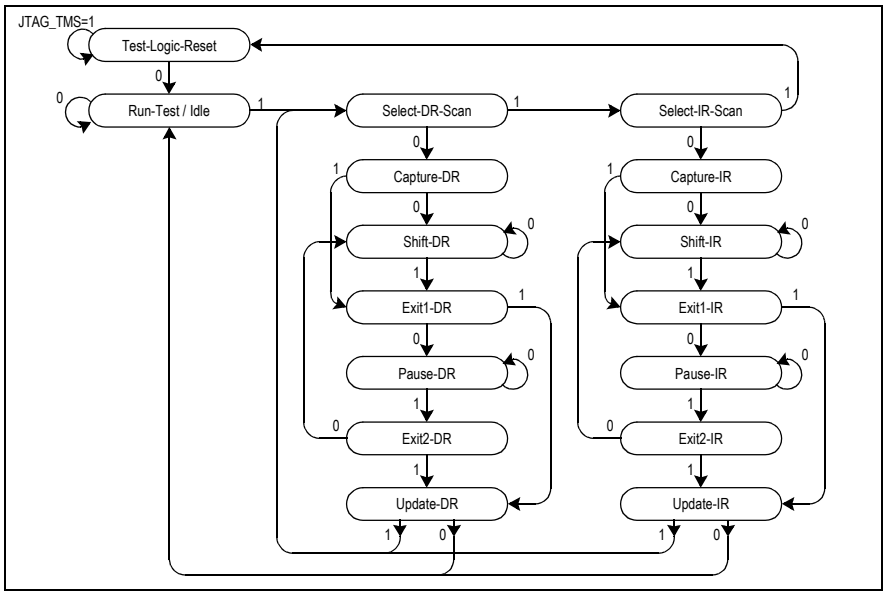


Figure 20.23 EJTAG TAP Controller State Diagram

The behavior of the functional states shown in the figure is described below. The non-functional states are intermediate states in which no registers in the TAP change, and are not described here. Events in the following subsections are described with relation to the rising and falling edge of JTAG_TCK. The described events take place when the TAP controller is in the corresponding state when the clock changes. The EJTAG TAP controller is forced into the Test-Logic-Reset state at power-up either by an active (power-up reset circuit) low value or static low value on JTAG_TRST_N. The Test-Logic-Reset state is also reached after five rising edges on JTAG_TCK while EJTAG_TMS is set to one.

Notes

Test-Logic-Reset State

When the Test-Logic-Reset state is entered, the Instruction register is loaded with the IDCODE instruction, and any EJTAGBOOT indication is cleared. This state ensures that the TAP does not interfere with the normal operation of the CPU core. The TAP controller always reaches this state after five rising edges on JTAG_TCK when EJTAG_TMS is set to 1. A low value on JTAG_TRST_N immediately places the TAP controller in this state asynchronous to JTAG_TCK.

Capture-IR State

In the Capture-IR state, the two LSBs of the Instruction register are loaded with the value 012, and the upper MSBs are loaded with implementation-dependent values. Both values are loaded on the rising edge of JTAG_TCK.

Shift-IR State

In the Shift-IR state, the LSB of the Instruction register is output on JTAG_TDO on the falling edge of JTAG_TCK. The Instruction register is shifted one position from MSB to LSB on the rising edge of JTAG_TCK, with the MSB shifted in from JTAG_TDI. The value in the Instruction register does not take effect until the Update-IR state. Figure 20.24 shows the shifting direction for the Instruction register.

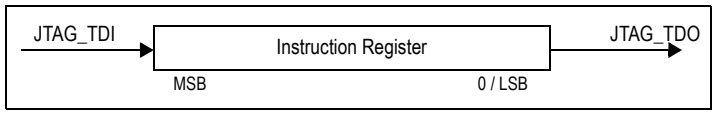


Figure 20.24 JTAG_TDI to JTAG_TDO Path in Shift Mode State

The length of the Instruction register is specified in section “Instruction Register and Special Instructions” on page 20-58. The value loaded in the Capture-IR state is used as the initial value for the Instruction register when shifting starts. Thus, it is not possible to read out the previous value of the Instruction register.

Update-IR State

In the Update-IR state, the value in the Instruction register takes effect on the rising or falling edge of JTAG_TCK.

Capture-DR State

In the Capture-DR state, the value of the selected data register(s) is captured on the rising edge of JTAG_TCK for shifting out in the Shift-DR state. The Capture-DR state reads the data, in order to output this read value in the Shift-DR state. The Instruction register controls the selection of the following data register(s): Bypass, Device ID, Implementation, EJTAG Control, Address, and Data register(s).

Shift-DR State

In the Shift-DR state, the LSB of the selected data register(s) is output on JTAG_TDO on the falling edge of JTAG_TCK. The selected data register(s) is shifted one position from MSB to LSB on the rising edge of JTAG_TCK, with JTAG_TDI shifted in at the MSB. The value(s) shifted into the register(s) does not take effect until the Update-DR state. Figure 20.25 shows the shifting direction for the selected data register.

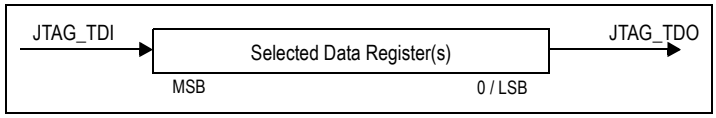


Figure 20.25 JTAG_TDI to JTAG_TDO Path for Selected Data Register(s) in Shift-DR State

The length of the shift path depends on the selected data register(s).

Update-DR State

In the Update-DR state, the update of the selected data register(s) with the value from the Shift-DR state occurs on the falling or rising edge of JTAG_TCK. This update writes the selected register(s).

Notes

Instruction Register and Special Instructions

The Instruction register controls selection of accessed data register(s), and controls the setting and clearing of the EJTAGBOOT indication. The Instruction register is five or more bits wide when used with EJTAG. Table 20.42 shows the allocation of the TAP instruction.

Code	Instruction	Function
All 0's	(Free for other use)	Free for other use, such as JTAG boundary scan
0x01	IDCODE	Selects Device Identification (ID) register
0x02	(Free for other use)	Free for other use, such as JTAG boundary scan
0x03	IMPCODE	Selects Implementation register
0x04 — 0x07	(Free for other use)	Free for other use, such as JTAG boundary scan
0x08	ADDRESS	Selects Address register
0x09	DATA	Selects Data register
0x0A	CONTROL	Selects EJTAG Control register
0x0B	ALL	Selects the Address, Data and EJTAG Control registers
0x0C	EJTAGBOOT	Makes the processor take a debug exception after reset
0x0D	NORMALBOOT	Makes the processor execute the reset handler after reset
0x0E	FASTDATA	Selects the Data and Fastdata registers
0x0F	(EJTAG reserved)	Reserved for future EJTAG use
0x010	TCBCONTROLA	Selects the control register TCBTraceControl in the Trace Control Block
0x011	TCBCONTROLB	Selects another trace control block register
0x012	TCBADDRESS	Selects the address register used in the trace control block
0x013 — 0x1B	(EJTAG reserved)	Reserved for future EJTAG use
0x01C — All 1's	(Free for other use)	Free for other use, such as JTAG boundary scan
All 1's	BYPASS	Select Bypass register

Table 20.42 EJTAG TAP Instruction Overview

The instructions IDCODE, IMPCODE, ADDRESS, DATA, CONTROL, and BYPASS select a single data register, as indicated in the table. The unused instructions reserved for EJTAG select the Bypass register. The ALL, EJTAGBOOT, NORMALBOOT, and FASTDATA instructions are described in the following subsections. The instructions that are related to trace registers in the trace control block (TCB) are described in the Trace Control Block Specification document. Any EJTAGBOOT indication is cleared at power-up either by a low value on the JTAG_TRST_N or by a power-up reset circuit, and the Instruction register is loaded with the IDCODE instruction.

ALL Instruction

The Address, Data, and EJTAG Control data registers are selected at once with the ALL instruction, as shown in Figure 20.26.

Notes

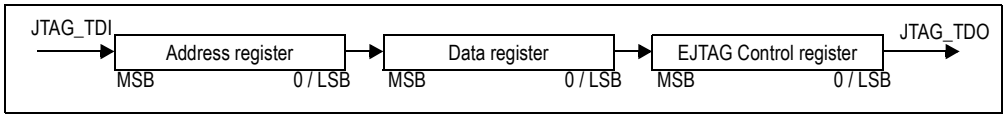


Figure 20.26 JTAG_TDI to JTAG_TDO Path in Shft-DR State and ALL Instruction is Selected

EJTAGBOOT and NORMALBOOT Instructions

The EJTAGBOOT and NORMALBOOT instructions control whether a debug interrupt is requested as a result of a reset. If EJTAGBOOT is indicated then a debug interrupt is requested at reset, and a Debug Interrupt exception is taken right after the Reset exception. The debug exception handler is in this case fetched from the probe through dmseg. It is possible to take the debug exception and execute the debug handler from the probe even if no instructions can be fetched from the reset handler. This condition guarantees that the system will not hang at reset when the EJTAGBOOT feature is used, not even if the normal memory system does not work properly.

An internal EJTAGBOOT indication holds information on the action to take at a processor reset, and this is set when the EJTAGBOOT instruction takes effect in the Update-IR state. The indication is cleared when the NORMALBOOT instruction takes effect in the Update-IR state, or when the Test-Logic-Reset state is entered, for example, when JTAG_TRST_N is asserted low. The requirement of clearing the internal EJTAGBOOT indication when the Test-Logic-Reset state is entered, and not on a JTAG_TCK clock when in the state, ensures that the indication can be cleared with five clocks on JTAG_TCK when EJTAG_TMS is high.

The internal EJTAGBOOT indication is cleared at power-up either by a low value on the JTAG_TRST_N or by a power-up reset circuit. Thus, the processor executes the reset handler after power-up unless the EJTAGBOOT instruction is given through the EJTAG TAP. The Bypass register is selected when the EJTAGBOOT or NORMALBOOT instruction is given. The EjtagBrk, ProbEn, and ProbTrap bits in the EJTAG Control register follow the internal EJTAGBOOT indication. They are all set at processor reset if a Debug Interrupt exception is to be generated, with execution of the debug handler from the probe.

FASTDATA Instruction

This selects the Data and the Fastdata registers at once, as shown in Figure 20.27.

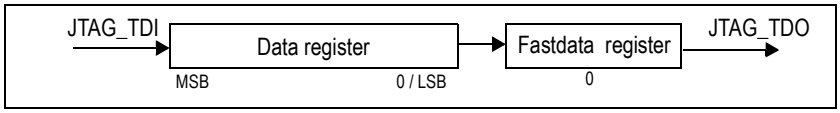


Figure 20.27 JTAG_TDI to JTAG_TDO Path in Shift-DR State and FASTDATA Instruction is Selected

TAP Data Registers

Table 20.43 summarizes the data registers in the EJTAG TAP. Complete descriptions of these registers are given in the following sections.

Instruction Used to Access Register	Register Name	Function	Reference	Compliance
IDCODE	Device ID	Identifies device and accessed processor in the device.	"Device Identification (ID) Register (TAP Instruction IDCODE)" on page 20-61	Required

Table 20.43 EJTAG TAP Data Registers (Part 1 of 2)

Notes

Instruction Used to Access Register	Register Name	Function	Reference	Compliance
IMPCODE	Implementation	Identifies main debug features implemented and accessible through the TAP.	"Implementation Register (TAP Instruction IMPCODE)" on page 20-61	Required
DATA, ALL, or FASTDATA	Data	Data register for processor access.	"Data Register (TAP Instruction DATA, ALL, or FASTDATA)" on page 20-62.	Required
ADDRESS or ALL	Address	Address register for processor access.	"Address Register (TAP Instruction ADDRESS or ALL)" on page 20-63	Required
CONTROL or ALL	EJTAG Control	Control register for most EJTAG features used through the TAP.	"EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)" on page 20-64	Required
BYPASS, EJTAG-BOOT, NORMAL-BOOT, or unused EJTAG instructions	Bypass	Provides a one bit shift path through the TAP.	"Bypass Register (TAP Instruction BYPASS, (EJTAG/NORMAL) BOOT, or Unused)" on page 20-68	Required
FASTDATA	Fastdata	Provides a one bit register whose value is tagged to the front of the Data register to capture the value of the processor access pending (PrAcc) bit in the EJTAG Control register.	"FASTDATA Instruction" on page 20-59	Required with EJTAG version 02.60 and higher.
TCBCONTROLA	TCBControlA	Implemented and used in the Trace Control Block (TCB). Used by external probe (debugger) software to control tracing output from the core.	See TCB documentation	Required with EJTAG version 02.60 and higher if trace logic is implemented.
TCBCONTROLB	TCBControlB	Implemented and used in the Trace Control Block (TCB). Controls tracing configuration options	See TCB documentation	Required with EJTAG version 02.60 and higher if trace logic is implemented.
TCBADDRESS	TCBAddress	Implemented and used in the TCB. Used to address the on-chip trace memory, if present.	See TCB documentation	Required with EJTAG version 02.60 and higher if trace logic is implemented.

Table 20.43 EJTAG TAP Data Registers (Part 2 of 2)

A read of a data register corresponds only to the Capture-DR state of the TAP controller, and a write of the data register corresponds to the Update-DR state only. The initial states of these registers are specified with either a reset state or a power-up state. If a reset state is specified, then the indicated value is applied

Notes

to the register when a processor reset is applied. If a power-up state is specified, then the indicated value is applied at power-up reset. JTAG_TCK does not have to be running in order for a processor reset to reset the registers.

Device Identification (ID) Register (TAP Instruction IDCODE)

Compliance Level: Required with EJTAG TAP feature.

The Device ID register is a 32-bit read-only register that identifies the specific device implementing EJTAG. This register is also defined in IEEE 1149.1. The Device ID register holds a unique number among different devices with EJTAG compliant processors implemented. It is recommended that the register is also unique amongst different EJTAG compliant processors in the same device. Figure 20.28 shows the format of the Device ID register and Table 20.44 describes the Device ID register fields

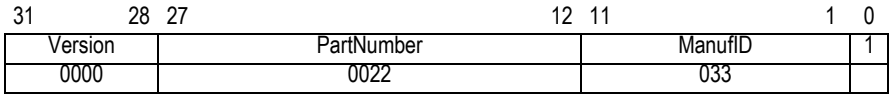


Figure 20.28 Device ID Register Format

Fields		Description	Read/ Write	Power-up State	Compli-ance
Name	Bits				
Version	31_28	Identifies the version of a specific device.	R	0x0	Required
Part Number	27:12	Identifies the part number of a specific device.	R	0x0022	Required
ManufID	11:1	Identifies the manufacturer identity code.	R	0x33	Required
1	0	Ignored on write; returns one on read.	R	0x1	Required

Table 20.44 Device ID Register Field Description

Implementation Register (TAP Instruction IMPCODE)

Compliance Level: Required with EJTAG TAP feature.

The Implementation register is a 32-bit read-only register that identifies features implemented in this EJTAG compliant processor, mainly those accessible from the TAP.

Figure 20.29 shows the format of the Implementation register and Table 20.45 describes the Implementation register fields.

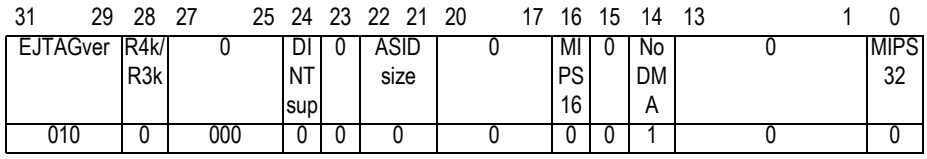


Figure 20.29 Implementation Register Format

Notes

Fields		Description	Read/ Write	Power-up State	Compli-ance
Name	Bits				
EJTAGver	31:29	Version 2.6	R	0x2	Required
R4k/Rk3	28	Indicated Rk4 or Rk3 privileged environment: 0: R4k privileged environment	R	0x0	Required
DINTsup	24	Indicates support for DINT signal from probe: 0: DINT signal from the probe is not supported by this processor.	R	0x0	Required
ASIDsize	22:21	Indicates size of the ASID field: 0: No ASID in implementation	R	0x0	Required
MIPS16	16	Indicates MIPS16™ ASE support in the processor: 0: No MIPS16 support	R	0x0	Required
NoDMA	14	Indicates no EJTAG DMA support: 1: No EJTAG DMA support	R	0x1	Required
MIPS32/64	0	Indicates 32-bit or 64-bit processor: 0: 32-bit processor See the R4k/R3k bit for indication of privileged environment.	R	0x0	Required
0	27:25, 23, 20:17, 15, 13:1	Ignored on writes; return zeros on reads.	R	0x0	Required

Table 20.45 Implementation Register Field Description

Data Register (TAP Instruction DATA, ALL, or FASTDATA)

Compliance Level: Required with EJTAG TAP feature.

The read/write Data register is used for opcode and data transfers during processor accesses. The width of the Data register is 32 bits for 32-bit processors and 64 bits for 64-bit processor. The value read in the Data register is valid only if a processor access for a write is pending, in which case the data register holds the store value. The value written to the Data register is only used if a processor access for a pending read is finished afterwards, in which case the data value written is the value for the fetch or load. This behavior implies that the Data register is not a memory location where a previously written value can be read afterwards. Figure 20.30 shows the format of the Data register and Table 20.46 describes the Data register field.

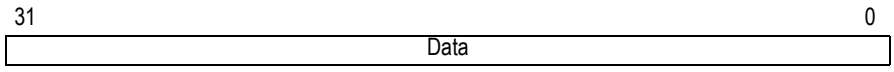


Figure 20.30 Data Register Format

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
Data	31:0	Data used by processor access.	R/W	Undefined	Required

Table 20.46 Data Register Field Description

The contents of the Data register are not aligned but hold data as it is seen on a data bus for an external memory system. Thus the bytes are positioned in the Data register based on access size, address, and endianess. The bytes not accessed for a processor access write are undefined, and the bytes not accessed for a processor access read can be written with any value by the probe shifting the value into the Data register.

Table 20.47 shows the byte positioning for a 32-bit processor (MIPS32/64 = 0), in which case the two LSBs of the Address register are used. Byte 0 refers to bits 7:0, byte 1 refers to bits 15:8, byte 2 refers to bits 23:16, and byte 3 refers to bits 31:24, independent of endianess.

Psz from ECR	Size	Address [1:0]	Little Endian				Big Endian			
			3	2	1	0	3	2	1	0
0	Byte	00_2								
		01_2								
		10_2								
		11_2								
1	Halfword	00_2								
		10_2								
2	Word	00_2								
3	Triple	00_2								
		01_2								
Reserved			n.a.				n.a.			

Table 20.47 Data Register Contents for 32-bit Processors

Address Register (TAP Instruction ADDRESS or ALL)

Compliance Level: Required with EJTAG TAP feature.

The read-only Address register provides the address for a processor access. The width of the register corresponds to the size of the physical address in the processor implementation (from 32 to 64 bits). The specific length is determined by shifting through the Address register, because the length is not indicated elsewhere. The value read in the register is valid if a processor access is pending, otherwise the value is undefined. The two or three LSBs of the register are used with the Psz field from the EJTAG Control register to indicate the size and data position of the pending processor access transfer. These bits are not taken directly from the address referenced by the load/store.

Figure 20.31 shows the format of the Address register and Table 20.48 describes the Address register field.

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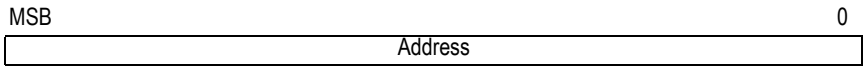


Figure 20.31 Address Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
Address	MSB:0	Address used by processor access.	R	Undefined	Required

Table 20.48 Address Register Field Description

EJTAG Control Register (ECR) (TAP Instruction CONTROL or ALL)

Compliance Level: Required with EJTAG TAP feature.

The 32-bit EJTAG Control Register (ECR) handles processor reset and soft reset indication, Debug Mode indication, access start, finish, and size and read/write indication. The ECR also:

- *controls debug vector location and indication of serviced processor accesses,*
- *allows a debug interrupt request,*
- *indicates processor low-power mode, and*
- *allows implementation-dependent processor and peripheral resets.*

The EJTAG Control register is not updated/written in the Update-DR state unless the Reset occurred; that is Rocc (bit 31) is either already 0 or is written to 0 at the same time. This condition ensures proper handling of processor accesses after a reset. Reset of the processor can be indicated through the Rocc bit in the JTAG_TCK domain a number of JTAG_TCK cycles after it is removed in the processor clock domain in order to allow for proper synchronization between the two clock domains. Bits that are R/W in the register return their written value on a subsequent read, unless other behavior is defined. Internal synchronization ensures that a written value is updated for reading immediately afterwards, even when the TAP controller takes the shortest path from the Update-DR to Capture-DR state. Figure 20.32 shows the format of the EJTAG Control register and Table 20.49 describes the EJTAG Control register fields.

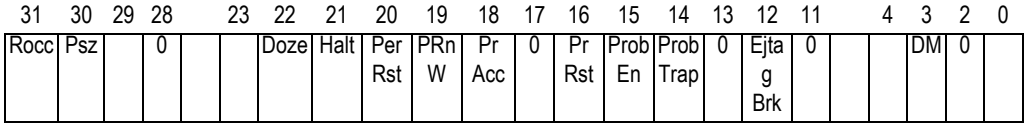


Figure 20.32 EJTAG Control Register Format

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
Rocc	31	Indicates if a processor reset or soft reset has occurred since the bit was cleared: 0: No reset occurred 1: Reset occurred The Rocc bit stays set as long as reset is applied. This bit must be cleared to acknowledge that the reset was detected. The EJTAG Control register is not updated in the Update-DR state unless Rocc is 0 or written to 0 at the same time. This is in order to ensure correct handling of the processor access after reset.	R/W0	1	Required
Psz	30:29	Indicates the size of a pending processor access, in combination with the Address register: 32-bit processor MIPS32=0 MIPS32=1 0: Byte Byte 1: Halfword Halfword 2: Word Word, 5-7 bytes 3: Triple Triple, Doubleword A full description is located in section "Data Register (TAP Instruction DATA, ALL, or FASTDATA)" on page 20-62, including reserved combinations with Address register bits. This field is valid only when a processor access is pending, otherwise the read value is undefined.	R	Undefined	Required
Doze	22	Indicates if the processor is in low-power mode: 0: Processor is not in low-power mode 1: Processor is in low-power mode Doze indicates Reduced Power (RP) and WAIT, and other implementation-dependent low-power modes. If the implementation does not support low-power modes, then this bit always reads as 0.	R	0	Required
Halt	21	Indicates if the internal system bus clock is running: 0: Internal system bus clock is running 1: Internal system bus clock is stopped Halt indicates WAIT, and other implementation-dependent events that stop the system bus clock. If the implementation does not support a halt state, then the bit always reads as 0.	R	0	Required

Table 20.49 EJTAG Control Register Field Description (Part 1 of 3)

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
PerRst	20	Not used on RC32438. (Controls the peripheral reset with implementation-dependent behavior.)	R/W	0	Optional
PRnW	19	Indicates read or write of a pending processor access: 0: Read processor access, for a fetch/load access 1: Write processor access, for a store access This value is defined only when a processor access is pending.	R	Undefined	Required
PrAcc	18	Indicates a pending processor access and controls finishing of a pending processor access. When read: 0: No pending processor access 1: Pending processor access A write of 0 finishes a processor access if pending; otherwise operation of the processor is UNDEFINED if the bit is written to 0 when no processor access is pending. A write of 1 is ignored. The FASTDATA access can clear this bit.	R/W0	0	Required
PrRst	16	Controls the RC32438 reset: 0: No reset applied 1: Soft (warm) reset applied to entire RC32438 device.	R/W	0	Optional
ProbEn	15	Controls whether the probe handles accesses to dmseg through servicing of processors accesses: 0: Probe does not service processors accesses 1: Probe will service processor accesses The ProbEn bit is reflected as a read-only bit in the Debug Control Register (DCR) bit 0. When this bit is changed, then it is guaranteed that the new value has taken effect in the DCR when it can be read back here. This handshake mechanism ensures that the setting from the JTAG_TCK clock domain takes effect in the processor clock domain. However, a change of the ProbEn prior to setting the EjtagBrk bit will be effective for the debug handler. Not all combinations of ProbEn and ProbTrap are allowed, see section “Combinations of ProbTrap and ProbEn” on page 20-68.	R/W	See section “EJTAG-BOOT Indication Determines Reset Value of EjtagBrk, ProbTrap and ProbEn” on page 20-68	Required

Table 20.49 EJTAG Control Register Field Description (Part 2 of 3)

Notes

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
ProbTrap	14	Controls location of the debug exception vector: 0: Normal memory 0xBFC0 0480 1: in dmseg at 0xFF20 0200 When this bit is changed, then it is guaranteed that the new value is indicated to the processor when it can be read back here. This handshake mechanism ensures that the setting from the JTAG_TCK clock domain takes effect in the processor clock domain. However, a change of the ProbTrap prior to setting the EjtagBrk bit will be effective at the debug exception. Not all combinations of ProbEn and ProbTrap are allowed, see section"Combinations of ProbTrap and ProbEn" on page 20-68.	R/W	See section "EJTAG-BOOT Indication Determines Reset Value of EjtagBrk, ProbTrap and ProbEn" on page 20-68	Required
EjtagBrk	12	Requests a Debug Interrupt exception to the processor when this bit is written as 1. The debug exception request is ignored if the processor is already in debug at the time of the request. A write of 0 is ignored. The debug request restarts the processor clock if the processor was in a low-power mode. The read value indicates a pending Debug Interrupt exception requested through this bit: 0: No pending Debug Interrupt exception requested through this bit 1: Pending Debug Interrupt exception The read value can, but is not required to, indicate other pending DINT debug requests (for example, through the DINT signal). This bit is cleared by hardware when the processor enters Debug Mode.	R/W1	See section "EJTAG-BOOT Indication Determines Reset Value of EjtagBrk, ProbTrap and ProbEn" on page 20-68	Required
DM	3	Indicates if the processor is in Debug Mode: 0: Processor is in Non-Debug Mode 1: Processor is in Debug Mode	R	0	Required
0	28:23, 17, 13, 11:4, 2:0	Must be written as zeros; return zeros on reads.	0	0	Required

Table 20.49 EJTAG Control Register Field Description (Part 3 of 3)

Notes

EJTAGBOOT Indication Determines Reset Value of EjtagBrk, ProbTrap and ProbEn

The reset value of the EjtagBrk, ProbTrap, and ProbEn bits follows the setting of the internal EJTAG-BOOT indication. If the EJTAGBOOT instruction has been given, and the internal EJTAGBOOT indication is active, then the reset value of the three bits is set (1), otherwise the reset value is clear (0). The results of setting these bits are:

- *A Debug Interrupt exception is requested right after reset because EjtagBrk is set*
- *The debug handler is executed from the EJTAG memory because ProbTrap is set to indicate debug vector in EJTAG memory at 0xFF20 0200*
- *Service of the processor access is indicated because ProbEn is set.*

Thus, it is possible to execute the debug handler right after reset, without executing any instructions from the normal reset handler.

Combinations of ProbTrap and ProbEn

Use of ProbTrap and ProbEn allows independent specification of the debug exception vector location and availability of EJTAG memory. Behavior for the different combinations is shown in Table 20.50. Note that not all combinations are allowed.

ProbTrap	ProbEn	Debug Exception Vector	Processor Accesses
0	0	Normal memory at 0xBFC0 0480	Not serviced by probe
0	1		Not serviced by probe
1	0	If these two bits are changed to this state, the operation of the processor is UNDEFINED, indicating that the debug exception vector is in EJTAG memory, but the probe will not service processor accesses.	
1	1	EJTAG memory at 0xFF20 0200	Serviced by Probe

Table 20.50 Combinations of ProbTrap and ProbEn

Bypass Register (TAP Instruction BYPASS, (EJTAG/NORMAL) BOOT, or Unused)

Compliance Level: Required with EJTAG TAP.

The Bypass register is a one-bit read-only register, which provides a minimum shift path through the TAP. This register is also defined in IEEE 1149.1. Figure 20.33 shows the format of the Bypass register and Table 20.51 describes the Bypass register field.

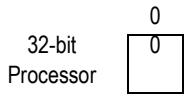


Figure 20.33 Bypass Register Format

Fields		Description	Read/ Write	Reset State	Compli-ance
Name	Bit				
0	0	Ignored on writes; returns zero on reads.	R	0	Required

Table 20.51 Bypass Register Field Description

Examples of Use

An example of the TAP operation is shown in Figure 20.34.

Notes

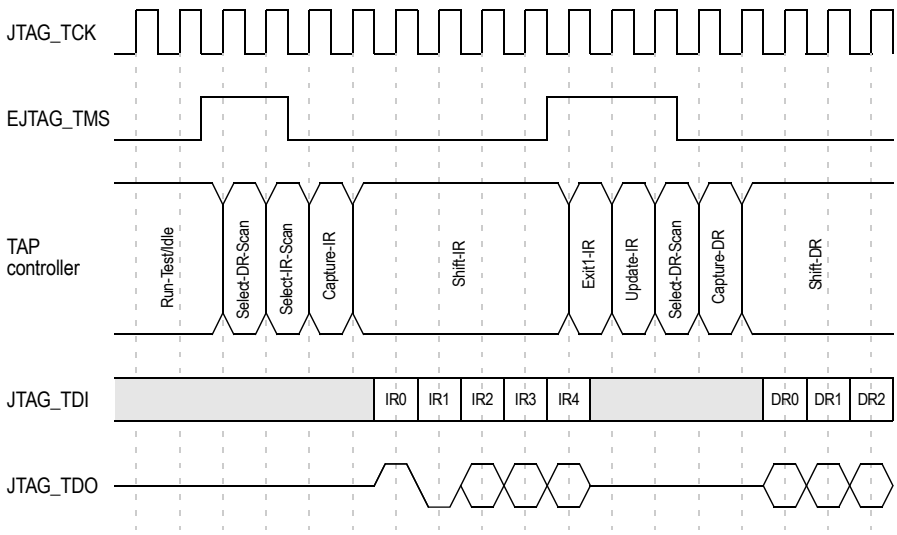


Figure 20.34 TAP Operation Example

The five-bit Instruction register is initially loaded with 000012. The first bit shifted out of the Instruction register is a 1 followed by four 0's. IR0 to IR4 indicate the new value for the Instruction register. IR0, the new LSB, is shifted in first, because it will be at the LSB position once all five bits are shifted in. This example is similar for the selected data register.

Rocc Bit Usage

The R/W0 Rocc bit in the EJTAG Control register acknowledges that the probe has seen a processor reset, and further accesses take this reset into account. This bit is set at reset. The probe must clear it as an acknowledge of the reset. All other writes to the EJTAG Control register, except for the reset acknowledge, should write 1 to this bit in order to not acknowledge any resets occurring between reads and writes of the EJTAG Control register. Correct use of the Rocc bit ensures safe handling of processor access even across reset. An example is the following scenario:

1. A processor access is pending and the PrAcc is read with value 1 (Rocc has been cleared previously).
2. The Address and Data registers are accessed and set up to handle the processor access.
3. The EJTAG Control register is accessed to finish the processor access. The register is read in the Capture-DR state. Shifting in of the value to write begins.
4. A reset of the processor occurs, the Rocc bit is set, and the PrAcc bit is cleared.
5. A new processor access occurs, because EJTAGBOOT was indicated.
6. A write of the EJTAG Control register is attempted with PrAcc equal to 0 and Rocc equal to 1, but the write does not occur because the Rocc bit is set. The new processor access that was not seen is not finished.
7. Polling of the EJTAG Control register continues. The probe detects that the Rocc bit is set.
8. The probe writes the EJTAG Control register with Rocc equal to 0 to acknowledge that the probe has seen the reset.
9. The new processor access is serviced as usual.

Inhibiting writes to the EJTAG Control register because of the Rocc bit ensures that the new processor access is not finished by mistake due to detection of a pending processor access before the reset occurred.

Notes

EJTAG Memory Access Through Processor Access

The processor access feature makes it possible for the probe to handle accesses from the processor to the specific EJTAG memory area (dmseg). The processor can execute a debug handler from EJTAG memory, whereby applications that are not prepared with EJTAG code in the system memory can still be debugged. The probe can get information about the access through the TAP, as shown in Table 20.52.

Information	Field and Register
Pending processor access	PrAcc field in the EJTAG Control register
Read or write access	PRnW field in the EJTAG Control register
Size and data location	Psz field in EJTAG Control register, and two or three LSBs in the Address register
Address	Address register
Data	Data register

Table 20.52 Information Provided to Probe at Processor Access

The servicing of processor accesses works with a polling scheme, where the PrAcc bit is polled until a pending processor access is indicated by PrAcc equal to 1. Then the Address register is read to get the address of the transaction, and the Data register is accessed to get the write data or provide the read data. Finally the PrAcc bit is cleared, in order to finish the access from the processor.

In addition, the ProbTrap and ProbEn bits control the debug exception vector location and the indication to the processor that the probe will service accesses to the EJTAG memory through processor accesses. Handling of processor access in relation to reset requires specific handling. A pending processor access is cleared at reset. At the same time, the Rocc bit is set, thereby inhibiting any processor accesses to be finished until Rocc is cleared. Thus, the probe will have to acknowledge that a reset occurred, preventing it from accidentally finishing a processor access that occurred before the reset. A pending processor access can only finish if the probe clears PrAcc or a processor reset occurs.

The width of the Address register is 32 to 64 bits. The specific length is determined by shifting a known bit pattern through the register. The following sections show examples of servicing read and write processor accesses.

Write Processor Access

Figure 20.35 shows a possible flow for servicing a write processor access. The example implements a 32-bit processor with 32-bit Address register, running in little-endian mode. A halfword store is performed to address 0xFF20 1232 of value 0x5678.

Notes

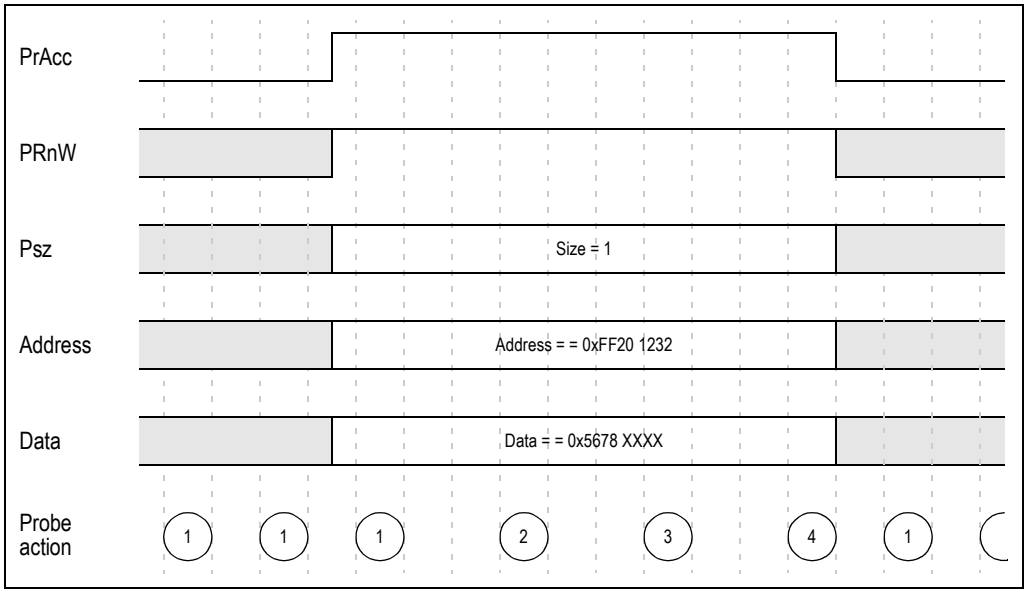


Figure 20.35 Write Processor Access Example

The different probe actions shown on the figure are described below:

1. The EJTAG Control register is polled to get the indication for a pending PrAcc bit. The PrAcc bit is written to 1 when polling, in order to prevent a processor access from finishing before being serviced. The values of PRnW and Psz are saved when PrAcc indicates a pending processor access.
2. The Address register is read. It contains the address of the store resulting in the write processor access.
3. The Data register is read, which contains the data from the store resulting in the write processor access.
4. The PrAcc bit is written to 0, in order to finish the processor access.

The probe must update the appropriate bytes in its internal memory used for EJTAG memory with the value of the write. Note that the two lower bytes of the Data register are undefined, and that the two lower bytes of the saved register are shifted up on the two high bytes in the Data register as on a data bus for an external memory system. The Address register in this case contains the address from the store; however, for some accesses, this is not the case because the two LSBs (32-bit processor) are modified for some accesses depending on size and address.

Read Processor Access

Figure 20.36 shows a possible flow for servicing a read processor access. The example implements a 64-bit processor with 36-bit Address register. A doubleword load/fetch from address 0xFF20 3450 is shown in the figure.

Notes

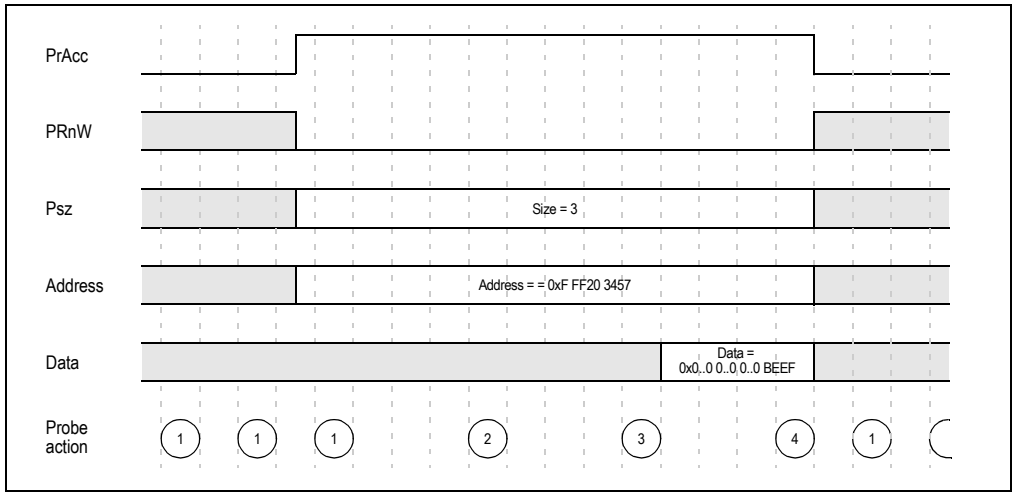


Figure 20.36 Read Processor Access Example

The different probe actions shown in the above figure are described below:

1. The EJTAG Control register is polled to get the indication for a pending PrAcc bit. The PrAcc bit is written to 1 when polling, in order to prevent a processor access from finishing before being serviced. The values of PRnW and Psz are saved when PrAcc indicates a pending processor access.
2. The Address register is read. It contains the address of the load/fetch resulting in the write processor access, with the three LSBs (64-bit processor) modified to allow size indication together with the Psz.
3. The Data register is written with the data to return for the load/fetch, resulting in the read processor access.
4. The PrAcc bit is cleared in order to finish the processor access.

The probe must provide data for the read processor access from the internal EJTAG memory. Note that the Address register does not contain the direct address from the access, because the three LSBs (64-bit processor) are modified to indicate the size in conjunction with Psz. Also notice that in this case, there is no shifting of the data returned for the processor access by writing to the Data register, because a doubleword is provided. For other accesses, the Data register must be written with a shifted value depending on the specific access.

Probe Interfaces

The off-chip interface forms the connection from the chip over the target system PCB and to the probe connector, thereby allowing the probe to connect to the target processor. The probe connection is optional in the target system.

Mechanical Connector

Figure 20.37 shows the recommended EJTAG connector on a target system. The connector is a common pin strip with dimensions 0.100” x 0.100”, for example, SAMTEC part number TSW-107-23-L-D or compatible. The socket on the probe side must allow for a straight pin connector on the target system.

Notes

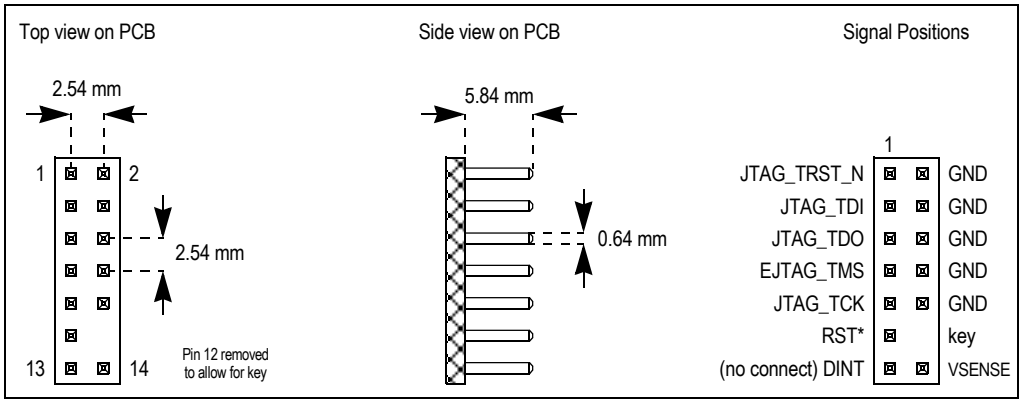


Figure 20.37 EJTAG Connector Mechanical Dimensions

Table 20.53 shows the pin assignments for the connector.

Pin	Signal	Direction	Pin	Signal	Direction
1	JTAG_TRST_N Test reset input	Input	2	Ground	Gnd
3	JTAG_TDI Test data input	Input	4	Ground	Gnd
5	JTAG_TDO Test data output	Output	6	Ground	Gnd
7	EJTAG_TMS Test mode select input	Input	8	Ground	Gnd
9	JTAG_TCK Test clock input	Input	10	Ground	Gnd
11	RST* System reset	Input	12	key - pin removed on connector	NA
13	DINT (no connect) Debug interrupt	Input	14	VSENSE Voltage Sense for I/O	Output

Table 20.53 EJTAG Connector Pinout

Note: Pin 12 on the target system connector should be removed to provide keying, thus ensuring the probe is correctly connected to the target system.

Target System PCB Design

This section provides guidelines for using the EJTAG connector on a target system.

Electrical Connection

The IEEE 1149.1 specification requires that the JTAG and EJTAG TAP controllers be reset at power-up whether or not the interfaces are used for a boundary scan or a probe. Reset can occur through a pull-down resistor on JTAG_TRST_N if the probe is not connected. However, on-chip pull-up resistors are implemented on the RC32438 due to an IEEE 1149.1 requirement. Having on-chip pull-up and external pull-down resistors for the JTAG_TRST_N signal requires special care in the design to ensure that a valid logical level is provided to JTAG_TRST_N, such as using a small external pull-down resistor to ensure this level overrides the on-chip pull-up. An alternative is to use an active power-up reset circuit for JTAG_TRST_N, which drives JTAG_TRST_N low only at power-up and then holds JTAG_TRST_N high afterwards with a pull-up resistor. Figure 20.38 shows the electrical connection of the target system connector.

Notes

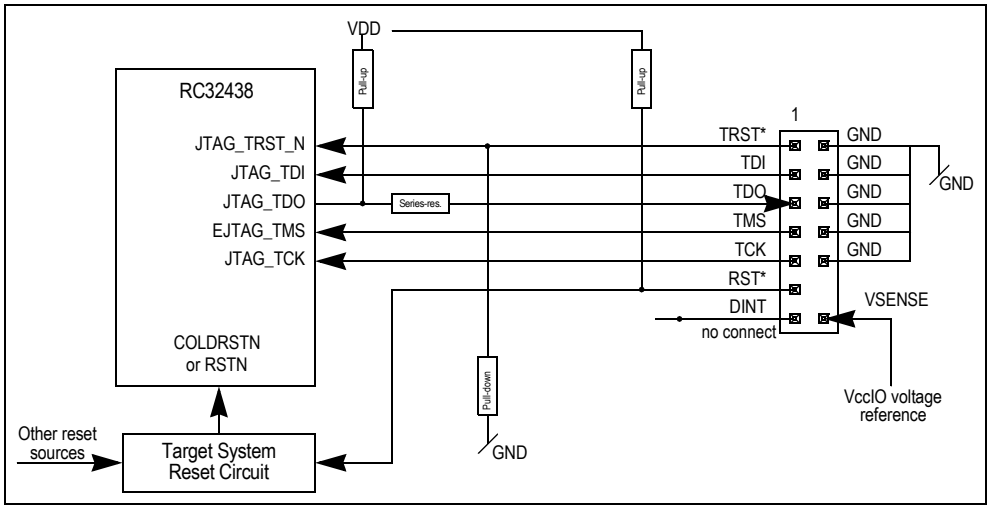


Figure 20.38 Target System Electrical EJTAG Connection

Using the EJTAG Probe

In Figure 20.38, the pull-up resistors for JTAG_TDO and RST*, the pull-down resistor for JTAG_TRST_N, and the series resistor for JTAG_TDO must be adjusted to the specific design. However, the recommended pull-up/down resistor is 1.0 kΩ because a low value reduces crosstalk on the cable to the connector, allowing higher JTAG_TCK frequencies. A typical value for the series resistor is 33 Ω. Recommended resistor values have ± 5% tolerance.

If a probe is used, the pull-up resistor on JTAG_TDO must ensure that the JTAG_TDO level is high when no probe is connected and the JTAG_TDO output is tri-stated. This requirement allows reliable connection of the probe if it is hooked-up when the power is already on (hot plug). The pull-up resistor value of around 47 kΩ should be sufficient. Optional diodes to protect against overshoot and undershoot voltage can be added on the signals of the chip with EJTAG.

If a probe is used, the RST* signal must have a pull-up resistor because it is controlled by an open-collector (OC) driver in the probe, and thus is actively pulled low only. The pull-up resistor is responsible for the high value when not driven by the probe of 25pF. The input on the target system reset circuit must be able to accept the rise time when the pull-up resistor charges the capacitance to a high logical level.
Vcc I/O must connect to a voltage reference that drops rapidly to below 0.5V when the target system loses power, even with a capacitive load of 25pF. The probe can thus detect the lost power condition.

System Reset Signal

The System Reset (RST*) signal from the probe is required to generate a reset of the target board. It is recommended that assertion of RST* results in a hard (cold) reset of the RC32438, but it is allowed to generate a soft (warm) reset.

The probe controls the RST* via an open-collector (OC) output. Thus, RST* is actively driven low when asserted (low) but is tri-stated when deasserted (high).

Voltage Sense for I/O Signal

The Voltage sense for I/O (VSENSE) indicates target power is applied and voltage levels are present at the probe I/O connections. With VSENSE, the probe can auto adjust the voltage level for the signals and can detect if power is lost at the target system.

Layout Considerations

Layout around the pin connector on the target system must provide for sufficient clearance for the probe to connect. Figure 20.39 shows the recommended clearance. Place the connector at the edge of the PCB. Avoid tall components around the connector to allow for easy access.

Notes

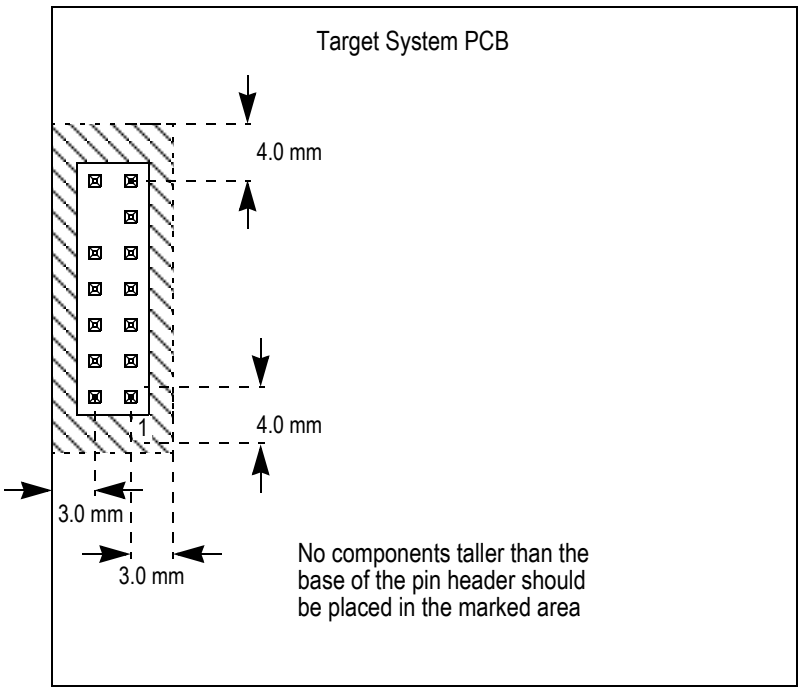


Figure 20.39 Target System Layout for EJTAG Connection

Probe Requirements and Recommendations

A probe connected to the target system at power-up is not allowed to drive the inputs before VSENSE indicates a stable voltage. JTAG_TRST_N is then asserted by the target system pull-down resistor at power-up, whereby a TAP reset is applied through JTAG_TRST_N. This step implies that inputs are not driven until the target system is powered up; otherwise the communication on the TAP might be undefined or damage could occur. At power-down, the probe is not allowed to drive the inputs after VSENSE has dropped under a certain level (see the section on Voltage Sense Timing in the RC32438 Data Sheet). The RST* signal is an exception to the above description because it can be driven low by the probe during power-up.

Hot Plug in of Probe

The probe must not drive any inputs to the target system if it is connected while the system is running (hot plug). Detection of a stable Vcc I/O from the target system (VSENSE) is required before any input is allowed. To avoid spikes or changes in the input voltage to the target system when the probe is connected, the level of the signal on the probe must be adjusted to the same level as the signals on the target system. This adjustment can be done with large pull-up/down resistors (in the range of 150 kΩ) on the probe signals, so the level of these signals matches the level on the target system shown in Figure 20.39. The specific implementation of this feature is dependent on the probe, the driver type, etc. used in the probe.

JTAG_TDO Level when Tri-Stated

The probe must apply a pull-up resistor on JTAG_TDO to have a well-defined logical level when JTAG_TDO on the TAP is tri-stated. The pull-up on the target system ensures the level at hot plug. The size of the pull-up on the probe is expected to be 1.0 kΩ or more. The resistor value must be chosen so that the current on JTAG_TDO is ± 50 µA with $0 < V_{TDO} \leq$ VSENSE.

RST* Drive by Open Collector

The probe should drive the RST* signal with an open-collector (OC) output driver to allow for easy connection of the RST* signal in the target system.

Notes

Changing EJTAG_TMS and JTAG_TDI

It is recommended that the EJTAG_TMS and JTAG_TDI signals driven by the probe change in relation to the falling edge generated on the JTAG_TCK, since this ensures a high setup and hold time for the EJTAG_TMS and JTAG_TDI in relation to the rising edge of JTAG_TCK, on which these signals are sampled by the target processor. If the JTAG_TCK clock speed can be adjusted by extending the high and low period time of the JTAG_TCK clock, then the behavior described above will also make the probe work even with a target processor not respecting setup and hold time, simply by lowering the JTAG_TCK frequency.

Connecting Multiple EJTAG Controllers

This section is concerned with building a multi-core system where each core has its own EJTAG TAP controller, but share one set of external EJTAG TAP controller pins. Note that this section does not attempt to address the full issue of multi-core debug, which involves resolving debugger issues and other hardware issues such as debug signalling among multiple cores, and handling breakpoints across multiple cores, etc. Figure 20.40 shows the recommended daisy-chain connection for a multi-core configuration, where the JTAG_TCK, JTAG_TMS and JTAG_TRST_N signals of all the TAP controllers are connected together. The JTAG_TDI and JTAG_TDO signals are daisy chained together so that the information flow between the selected register of all the TAP controllers is a continuous sequence.

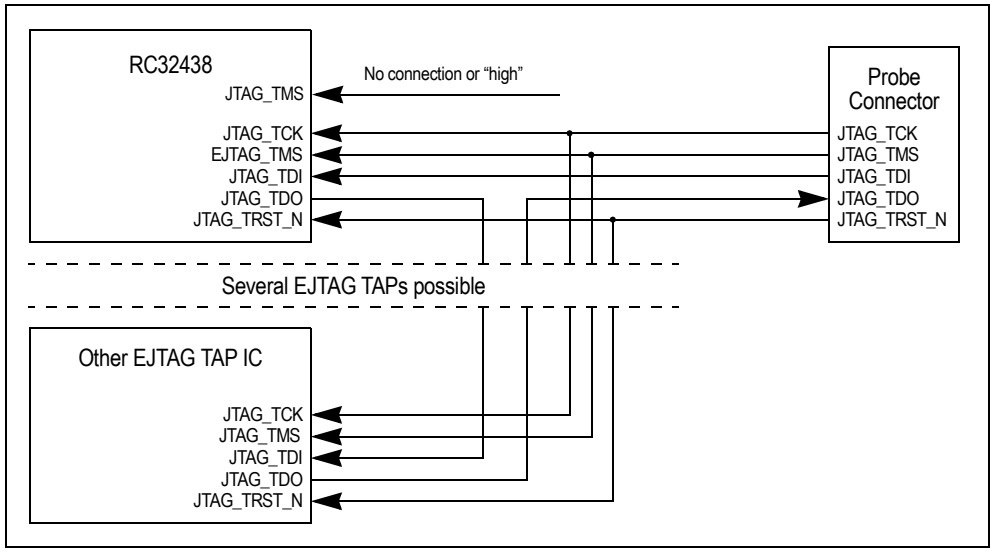


Figure 20.40 Daisy Chaining of Multi-core EJTAG TAP Controllers

The simplest usage model for this multi-core connection, under most circumstance, uses only one "active" device. This is accomplished by including BYPASS TAP instruction for "non-active" devices in every TAP command chain sent by the debugger. "Non-active" devices only get attention when made "active". Note that it is not necessary that only one device be "active" at a time; rather, it depends entirely on how the debugger and the end-user want to control the multiple on-chip TAP controllers.

It is recommended that the EJTAG TAPs are connected in a single daisy-chain without any non-EJTAG TAPs in that chain, since this provides the fastest access to the EJTAG TAPs and allows most debug software packages to operate the EJTAG TAPs.

Connecting EJTAG and JTAG Controllers

Special care must be taken by the system designer if both the EJTAG TAP and JTAG TAP are connected in the same chain. There are several ways to make the connection.

Notes

The first alternative is to combine the EJTAG and JTAG devices in the same data chain. The EJTAG_TMS and JTAG_TMS can be tied together. In this case, the system designer must ensure that both the EJTAG debug hardware and software and the external device using the TAPs can apply the BYPASS TAP instruction when the TAPs unrelated to the current operation are to be made “non-active”.

Another alternative is to use two connectors, one for an EJTAG chain and one for a JTAG chain.

A third alternative is to use jumpers on the circuit board to steer two scan chains to either EJTAG for debug or JTAG for boundary scan (refer to Figure 20.41). Jumper block X1 isolates the two scan chains. Jumper X2 allows the unused TMS pins to be held high while not in use. For example, if Jumper X2 was in the EJTAG position, the JTAG_TMS signal is pulled up by the resistor. The RC32438 JTAG_TMS pin contains an internal pull-up, so this pin could be left disconnected without the external pull-up if there are no other connections to it. The jumpers can be made to default to the JTAG position for ease of boundary scan testing.

Note that in all cases, when using JTAG only, the cable can be connected to pins 1-10 on the connector, since the remaining pins are not used for JTAG.

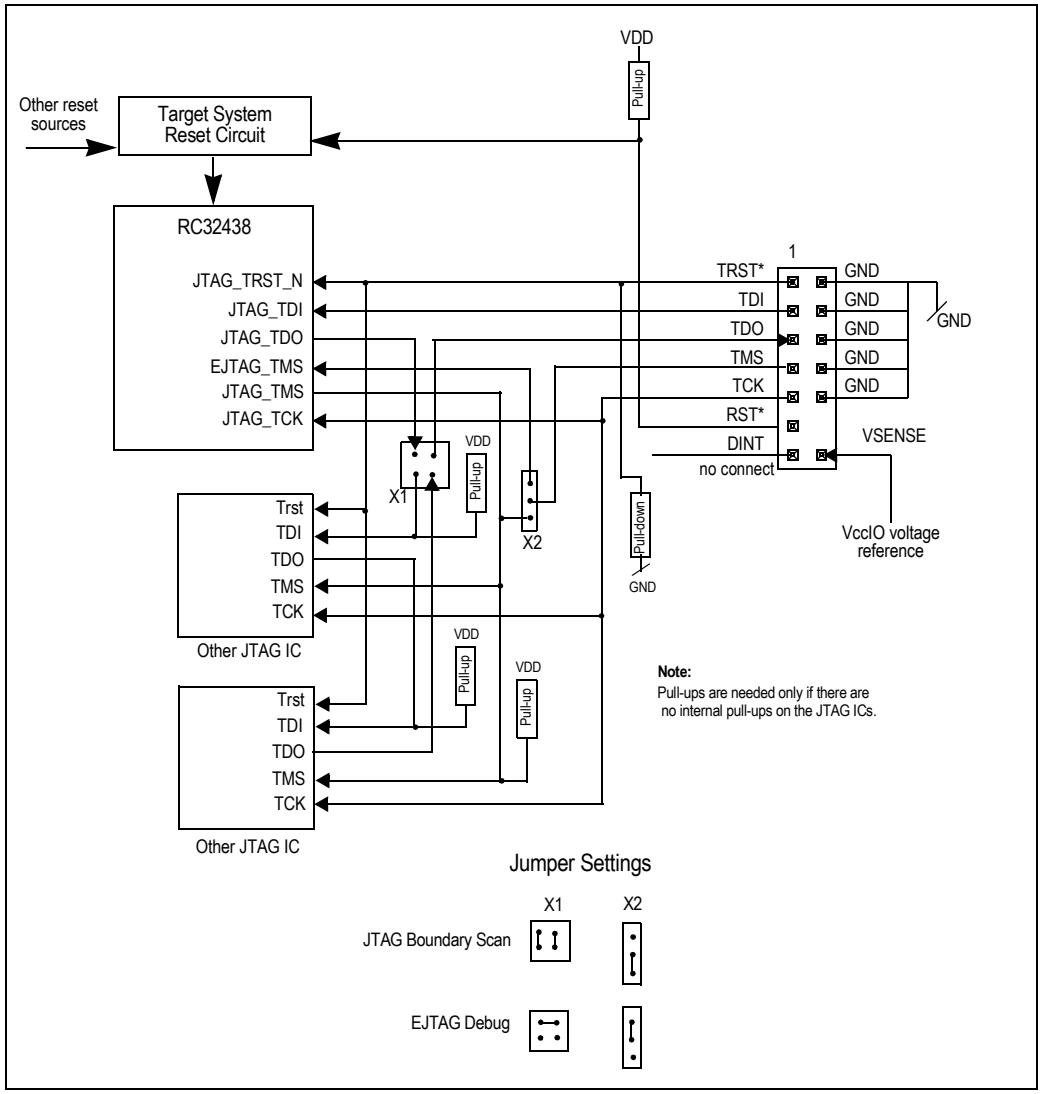


Figure 20.41 Connecting EJTAG and JTAG Controllers

Notes

4Kc Processor Core Instructions

Notes

Introduction

This Appendix contains additional information about the 4Kc processor core instruction set. Chapter 2 of this manual contains a description of the processor core and its operation.

Understanding the Instruction Set

Figure A.1 shows an example instruction.

Notes

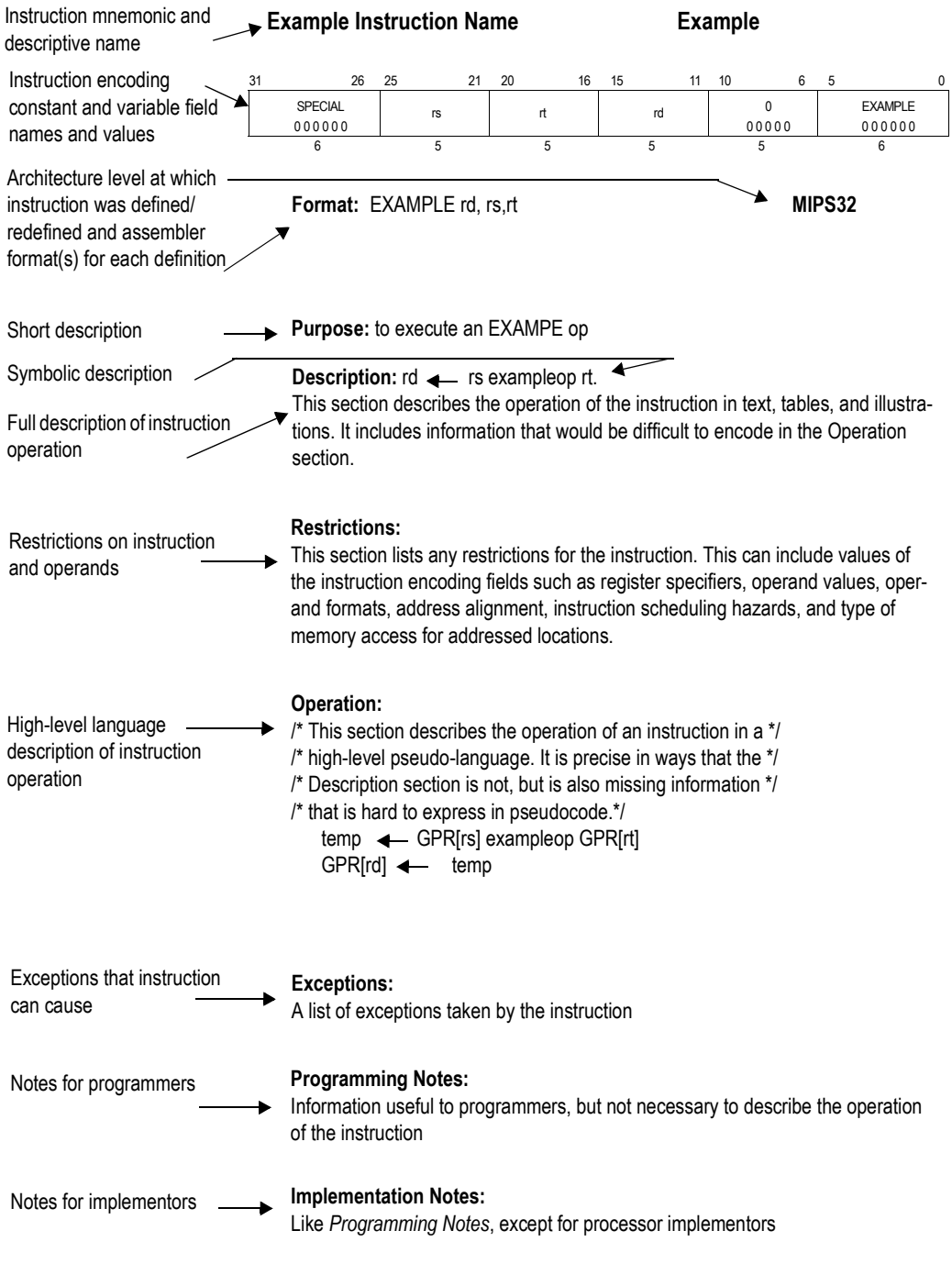


Figure A.1 Example of Instruction Description

Instruction Fields

Fields encoding the instruction word are shown in register form at the top of the instruction description. The following rules are followed:

The values of constant fields and the opcode names for opcode fields are listed in uppercase (SPECIAL and ADD in Figure A.2).

All variable fields are listed with the lowercase names used in the instruction description (rs, rt and rd in Figure A.2).

Fields that contain zeros but are not named are unused fields that are required to be zero (bits 10:6

Notes

in Figure A.2) If such fields are set to non-zero values, the operation of the processor is UNPREDICTABLE.

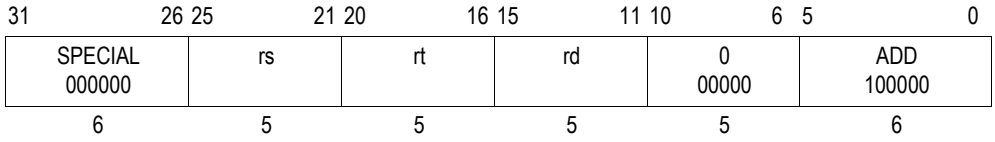


Figure A.2 Example of Instruction Fields

Instruction Descriptive Name and Mnemonic

The instruction descriptive name and mnemonic are printed as page headings for each instruction, as shown in Figure A.3.

Add Word	Add

Figure A.3 Example of Instruction Descriptive and Mnemonic Name

Format Field

The assembler formats for the instruction and the architecture level at which the instruction was originally defined are given in the Format field. If the instruction definition was later extended, the architecture levels at which it was extended and the assembler formats for the extended definition are shown in their order of extension (for an example, see C.cond.fmt). The MIPS architecture levels are inclusive; higher architecture levels include all instructions in previous levels. Extensions to instructions are backwards compatible. The original assembler formats are valid for the extended architecture.

Format: ADD rd, rs rt	MIPS32

Figure A.4 Example of Instruction Format

The assembler format is shown with literal parts of the assembler instruction printed in uppercase characters. The variable parts, the operands, are shown as the lowercase names of the appropriate fields. The architectural level at which the instruction was first defined, for example “MIPS32” is shown at the right side of the page.

Purpose Field

The Purpose field gives a short description of the use of the instruction.

Purpose:

To add 32-bit integers. If an overflow occurs, then trap.

Figure A.5 Example of Instruction Purpose

Description Field

If a one-line symbolic description of the instruction is feasible, it appears immediately to the right of the Description heading. The main purpose is to show how fields in the instruction are used in the arithmetic or logical operation.

Notes

Description: rd ← rs + rt

The 32-bit word value in GPR rt is added to the 32-bit value in DPR rs to produce a 32-bit result.

If the addition results in 32-bit 2's complement arithmetic overflow, the destination register is not modified and an Integer Overflow exception occurs.

If the addition does not overflow, the 32-bit result is placed into GPR rd.

Figure A.6 Example of Instruction Description

The body of the section is a description of the operation of the instruction in text, tables, and figures. This description complements the high-level language description in the Operation section.

This section uses acronyms for register descriptions. "GPR rt" is CPU general-purpose register specified by the instruction field rt.

Restrictions Field

The Restrictions field documents any possible restrictions that may affect the instruction. Most restrictions fall into one of the following six categories:

Valid values for instruction fields (for example, see floating-point ADD.fmt)

Alignment requirements for memory addresses (for example, see LW)

Valid values of operands (for example, see DADD)

Valid operand formats (for example, see floating-point ADD.fmt)

Order of instructions necessary to guarantee correct execution. These ordering constraints avoid pipeline hazards for which some processors do not have hardware interlocks (for example, see MUL).

Valid memory access types (for example, see LL/SC).

Restrictions:

Processor operation is UNPREDICTABLE if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Figure A.7 Example of Instruction Restrictions

Operation Field

The Operation field describes the operation of the instruction as pseudocode in a high-level language notation resembling Pascal (see Figure A.8). This formal description complements the Description section; it is not complete in itself because many of the restrictions are either difficult to include in the pseudocode or are omitted for legibility.

Notes

Operation:

temp ← (GPR[rs]$_{31}$||GPR[rs]$_{31..0}$) + (GPR[rt]$_{31}$||GPR[rt]$_{31..0}$)

if temp32 ≠ temp$_{31}$ then
SignalException(IntergerOverflow)
else
GPR[rd] ← temp
endif

Figure A.8 Sample Instruction Operation

Exceptions Field

The Exceptions field lists the exceptions that can be caused by Operation of the instruction. It omits exceptions that can be caused by the instruction fetch, for instance, TLB Refill, and also omits exceptions that can be caused by asynchronous external events such as an Interrupt. Although a Bus Error exception may be caused by the operation of a load or store instruction, this section does not list Bus Error for load and store instructions because the relationship between load and store instructions and external error indications, like Bus Error, are dependent upon the implementation.

Exceptions:

Integer Overflow

Figure A.9 Sample Instruction Exception

An instruction may cause implementation-dependent exceptions that are not present in the Exceptions section.

Programming Notes and Implementation Notes Fields

The Notes sections contain material that is useful for programmers and implementors, respectively, but that is not necessary to describe the instruction and does not belong in the description sections.

Programming Notes:

ADDU performs the same arithmetic operation but does not trap on overflow.

Figure A.10 Sample Instruction Programming Notes

Operation Section Notation and Functions

In an instruction description, the Operation section uses a high-level language notation to describe the operation performed by each instruction. The contents of the Operation section are described here, including the special symbols and functions that are used.

Instruction Execution Ordering

Each of the high-level language statements in the Operations section are executed sequentially (except as constrained by conditional and loop constructs).

Notes

Special Symbols in Pseudocode Notation

Special symbols used in the pseudocode notation are listed in Table A.1.

Symbol	Meaning
←	Assignment
=, ≠	Tests for equality and Inequality
||	Bit string concatenation
x^y	A *y*-bit string formed by *y* copies of the single-bit value *x*
b#n	A constant value *n* in base *b*. For instance 10#100 represents the decimal value 100, 2#100 represents the binary value 100 (decimal 4), and 16#100 represents the hexadecimal value 100 (decimal 256). If the "b#" prefix is omitted, the default base is 10.
$x_{y..z}$	Selection of bits *y* through *z* of bit string *x*. Little-endian bit notation (rightmost bit is 0) is used. If *y* is less than *z*, this expression is an empty (zero length) bit string.
+, −	2's complement or floating-point arithmetic: addition, subtraction
*, ×	2's complement or floating point multiplication (both used for either)
div	2's complement integer division
mod	2's complement modulo
/	Floating-point division
<	2's complement less-than comparison
>	2's complement greater-than comparison
≤	2's complement less-than or equal comparison
≥	2's complement greater-than or equal comparison
nor	Bitwise logical NOR
xor	Bitwise logical XOR
and	Bitwise logical AND
or	Bitwise logical OR
GPRLEN	The length in bits (32 or 64) of the CPU general-purpose registers
GPR[x]	CPU general-purpose register *x*. The content of *GPR[0]* is always zero.
CPR[z,x,s]	Coprocessor unit *z*, general register *x*, select *s*
CCR[z,x]	Coprocessor unit *z*, control register *x*
Xlat[x]	Translation of the MIPS16 GPR number *x* into the corresponding 32-bit GPR number
BigEndianMem	Endian mode as configured at chip reset (0 →Little-Endian, 1 → Big-Endian). Specifies the endianness of the memory interface (see LoadMemory and StoreMemory sections in this chapter), and the endianness of Kernel and Supervisor mode execution.
BigEndianCPU	The endianness for load and store instructions (0 → Little-Endian, 1 → Big-Endian). In User mode, this endianness may be switched by setting the *RE* bit in the *Status* register. Thus, BigEndianCPU may be computed as (BigEndianMem XOR ReverseEndian).

Table A.1 Symbols Used in Instruction Operation Statements (Part 1 of 2)

Notes

Symbol	Meaning
ReverseEndian	Signal to reverse the endianness of load and store instructions. This feature is available in User mode only, and is implemented by setting the *RE* bit of the *Status* register. Thus, ReverseEndian may be computed as (SR_{RE} and User mode).
LLbit	Bit of **virtual** state used to specify operation for instructions that provide atomic read-modify-write. *LLbit* is set when a linked load occurs; it is tested and cleared by the conditional store. It is cleared, during other CPU operation, when a store to the location would no longer be atomic. In particular, it is cleared by exception return instructions.
I:, I+n:, I-n:	This occurs as a prefix to *Operation* description lines and functions as a label. It indicates the instruction time during which the pseudocode appears to "execute." Unless otherwise indicated, all effects of the current instruction appear to occur during the instruction time of the current instruction. No label is equivalent to a time label of **I**. Sometimes effects of an instruction appear to occur either earlier or later — that is, during the instruction time of another instruction. When this happens, the instruction operation is written in sections labeled with the instruction time, relative to the current instruction **I**, in which the effect of that pseudocode appears to occur. For example, an instruction may have a result that is not available until after the next instruction. Such an instruction has the portion of the instruction operation description that writes the result register in a section labeled **I+1**. The effect of pseudocode statements for the current instruction labelled **I+1** appears to occur "at the same time" as the effect of pseudocode statements labeled **I** for the following instruction. Within one pseudocode sequence, the effects of the statements take place in order. However, between sequences of statements for different instructions that occur "at the same time," there is no defined order. Programs must not depend on a particular order of evaluation between such sections.
PC	The *Program Counter* value. During the instruction time of an instruction, this is the address of the instruction word. The address of the instruction that occurs during the next instruction time is determined by assigning a value to *PC* during an instruction time. If no value is assigned to *PC* during an instruction time by any pseudocode statement, it is automatically incremented by either 2 (in the case of a 16-bit MIPS16 instruction) or 4 before the next instruction time. A taken branch assigns the target address to the *PC* during the instruction time of the instruction in the branch delay slot.
PABITS	The number of physical address bits implemented is represented by the symbol PABITS. As such, if 36 physical address bits were implemented, the size of the physical address space would be $2^{PABITS} = 2^{36}$ bytes.

Table A.1 Symbols Used in Instruction Operation Statements (Part 2 of 2)

Pseudocode Functions

There are several functions used in the pseudocode descriptions. These are used either to make the pseudocode more readable, to abstract implementation-specific behavior, or both. These functions include the following: Load Memory and Store Memory Functions, and Miscellaneous Functions.

Load Memory and Store Memory Functions

Regardless of byte ordering (big- or little-endian), the address of a halfword, word, or doubleword is the smallest byte address of the bytes that form the object. For big-endian ordering this is the most-significant byte; for a little-endian ordering this is the least-significant byte.

In the Operation pseudocode for load and store operations, the following functions summarize the handling of virtual addresses and the access of physical memory. The size of the data item to be loaded or stored is passed in the AccessLength field. The valid constant names and values are shown in Table 11-2. The bytes within the addressed unit of memory (word for 32-bit processors or doubleword for 64-bit processors) that are used can be determined directly from the AccessLength and the two or three low-order bits of the address.

Notes

AddressTranslation

The AddressTranslation function translates a virtual address to a physical address and its cache coherence algorithm, describing the mechanism used to resolve the memory reference.

Given the virtual address vAddr, and whether the reference is to Instructions or Data (IorD), find the corresponding physical address (pAddr) and the cache coherence algorithm (CCA) used to resolve the reference. If the virtual address is in one of the unmapped address spaces, the physical address and CCA are determined directly by the virtual address. If the virtual address is in one of the mapped address spaces then the TLB determines the physical address and access type; if the required translation is not present in the TLB or the desired access is not permitted, the function fails and an exception is taken.

```
(pAddr, CCA) ← AddressTranslation (vAddr, IorD, LorS)

    /* pAddr:  physical address */
    /* CCA:    Cache Coherence Algorithm, the method used to access caches*/
    /*         and memory and resolve the reference */

    /* vAddr:  virtual address */
    /* IorD:    Indicates whether access is for INSTRUCTION or DATA */
    /* LorS:    Indicates whether access is for LOAD or STORE */

    /* See the address translation description for the appropriate MMU */
    /* type in Volume III of this book for the exact translation mechanism */

endfunction AddressTranslation
```

LoadMemory

The LoadMemory function loads a value from memory.

This action uses cache and main memory as specified in both the Cache Coherence Algorithm (CCA) and the access (IorD) to find the contents of AccessLength memory bytes, starting at physical location pAddr. The data is returned in a fixed-width naturally aligned memory element (MemElem). The low-order two (or three) bits of the address and the AccessLength indicate which of the bytes within MemElem need to be passed to the processor. If the memory access type of the reference is uncached, only the referenced bytes are read from memory and marked as valid within the memory element. If the access type is cached but the data is not present in cache, an implementation-specific size and alignment block of memory is read and loaded into the cache to satisfy a load reference. At a minimum, this block is the entire memory element.

```
MemElem ← LoadMemory (CCA, AccessLength, pAddr, vAddr, IorD)

    /* MemElem:  Data is returned in a fixed width with a */
    /*           natural alignment. The width is the same size */
    /*           as the CPU general-purpose register, */
    /*           32 or 64 bits, aligned on a 32- or 64-bit */
    /*           boundary, respectively. */
    /* CCA:      Cache Coherence Algorithm, the method used to */
    /*           access caches and memory and resolve the reference */

    /* AccessLength: Length, in bytes, of access */
    /* pAddr:    physical address */
    /* vAddr:    virtual address */
    /* IorD:     Indicates whether access is for Instructions or Data */

endfunction LoadMemory
```

StoreMemory

The StoreMemory function stores a value to memory.

Notes

The specified data is stored into the physical location pAddr using the memory hierarchy (data caches and main memory) as specified by the Cache Coherence Algorithm (CCA). The MemElem contains the data for an aligned, fixed-width memory element (a word for 32-bit processors, a doubleword for 64-bit processors), though only the bytes that are actually stored to memory need be valid. The low-order two (or three) bits of pAddr and the AccessLength field indicate which of the bytes within the MemElem data should be stored; only these bytes in memory will actually be changed.

```
StoreMemory (CCA, AccessLength, MemElem, pAddr, vAddr)

    /* CCA:        Cache Coherence Algorithm, the method used to access */
    /*             caches and memory and resolve the reference. */
    /* AccessLength: Length, in bytes, of access */
    /* MemElem:    Data in the width and alignment of a memory element. */
    /*             The width is the same size as the CPU general */
    /*             purpose register, either 4 or 8 bytes, aligned on */
    /*             a 4- or 8-byte boundary. For a partial-memory-element */
    /*             store, only the bytes that will be*/
    /*             stored must be valid.*/
    /* pAddr:      physical address */
    /* vAddr:      virtual address */
```

Prefetch

The Prefetch function prefetches data from memory.

Prefetch is an advisory instruction for which an implementation-specific action is taken. The action taken may increase performance but must not change the meaning of the program or alter architecturally visible state.

```
Prefetch (CCA, pAddr, vAddr, DATA, hint)

    /* CCA:        Cache Coherence Algorithm, the method used to access */
    /*             caches and memory and resolve the reference. */
    /* pAddr:      physical address */
    /* vAddr:      virtual address */
    /* DATA:       Indicates that access is for DATA */
    /* hint:       hint that indicates the possible use of the data */

endfunction Prefetch
```

Table A.2 lists the data access lengths and their labels for loads and stores.

AccessLength Name	Value	Meaning
WORD	3	4 bytes (32 bits)
TRIPLEBYTE	2	3 bytes (24 bits)
HALFWORD	1	2 bytes (16 bits)
BYTE	0	1 byte (8 bits)

Table A.2 AccessLength Specifications for Loads/Stores

Miscellaneous Functions

This section lists miscellaneous functions not covered in previous sections.

SyncOperation

The SyncOperation function orders loads and stores to synchronize shared memory.

Notes

This action makes the effects of the synchronizable loads and stores indicated by type occur in the same order for all processors.

```
SyncOperation(stype)

    /* stype:      Type of load/store ordering to perform. */

    /* Perform implementation-dependent operation to complete the */
    /* required synchronization operation */

endfunction SyncOperation
```

SignalException

The SignalException function signals an exception condition.

This action results in an exception that aborts the instruction. The instruction operation pseudocode never sees a return from this function call.

```
SignalException(Exception, argument)

    /* Exception:      The exception condition that exists. */
    /* argument:       An exception-dependent argument, if any */

endfunction SignalException
```

NullifyCurrentInstruction

The NullifyCurrentInstruction function nullifies the current instruction.

The instruction is aborted. For branch-likely instructions, nullification kills the instruction in the delay slot during its execution.

```
NullifyCurrentInstruction()

endfunction NullifyCurrentInstruction
```

CoprocessorOperation

The CoprocessorOperation function performs the specified Coprocessor operation.

```
CoprocessorOperation (z, cop_fun)

    /* z:          Coprocessor unit number */
    /* cop_fun:    Coprocessor function from function field of instruction */

    /* Transmit the cop_fun value to coprocessor z */

endfunction CoprocessorOperation
```

JumpDelaySlot

The JumpDelaySlot function is used in the pseudocode for the four PC-relative instructions. The function returns TRUE if the instruction at vAddr is executed in a jump delay slot. A jump delay slot always immediately follows a JR, JAL, JALR, or JALX instruction.

```
JumpDelaySlot(vAddr)

    /* vAddr: Virtual address */

endfunction JumpDelaySlot
```

Notes

Op and Function Subfield Notation

In some instructions, the instruction subfields op and function can have constant 5- or 6-bit values. When reference is made to these instructions, uppercase mnemonics are used. For instance, in the floating-point ADD instruction, op=COP1 and function=ADD. In other cases, a single field has both fixed and variable subfields, so the name contains both uppercase and lowercase characters.

CPU Opcode Map

- *CAPITALIZED text indicates an opcode mnemonic*
- *Italicized text indicates to look at the specified opcode submap for further instruction bit decode*
- *Entries containing the a symbol indicate that a reserved instruction fault occurs if the core executes this instruction.*
- *Entries containing the b symbol indicate that a coprocessor unusable exception occurs if the core executes this instruction.*

opcode		bits 28...26							
		0	1	2	3	4	5	6	7
bits 31...29		000	001	010	011	100	101	110	111
0	000	Special	RegImm	J	JAL	BEQ	BNE	BLEZ	BGTZ
1	001	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI
2	010	COP0	β	β	β	BEQL	BNEL	BLEZL	BGTZL
3	011	α	α	α	α	Special2	α	α	α
4	100	LB	LH	LWL	LW	LBU	LHU	LWR	α
5	101	SB	SH	SWL	SW	α	α	SWR	CACHE
6	110	LL	β	β	PREF	α	β	β	α
7	111	SC	β	β	α	α	β	β	α

Table A.3 Encoding of the Opcode Field

function		bits 2...0							
		0	1	2	3	4	5	6	7
bits 5...3		000	001	010	011	100	101	110	111
0	000	SLL	β	SRL	SRA	SLLV	α	SRLV	SRAV
1	001	JR	JALR	MOVZ	MOVN	SYSCALL	BREAK	α	SYNC
2	010	MFHI	MTHI	MFLO	MTLO	α	α	α	α
3	011	MULT	MULTU	DIV	DIVU	α	α	α	α
4	100	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR
5	101	α	α	SLT	SLTU	α	α	α	α
6	110	TGE	TGEU	TLT	TLTU	TEQ	α	TNE	α
7	111	α	α	α	α	α	α	α	α

Table A.4 Special Opcode Encoding of Function Field

Notes

function		bits 2...0							
bits 5...3		0 000	1 001	2 010	3 011	4 100	5 101	6 110	7 111
0	000	MADD	MADDU	MUL	α	MSUB	MSUBU	α	α
1	001	α	α	α	α	α	α	α	α
2	010	α	α	α	α	α	α	α	α
3	011	α	α	α	α	α	α	α	α
4	100	CLZ	CLO	α	α	α	α	α	α
5	101	α	α	α	α	α	α	α	α
6	110	α	α	α	α	α	α	α	α
7	111	α	α	α	α	α	α	α	SDBBP

Table A.5 Special2 Opcode Encoding of Function Field

rt		bits 18...16							
bits 20...19		0 000	1 001	2 010	3 011	4 100	5 101	6 110	7 111
0	BLTZ	BGEZ	BLTZL	BGEZL	α	α	α	α	α
1	TGEI	TGEIU	TLTI	TLTIU	TEQI	α	TNEI	α	α
2	BLTZAL	BGEZAL	BLTZALL	BGEZALL	α	α	α	α	α
3	α	α	α	α	α	α	α	α	α

Table A.6 Reglmm Encoding of rt Field

rs		bits 23...21							
bits 25...24		0 000	1 001	2 010	3 011	4 100	5 101	6 110	7 111
0	00	MFCO	α	α	α	MTCO	α	α	α
1	01	α	α	α	α	α	α	α	α
2	10	CO							
3	11								

Table A.7 COP0 Encoding of rs Field

Notes

function		bits 2...0							
bits 5...3		0 000	1 001	2 010	3 011	4 100	5 101	6 110	7 111
0	000	α	TLBR	TLBWI	α	α	α	TLBWR	α
1	001	TLBP	α	α	α	α	α	α	α
2	010	α	α	α	α	α	α	α	α
3	011	ERET	α	α	α	α	α	α	DERET
4	100	WAIT	α	α	α	α	α	α	α
5	101	α	α	α	α	α	α	α	α
6	110	α	α	α	α	α	α	α	α
7	111	α	α	α	α	α	α	α	α

Table A.8 CP0 Encoding of Function Field when rs=CO

Instruction Set

This section describes the core instructions. Table A.9 lists the instructions in alphabetical order, followed by a detailed description of each instruction.

Instruction	Description	Function
ADD	Integer Add	Rd = Rs + Rt
ADDI	Integer Add Immediate	Rt = Rs + Immed
ADDIU	Unsigned Integer Add Immediate	Rt = Rs $+_U$ Immed
ADDU	Unsigned Integer Add	Rd = Rs $+_U$ Rt
AND	Logical AND	Rd = Rs & Rt
ANDI	Logical AND Immediate	Rt = Rs & (0_{16} || Immed)
B	Unconditional Branch (Assembler idiom for: BEQ r0, r0, offset)	PC += (int)offset
BAL	Branch and Link (Assembler idiom for: BGEZAL r0, offset)	GPR[31] = PC + 8 PC += (int)offset
BEQ	Branch On Equal	if Rs == Rt PC += (int)offset
BEQL	Branch On Equal Likely	if Rs == Rt PC += (int)offset else Ignore Next Instruction

Table A.9 Instruction Set (Part 1 of 6)

Notes

Instruction	Description	Function
BGEZ	Branch on Greater Than or Equal To Zero	if !Rs[31] PC += (int)offset
BGEZAL	Branch on Greater Than or Equal To Zero And Link	GPR[31] = PC + 8 if !Rs[31] PC += (int)offset
BGEZALL	Branch on Greater Than or Equal To Zero And Link Likely	GPR[31] = PC + 8 if !Rs[31] PC += (int)offset else Ignore Next Instruction
BGEZL	Branch on Greater Than or Equal To Zero Likely	if !Rs[31] PC += (int)offset else Ignore Next Instruction
BGTZ	Branch on Greater Than Zero	if !Rs[31] && Rs != 0 PC += (int)offset
BGTZL	Branch on Greater Than Zero Likely	if !Rs[31] && Rs != 0 PC += (int)offset else Ignore Next Instruction
BLEZ	Branch on Less Than or Equal to Zero	if Rs[31] || Rs == 0 PC += (int)offset
BLEZL	Branch on Less Than or Equal to Zero Likely	if Rs[31] || Rs == 0 PC += (int)offset else Ignore Next Instruction
BLTZ	Branch on Less Than Zero	if Rs[31] PC += (int)offset
BLTZAL	Branch on Less Than Zero And Link	GPR[31] = PC + 8 if Rs[31] PC += (int)offset
BLTZALL	Branch on Less Than Zero And Link Likely	GPR[31] = PC + 8 if Rs[31] PC += (int)offset else Ignore Next Instruction
BLTZL	Branch on Less Than Zero Likely	if Rs[31] PC += (int)offset else Ignore Next Instruction

Table A.9 Instruction Set (Part 2 of 6)

Notes

Instruction	Description	Function
BNE	Branch on Not Equal	if Rs != Rt PC += (int)offset
BNEL	Branch on Not Equal Likely	if Rs != Rt PC += (int)offset else Ignore Next Instruction
BREAK	Breakpoint	Break Exception
CACHE	Cache Operation	See Cache Description
COP0	Coprocessor 0 Operation	See Coprocessor Description
CLO	Count Leading Ones	Rd = NumLeadingOnes(Rs)
CLZ	Count Leading Zeroes	Rd = NumLeadingZeroes(Rs)
DERET	Return from Debug Exception	PC = DEPC Exit Debug Mode
DIV	Divide	LO = (int)Rs / (int)Rt HI = (int)Rs % (int)Rt
DIVU	Unsigned Divide	LO = (uns)Rs / (uns)Rt HI = (uns)Rs % (uns)Rt
ERET	Return from Exception	if SR[2] PC = ErrorEPC else PC = EPC SR[1] = 0 SR[2] = 0 LL = 0
J	Unconditional Jump	PC = PC[31:28] || offset<<2
JAL	Jump and Link	GPR[31] = PC + 8 PC = PC[31:28] || offset<<2
JALR	Jump and Link Register	Rd = PC + 8 PC = Rs
JR	Jump Register	PC = Rs
LB	Load Byte	Rt = (byte)Mem[Rs+offset]
LBU	Unsigned Load Byte	Rt = (ubyte))Mem[Rs+offset]
LH	Load Halfword	Rt = (half)Mem[Rs+offset]
LHU	Unsigned Load Halfword	Rt = (uhalf)Mem[Rs+offset]
LL	Load Linked Word	Rt = Mem[Rs+offset] LL = 1 LLAdr = Rs + offset

Table A.9 Instruction Set (Part 3 of 6)

Notes

Instruction	Description	Function
LUI	Load Upper Immediate	Rt = immediate << 16
LW	Load Word	Rt = Mem[Rs+offset]
LWL	Load Word Left	See LWL instruction on page A-53.
LWR	Load Word Right	See LWR instruction on page A-55.
MADD	Multiply - Add	HI, LO += (int)Rs * (int)Rt
MADDU	Multiply - Add Unsigned	HI, LO += (uns)Rs * (uns)Rt
MFC0	Move From Coprocessor 0	Rt = CPR[0, n, sel] = Rt
MFHI	Move From HI	Rd = HI
MFLO	Move From LO	Rd = LO
MOVN	Move Conditional on Not Zero	if GPR[rt] ≠ 0 then GPR[rd] ← GPR[rs]
MOVZ	Move Conditional on Zero	if GPR[rt] = 0 then GPR[rd] ← GPR[rs]
MSUB	Multiply-Subtract	HI, LO –= (int)Rs * (int)Rt
MSUBU	Multiply-Subtract Unsigned	HI, LO –= (uns)Rs * (uns)Rt
MTC0	Move To Coprocessor 0	CPR[0, n] = Rt SEL
MTHI	Move To HI	HI = Rs
MTLO	Move To LO	LO = Rs
MUL	Multiply with register write	HI | LO =Unpredictable Rd = LO
MULT	Integer Multiply	HI | LO = (int)Rs * (int)Rd
MULTU	Unsigned Multiply	HI | LO = (uns)Rs * (uns)Rd
NOP	No Operation (Assembler idiom for: SLL r0, r0, r0)	
NOR	Logical NOR	Rd = ~(Rs | Rt)
OR	Logical OR	Rd = Rs | Rt
ORI	Logical OR Immediate	Rt = Rs | Immed
PREF	Prefetch	Load Specified Line into Cache
SB	Store Byte	(byte)Mem[Rs+offset] = Rt

Table A.9 Instruction Set (Part 4 of 6)

Notes

Instruction	Description	Function
SC	Store Conditional Word	if LL =1 mem[Rxoffs] = Rt Rt = LL
SDBBP	Software Debug Break Point	Trap to SW Debug Handler
SH	Store Half	(half)Mem[Rs+offset] = Rt
SLL	Shift Left Logical	Rd = Rt << sa
SLLV	Shift Left Logical Variable	Rd = Rt << Rs[4:0]

SLT	Set on Less Than	if (int)Rs < (int)Rt
		Rd = 1
		else
		Rd = 0

SLTI	Set on Less Than Immediate	if (int)Rs < (int)Immed
		Rt = 1
		else
		Rt = 0

SLTIU	Set on Less Than Immediate Unsigned	if (uns)Rs < (uns)Immed
		Rt = 1
		else
		Rt = 0

SLTU	Set on Less Than Unsigned	if (uns)Rs < (uns)Immed
		Rd = 1
		else
		Rd = 0

SRA	Shift Right Arithmetic	Rd = (int)Rt >> sa
SRAV	Shift Right Arithmetic Variable	Rd = (int)Rt >> Rs[4:0]
SRL	Shift Right Logical	Rd = (uns)Rt >> sa
SRLV	Shift Right Logical Variable	Rd = (uns)Rt >> Rs[4:0]
SSNOP	Superscalar Inhibit No Operation	
SUB	Integer Subtract	Rt = (int)Rs - (int)Rd
SUBU	Unsigned Subtract	Rt = (uns)Rs - (uns)Rd
SW	Store Word	Mem[Rs+offset] = Rt
SWL	Store Word Left	See Store Word Left instruction on
SWR	Store Word Right	SeeStore Word Right instruction on
SYNC	Synchronize	See SYNC instruction on page A-88

Table A.9 Instruction Set (Part 5 of 6)

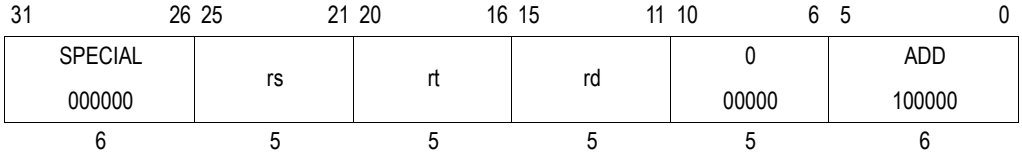
Notes

Instruction	Description	Function
SYSCALL	System Call	SystemCallException
TEQ	Trap if Equal	if Rs == Rt TrapException
TEQI	Trap if Equal Immediate	if Rs == (int)Immed TrapException
TGE	Trap if Greater Than or Equal	if (int)Rs >= (int)Rt TrapException
TGEI	Trap if Greater Than or Equal Immediate	if (int)Rs >= (int)Immed TrapException
TGEIU	Trap if Greater Than or Equal Immediate Unsigned	if (uns)Rs >= (uns)Immed TrapException
TGEU	Trap if Greater Than or Equal Unsigned	if (uns)Rs >= (uns)Rt TrapException
TLBWI	Write Indexed TLB Entry	See TLBWI instruction on page A-95
TLBWR	Write Random TLB Entry	See TLBWR instruction on page A-96
TLBP	Probe TLB for Matching Entry	See TLBP instruction on page A-93
TLBR	Read Index for TLB Entry	See TLBR instruction on page A-94
TLT	Trap if Less Than	if (int)Rs < (int)Rt TrapException
TLTI	Trap if Less Than Immediate	if (int)Rs < (int)Immed TrapException
TLTIU	Trap if Less Than Immediate Unsigned	if (uns)Rs < (uns)Immed TrapException
TLTU	Trap if Less Than Unsigned	if (uns)Rs < (uns)Rt TrapException
TNE	Trap if Not Equal	if Rs != Rt TrapException
TNEI	Trap if Not Equal Immediate	if Rs != (int)Immed TrapException
WAIT	Wait for Interrupts	Stall until interrupt occurs
XOR	Exclusive OR	Rd = Rs ^ Rt
XORI	Exclusive OR Immediate	Rt = Rs ^ (uns)Immed

Table A.9 Instruction Set (Part 6 of 6)

Notes

Add Word **ADD**



Format: ADD rd, rs, rt **MIPS32**

Purpose:

To add 32-bit integers. If an overflow occurs, then trap.

Description: rd ← rs + rt

The 32-bit word value in GPR *rt* is added to the 32-bit value in GPR *rs* to produce a 32-bit result.

- If the addition results in 32-bit 2's complement arithmetic overflow, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rd*.

Restrictions:

None

Operation:

```
temp ← (GPR[rs]31||GPR[rs]31..0) + (GPR[rt]31||GPR[rt]31..0)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rd] ← temp
endif
```

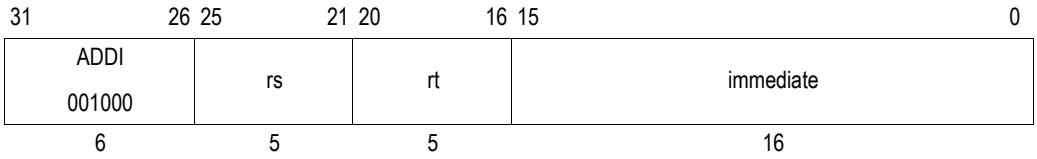
Exceptions:

Integer Overflow

Programming Notes:

ADDU performs the same arithmetic operation but does not trap on overflow.

Add Immediate Word **ADDI**



Format: ADDI rt, rs, immediate **MIPS32**

Purpose:

To add a constant to a 32-bit integer. If overflow occurs, then trap.

Notes

Description: rt ← rs + immediate

The 16-bit signed *immediate* is added to the 32-bit value in GPR *rs* to produce a 32-bit result.

- If the addition results in 32-bit 2's complement arithmetic overflow, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rt*.

Restrictions:

None

Operation:

```
temp ← (GPR[rs]31||GPR[rs]31..0) + sign_extend(immediate)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rt] ← temp
endif
```

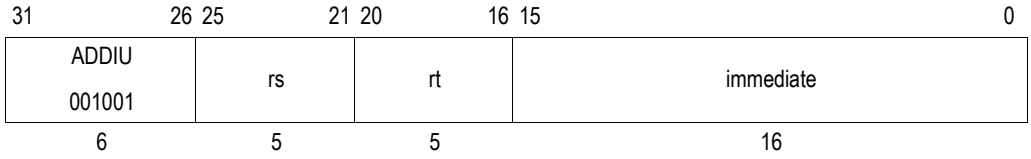
Exceptions:

Integer Overflow

Programming Notes:

ADDIU performs the same arithmetic operation but does not trap on overflow.

Add Immediate Unsigned Word **ADDIU**



Format: ADDIU rt, rs, immediate **MIPS32**

Purpose:

To add a constant to a 32-bit integer.

Description: rt ← rs + immediate

The 16-bit signed *immediate* is added to the 32-bit value in GPR *rs* and the 32-bit arithmetic result is placed into GPR *rt*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← GPR[rs] + sign_extend(immediate)
GPR[rt] ← temp
```

Exceptions:

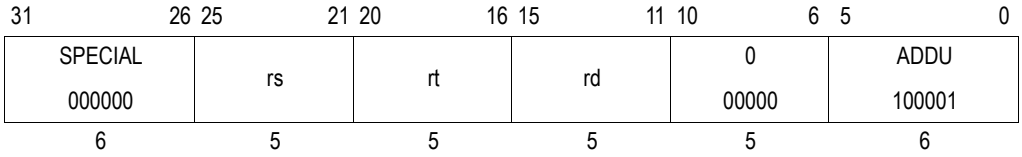
None

Notes

Programming Notes:

The term “unsigned” in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.

Add Unsigned Word **ADDU**



Format: ADDU rd, rs, rt **MIPS32**

Purpose:

To add 32-bit integers.

Description: rd ← rs + rt

The 32-bit word value in GPR *rt* is added to the 32-bit value in GPR *rs* and the 32-bit arithmetic result is placed into GPR *rd*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← GPR[rs] + GPR[rt]
GPR[rd] ← temp
```

Exceptions:

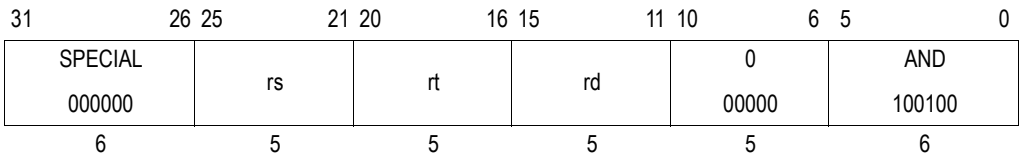
None

Programming Notes:

The term “unsigned” in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.

Notes

And **AND**



Format: AND rd, rs, rt **MIPS32**

Purpose:

To do a bitwise logical AND.

Description: rd ← rs AND rt

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical AND operation. The result is placed into GPR *rd*.

Restrictions:

None

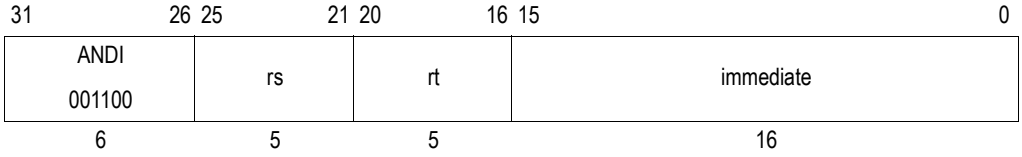
Operation:

```
GPR[rd] ← GPR[rs] and GPR[rt]
```

Exceptions:

None

And Immediate **ANDI**



Format: ANDI rt, rs, immediate **MIPS32**

Purpose:

To do a bitwise logical AND with a constant.

Description: rt ← rs AND immediate

The 16-bit *immediate* is zero-extended to the left and combined with the contents of GPR *rs* in a bitwise logical AND operation. The result is placed into GPR *rt*.

Restrictions:

None

Notes

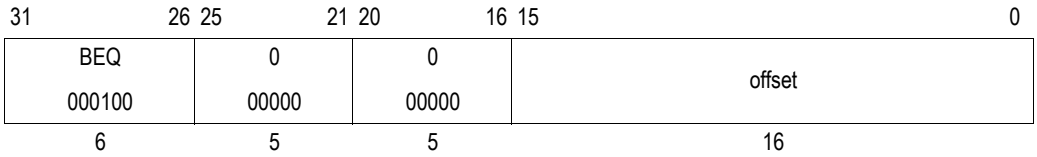
Operation:

GPR[rt] ← GPR[rs] and zero_extend(immediate)

Exceptions:

None

Unconditional Branch **B**



Format: B offset **Assembly Idiom**

Purpose:

To do an unconditional branch.

Description: branch

B offset is the assembly idiom used to denote an unconditional branch. The actual instruction is interpreted by the hardware as BEQ r0, r0, offset.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

I: target_offset ← sign_extend(offset || 0^2)
I+1: PC ← PC + target_offset

Exceptions:

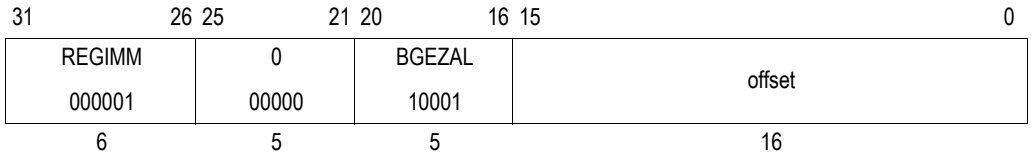
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 Kbytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Notes

Branch and Link **BAL**



Format: BAL rs, offset **Assembly Idiom**

Purpose:

To do an unconditional PC-relative procedure call.

Description: procedure_call

BAL offset is the assembly idiom used to denote an unconditional branch. The actual instruction is interpreted by the hardware as BGEZAL r0, offset.

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        GPR[31] ← PC + 8
I+1:    PC ← PC + target_offset
```

Exceptions:

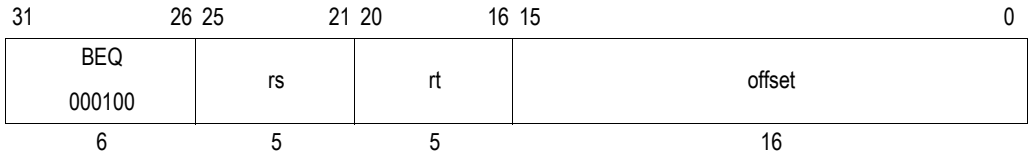
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

Notes

Branch on Equal **BEQ**



Format: BEQ rs, rt, offset **MIPS32**

Purpose:

To compare GPRs, then do a PC-relative conditional branch.

Description: if rs = rt then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are equal, branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
            condition ← (GPR[rs] = GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

Exceptions:

None

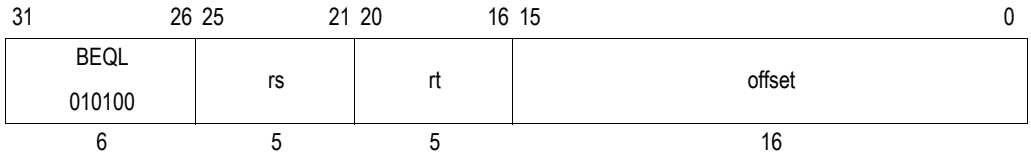
Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 Kbytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

BEQ r0, r0 offset, expressed as B offset, is the assembly idiom used to denote an unconditional branch.

Notes

Branch on Equal Likely **BEQL**



Format: BEQL rs, rt, offset **MIPS32**

Purpose:

To compare GPRs, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Description: if rs = rt then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are equal, branch to the target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
            condition ← (GPR[rs] = GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

None

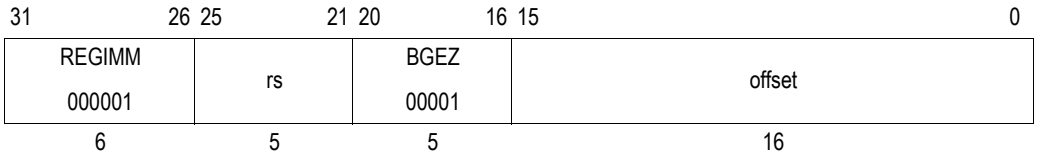
Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Notes

Branch on Greater Than or Equal to Zero **BGEZ**



Format: BGEZ rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch.

Description: if rs ≥ 0 then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≥ 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

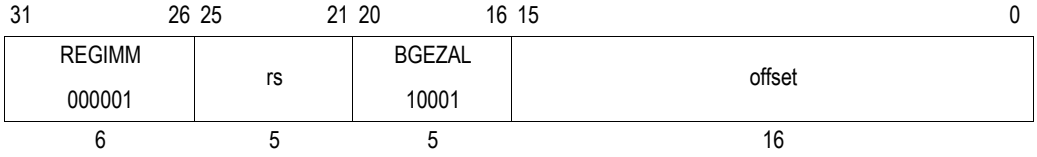
Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Branch on Greater Than or Equal to Zero and Link **BGEZAL**



Format: BGEZAL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional procedure call.

Notes

Description: if rs ≥ 0 then procedure_call

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≥ 0^GPRLEN
        GPR[31] ← PC + 8
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

Exceptions:

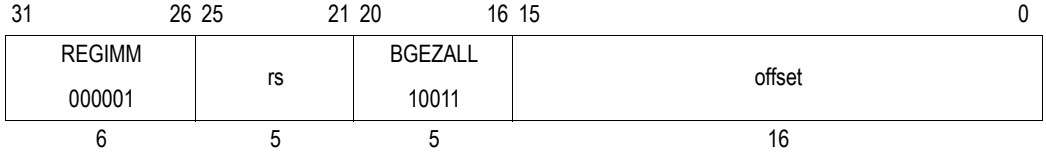
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

BGEZAL r0, offset, expressed as BAL offset, is the assembly idiom used to denote a PC-relative branch and link. BAL is used in a manner similar to JAL, but provides PC-relative addressing and a more limited target PC range.

Branch on Greater Than or Equal to Zero and Link Likely **BGEZALL**



Format: BGEZALL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional procedure call; execute the delay slot only if the branch is taken.

Notes

Description: if rs ≥ 0 then procedure_call_likely

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≥ 0^GPRLEN
        GPR[31] ← PC + 8
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

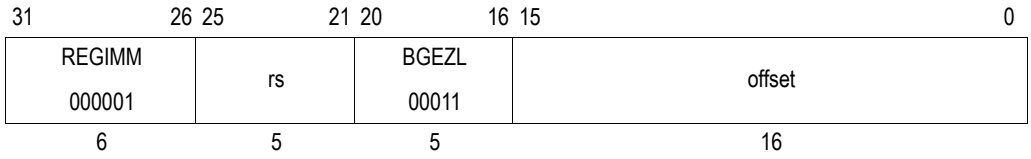
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Branch on Greater Than or Equal to Zero Likely **BGEZL**



Format: BGEZL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Notes

Description: if rs ≥ 0 then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≥ 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

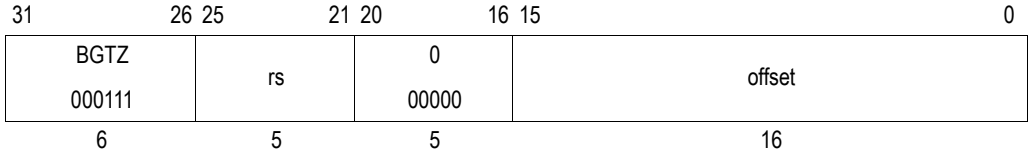
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Branch on Greater Than Zero **BGTZ**



Format: BGTZ rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch.

Description: if rs > 0 then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than zero (sign bit is 0 but value not zero), branch to the effective target address after the instruction in the delay slot is executed.

Notes

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] > 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

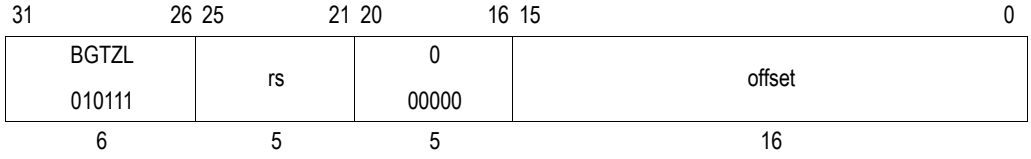
Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Branch on Greater Than Zero Likely **BGTZL**



Format: BGTZL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Description: if rs > 0 then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than zero (sign bit is 0 but value not zero), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Notes

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] > 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

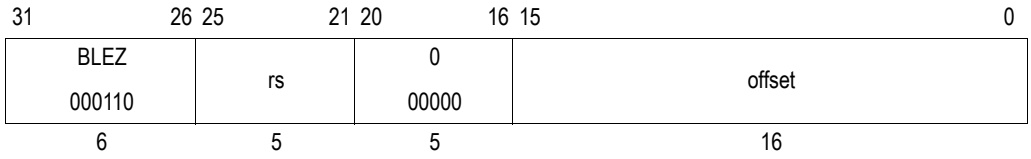
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Branch on Less Than or Equal to Zero **BLEZ**



Format: BLEZ rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch.

Description: if rs ≤ 0 then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than or equal to zero (sign bit is 1 or value is zero), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≤ 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

Exceptions:

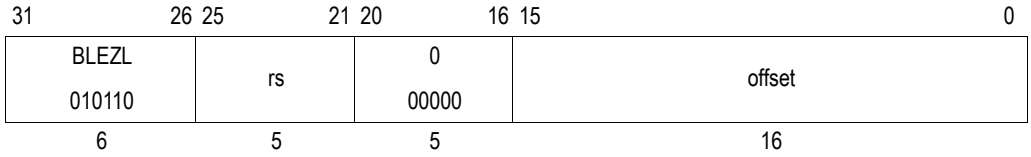
None

Notes

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Branch on Less Than or Equal to Zero Likely **BLEZL**



Format: BLEZL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Description: if rs ≤ 0 then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than or equal to zero (sign bit is 1 or value is zero), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] ≤ 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

None

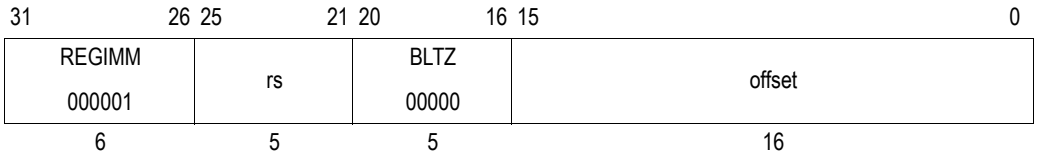
Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Notes

Branch on Less Than Zero **BLTZ**



Format: BLTZ rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch.

Description: if rs < 0 then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] < 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

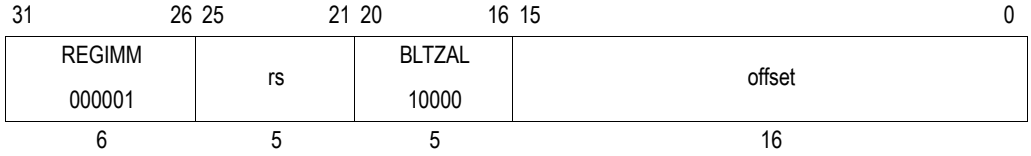
Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

Branch on Less Than Zero and Link **BLTZAL**



Format: BLTZAL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional procedure call.

Notes

Description: if rs < 0 then procedure_call

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is UNPREDICTABLE. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] < 0^GPRLEN
        GPR[31] ← PC + 8
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

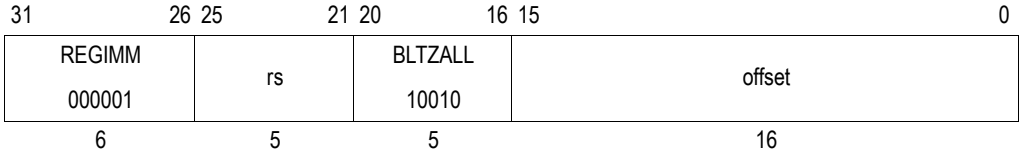
Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

Branch on Less Than Zero and Link Likely **BLTZALL**



Format: BLTZALL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional procedure call; execute the delay slot only if the branch is taken.

Description: if rs < 0 then procedure_call_likely

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the

Notes

instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is UNPREDICTABLE. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] < 0^GPRLEN
        GPR[31] ← PC + 8
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

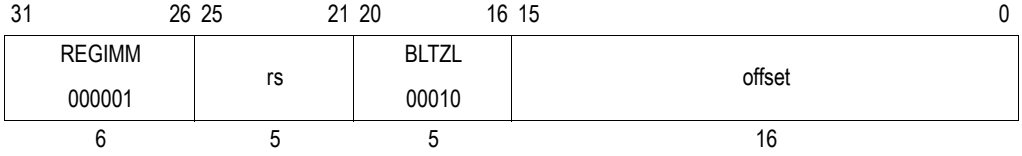
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Branch on Less Than Zero Likely **BLTZL**



Format: BLTZL rs, offset **MIPS32**

Purpose:

To test a GPR, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Description: if rs < 0 then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-rela-

Notes

tive effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← GPR[rs] < 0^GPRLEN
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

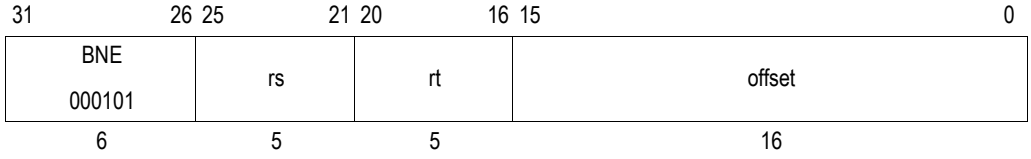
None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Branch on Not Equal **BNE**



Format: BNE rs, rt, offset **MIPS32**

Purpose:

To compare GPRs, then do a PC-relative conditional branch.

Description: if rs ≠ rt then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are not equal, branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Notes

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← (GPR[rs] ¼ GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        endif
```

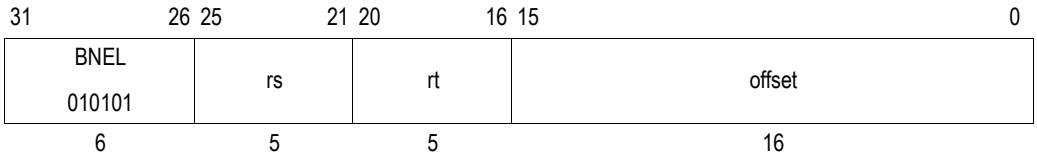
Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Branch on Not Equal Likely **BNEL**



Format: BNEL rs, rt, offset **MIPS32**

Purpose:

To compare GPRs, then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.

Description: if rs ≠ rt then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (not the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are not equal, branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      target_offset ← sign_extend(offset || 0^2)
        condition ← (GPR[rs] ¼ GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        else
            NullifyCurrentInstruction()
        endif
```

Exceptions:

None

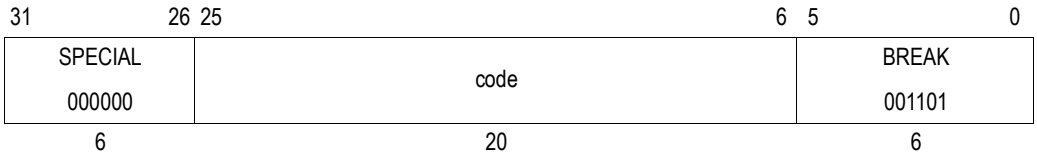
Notes

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ± 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

Software is strongly encouraged to avoid the use of the Branch Likely instructions, as they will be removed from a future revision of the MIPS Architecture.

Breakpoint **BREAK**



Format: BREAK **MIPS32**

Purpose:

To cause a Breakpoint exception.

Description:

A breakpoint exception occurs, immediately and unconditionally transferring control to the exception handler. The *code* field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

Restrictions:

None

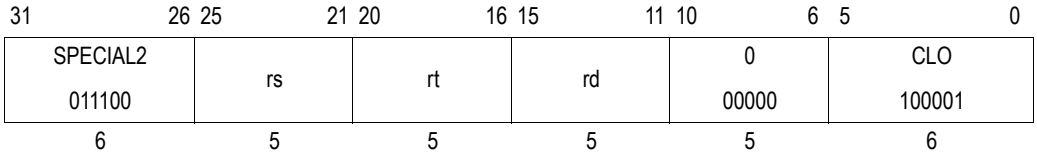
Operation:

```
SignalException(Breakpoint)
```

Exceptions:

Breakpoint

Count Leading Ones in Word **CLO**



Format: CLO rd, rs **MIPS32**

Purpose:

To Count the number of leading ones in a word.

Description: rd ← count_leading_ones rs

Bits 31..0 of GPR *rs* are scanned from most significant to least significant bit. The number of leading ones is counted and the result is written to GPR *rd*. If all of bits 31..0 were set in GPR *rs*, the

Notes

result written to GPR *rd* is 32.

Restrictions:

To be compliant with the MIPS32 and MIPS64 Architecture, software must place the same GPR number in both the *rt* and *rd* fields of the instruction. The operation of the instruction is **UNPREDICTABLE** if the *rt* and *rd* fields of the instruction contain different values.

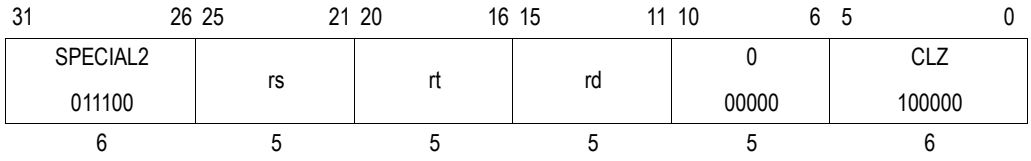
Operation:

```
temp ← 32
for i in 31 .. 0
    if GPR[rs]i = 0 then
        temp ← 31 - i
        break
    endif
endfor
GPR[rd] ← temp
```

Exceptions:

None

Count Leading Zeros in Word **CLZ**



Format: CLZ rd, rs **MIPS32**

Purpose

Count the number of leading zeros in a word.

Description: rd ← count_leading_zeros rs

Bits 31..0 of GPR *rs* are scanned from most significant to least significant bit. The number of leading zeros is counted and the result is written to GPR *rd*. If no bits were set in GPR *rs*, the result written to GPR *rt* is 32.

Restrictions:

To be compliant with the MIPS32 and MIPS64 Architecture, software must place the same GPR number in both the *rt* and *rd* fields of the instruction. The operation of the instruction is **UNPREDICTABLE** if the *rt* and *rd* fields of the instruction contain different values.

Notes

Operation:

```
temp ← 32
for i in 31 .. 0
      if GPR[rs]i = 1 then
            temp ← 31 - i
            break
      endif
endfor
GPR[rd] ← temp
```

Exceptions:

None

Debug Exception Return **DERET**

31 26	25	24 6	5 0
COP0	CO	0	DERET
010000	1	000 0000 0000 0000 0000	011111
6	1	19	6

Format: DERET **EJTAG**

Purpose:

To Return from a debug exception.

Description:

DERET returns from Debug Mode and resumes non-debug execution at the instruction whose address is contained in the *DEPC* register. DERET does not execute the next instruction (i.e. it has no delay slot).

Restrictions:

A DERET placed between an LL and SC instruction does not cause the SC to fail.

If the DEPC register with the return address for the DERET was modified by an MTC0 or a DMTC0 instruction, a CP0 hazard exists that must be removed via software insertion of the appropriate number of SSNOP instructions.

The DERET instruction implements a software barrier for all changes in the CP0 state that could affect the fetch and decode of the instruction at the PC to which the DERET returns, such as changes to the effective ASID, user-mode state, and addressing mode.

This instruction is legal only if the processor is executing in Debug Mode.The operation of the processor is **UNDEFINED** if a DERET is executed in the delay slot of a branch or jump instruction.

Notes

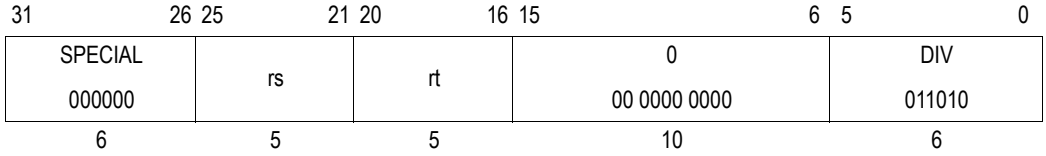
Operation:

```
Debug_DM ← 0
Debug_IEXI ← 0
if IsMIPS16Implemented() then
    PC ← DEPC_31..1 || 0
    ISAMode ← 0 || DEPC_0
else
    PC ← DEPC
endif
```

Exceptions:

Coprocessor Unusable Exception
Reserved Instruction Exception

Divide Word **DIV**



31–26	25–21	20–16	15–6	5–0
SPECIAL 000000	rs	rt	0 00 0000 0000	DIV 011010
6	5	5	10	6

Format: DIV rs, rt **MIPS32**

Purpose:

To divide a 32-bit signed integers.

Description: (LO, HI) ← rs / rt

The 32-bit word value in GPR *rs* is divided by the 32-bit value in GPR *rt,* treating both operands as signed values. The 32-bit quotient is placed into special register *LO* and the 32-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If the divisor in GPR *rt* is zero, the arithmetic result value is **UNPREDICTABLE**.

Operation:

```
q   ← GPR[rs]_31..0 div GPR[rt]_31..0
LO  ← q
r   ← GPR[rs]_31..0 mod GPR[rt]_31..0
HI  ← r
```

Exceptions:

None

Programming Notes:

No arithmetic exception occurs under any circumstances. If divide-by-zero or overflow conditions are detected and some action taken, then the divide instruction is typically followed by additional instructions to check for a zero divisor and/or for overflow. If the divide is asynchronous then the zero-divisor check can execute in parallel with the divide. The action taken on either divide-by-zero or overflow is either a convention within the program itself, or more typically within the system software; one possibility is to take a BREAK exception with a *code* field value to signal the

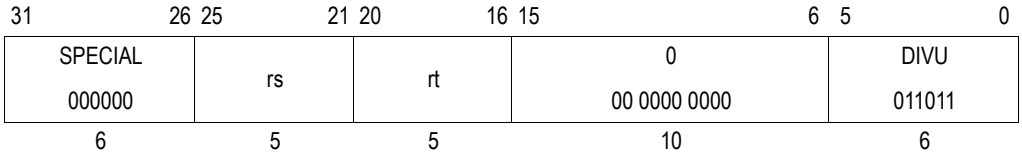
Notes

problem to the system software.

As an example, the C programming language in a UNIX® environment expects division by zero to either terminate the program or execute a program-specified signal handler. C does not expect overflow to cause any exceptional condition. If the C compiler uses a divide instruction, it also emits code to test for a zero divisor and execute a BREAK instruction to inform the operating system if a zero is detected.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Divide Unsigned Word **DIVU**



Format: DIVU rs, rt **MIPS32**

Purpose:

To divide a 32-bit unsigned integers.

Description: (LO, HI) ← rs / rt

The 32-bit word value in GPR *rs* is divided by the 32-bit value in GPR *rt,* treating both operands as unsigned values. The 32-bit quotient is placed into special register *LO* and the 32-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If the divisor in GPR *rt* is zero, the arithmetic result value is undefined.

Operation:

```
q  ← (0 || GPR[rs]31..0) div (0 || GPR[rt]31..0)
r  ← (0 || GPR[rs]31..0) mod (0 || GPR[rt]31..0)
LO ← sign_extend(q31..0)
HI ← sign_extend(r31..0)
```

Exceptions:

None

Programming Notes:

See “Programming Notes” for the DIV instruction.

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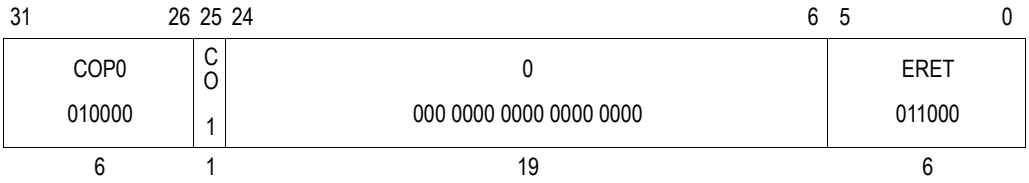
Exception Return **ERET**



Format: ERET **MIPS32**

Purpose:

To return from interrupt, exception, or error trap.

Description:

ERET returns to the interrupted instruction at the completion of interrupt, exception, or error trap processing. ERET does not execute the next instruction (i.e., it has no delay slot).

Restrictions:

The operation of the processor is **UNDEFINED** if an ERET is executed in the delay slot of a branch or jump instruction.

An ERET placed between an LL and SC instruction will always cause the SC to fail.

ERET implements a software barrier for all changes in the CP0 state that could affect the fetch and decode of the instruction at the PC to which the ERET returns, such as changes to the effective ASID, user-mode state, and addressing mode.

Operation:

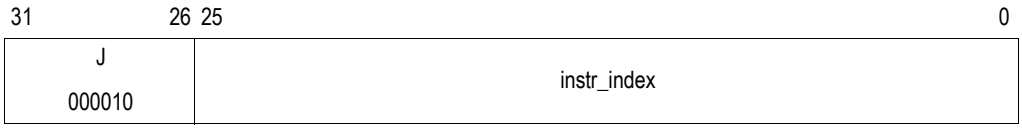
```
if Status_ERL = 1 then
    temp ← ErrorEPC
    Status_ERL ← 0
else
    temp ← EPC
    Status_EXL ← 0
endif
if IsMIPS16Implemented() then
    PC ← temp_31..1 || 0
    ISAMode ← temp_0
else
    PC ← temp
endif
LLbit ← 0
```

Exceptions:

Coprocessor Unusable Exception

Notes

Jump **J**



Format: J target **MIPS32**

Purpose:

To branch within the current 256 MB-aligned region.

Description:

This is a PC-region branch (not PC-relative); the effective target address is in the "current" 256 MB-aligned region. The low 28 bits of the target address is the *instr_index* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction in the delay slot (not the branch itself).

Jump to the effective target address. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:
I+1:  PC ← PC_GPRLEN..28 || instr_index || 0^2
```

Exceptions:

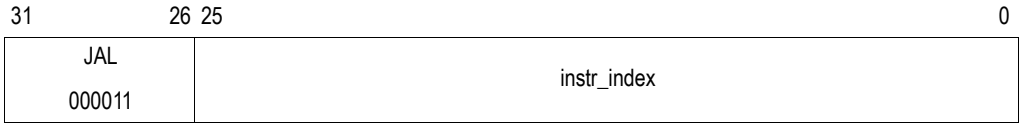
None

Programming Notes:

Forming the branch target address by catenating PC and index bits rather than adding a signed offset to the PC is an advantage if all program code addresses fit into a 256 MB region aligned on a 256 MB boundary. It allows a branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative offset.

This definition creates the following boundary case: When the jump instruction is in the last word of a 256 MB region, it can branch only to the following 256 MB region containing the branch delay slot.

Jump and Link **JAL**



Format: JAL target **MIPS32**

Notes

Purpose:

To execute a procedure call within the current 256 MB-aligned region.

Description:

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, at which location execution continues after a procedure call.

This is a PC-region branch (not PC-relative); the effective target address is in the “current” 256 MB-aligned region. The low 28 bits of the target address is the *instr_index* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction in the delay slot (not the branch itself).

Jump to the effective target address. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself.

Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:    GPR[31]  ← PC + 8
I+1:  PC       ← PC_GPRLEN..28 || instr_index || 0^2
```

Exceptions:

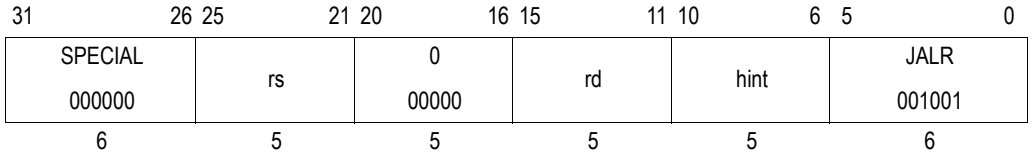
None

Programming Notes:

Forming the branch target address by catenating PC and index bits rather than adding a signed offset to the PC is an advantage if all program code addresses fit into a 256 MB region aligned on a 256 MB boundary. It allows a branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative offset.

This definition creates the following boundary case: When the branch instruction is in the last word of a 256 MB region, it can branch only to the following 256 MB region containing the branch delay slot.

Jump and Link Register **JALR**



Format: JALR rs (rd = 31 implied) **MIPS32**
JALR rd, rs **MIPS32**

Purpose:

To execute a procedure call to an instruction address in a register

Description: rd ← return_addr, PC ← rs

Place the return address link in GPR *rd*. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

Notes

For processors that do not implement the MIPS16 ASE:

- Jump to the effective target address in GPR *rs*. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself.

For processors that do implement the MIPS16 ASE:

- Jump to the effective target address in GPR *rs*. Set the *ISA Mode* bit to the value in GPR *rs* bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one

At this time the only defined hint field value is 0, which sets default handling of JALR. Future versions of the architecture may define additional hint values.

Restrictions:

Register specifiers *rs* and *rd* must not be equal, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

The effective target address in GPR *rs* must be naturally-aligned. For processors that do not implement the MIPS16 ASE, if either of the two least-significant bits are not zero, an Address Error exception occurs when the branch target is subsequently fetched as an instruction. For processors that do implement the MIPS16 ASE, if bit 0 is zero and bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:      temp ← GPR[rs]
        GPR[rd]   ← PC + 8
I+1:if Config1CA = 0 then
            PC   ← temp
        else
            PC ← tempGPRLEN-1..1 || 0
            ISAMode ¨ temp0
        endif
```

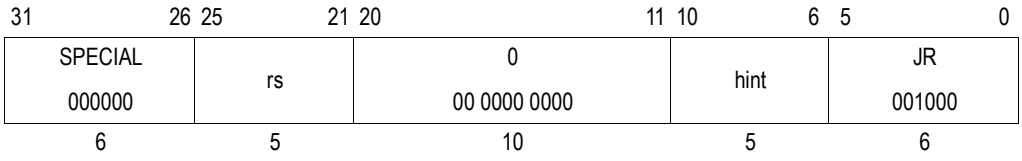
Exceptions:

None

Programming Notes:

This is the only branch-and-link instruction that can select a register for the return link; all other link instructions use GPR 31. The default register for GPR *rd*, if omitted in the assembly language instruction, is GPR 31.

Jump Register **JR**



Format: JR rs **MIPS32**

Notes

Purpose:

To execute a branch to an instruction address in a register.

Description: PC ← rs

Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.

For processors that implement the MIPS16 ASE, set the *ISA Mode* bit to the value in GPR *rs* bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

Restrictions:

The effective target address in GPR *rs* must be naturally-aligned. For processors that do not implement the MIPS16 ASE, if either of the two least-significant bits are not zero, an Address Error exception occurs when the branch target is subsequently fetched as an instruction. For processors that do implement the MIPS16 ASE, if bit 0 is zero and bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

At this time the only defined hint field value is 0, which sets default handling of JR. Future versions of the architecture may define additional hint values.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

Operation:

```
I:    temp ← GPR[rs]
I+1:  if Config1CA = 0 then
          PC   ← temp
      else
          PC ← tempGPRLEN-1..1 || 0
          ISAMode ← temp0
      endif
```

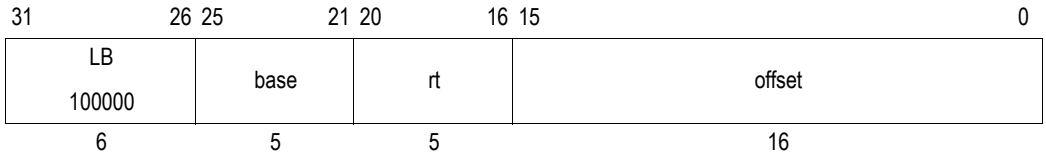
Exceptions:

None

Programming Notes:

Software should use the value 31 for the *rs* field of the instruction word on return from a JAL, JALR, or BGEZAL, and should use a value other than 31 for remaining uses of JR.

Load Byte **LB**



Format: LB rt, offset(base) **MIPS32**

Purpose:

To load a byte from memory as a signed value.

Notes

Description: rt ← memory[base+offset]

The contents of the 8-bit byte at the memory location specified by the effective address are fetched, sign-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

None

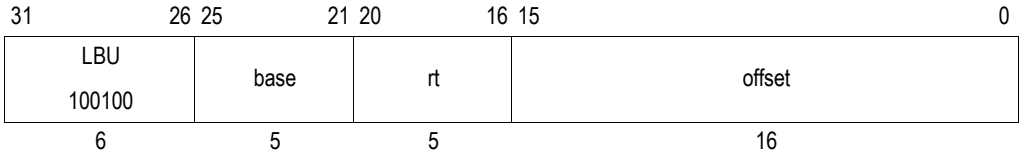
Operation:

```
vAddr      ← sign_extend(offset) + GPR[base]
(pAddr, CCA)   ← AddressTranslation (vAddr, DATA, LOAD)
pAddr      ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
memword    ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte       ← vAddr_1..0 xor BigEndianCPU^2
GPR[rt]    ← sign_extend(memword_7+8*byte..8*byte)
```

Exceptions:

TLB Refill, TLB Invalid, Address Error

Load Byte Unsigned **LBU**



Format: LBU rt, offset(base) **MIPS32**

Purpose:

To load a byte from memory as an unsigned value.

Description: rt ← memory[base+offset]

The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

None

Operation:

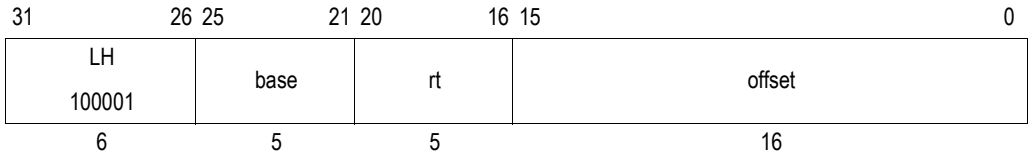
```
vAddr      ← sign_extend(offset) + GPR[base]
(pAddr, CCA)   ← AddressTranslation (vAddr, DATA, LOAD)
pAddr      ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
memword    ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte       ← vAddr_1..0 xor BigEndianCPU^2
GPR[rt]    ← zero_extend(memword_7+8*byte..8*byte)
```

Exceptions:

TLB Refill, TLB Invalid, Address Error

Notes

Load Halfword **LH**



Format: LH rt, offset(base) **MIPS32**

Purpose:

To load a halfword from memory as a signed value.

Description: rt ← memory[base+offset]

The contents of the 16-bit halfword at the memory location specified by the aligned effective address are fetched, sign-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally-aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

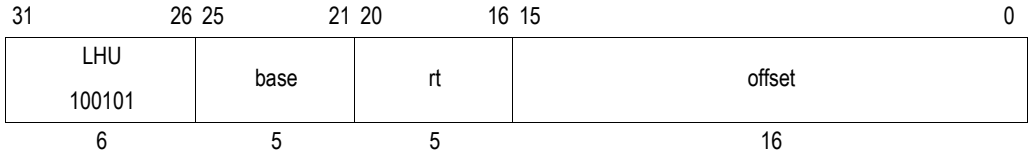
Operation:

```
vAddr     ← sign_extend(offset) + GPR[base]
if vAddr0 ≠ 0 then
      SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr     ← pAddrPSIZE–1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword       ← LoadMemory (CCA, HALFWORD, pAddr, vAddr, DATA)
byte      ← vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt]   ← sign_extend(memword15+8*byte..8*byte)
```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Halfword Unsigned **LHU**



Format: LHU rt, offset(base) **MIPS32**

Purpose:

To load a halfword from memory as an unsigned value.

Description: rt ← memory[base+offset]

The contents of the 16-bit halfword at the memory location specified by the aligned effective address are fetched, zero-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to

Notes

the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally-aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

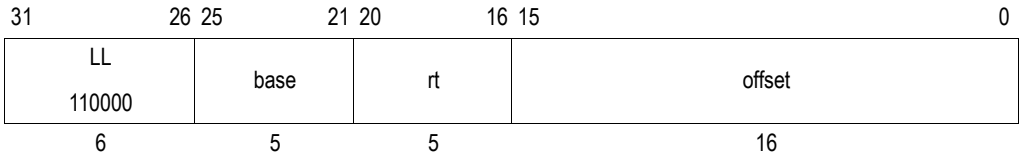
Operation:

```
vAddr      ← sign_extend(offset) + GPR[base]
if vAddr0 ≠ 0 then
      SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr      ← pAddrPSIZE–1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword        ← LoadMemory (CCA, HALFWORD, pAddr, vAddr, DATA)
byte       ← vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt]    ← zero_extend(memword15+8*byte..8*byte)
```

Exceptions:

TLB Refill, TLB Invalid, Address Error

Load Linked Word **LL**



Format: LL rt, offset(base) **MIPS32**

Purpose:

To load a word from memory for an atomic read-modify-write.

Description: rt ← memory[base+offset]

The LL and SC instructions provide the primitives to implement atomic read-modify-write (RMW) operations for cached memory locations.

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address. The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched, sign-extended to the GPR register length if necessary, and written into GPR *rt*.

This begins a RMW sequence on the current processor. There can be only one active RMW sequence per processor. When an LL is executed it starts an active RMW sequence replacing any other sequence that was active.

The RMW sequence is completed by a subsequent SC instruction that either completes the RMW sequence atomically and succeeds, or does not and fails.

Executing LL on one processor does not cause an action that, by itself, causes an SC for the same block to fail on another processor. An execution of LL does not have to be followed by execution of SC; a program is free to abandon the RMW sequence without attempting a write.

Restrictions:

The addressed location must be cached; if it is not, the result is undefined. The effective address must be naturally-aligned. If either of the 2 least-significant bits of the effective address is non-

Notes

zero, an Address Error exception occurs.

Operation:

```
vAddr      ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 0^2 then
      SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt]    ← memword
LLbit      ← 1
```

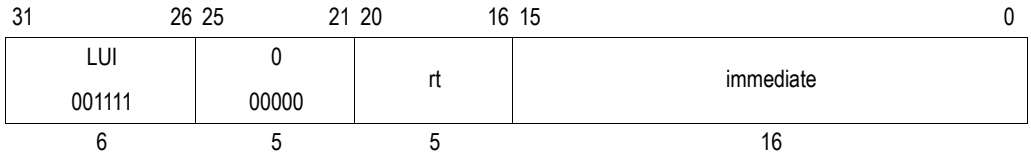
Exceptions:

TLB Refill, TLB Invalid, Address Error, Reserved Instruction

Programming Notes:

There is no Load Linked Word Unsigned operation corresponding to Load Word Unsigned.

Load Upper Immediate **LUI**



Format: LUI rt, immediate **MIPS32**

Purpose:

To load a constant into the upper half of a word.

Description: rt ← immediate || 0^{16}

The 16-bit *immediate* is shifted left 16 bits and concatenated with 16 bits of low-order zeros. The 32-bit result is placed into GPR *rt*.

Restrictions:

None

Operation:

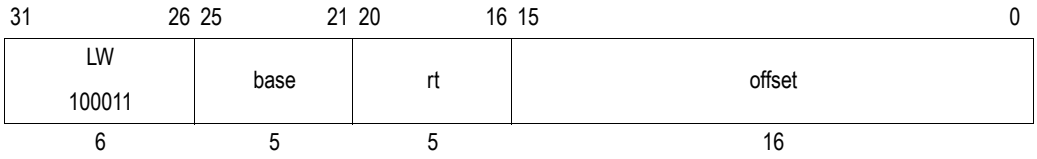
```
GPR[rt] ← immediate || 0^16
```

Exceptions:

None

Notes

Load Word **LW**



Format: LW rt, offset(base) **MIPS32**

Purpose:

To load a word from memory as a signed value.

Description: rt ← memory[base+offset]

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched, sign-extended to the GPR register length if necessary, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

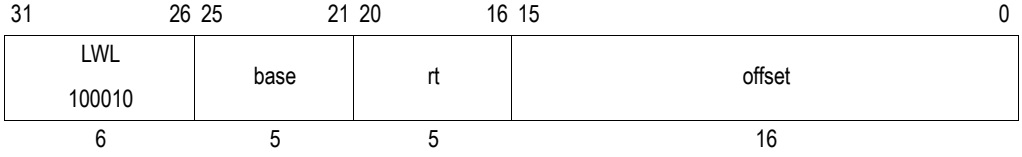
Operation:

```
vAddr      ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 0^2 then
      SignalException(AddressError)
endif
(pAddr, CCA)   ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt]    ← memword
```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Word Left **LWL**



Format: LWL rt, offset(base) **MIPS32**

Purpose:

To load the most-significant part of a word as a signed value from an unaligned memory address.

Description: rt ← rt MERGE memory[base+offset]

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*. *EffAddr* is the address of the most-significant of 4 consecutive bytes forming a word *(W)* in memory starting at an arbitrary byte boundary.

Notes

The most-significant 1 to 4 bytes of *W* is in the aligned word containing the *EffAddr*. This part of *W* is loaded into the most-significant (left) part of the word in GPR *rt*. The remaining least-significant part of the word in GPR *rt* is unchanged.

Figure A.11 illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the most-significant byte at 2. First, LWL loads these 2 bytes into the left part of the destination register word and leaves the right part of the destination word unchanged. Next, the complementary LWR loads the remainder of the unaligned word.

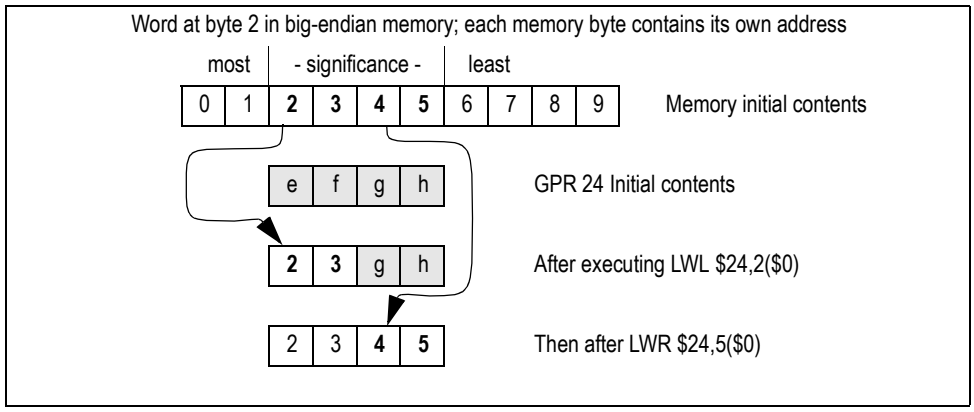


Figure A.11 Unaligned Word Load Using LWL and LWR

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ($vAddr_{1..0}$), and the current byte-ordering mode of the processor (big- or little-endian). Figure A.12 shows the bytes loaded for every combination of offset and byte ordering.

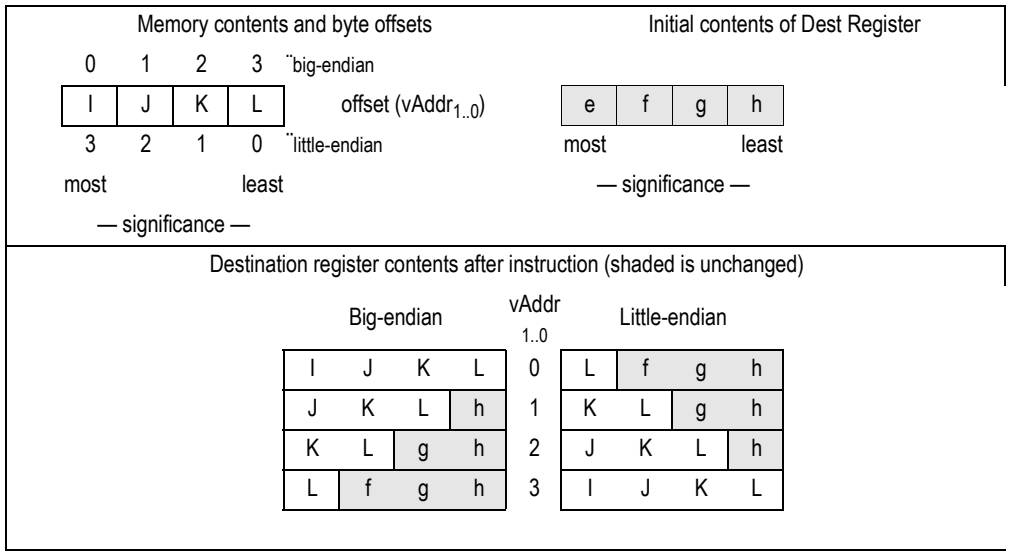


Figure A.12 Bytes Loaded by LWL Instruction

Restrictions:

None

Notes

Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
(pAddr, CCA)  ← AddressTranslation (vAddr, DATA, LOAD)
pAddr       ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
if BigEndianMem = 0 then
      pAddr       ← pAddr_PSIZE-1..2 || 0^2
endif
byte        ← vAddr_1..0 xor BigEndianCPU^2
memword     ← LoadMemory (CCA, byte, pAddr, vAddr, DATA)
temp        ← memword_7+8*byte..0 || GPR[rt]_23-8*byte..0
GPR[rt]     ← temp
```

Exceptions:

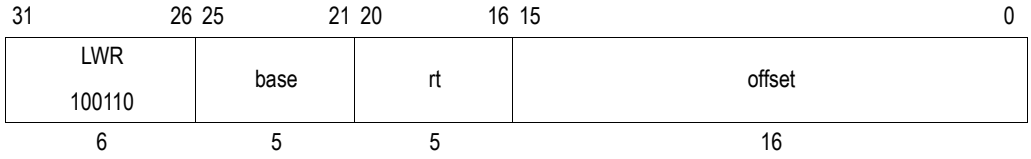
None

TLB Refill, TLB Invalid, Bus Error, Address Error

Programming Notes:

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

Load Word Right **LWR**



Format: LWR rt, offset(base) **MIPS32**

Purpose:

To load the least-significant part of a word from an unaligned memory address as a signed value.

Description: rt ← rt MERGE memory[base+offset]

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*. *EffAddr* is the address of the least-significant of 4 consecutive bytes forming a word *(W)* in memory starting at an arbitrary byte boundary.

A part of *W*, the least-significant 1 to 4 bytes, is in the aligned word containing *EffAddr*. This part of *W* is loaded into the least-significant (right) part of the word in GPR *rt*. The remaining most-significant part of the word in GPR *rt* is unchanged.

Executing both LWR and LWL, in either order, delivers a sign-extended word value in the destination register. Figure A.13 illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the least-significant byte at 5. First, LWR loads these 2 bytes into the right part of the destination register. Next, the complementary LWL loads the remainder of the unaligned word.

Notes

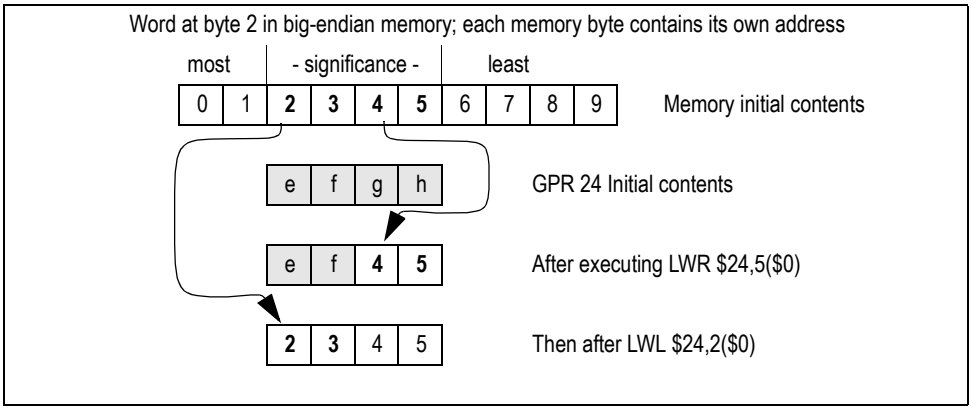


Figure A.13 Unaligned Word Load Using LWL and LWR

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ($vAddr_{1..0}$), and the current byte-ordering mode of the processor (big- or little-endian). Figure A.14 shows the bytes loaded for every combination of offset and byte ordering.

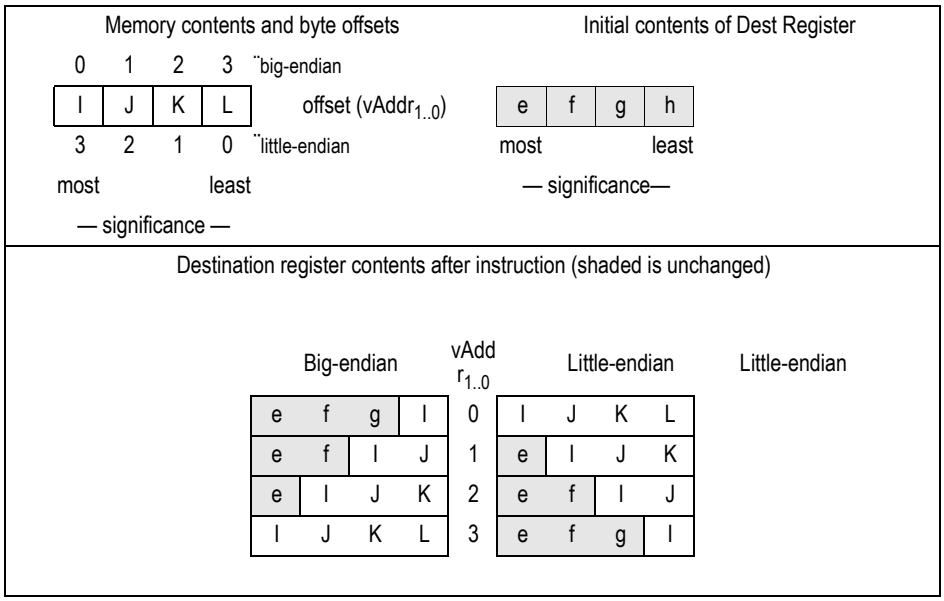


Figure A.14 Bytes Loaded by LWL Instruction

Restrictions:

None

Notes

Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
(pAddr, CCA)  ← AddressTranslation (vAddr, DATA, LOAD)
pAddr       ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
if BigEndianMem = 0 then
      pAddr       ← pAddr_PSIZE-1..2 || 0^2
endif
byte        ← vAddr_1..0 xor BigEndianCPU^2
memword     ← LoadMemory (CCA, byte, pAddr, vAddr, DATA)
temp        ← memword_31..32-8*byte || GPR[rt]_31–8*byte..0
GPR[rt]     ← temp
```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Programming Notes:

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

Multiply and Add Word to Hi,Lo **MADD**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL2	rs	rt	0	0	MADD
011100			0000	00000	000000
6	5	5	5	5	6

Format: MADD rs, rt **MIPS32**

Purpose:

To multiply two words and add the result to Hi, Lo.

Description: (LO,HI) ← (rs × rt) + (LO,HI)

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The product is added to the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← (HI || LO) + (GPR[rs] × GPR[rt])
HI ← temp_63..32
LO ← temp_31..0
```

Exceptions:

None

Notes

Programming Notes:

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Multiply and Add Unsigned Word to Hi,Lo **MADDU**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL2	rs	rt	0	0	MADDU
011100			00000	00000	000001
6	5	5	5	5	6

Format: MADDU rs, rt **MIPS32**

Purpose:

To multiply two unsigned words and add the result to Hi, Lo.

Description: (LO,HI) ← (rs × rt) + (LO,HI)

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as unsigned values, to produce a 64-bit result. The product is added to the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← (HI || LO) + (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

Exceptions:

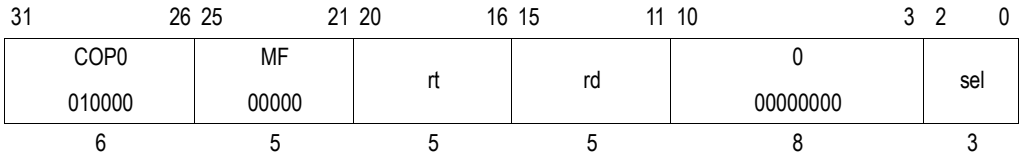
None

Programming Notes:

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Notes

Move from Coprocessor 0 **MFC0**



Format: MFC0 rt, rd **MIPS32**
MFC0 rt, rd, sel **MIPS32**

Purpose:

To move the contents of a coprocessor 0 register to a general register.

Description: rt ← CPR[0,rd,sel]

The contents of the coprocessor 0 register specified by the combination of rd and sel are loaded into general register rt. Note that not all coprocessor 0 registers support the sel field. In those instances, the sel field must be zero.

Restrictions:

The results are **UNDEFINED** if coprocessor 0 does not contain a register as specified by *rd* and *sel*.

Operation:

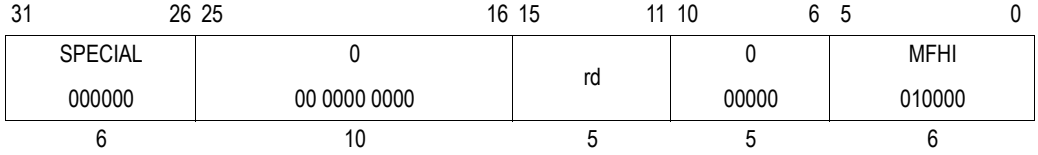
```
data ← CPR[0,rd,sel]
GPR[rt] ← data
```

Exceptions:

Coprocessor Unusable

Reserved Instruction

Move From HI Register **MFHI**



Format: MFHI rd **MIPS32**

Purpose:

To copy the special purpose *HI* register to a GPR.

Description: rd ← HI

The contents of special register *HI* are loaded into GPR *rd*.

Restrictions:

None

Notes

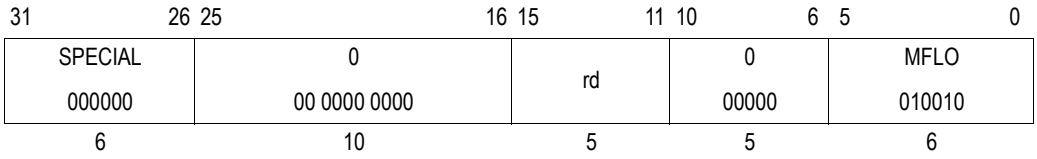
Operation:

GPR[rd] ← HI

Exceptions:

None

Move From LO Register **MFLO**



Format: MFLO rd **MIPS32**

Purpose:

To copy the special purpose *LO* register to a GPR.

Description: rd ← LO

The contents of special register *LO* are loaded into GPR *rd*.

Restrictions: None

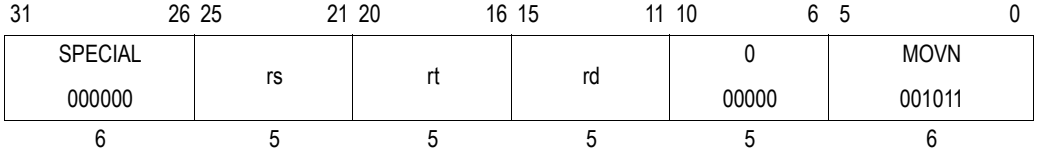
Operation:

GPR[rd] ← LO

Exceptions:

None

Move Conditional on Not Zero **MOVN**



Format: MOVN rd, rs, rt **MIPS32**

Purpose:

To conditionally move a GPR after testing a GPR value

Description: if rt ≠ 0 then rd ← rs

If the value in GPR *rt* is not equal to zero, then the contents of GPR *rs* are placed into GPR *rd*.

Restrictions:

None

Notes

Operation:

```
if GPR[rt] ≠ 0 then
    GPR[rd] ← GPR[rs]
endif
```

Exceptions:

None

Programming Notes:

The non-zero value tested here is the *condition true* result from the SLT, SLTI, SLTU, and SLTIU comparison instructions.

Move Conditional on Zero **MOVZ**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 000000	rs	rt	rd	0 00000	MOVZ 001010
6	5	5	5	5	6

Format: MOVZ rd, rs, rt **MIPS32**

Purpose:

To conditionally move a GPR after testing a GPR value.

Description: if rt = 0 then rd ← rs

If the value in GPR *rt* is equal to zero, then the contents of GPR *rs* are placed into GPR *rd*.

Restrictions:

None

Operation:

```
if GPR[rt] = 0 then
    GPR[rd] ← GPR[rs]
endif
```

Exceptions:

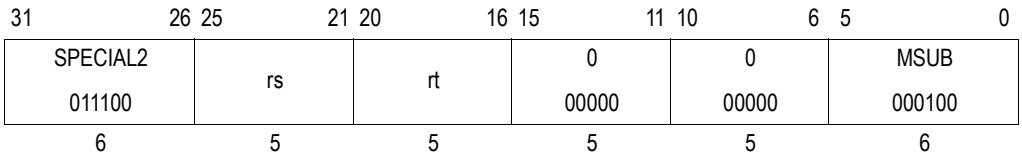
None

Programming Notes:

The zero value tested here is the *condition false* result from the SLT, SLTI, SLTU, and SLTIU comparison instructions.

Notes

Multiply and Subtract Word to Hi,Lo **MSUB**



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL2	rs	rt	0	0	MSUB
011100			00000	00000	000100
6	5	5	5	5	6

Format: MSUB rs, rt **MIPS32**

Purpose:

To multiply two words and subtract the result from Hi, Lo.

Description: (LO,HI) ← (rs × rt) - (LO,HI)

The 32-bit word value in GPR *rs* is multiplied by the 32-bit value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← (HI || LO) - (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

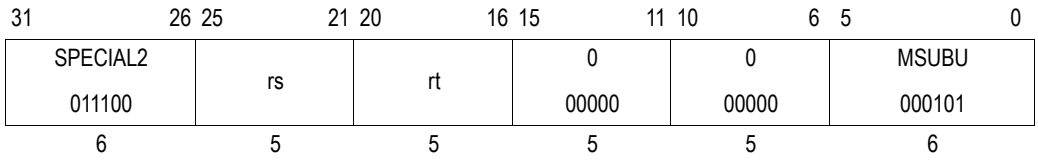
Exceptions:

None

Programming Notes:

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Multiply and Subtract Word to Hi,Lo **MSUBU**



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL2	rs	rt	0	0	MSUBU
011100			00000	00000	000101
6	5	5	5	5	6

Format: MSUBU rs, rt **MIPS32**

Purpose:

To multiply two words and subtract the result from Hi, Lo.

Notes

Description: (LO,HI) ← (rs × rt) - (LO,HI)

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as unsigned values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← (HI || LO) - (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

Exceptions:

None

Programming Notes:

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Move to Coprocessor 0 **MTC0**

31 26	25 21	20 16	15 11	10 3	2 0
COP0	MT	rt	rd	0	sel
010000	00100			0000 000	
6	5	5	5	8	3

Format: MTC0 rt, rd **MIPS32**
MTC0 rt, rd, sel **MIPS32**

Purpose:

To move the contents of a general register to a coprocessor 0 register.

Description: CPR[r0, rd, sel] ← rt

The contents of general register rt are loaded into the coprocessor 0 register specified by the combination of rd and sel. Not all coprocessor 0 registers support the sel field. In those instances, the sel field must be set to zero.

Restrictions:

The results are **UNDEFINED** if coprocessor 0 does not contain a register as specified by *rd* and *sel*.

Notes

Operation:

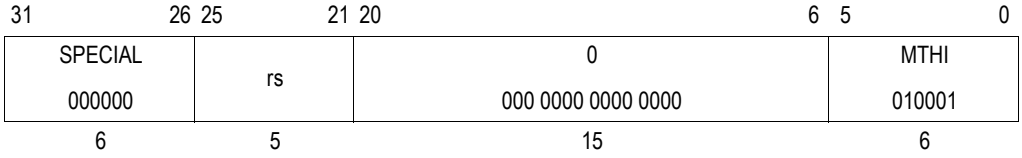
CPR[0,rd,sel] ← data

Exceptions:

Coprocessor Unusable

Reserved Instruction

Move to HI Register **MTHI**



Format: MTHI rs **MIPS32**

Purpose:

To copy a GPR to the special purpose *HI* register.

Description: HI ← rs

The contents of GPR *rs* are loaded into special register *HI*.

Restrictions:

A computed result written to the *HI*/*LO* pair by DIV, DIVU,MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either *HI* or *LO*.

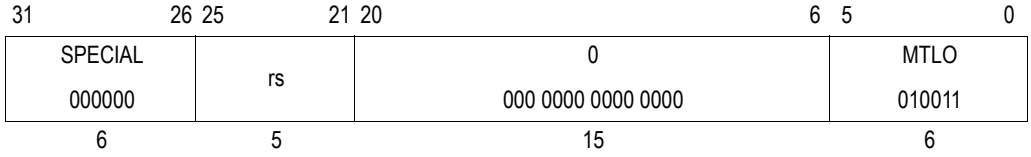
Operation:

HI ← GPR[rs]

Exceptions:

None

Move to LO Register **MTLO**



Format: MTLO rs **MIPS32**

Purpose:

To copy a GPR to the special purpose *LO* register.

Description: LO ← rs

The contents of GPR *rs* are loaded into special register *LO*.

Notes

Restrictions:

A computed result written to the *HI*/*LO* pair by DIV, DIVU, MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either *HI* or *LO*.

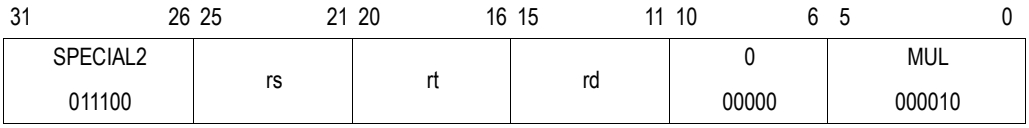
Operation:

```
LO ← GPR[rs]
```

Exceptions:

None

Multiply Word to GPR **MUL**



Format: MUL rd, rs, rt **MIPS32**

Purpose:

To multiply two words and write the result to a GPR.

Description: rd ← rs × rt

The 32-bit word value in GPR *rs* is multiplied by the 32-bit value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The least significant 32 bits of the product are written to GPR *rd*. The contents of *HI* and *LO* are **UNPREDICTABLE** after the operation. No arithmetic exception occurs under any circumstances.

Restrictions:

Note that this instruction does not provide the capability of writing the result to the HI and LO registers.

Operation:

```
temp ← GPR[rs] × GPR[rt]
GPR[RD] ← GPR31..0
HI ← UPPREDICTABLE
LO ← UNPREDICTABLE
```

Exceptions:

None

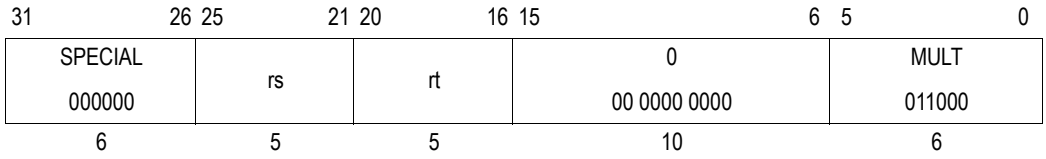
Programming Notes:

Programs that require overflow detection must check for it explicitly.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Notes

Multiply Word **MULT**



Format: MULT rs, rt **MIPS32**

Purpose:

To multiply 32-bit signed integers.

Description: (LO, HI) ← rs × rt

The 32-bit word value in GPR *rt* is multiplied by the 32-bit value in GPR *rs*, treating both operands as signed values, to produce a 64-bit result. The low-order 32-bit word of the result is placed into special register *LO*, and the high-order 32-bit word is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

$$\begin{aligned} prod &\leftarrow GPR[rs]_{31..0} \times GPR[rt]_{31..0} \\ LO &\leftarrow prod_{31..0} \\ HI &\leftarrow prod_{63..32} \end{aligned}$$

Exceptions:

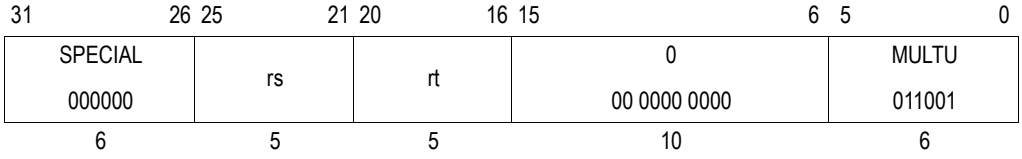
None

Programming Notes:

Programs that require overflow detection must check for it explicitly.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

Multiply Unsigned Word **MULTU**



Format: MULTU rs, rt **MIPS32**

Purpose:

To multiply 32-bit unsigned integers.

Notes

Description: (LO, HI) ← rs × rt

The 32-bit word value in GPR *rt* is multiplied by the 32-bit value in GPR *rs*, treating both operands as unsigned values, to produce a 64-bit result. The low-order 32-bit word of the result is placed into special register *LO*, and the high-order 32-bit word is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

None

Operation:

$$\begin{aligned} prod &\leftarrow (0 \,||\, GPR[rs]_{31..0}) \times (0 \,||\, GPR[rt]_{31..0}) \\ LO &\leftarrow prod_{31..0} \\ HI &\leftarrow prod_{63..32} \end{aligned}$$

Exceptions:

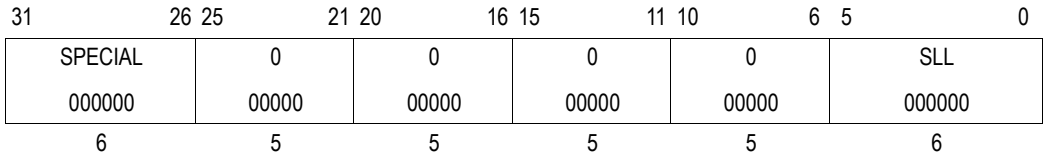
None

Programming Notes:

Programs that require overflow detection must check for it explicitly.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

No Operation **NOP**



Format: NOP **Assembly Idiom**

Purpose:

To perform no operation.

Description:

NOP is the assembly idiom used to denote no operation. The actual instruction is interpreted by the hardware as SLL r0, r0, 0.

Restrictions:

None

Operation:

None

Exceptions:

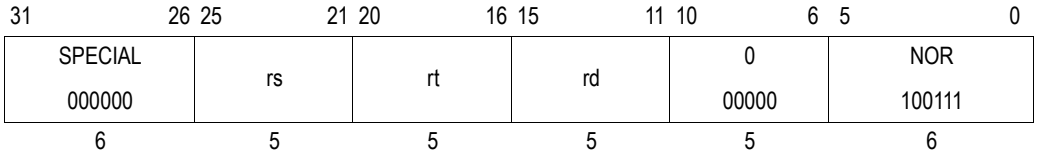
None

Notes

Programming Notes:

The zero instruction word, which represents SLL, r0, r0, 0, is the preferred NOP for software to use to fill branch and jump delay slots and to pad out alignment sequences.

Not Or **NOR**



Format: NOR rd, rs, rt **MIPS32**

Purpose:

To do a bitwise logical NOT OR.

Description: rd ← rs NOR rt

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical NOR operation. The result is placed into GPR *rd*.

Restrictions:

None

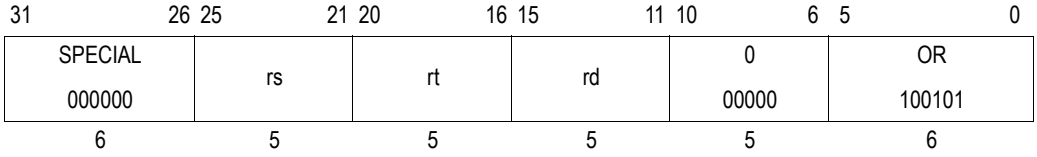
Operation:

```
GPR[rd] ← GPR[rs] nor GPR[rt]
```

Exceptions:

None

Or **OR**



Format: OR rd, rs, rt **MIPS32**

Purpose:

To do a bitwise logical OR.

Description: rd ← rs or rt

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical OR operation. The result is placed into GPR *rd*.

Restrictions:

None

Notes

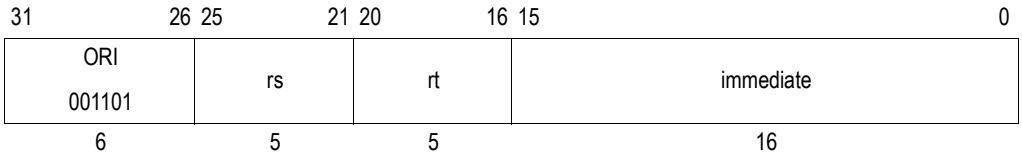
Operation:

GPR[rd] ← GPR[rs] or GPR[rt]

Exceptions:

None

Or Immediate **ORI**



Format: ORI rt, rs, immediate **MIPS32**

Purpose:

To do a bitwise logical OR with a constant.

Description: rt ← rs or immediate

The 16-bit *immediate* is zero-extended to the left and combined with the contents of GPR *rs* in a bitwise logical OR operation. The result is placed into GPR *rt*.

Restrictions:

None

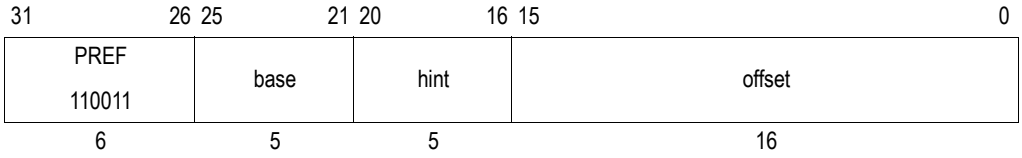
Operation:

GPR[rt] ← GPR[rs] or zero_extend(immediate)

Exceptions:

None

Prefetch **PREF**



Format: PREF hint,offset(base) **MIPS32**

Purpose:

To move data between memory and cache.

Description: prefetch_memory(base+offset)

PREF adds the 16-bit signed *offset* to the contents of GPR *base* to form an effective byte address. The *hint* field supplies information about the way that the data is expected to be used.

PREF is an advisory instruction that may change the performance of the program. However, for all *hint* values and all effective addresses, it neither changes the architecturally visible state nor

Notes

does it alter the meaning of the program.

PREF does not cause addressing-related exceptions. If the address specified would cause an addressing exception, the exception condition is ignored and no data movement occurs. However even if no data is prefetched, some action that is not architecturally visible, such as writeback of a dirty cache line, can take place.

PREF never generates a memory operation for a location with an *uncached* memory access type. If PREF results in a memory operation, the memory access type used for the operation is determined by the memory access type of the effective address, just as it would be if the memory operation had been caused by a load or store to the effective address.

The *hint* field supplies information about the way the data is expected to be used. A *hint* value cannot cause an action to modify architecturally visible state.

Any of the following conditions causes the 4Kc core to treat a PREF instruction as a NOP.

- *A reserved hint value is used*
- *Writeback-invalidate (25) hint value is used*
- *The address has a translation error*
- *The address maps to an uncacheable page*
- *The data is already in the cache*
- *There is already another load/prefetch outstanding*

In all other cases, except when *hint* equals 25, execution of the PREF instruction initiates an external bus read transaction. PREF is a non-blocking operation and does not cause the pipeline to stall while waiting for the data to be returned.

Value	Name	Data Use and Desired Prefetch Action
0	load	Use: Prefetched data is expected to be read (not modified). Action: Fetch data as if for a load.
1	store	Use: Prefetched data is expected to be stored or modified. Action: Fetch data as if for a store.
2-3	Reserved	Reserved - treated as a NOP
4	load_streamed	Use: Prefetched data is expected to be read (not modified) but not reused extensively; it “streams” through cache. Action: Fetch data as if for a load and place it in the cache so that it does not displace data prefetched as “retained.”
5	store_streamed	Use: Prefetched data is expected to be stored or modified but not reused extensively; it “streams” through cache. Action: Fetch data as if for a store and place it in the cache so that it does not displace data prefetched as “retained.”
6	load_retained	Use: Prefetched data is expected to be read (not modified) and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a load and place it in the cache so that it is not displaced by data prefetched as “streamed.”
7	store_retained	Use: Prefetched data is expected to be stored or modified and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a store and place it in the cache so that it is not displaced by data prefetched as “streamed.”
8-24	Reserved	Reserved - treated as a NOP.

Table A.10 Values of the *hint* Field for the PREF Instruction (Part 1 of 2)

Notes

Value	Name	Data Use and Desired Prefetch Action
25	writeback_invalidate (also known as “nudge”)	Use: Data is no longer expected to be used. Treated as a NOP.
26-29	Implementation Depen-dent	Reserved - treated as a NOP.
30	PrepareForStore	Use: Prepare the cache for writing an entire line, without the overhead involved in filling the line from memory. Reserved - treated as a NOP.
31	Implementation Depen-dent	Reserved - treated as a NOP.

Table A.10 Values of the *hint* Field for the PREF Instruction (Part 2 of 2)

Restrictions:

None

Operation:

```
vAddr ← GPR[base] + sign_extend(offset)
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)
Prefetch(CCA, pAddr, vAddr, DATA, hint)
```

Exceptions:

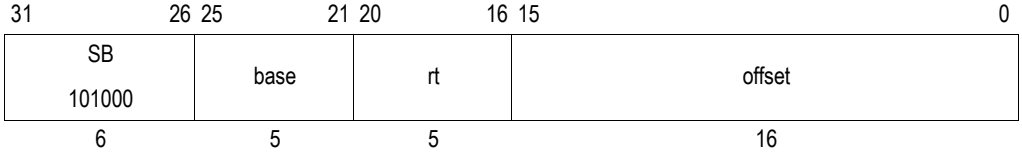
Prefetch does not take any TLB-related or address-related exceptions under any circumstances.

Programming Notes:

Prefetch cannot prefetch data from a mapped location unless the translation for that location is present in the TLB. Locations in memory pages that have not been accessed recently may not have translations in the TLB, so prefetch may not be effective for such locations.

Prefetch does not cause addressing exceptions. It does not cause an exception to prefetch using an address pointer value before the validity of a pointer is determined.

Store Byte **SB**



Format: SB rt, offset(base) **MIPS32**

Purpose:

To store a byte to memory.

Description: memory[base+offset] ← rt

The least-significant 8-bit byte of GPR *rt* is stored in memory at the location specified by the effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Notes

Restrictions:

None

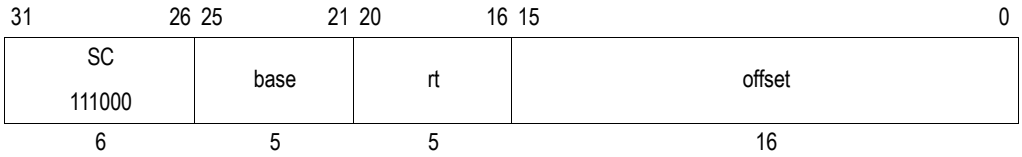
Operation:

```
vAddr          ← sign_extend(offset) + GPR[base]
(pAddr, CCA)   ← AddressTranslation (vAddr, DATA, STORE)
pAddr          ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
bytesel        ← vAddr_1..0 xor BigEndianCPU^2
dataword       ← GPR[rt]_31–8*bytesel..0 || 0^8*bytesel
StoreMemory (CCA, BYTE, dataword, pAddr, vAddr, DATA)
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error

Store Conditional Word **SC**



Format: SC rt, offset(base) **MIPS32**

Purpose:

To store a word to memory to complete an atomic read-modify-write.

Description: if atomic_update then memory[base+offset] ← rt, rt ← 1 else rt ← 0

The LL and SC instructions provide primitives to implement atomic read-modify-write (RMW) operations for cached memory locations.

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address.

The SC completes the RMW sequence begun by the preceding LL instruction executed on the processor. To complete the RMW sequence atomically, the following occur:

- The least-significant 32-bit word of GPR *rt* is stored into memory at the location specified by the aligned effective address.
- A 1, indicating success, is written into GPR *rt*.

Otherwise, memory is not modified and a 0, indicating failure, is written into GPR *rt*.

If the following event occurs between the execution of LL and SC, the SC fails:

- An exception occurs on the processor executing the LL/SC.

If either of the following events occurs between the execution of LL and SC, the SC may succeed or it may fail; the success or failure is not predictable. Portable programs should not cause one of these events.

- A load, store, or prefetch is executed on the processor executing the LL/SC.
- The instructions executed starting with the LL and ending with the SC do not lie in a 2048-byte contiguous region of virtual memory. The region does not have to be aligned, other than the alignment required for instruction words.

The following conditions must be true or the result of the SC is undefined:

- Execution of SC must have been preceded by execution of an LL instruction.

Notes

- A RMW sequence executed without intervening exceptions must use the same address in the LL and SC. The address is the same if the virtual address, physical address, and cache-coherence algorithm are identical.

Atomic RMW is provided only for cached memory locations. The extent to which the detection of atomicity operates correctly depends on the system implementation and the memory access type used for the location:

- **MP atomicity:** To provide atomic RMW among multiple processors, all accesses to the location must be made with a memory access type of *cached coherent*.
- **Uniprocessor atomicity:** To provide atomic RMW on a single processor, all accesses to the location must be made with memory access type of either *cached noncoherent* or *cached coherent*. All accesses must be to one or the other access type, and they may not be mixed.

I/O System: To provide atomic RMW with a coherent I/O system, all accesses to the location must be made with a memory access type of *cached coherent*. If the I/O system does not use coherent memory operations, then atomic RMW cannot be provided with respect to the I/O reads and writes.

Restrictions:

The addressed location must have a memory access type of *cached noncoherent* or *cached coherent*; if it does not, the result is undefined.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 0^2 then
      SignalException(AddressError)
endif
(pAddr, CCA)← AddressTranslation (vAddr, DATA, STORE)
dataword  ← GPR[rt]
if LLbit then
      StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
endif
GPR[rt]     ← 0^31 || LLbit
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Reserved Instruction

Programming Notes:

LL and SC are used to atomically update memory locations, as shown below.

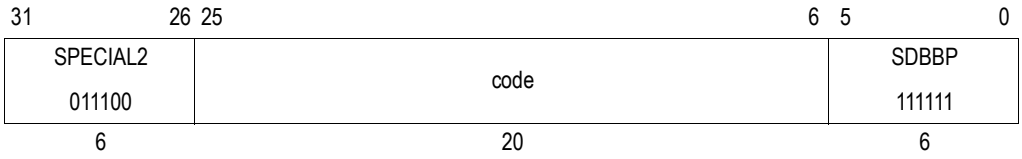
```
L1:
      LL      T1, (T0)      # load counter
      ADDI    T2, T1, 1     # increment
      SC      T2, (T0)      # try to store, checking for atomicity
      BEQ     T2, 0, L1     # if not atomic (0), try again
      NOP                   # branch-delay slot
```

Exceptions between the LL and SC cause SC to fail, so persistent exceptions must be avoided. Some examples of these are arithmetic operations that trap, system calls, and floating point operations that trap or require software emulation assistance.

LL and SC function on a single processor for *cached noncoherent* memory so that parallel programs can be run on uniprocessor systems that do not support *cached coherent* memory access types.

Notes

Software Debug Breakpoint **SDBBP**



Format: SDBBP code **EJTAG**

Purpose:

To cause a debug breakpoint exception.

Description:

This instruction causes a debug exception, passing control to the debug exception handler. The code field can be used for passing information to the debug exception handler, and is retrieved by the debug exception handler only by loading the contents of the memory word containing the instruction, using the DEPC register. The CODE field is not used in any way by the hardware.

Restrictions:

None

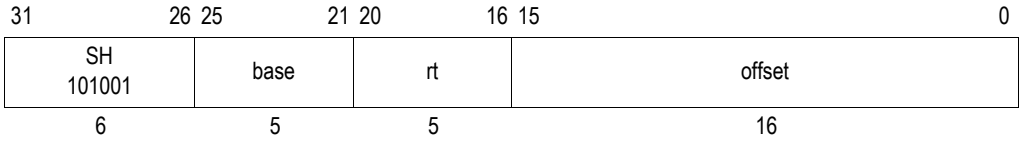
Operation:

```
If Debug_DM = 0 then
    SignalDebugBreakpointException()
else
    SignalDebugModeBreakpointException()
endif
```

Exceptions:

Debug Breakpoint Exception

Store Halfword **SH**



Format: SH rt, offset(base) **MIPS32**

Purpose:

To store a halfword to memory.

Description: memory[base+offset] ← rt

The least-significant 16-bit halfword of register *rt* is stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Notes

Restrictions:

The effective address must be naturally-aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

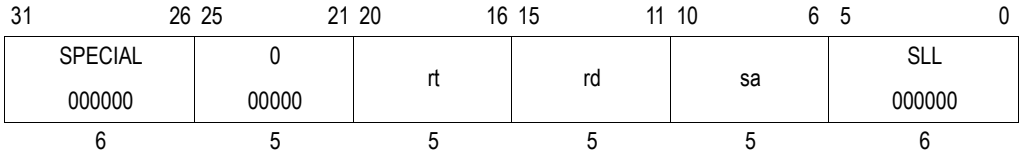
Operation:

```
vAddr      ← sign_extend(offset) + GPR[base]
if vAddr0 ≠ 0 then
      SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr      ← pAddrPSIZE-1..2 || (pAddr11..0 xor (ReverseEndian || 0))
bytesel    ← vAddr11..0 xor (BigEndianCPU || 0)
dataword   ← GPR[rt]31–8*bytesel..0 || 0^8*bytesel
StoreMemory (CCA, HALFWORD, dataword, pAddr, vAddr, DATA)
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error

Shift Word Left Logical **SLL**



Format: SLL rd, rt, sa **MIPS32**

Purpose:

To left-shift a word by a fixed number of bits.

Description: rd ← rt << sa

The contents of the low-order 32-bit word of GPR *rt* are shifted left, inserting zeros into the emptied bits; the word result is placed in GPR *rd*. The bit-shift amount is specified by *sa*.

Restrictions:

None

Operation:

```
s          ← sa
temp       ← GPR[rt](31-s)..0 || 0^s
GPR[rd]    ← temp
```

Exceptions:

None

Programming Notes:

SLL r0, r0, 0, expressed as NOP, is the assembly idiom used to denote no operation.

SLL r0, r0, 1, expressed as SSNOP, is the assembly idiom used to denote no operation that causes an issue break on superscalar processors.

Notes

Shift Word Left Logical Variable **SLLV**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 000000	rs	rt	rd	0 00000	SLLV 000100
6	5	5	5	5	6

Format: SLLV rd, rt, rs **MIPS32**

Purpose: To left-shift a word by a variable number of bits.

Description: rd ← rt << rs

The contents of the low-order 32-bit word of GPR *rt* are shifted left, inserting zeros into the emptied bits; the result word is placed in GPR *rd*. The bit-shift amount is specified by the low-order 5 bits of GPR *rs.*

Restrictions: None

Operation:

```
s       ← GPR[rs]4..0
temp    ← GPR[rt](31-s)..0 || 0^s
GPR[rd] ← temp
```

Exceptions: None

Programming Notes:

None

Set on Less Than **SLT**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 000000	rs	rt	rd	0 00000	SLT 101010
6	5	5	5	5	6

Format: SLT rd, rs, rt **MIPS32**

Purpose:

To record the result of a less-than comparison.

Description: rd ← (rs < rt)

Compare the contents of GPR *rs* and GPR *rt* as signed integers and record the Boolean result of the comparison in GPR *rd*. If GPR *rs* is less than GPR *rt,* the result is 1 (true); otherwise, it is 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Notes

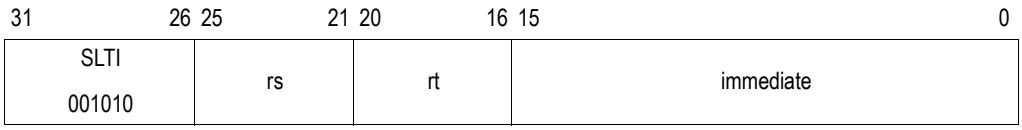
Operation:

```
if GPR[rs] < GPR[rt] then
    GPR[rd] ← 0^(GPRLEN-1) || 1
else
    GPR[rd] ← 0^GPRLEN
endif
```

Exceptions:

None

Set on Less Than Immediate **SLTI**



Format: SLTI rt, rs, immediate **MIPS32**

Purpose:

To record the result of a less-than comparison with a constant

Description: rt ← (rs < immediate)

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers and record the Boolean result of the comparison in GPR *rt*. If GPR *rs* is less than *immediate,* the result is 1 (true); otherwise, it is 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

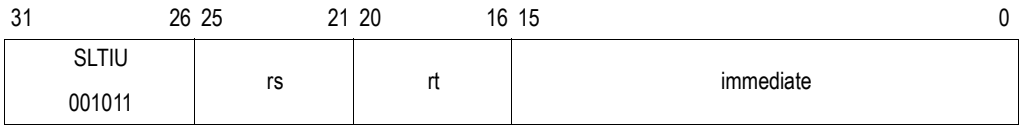
Operation:

```
if GPR[rs] < sign_extend(immediate) then
    GPR[rd] ← 0^(GPRLEN-1) || 1
else
    GPR[rd] ← 0^GPRLEN
endif
```

Exceptions:

None

Set on Less Than Immediate Unsigned **SLTIU**



Format: SLTIU rt, rs, immediate **MIPS32**

Notes

Purpose:

To record the result of an unsigned less-than comparison with a constant.

Description: rt ← (rs < immediate)

Compare the contents of GPR *rs* and the sign-extended 16-bit *immediate* as unsigned integers and record the Boolean result of the comparison in GPR *rt*. If GPR *rs* is less than *immediate,* the result is 1 (true); otherwise, it is 0 (false).

Because the 16-bit *immediate* is sign-extended before comparison, the instruction can represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Operation:

```
if (0 || GPR[rs]) < (0 || sign_extend(immediate)) then
    GPR[rd] ← 0^(GPRLEN-1) || 1
else
    GPR[rd] ← 0^GPRLEN
endif
```

Exceptions:

None

Set on Less Than Unsigned **SLTU**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL	rs	rt	rd	0	SLTU
000000				00000	101011
6	5	5	5	5	6

Format: SLTU rd, rs, rt **MIPS32**

Purpose:

To record the result of an unsigned less-than comparison.

Description: rd ← (rs < rt)

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers and record the Boolean result of the comparison in GPR *rd*. If GPR *rs* is less than GPR *rt,* the result is 1 (true); otherwise, it is 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Notes

Operation:

```
if (0 || GPR[rs]) < (0 || GPR[rt]) then
    GPR[rd] ← 0^(GPRLEN-1) || 1
else
    GPR[rd] ← 0^GPRLEN
endif
```

Exceptions:

None

Shift Word Right Arithmetic — SRA

31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL 000000	0 00000	rt	rd	sa	SRA 000011
6	5	5	5	5	6

Format: SRA rd, rt, sa **MIPS32**

Purpose:

To execute an arithmetic right-shift of a word by a fixed number of bits.

Description: rd ← rt >> sa (arithmetic)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, duplicating the sign-bit (bit 31) in the emptied bits; the word result is placed in GPR *rd*. The bit-shift amount is specified by *sa*.

Restrictions:

None

Operation:

```
s       ← sa
temp    ← (GPR[rt]_31)^s || GPR[rt]_31..s
GPR[rd] ← temp
```

Exceptions:

None

Shift Word Right Arithmetic Variable — SRAV

31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL 000000	rs	rt	rd	0 00000	SRAV 000111
6	5	5	5	5	6

Format: SRAV rd, rt, rs **MIPS32**

Purpose:

To execute an arithmetic right-shift of a word by a variable number of bits.

Notes

Description: rd ← rt >> rs (arithmetic)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, duplicating the sign-bit (bit 31) in the emptied bits; the word result is placed in GPR *rd*. The bit-shift amount is specified by the low-order 5 bits of GPR *rs*.

Restrictions:

None

Operation:

$s \leftarrow GPR[rs]_{4..0}$
$temp \leftarrow (GPR[rt]_{31})^{s} \,||\, GPR[rt]_{31..s}$
$GPR[rd] \leftarrow temp$

Exceptions:

None

Shift Word Right Logical **SRL**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL	0	rt	rd	sa	SRL
000000	00000				000010
6	5	5	5	5	6

Format: SRL rd, rt, sa **MIPS32**

Purpose:

To execute a logical right-shift of a word by a fixed number of bits

Description: rd ← rt >> sa (logical)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, inserting zeros into the emptied bits; the word result is placed in GPR *rd*. The bit-shift amount is specified by *sa*.

Restrictions:

None

Operation:

$s \leftarrow sa$
$temp \leftarrow 0^{s} \,||\, GPR[rt]_{31..s}$
$GPR[rd] \leftarrow temp$

Exceptions:

None

Notes

Shift Word Right Logical Variable **SRLV**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL	rs	rt	rd	0	SRLV
000000				00000	000110
6	5	5	5	5	6

Format: SRLV rd, rt, rs **MIPS32**

Purpose:

To execute a logical right-shift of a word by a variable number of bits.

Description: rd ← rt >> rs (logical)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, inserting zeros into the emptied bits; the word result is placed in GPR *rd*. The bit-shift amount is specified by the low-order 5 bits of GPR *rs*.

Restrictions:

None

Operation:

s ← $GPR[rs]_{4..0}$
temp ← 0^s || $GPR[rt]_{31..s}$
GPR[rd] ← temp

Exceptions:

None

Superscalar No Operation **SSNOP**

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL	0	0	0	1	SLL
000000	00000	00000	00000	00001	000000
6	5	5	5	5	6

Format: SSNOP **MIPS32**

Purpose:

Break superscalar issue on a superscalar processor.

Description:

SSNOP is the assembly idiom used to denote superscalar no operation. The actual instruction is interpreted by the hardware as SLL r0, r0, 1.

This instruction alters the instruction issue behavior on a superscalar processor by forcing the SSNOP instruction to single-issue. The processor must then end the current instruction issue between the instruction previous to the SSNOP and the SSNOP. The SSNOP then issues alone in the next issue slot.

On a single-issue processor, this instruction is a NOP that takes an issue slot.

Notes

Restrictions:

None

Operation:

None

Exceptions:

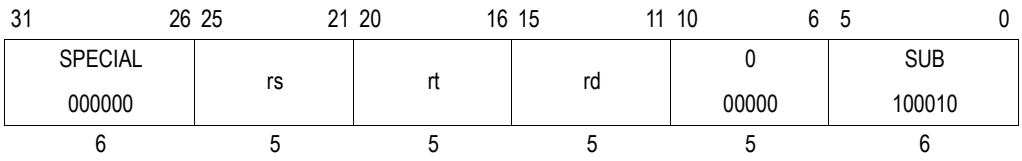
None

Programming Notes:

SSNOP is intended for use primarily to allow the programmer control over CP0 hazards by converting instructions into cycles in a superscalar processor. For example, to insert at least two cycles between an MTC0 and an ERET, one would use the following sequence:

```
mtc0    x,y
ssnop
ssnop
eret
```

Subtract Word **SUB**



Format: SUB rd, rs, rt **MIPS32**

Purpose:

To subtract 32-bit integers. If overflow occurs, then trap.

Description: rd ← rs - rt

The 32-bit word value in GPR *rt* is subtracted from the 32-bit value in GPR *rs* to produce a 32-bit result. If the subtraction results in 32-bit 2's complement arithmetic overflow, then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 32-bit result is placed into GPR *rd*.

Restrictions:

None

Operation:

```
temp ← (GPR[rs]31||GPR[rs]31..0) - (GPR[rt]31||GPR[rt]31..0)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rd] ← temp31..0
endif
```

Exceptions:

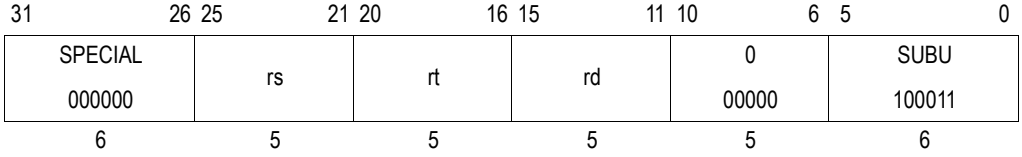
Integer Overflow

Notes

Programming Notes:

SUBU performs the same arithmetic operation but does not trap on overflow.

Subtract Unsigned Word **SUBU**



Format: SUBU rd, rs, rt **MIPS32**

Purpose:

To subtract 32-bit integers.

Description: rd ← rs - rt

The 32-bit word value in GPR *rt* is subtracted from the 32-bit value in GPR *rs* and the 32-bit arithmetic result is and placed into GPR *rd*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp     ← GPR[rs] - GPR[rt]
GPR[rd]  ← temp
```

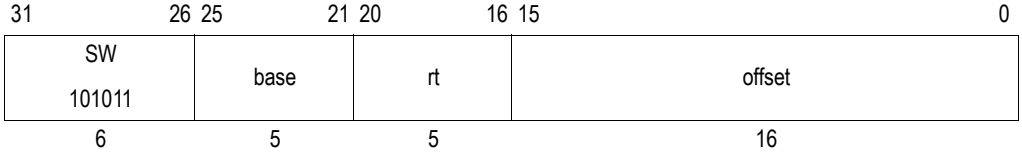
Exceptions:

None

Programming Notes:

The term “unsigned” in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. It is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.

Store Word **SW**



Format: SW rt, offset(base) **MIPS32**

Purpose:

To store a word to memory.

Notes

Description: memory[base+offset] ← rt

The least-significant 32-bit word of register *rt* is stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

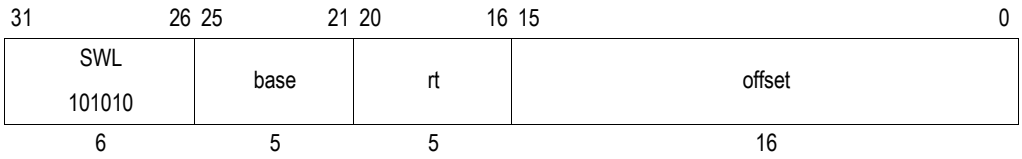
Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 0^2 then
      SignalException(AddressError)
endif
(pAddr, CCA)← AddressTranslation (vAddr, DATA, STORE)
dataword  ← GPR[rt]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error

Store Word Left **SWL**



Format: SWL rt, offset(base) **MIPS32**

Purpose:

To store the most-significant part of a word to an unaligned memory address.

Description: memory[base+offset] ← rt

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr*). *EffAddr* is the address of the most-significant of 4 consecutive bytes forming a word *(W*) in memory starting at an arbitrary byte boundary.

A part of *W*, the most-significant 1 to 4 bytes, is in the aligned word containing *EffAddr*. The same number of the most-significant (left) bytes from the word in GPR *rt* are stored into these bytes of *W*.

Figure A.15 illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is located in the aligned word containing the most-significant byte at 2. First, SWL stores the most-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWR stores the remainder of the unaligned word.

Notes

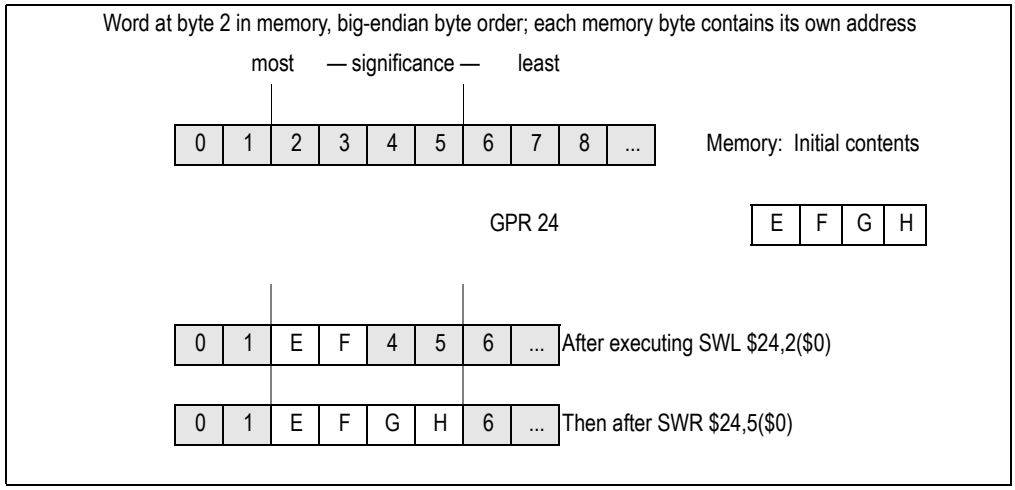


Figure A.15 Unaligned Word Store Using SWL and SWR

The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address (*vAddr1..0*)—and the current byte-ordering mode of the processor (big- or little-endian). Figure A.16 shows the bytes stored for every combination of offset and byte ordering.

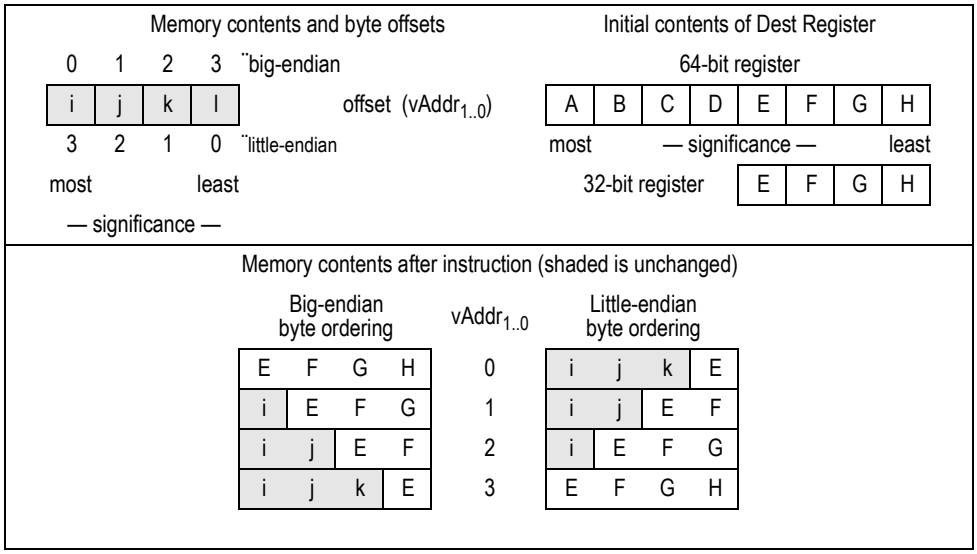


Figure A.16 Bytes Stored by an SWL Instruction

Restrictions:

None

Notes

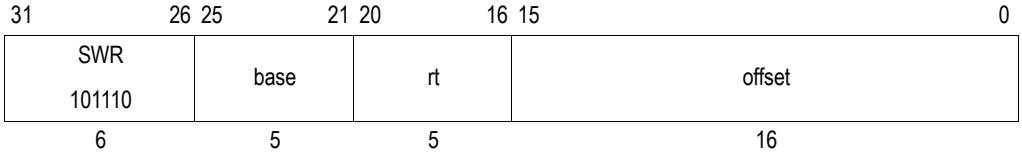
Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
(pAddr, CCA)← AddressTranslation (vAddr, DATA, STORE)
pAddr       ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
If BigEndianMem = 0 then
      pAddr ← pAddr_PSIZE-1..2 || 0^2
endif
byte        ← vAddr_1..0 xor BigEndianCPU^2
dataword    ← 0^(24–8*byte) || GPR[rt]_31..24–8*byte
StoreMemory(CCA, byte, dataword, pAddr, vAddr, DATA)
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error

Store Word Right **SWR**



Format: SWR rt, offset(base) **MIPS32**

Purpose:

To store the least-significant part of a word to an unaligned memory address.

Description: memory[base+offset] ← rt

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*. *EffAddr* is the address of the least-significant of 4 consecutive bytes forming a word *(W)* in memory starting at an arbitrary byte boundary.

A part of *W*, the least-significant 1 to 4 bytes, is in the aligned word containing *EffAddr*. The same number of the least-significant (right) bytes from the word in GPR *rt* are stored into these bytes of *W*.

Figure A.17 illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is contained in the aligned word containing the least-significant byte at 5. First, SWR stores the least-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWL stores the remainder of the unaligned word.

Notes

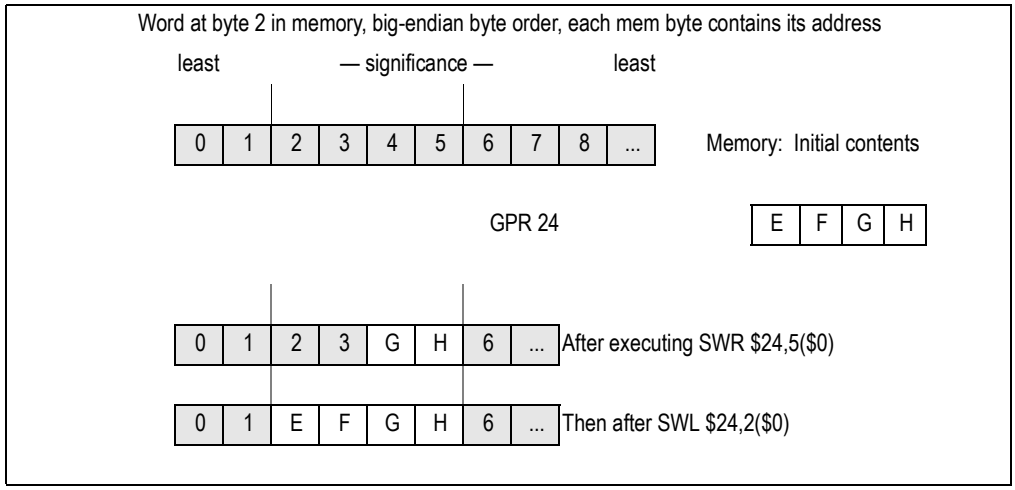


Figure A.17 Unaligned Word Store Using SWR and SW

The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address (*vAddr1..0*)—and the current byte-ordering mode of the processor (big- or little-endian). Figure A.18 shows the bytes stored for every combination of offset and byte-ordering.

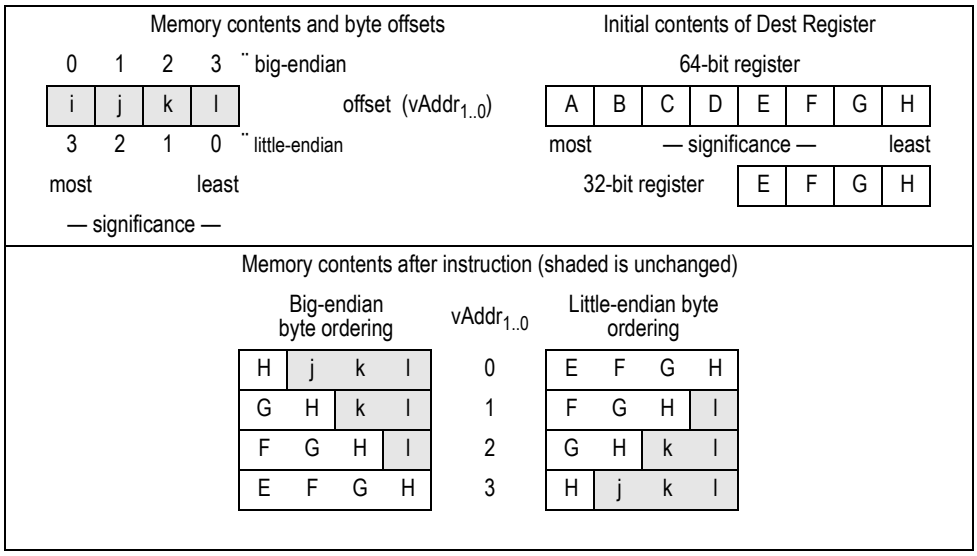


Figure A.18 Bytes Stored by SWR Instruction

Restrictions:

None

Notes

Operation:

```
vAddr       ← sign_extend(offset) + GPR[base]
(pAddr, CCA)← AddressTranslation (vAddr, DATA, STORE)
pAddr       ←  pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian^2)
If BigEndianMem = 0 then
      pAddr ← pAddr_PSIZE-1..2 || 0^2
endif
byte        ← vAddr_1..0 xor BigEndianCPU^2
dataword    ← GPR[rt]_31–8*byte || 0^8*byte
StoreMemory(CCA, WORD-byte, dataword, pAddr, vAddr, DATA)
```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error

Synchronize Shared Memory **SYNC**

31 – 26	25 – 21	20 – 16	15 – 11	10 – 6	5 – 0
SPECIAL	0		stype		SYNC
000000	00 0000 0000 0000 0				001111
6	15		5		6

Format: SYNC (stype = 0 implied) **MIPS32**

Purpose:

To order loads and stores.

Description:

Simple Description:

- SYNC affects only *uncached* and *cached coherent* loads and stores. The loads and stores that occur before the SYNC must be completed before the loads and stores after the SYNC are allowed to start.
- Loads are completed when the destination register is written. Stores are completed when the stored value is visible to every other processor in the system.
- SYNC is required, potentially in conjunction with SSNOP, to guarantee that memory reference results are visible across operating mode changes. For example, a SYNC is required on some implementations on entry to and exit from Debug Mode to guarantee that memory affects are handled correctly.

Detailed Description:

- SYNC does not guarantee the order in which instruction fetches are performed. The *stype* values 1-31 are reserved; they produce the same result as the value zero.
- Executing the SYNC instruction causes the write-through buffer to be flushed. The SYNC instruction stalls until all loads and stores are completed.
- The information presented here refers to the MIPS 4Kc core implementation of the SYNC instruction. For a more detailed description of the programming effects of SYNC on a generic MIPS32 processor, refer to the MIPS32 Architecture Reference Manual.

Restrictions:

The effect of SYNC on the global order of loads and stores for memory access types other than *uncached* and *cached coherent* is **UNPREDICTABLE**.

Notes

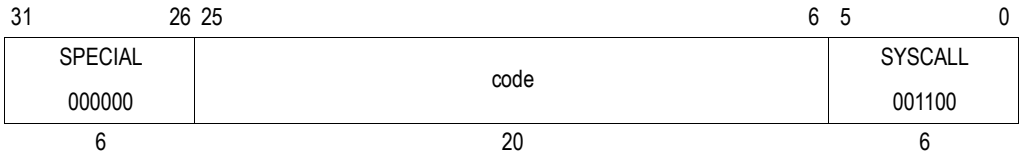
Operation:

SyncOperation(stype)

Exceptions:

None

System Call **SYSCALL**



Format: SYSCALL **MIPS32**

Purpose:

To cause a System Call exception.

Description:

A system call exception occurs, immediately and unconditionally transferring control to the exception handler.

The *code* field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

Restrictions:

None

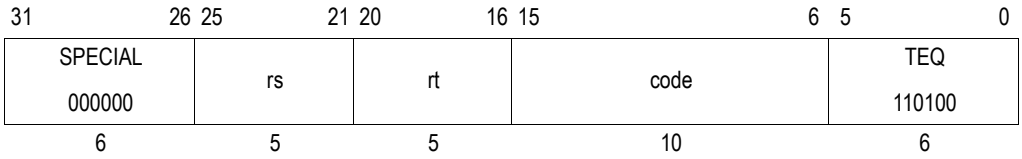
Operation:

SignalException(SystemCall)

Exceptions:

System Call

Trap if Equal **TEQ**



Format: TEQ rs, rt **MIPS32**

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs = rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is equal to GPR *rt,*

Notes

then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

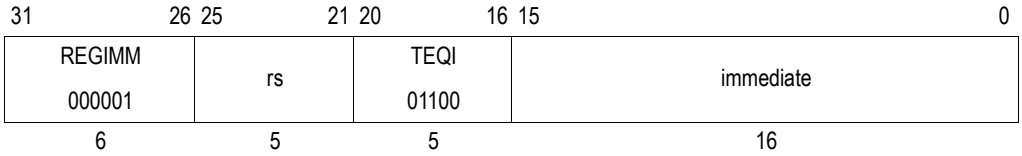
Operation:

```
if GPR[rs] = GPR[rt] then
      SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Equal Immediate **TEQI**



Format: TEQI rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs = immediate then Trap

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is equal to *immediate,* then take a Trap exception.

Restrictions:

None

Operation:

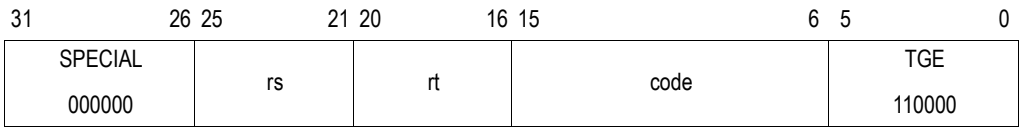
```
if GPR[rs] = sign_extend(immediate) then
            SignalException(Trap)
endif
```

Exceptions:

Trap

Notes

Trap if Greater or Equal — TGE



Format: TGE rs, rt **MIPS32**

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs ≥ rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is greater than or equal to GPR *rt*, then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

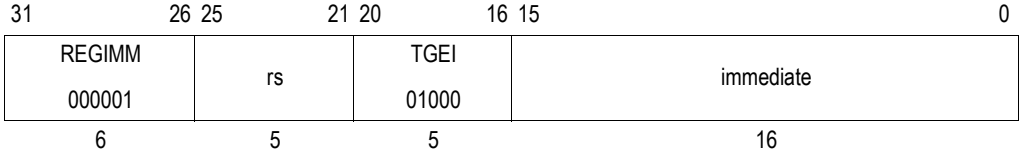
Operation:

```
if GPR[rs] ≥ GPR[rt] then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Greater or Equal Immediate — TGEI



Format: TGEI rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs ≥ immediate then Trap

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is greater than or equal to *immediate*, then take a Trap exception.

Restrictions:

None

Notes

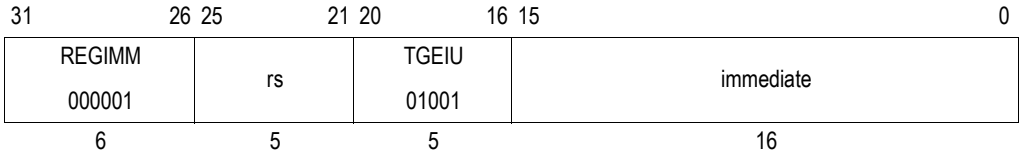
Operation:

```
if GPR[rs] ≥ sign_extend(immediate) then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Greater or Equal Immediate Unsigned **TGEIU**



Format: TGEIU rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs ≥ immediate then Trap

Compare the contents of GPR *rs* and the 16-bit sign-extended *immediate* as unsigned integers; if GPR *rs* is greater than or equal to *immediate*, then take a Trap exception.

Because the 16-bit *immediate* is sign-extended before comparison, the instruction can represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

Restrictions:

None

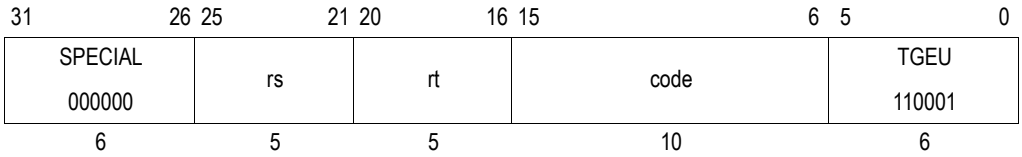
Operation:

```
if (0 || GPR[rs]) ≥ (0 || sign_extend(immediate)) then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Greater or Equal Unsigned **TGEU**



Format: TGEU rs, rt **MIPS32**

Notes

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs ≥ rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers; if GPR *rs* is greater than or equal to GPR *rt*, then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

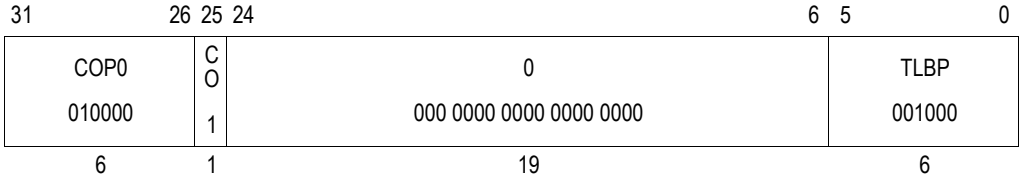
Operation:

```
if (0 || GPR[rs]) ≥ (0 || GPR[rt]) then
      SignalException(Trap)
endif
```

Exceptions:

Trap

Probe TLB for Matching Entry **TLBP**



Format: TLBP **MIPS32**

Purpose:

To find a matching entry in the TLB.

Description:

The *Index* register is loaded with the address of the TLB entry whose contents match the contents of the *EntryHi* register. If no TLB entry matches, the high-order bit of the *Index* register is set.

Restrictions:

None

Notes

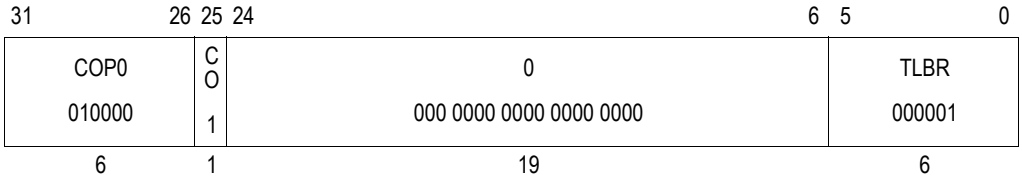
Operation:

```
Index ← 1 || UNPREDICTABLE[31]
for i in 0...TLBEntries-1
    if ((TLB[i]VPN2 and not (TLB[i]Mask)) =
                (EntryHiVPN2 and not (TLB[i]Mask))) and
        ((TLB[i]G = 1) or (TLB[i]ASID = EntryHiASID))then
        Index ← i
    endif
endfor
```

Exceptions:

Coprocessor Unusable

Read Indexed TLB Entry **TLBR**



Format: TLBR **MIPS32**

Purpose:

To read an entry from the TLB.

Description:

The *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers are loaded with the contents of the TLB entry pointed to by the Index register. Note that the value written to the *EntryHi*, *EntryLo0*, and *EntryLo1* registers may be different from that originally written to the TLB via these registers in that:

- The value returned in the G bit in both the *EntryLo0* and *EntryLo1* registers comes from the single G bit in the TLB entry. Recall that this bit was set from the logical AND of the two G bits in *EntryLo0* and *EntryLo1* when the TLB was written.
- The value returned in the ASID field of the *EntryHi* register is zero for those chips that implement a BAT-based MMU organization.

Restrictions:

The operation is **UNDEFINED** if the contents of the Index register are greater than or equal to the number of TLB entries in the processor.

Notes

Operation:

```
i ← Index
if i > (TLBEntries - 1) then
      UNDEFINED
endif
PageMask_Mask ← TLB[i]_Mask
EntryHi ←
                  TLB[i]_VPN2 ||
                  0^5 || TLB[i]_ASID
EntryLo1 ← 0^2 ||
                  TLB[i]_PFN1 ||
                  TLB[i]_C1 || TLB[i]_D1 || TLB[i]_V1 || TLB[i]_G
EntryLo0 ← 0^2 ||
                  TLB[i]_PFN0 ||
                  TLB[i]_C0 || TLB[i]_D0 || TLB[i]_V0 || TLB[i]_G
```

Exceptions:

Coprocessor Unusable

Write Indexed TLB Entry **TLBWI**

31 26	25	24 6	5 0
COP0	CO	0	TLBWI
010000	1	000 0000 0000 0000 0000	000010
6	1	19	6

Format: TLBWI **MIPS32**

Purpose:

To write a TLB entry indexed by the *Index* register.

Description:

The TLB entry pointed to by the Index register is written from the contents of the *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers. The information written to the TLB entry may be different from that in the *EntryHi*, *EntryLo0*, and *EntryLo1* registers, in that:

- The single G bit in the TLB entry is set from the logical AND of the G bits in the *EntryLo0* and *EntryLo1* registers.

Restrictions:

The operation is **UNDEFINED** if the contents of the Index register are greater than or equal to the number of TLB entries in the processor.

Notes

Operation:

```
i ← Index
TLB[i]Mask ←PageMaskMask
TLB[i]VPN2 ←EntryHiVPN2
TLB[i]ASID ←EntryHiASID
TLB[i]G ← EntryLo1G and EntryLo0G
TLB[i]PFN1 ← EntryLo1PFN
TLB[i]C1 ← EntryLo1C
TLB[i]D1 ← EntryLo1D
TLB[i]V1 ← EntryLo1V
TLB[i]PFN0 ← EntryLo0PFN
TLB[i]C0 ← EntryLo0C
TLB[i]D0 ← EntryLo0D
TLB[i]V0 ← EntryLo0V
```

Exceptions:

Coprocessor Unusable

Write Random TLB Entry **TLBWR**

31 26	25 24	6 5	0
COP0	CO	0	TLBWR
010000	1	000 0000 0000 0000 0000	000110
6	1	19	6

Format: TLBWR **MIPS32**

Purpose:

To write a TLB entry indexed by the *Random* register.

Description:

The TLB entry pointed to by the *Random* register is written from the contents of the *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers. The information written to the TLB entry may be different from that in the *EntryHi*, *EntryLo0*, and *EntryLo1* registers, in that:

- The value returned in the G bit in both the *EntryLo0* and *EntryLo1* registers comes from the single G bit in the TLB entry. Recall that this bit was set from the logical AND of the two G bits in *EntryLo0* and *EntryLo1* when the TLB was written.

Restrictions:

The operation is **UNDEFINED** if the contents of the Index register are greater than or equal to the number of TLB entries in the processor.

Notes

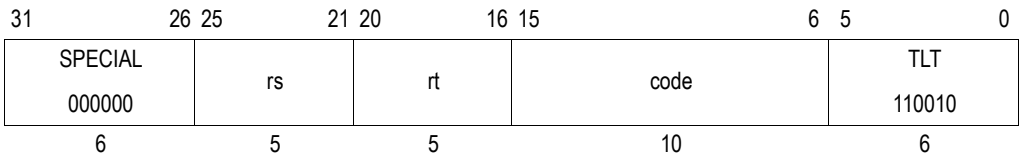
Operation:

```
i ← Random
TLB[i]Mask ← PageMaskMask
TLB[i]VPN2 ← EntryHiVPN2
TLB[i]ASID ← EntryHiASID
TLB[i]G ← EntryLo1G and EntryLo0G
TLB[i]PFN1 ← EntryLo1PFN
TLB[i]C1 ← EntryLo1C
TLB[i]D1 ← EntryLo1D
TLB[i]V1 ← EntryLo1V
TLB[i]PFN0 ← EntryLo0PFN
TLB[i]C0 ← EntryLo0C
TLB[i]D0 ← EntryLo0D
TLB[i]V0 ← EntryLo0V
```

Exceptions:

Coprocessor Unusable

Trap if Less Than **TLT**



Format: TLT rs, rt **MIPS32**

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs < rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is less than GPR *rt*, then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

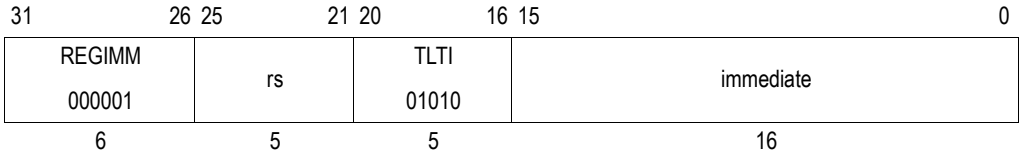
```
if GPR[rs] < GPR[rt] then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Notes

Trap if Less Than Immediate **TLTI**



Format: TLTI rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs < immediate then Trap

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is less than *immediate*, then take a Trap exception.

Restrictions:

None

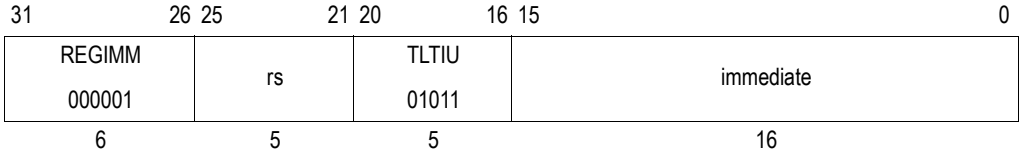
Operation:

```
if GPR[rs] < sign_extend(immediate) then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Less Than Immediate Unsigned **TLTIU**



Format: TLTIU rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs < immediate then Trap

Compare the contents of GPR *rs* and the 16-bit sign-extended *immediate* as unsigned integers; if GPR *rs* is less than *immediate*, then take a Trap exception.

Because the 16-bit *immediate* is sign-extended before comparison, the instruction can represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

Restrictions:

None

Notes

Operation:

```
if (0 || GPR[rs]) < (0 || sign_extend(immediate)) then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Less Than Unsigned **TLTU**

31 26	25 21	20 16	15 6	5 0
SPECIAL 000000	rs	rt	code	TLTU 110011
6	5	5	10	6

Format: TLTU rs, rt **MIPS32**

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs < rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers; if GPR *rs* is less than GPR *rt*, then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

```
if (0 || GPR[rs]) < (0 || GPR[rt]) then
    SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Not Equal **TNE**

31 26	25 21	20 16	15 6	5 0
SPECIAL 000000	rs	rt	code	TNE 110110
6	5	5	10	6

Format: TNE rs, rt **MIPS32**

Notes

Purpose:

To compare GPRs and do a conditional trap.

Description: if rs ≠ rt then Trap

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is not equal to GPR *rt*, then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

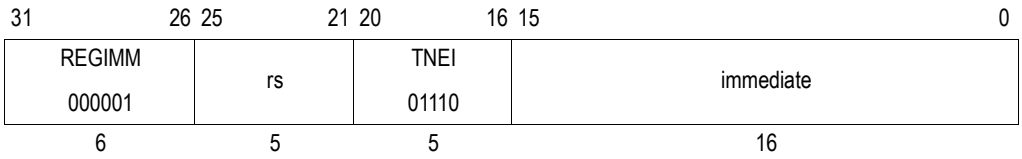
Operation:

```
if GPR[rs] ≠ GPR[rt] then
        SignalException(Trap)
endif
```

Exceptions:

Trap

Trap if Not Equal **TNEI**



Format: TNEI rs, immediate **MIPS32**

Purpose:

To compare a GPR to a constant and do a conditional trap.

Description: if rs ≠ immediate then Trap

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is not equal to *immediate*, then take a Trap exception.

Restrictions:

None

Operation:

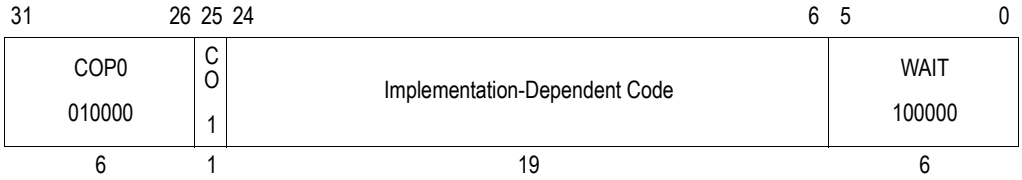
```
if GPR[rs] ≠ sign_extend(immediate) then
      SignalException(Trap)
endif
```

Exceptions:

Trap

Notes

Enter Standby Mode **WAIT**



Format: WAIT **MIPS32**

Purpose:

Wait for Event.

Description:

The WAIT instruction forces the core into low power mode. The pipeline is stalled and when all external requests are completed, the processor's main clock is stopped. The processor will restart when reset (SI_Reset or SI_ColdReset) is signaled, or a non-masked interrupt is taken (SI_NMI, SI_Int, or EJ_DINT). Note that the 4Kc core does not use the code field in this instruction.

Restrictions:

The operation of the processor is **UNDEFINED** if a WAIT instruction is placed in the delay slot of a branch or a jump.

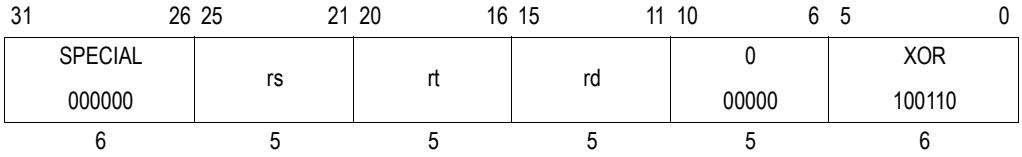
Operation:

```
Enter  lower power mode
```

Exceptions:

Coprocessor Unusable Exception

Exclusive OR **XOR**



Format: XOR rd, rs, rt **MIPS32**

Purpose:

To do a bitwise logical Exclusive OR.

Description: rd ← rs XOR rt

Combine the contents of GPR *rs* and GPR *rt* in a bitwise logical Exclusive OR operation and place the result into GPR *rd*.

Restrictions:

None

Notes

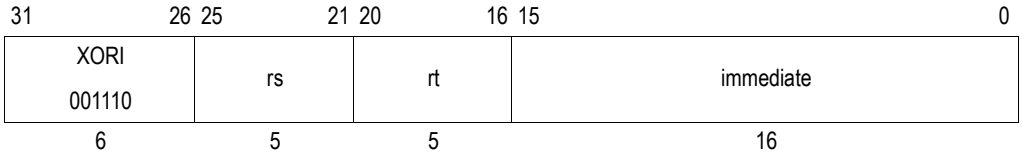
Operation:

GPR[rd] ← GPR[rs] xor GPR[rt]

Exceptions:

None

Exclusive OR Immediate **XORI**



Format: XORI rt, rs, immediate **MIPS32**

Purpose:

To do a bitwise logical Exclusive OR with a constant.

Description: rt ← rs XOR immediate

Combine the contents of GPR *rs* and the 16-bit zero-extended *immediate* in a bitwise logical Exclusive OR operation and place the result into GPR *rt.*

Restrictions:

None

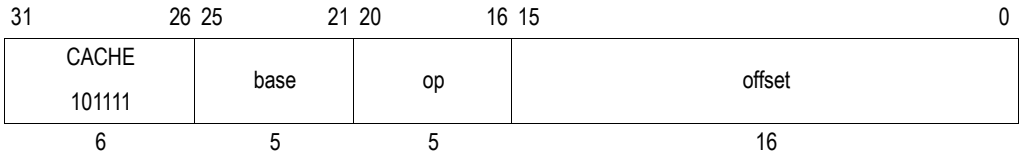
Operation:

GPR[rt] ← GPR[rs] xor zero_extend(immediate)

Exceptions:

None

Perform Cache Operation **CACHE**



Format: CACHE op, offset(base) **MIPS32**

Purpose:

To perform the cache operation specified by op.

Description:

The 16-bit offset is sign-extended and added to the contents of the base register to form an effective address. The effective address is used in one of the following ways based on the operation to

Notes

be performed and the type of cache as described in the following table.

Operation Requires	Type of Cache	Use of Effective Address
Address	Physical	The effective address is translated by the MMU to a physical address. The physical address is then used to address the cache.

Index	N/A	The effective address is translated by the MMU to a physical address. It is implementation dependent whether the effective address or the translated physical address is used to index the cache.
		Assuming that the total cache size in bytes is CS, the associativity is A, and the number of bytes per tag is BPT, the following calculations give the fields of the address which specify the way and the index:
		`OffsetBit ← Log2(BPT)`
		`IndexBit ← Log2(CS / A)`
		`WayBit ← IndexBit + Ceiling(Log2(A))`
		`Way ← Addr`$_{\texttt{WayBit-1..IndexBit}}$
		`Index ← Addr`$_{\texttt{IndexBit-1..OffsetBit}}$
		For a direct-mapped cache, the Way calculation is ignored and the Index value fully specifies the cache tag. This is shown symbolically in the figure below

Table A.11 Use of Effective Address

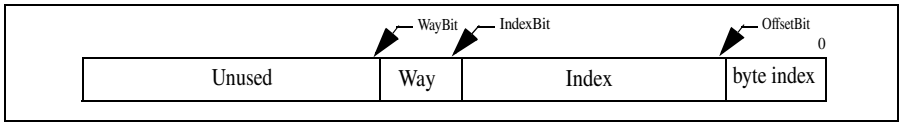


Figure A.19 Use of Address Fields to Select Index and Way

A TLB Refill and TLB Invalid (both with cause code equal TLBL) exception can occur on any operation. For index operations (where the address is used to index the cache but need not match the cache tag) software should use unmapped addresses to avoid TLB exceptions. This instruction never causes TLB Modified exceptions nor TLB Refill exceptions with a cause code of TLBS, nor data Watch exceptions.

A Cache Error exception may occur as a by-product of some operations performed by this instruction. For example, if a Writeback operation detects a cache or bus error during the processing of the operation, that error is reported via a Cache Error exception. Similarly, a Bus Error Exception may occur if a bus operation invoked by this instruction is terminated in an error.

An address Error Exception (with cause code equal AdEL) occurs if the effective address references a portion of the kernel address space which would normally result in such an exception.Data watch is not triggered by a cache instruction whose address matches the Watch register address match conditions.

Bits [17:16] of the instruction specify the cache on which to perform the operation, as follows:

Notes

Code	Name	Cache
2#00	I	Primary Instruction
2#01	D	Primary Data
2#10	T	Not supported
2#11	S	Not supported

Table A.12 Encoding of Bits [17:16] of CACHE Instruction

Bits [20:18] of the instruction specify the operation to perform. On Index Load Tag and Index Store Data operations, the specific word that is addressed is loaded into / read from the DataLo. All other cache instructions are line-based and the word and byte indexes will not affect their operation.

Code	Cache	Name	Effective Address Operand Type	Operation	Imple-mented ?
2#000	I	Index Invalidate	Index	Set the state of the cache block at the specified index to invalid. This encoding may be used by software to invalidate the entire instruction cache by stepping through all valid indices.	Yes
	D	Index Invalidate	Index	Set the state of the cache block at the specified index to invalid. This encoding may be used by software to invalidate the entire data cache by stepping through all valid indices. Note that Index Store Tag should be used to initialize the cache at power-up.	Yes
	S, T	Reserved	Index		No
2#001	I, D	Index Load Tag	Index	Read the tag for the cache block at the specified index into the TagLo Coprocessor 0 register. Also read the data corresponding to the byte index into the DataLo register.	Yes
2#010	I, D	Index Store Tag	Index	Write the tag for the cache block at the specified index from the TagLo Coprocessor 0 register. This encoding may be used by software to initialize the entire instruction or data caches by stepping through all valid indices. Doing so requires that the TagLo and TagHi registers associated with the cache be initialized first.	Yes
2#011	All	Reserved	Unspecified	Executed as a no-op.	No

Table A.13 Encoding of Bits [20:18] of CACHE Instruction ErrCtl[WST,SPR] Cleared (Part 1 of 2)

Notes

Code	Cache	Name	Effective Address Operand Type	Operation	Implemented?
2#100	I, D	Hit Invalidate	Address	If the cache block contains the specified address, set the state of the cache block to invalid. This encoding may be used by software to invalidate a range of addresses from the instruction cache by stepping through the address range by the line size of the cache.	Yes
	S, T	Reserved	Address		No
2#101	I	Fill	Address	Fill the cache from the specified address. The cache line is refetched even if it is already in the cache.	Yes
	D	Hit Invalidate	Address	If the cache block contains the specified address, set the state of the cache block to invalid. This encoding may be used by software to invalidate a range of addresses from the data cache by stepping through the address range by the line size of the cache.	Yes
	S, T	Reserved	Address		No
2#110	D	Reserved	Address	Executed as a no-op.	No
	S, T	Reserved	Address		No
2#111	I, D	Fetch and Lock	Address	If the cache does not contain the entire line at the specified address, it is fetched from memory, and the state is set to locked. If the cache already contains the line, set the state to locked. The lock state may be cleared by executing an Index Invalidate or Hit Invalidate operation to the locked line, or via an Index Store Tag operation to the line that clears the lock bit.	Yes

Table A.13 Encoding of Bits [20:18] of CACHE Instruction ErrCtl[WST,SPR] Cleared (Part 2 of 2)

Code	Cache	Name	Effective Address Operand Type	Operation	Implemented?
2#011	I, D	Index Store Data	Index	Write the DataLo Coprocessor 0 register contents at the way and byte index specified.	Yes
All others	All			All of the other codes behave the same as when ErrCtl[WST] is cleared.	

Table A.14 Encoding of Bits [20:18] of CACHE Instruction ErrCtl[WST] Set, ErrCtl[SPR] Cleared

Notes

Code	Cache	Name	Effective Address Operand Type	Operation	Imple-mented ?
2#001	I, D	Index Load Tag	Index	Read the SPRAM tag at the specified index into the TagLo Coprocessor 0 register.	Yes
2#010	I, D	Index Store Tag	Index	Update the SPRAM tag at the specified index from the TagLo Coprocessor 0 register.	Yes
2#011	I, D	Index Store Data	Index	Write the DataLo Coprocessor 0 register contents into the SPRAM at the word index specified.	Yes
All others	All			All of the other codes behave the same as when ErrCtl[SPR] is cleared	

Table A.15 Encoding of Bits [20:18] of CACHE Instruction ErrCtl[SPR] Set

Restrictions:

The operation of this instruction is **UNDEFINED** for any operation/cache combination that is not implemented.

The operation of this instruction is **UNDEFINED** if the operation requires an address, and that address is uncacheable.

Operation:

```
vAddr ← GPR[base] + sign_extend(offset)
(pAddr, uncached) ← AddressTranslation(vAddr, DataReadReference)
CacheOp(op, vAddr, pAddr)
```

Exceptions:

TLB Refill Exception.

TLB Invalid Exception

Coprocessor Unusable Exception

Address Error Exception

Bus Error Exception

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