

IBM

**PPC403GC Embedded Controller
User's Manual**

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This edition of *IBM PPC403GC Embedded Controller User's Manual* applies to the IBM PPC403GC-JA 32-bit embedded controller, as well as to subsequent IBM PowerPC 400 embedded controllers until otherwise indicated in new versions or technical newsletters.

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About This Book

This user's manual provides the architectural overview, programming model, and detailed information about the registers and the instruction set of the IBM™ PowerPC™ 403GC 32-bit RISC embedded controller.

The PPC403GC™ RISC embedded controller features :

- PowerPC Architecture™
- Single-cycle execution for most instructions
- Buffered, fly-by, or memory-to-memory four-channel DMA
- Direct-connect DRAM, SRAM, ROM and I/O interfaces
- On-chip 2KB instruction cache and 1KB copy-back data cache
- Serial and JTAG ports
- Controller for one critical and five noncritical interrupt lines
- Extensive development tool support

Who Should Use This Book

This book is for system hardware and software developers, and for application developers who need to understand the PPC403GC. The audience should understand embedded system design, operating systems, RISC processing, and design for testability.

How to Use This Book

This book describes the PPC403GC device architecture, programming model, external interfaces, internal registers, and instruction set. This book contains the following chapters:

Chapter 1	Overview
Chapter 2	Programming Model
Chapter 3	Memory and Peripheral Interface
Chapter 4	DMA Operations
Chapter 5	Reset and Initialization
Chapter 6	Interrupts, Exceptions, and Timers
Chapter 7	Serial Port Operation
Chapter 8	Instruction and Data Caches
Chapter 9	Memory Management
Chapter 10	Debugging
Chapter 11	Instruction Set
Chapter 12	Register Summary
Chapter 13	Signal Descriptions
Appendix A	Instruction Summary
Appendix B	Instructions By Category
Appendix C	Instruction Timing and Optimization

To assist in accessing material in these chapters, the book contains:

on page v	Table of Contents
on page xvii	List of Figures
on page xxiii	List of Tables
on page X-1	Index

Conventions

The following is a brief list of notational conventions frequently used in this manual. Also see Section 11.2 on page 11-2.

$\overline{\text{Active_Low}}$	An overbar indicates an active-low signal.
0x1f	Hexadecimal numbers
0b1001	Binary numbers
FLD	A named field.
FLD _b	A bit in a named field.
RA, RS, . . .	A general purpose register (GPR).
(RA)	The contents of a GPR.
(RA 0)	The contents of a GPR or the value 0.
REG _b	A bit in a named register.
REG _{b:b}	A range of bits in a named register.
REG _{b,b, . . .}	A list of bits, by number or name, in a named register.
REG[FLD]	A field of a named register.
CR _{FLD}	The field in the condition register pointed to by a field of an instruction.
24 _s	The sign bit is replicated (sign-extended) 24 times.
xx	Bit positions which are don't-cares.

Related Publications

The following publications contain related information:

- *PowerPC 403GC Data Sheet, SC22-9893-01*

To obtain copies of this publication, call the IBM PowerPC Literature Center at (800) POWERPC.

- *PowerPC Architecture (Customer Reorder Number 52G7487)*

To obtain copies of this publication, call the IBM Advanced Workstation Division Customer Fulfillment Center at (800) IBM-MIRS.

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Overview

This chapter presents the IBM PowerPC 403GC 32-bit RISC embedded controller (PPC403GC) as a specific implementation of the PowerPC Architecture. After a brief overview of the features of the PPC403GC, this chapter discusses the layered organization of the PowerPC Architecture. The chapter then discusses how the PPC403GC implements a variation of the PowerPC Architecture that has been optimized for embedded control applications. PPC403GC compliance with the PowerPC Architecture is discussed. Finally, the major functional units, instruction types, and register types of the PPC403GC are discussed, along with a block diagram to illustrate principal external interfaces and internal flow of data and control signals.

1.1 PPC403GC Overview

The PPC403GC 32-bit RISC embedded controller offers high performance and functional integration with low power consumption. The PPC403GC RISC CPU executes at sustained speeds approaching one cycle per instruction. On-chip caches and integrated DRAM and SRAM control functions reduce chip count and design complexity in systems, while improving system throughput. Features of the PPC403GC include:

- PowerPC RISC fixed-point CPU and PowerPC User Instruction Set Architecture
 - Thirty-two 32-bit general purpose registers
 - Branch prediction and folding
 - Single-cycle execution for most instructions
 - Hardware multiplier and divider for faster integer arithmetic
 - Enhanced string and multiple-word handling
- Glueless interfaces to DRAM, SRAM, ROM, and peripherals
 - 32-bit data bus
 - Addressing for 512MB of external memory and MMIO
 - Support for a wide range of memory timing parameters
 - Support for direct connection of byte, halfword, and fullword devices

- Memory Management Unit
 - MMU is precache (cache tags are physical addresses)
 - 64 entry fully associative TLB with software replacement
 - Each entry independently programmable to 1 of 8 page sizes (1K - 16M by powers of 4)
 - 16 protection zones
- Separate instruction cache and write-back data cache, both two-way set-associative
- Minimized interrupt latency
- Individually programmable on-chip controllers for:
 - Four DMA channels
 - DRAM, SRAM, and ROM banks
 - Peripherals
 - Serial port
 - External interrupts
- Flexible interface to external bus masters

1.2 PowerPC Architecture

The PowerPC Architecture comprises three levels of standards:

- PowerPC User Instruction Set Architecture, including the base user-level instruction set, user-level registers, programming model, data types, and addressing modes.
- PowerPC Virtual Environment Architecture, describing the memory model, cache model, cache-control instructions, address aliasing, and related issues. While accessible from the user level, these features are intended to be accessed from within library routines provided by the system software.
- PowerPC Operating Environment Architecture, including the memory management model, supervisor-level registers, and the exception model.

The first two levels of standards represent the instruction set and facilities available to the application programmer. The third level includes features such as system-level instructions which are not directly accessible by user applications.

The PowerPC Architecture helps to maximize cross-platform portability of applications developed for PowerPC processors, by guaranteeing application code compatibility across all PowerPC implementations. This is accomplished via compliance with the first level of

architectural standard, the PowerPC User Instruction Set Architecture, which is common for all PowerPC implementations.

1.2.1 The PPC403GC as a PowerPC Implementation

The PPC403GC implements the PowerPC User Instruction Set Architecture, user-level registers, programming model, data types, and addressing modes for 32-bit fixed-point operations. This PowerPC architectural standard specifies the instruction set and registers that should be provided to support user-level programs. The PPC403GC is fully compliant with specifications for 32-bit implementations of the PowerPC User Instruction Set Architecture. The 64-bit operations are not supported, nor are the floating point operations. Both of these kinds of operations are trapped and can be emulated in software.

Most of the architected features of the PPC403GC are compatible with the specifications for the PowerPC Virtual Environment and Operating Environment Architectures, as specified for compute processors such as the 600 family of PowerPC processors. In addition to these standard features, the PPC403GC provides a number of optimizations and extensions to these levels of the architecture. The full architecture of the PPC403GC is defined by the PowerPC Embedded Virtual Environment and Embedded Operating Environment Architecture specifications, together with the common PowerPC User Instruction Set Architecture.

The primary differences between the standard PowerPC Architecture and the embedded variation of it are the following:

- A simplified memory management mechanism, with enhancements for embedded applications.
- An enhanced, dual-level interrupt structure.
- An architected Device Control Register (DCR) address space for integrated system control functions (such as the DMA controller).
- The addition of several instructions to support these modified and extended resources.

Finally, some of the specific implementation features of the PPC403GC are beyond the scope of the architecture. These features are included to enhance performance, integrate functionality, and/or reduce system complexity in embedded control applications. Some of the details of these implementation features are discussed in Section 1.3 (PPC403GC Features).

1.3 PPC403GC Features

The PPC403GC consists of a highly pipelined processor core and several peripheral interface units: the Bus Interface Unit (BIU), the Memory Management Unit (MMU), the DMA controller, the serial port, the on-chip peripheral bus (OPB), the asynchronous interrupt controller, and the JTAG/debug port. The PowerPC User Instruction Set Architecture, device control registers, and special purpose registers provide a high degree of user control

over configuration and operation of the functional units, both interface and core.

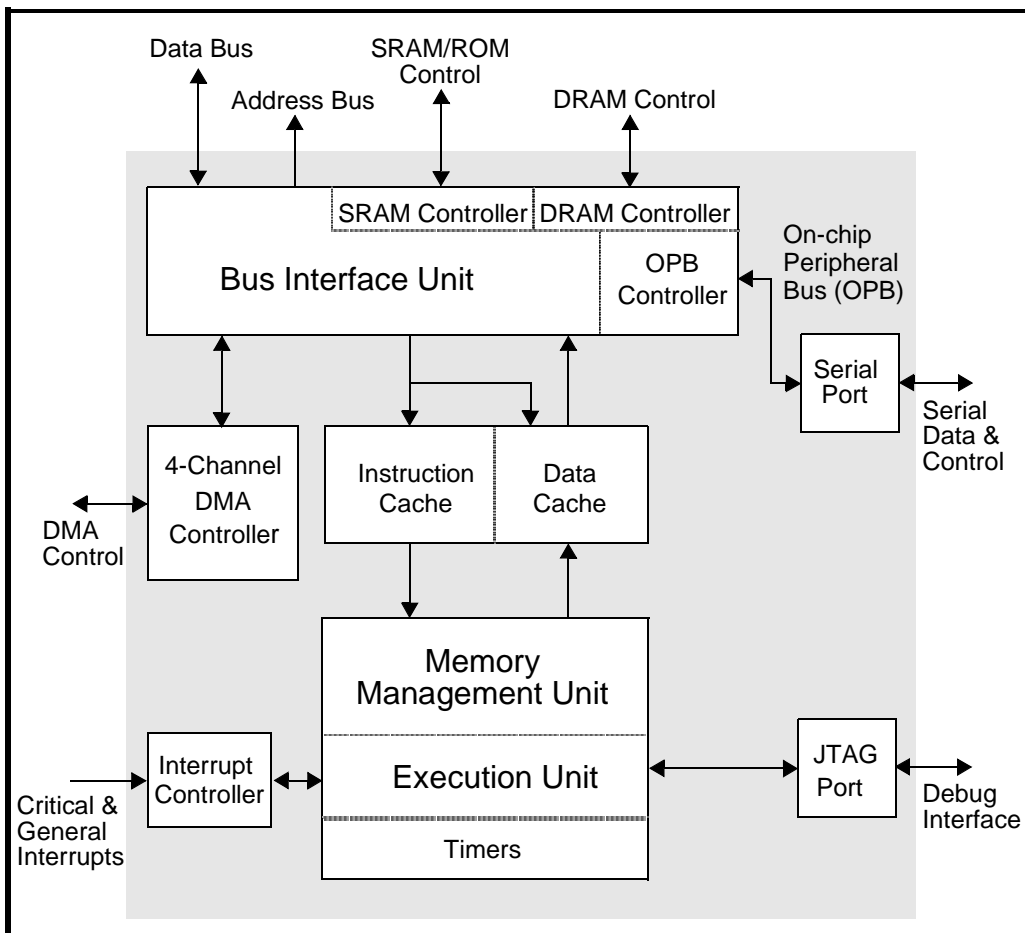


Figure 1-1. PPC403GC Block Diagram

1.3.1 RISC Core

The RISC core comprises four tightly-coupled functional units: the data cache unit (DCU), the instruction cache unit (ICU), the memory management unit (MMU), and the execution unit (EXU). Each cache unit consists of a data array, tag array, and control logic for cache management and addressing. The MMU provides address translation, protection functions, and storage attribute control for embedded applications; the MMU includes a fully-associative 64-entry Translation Lookaside Buffer (TLB). The EXU consists of general purpose registers (GPRs), special purpose registers (SPRs), ALU and multiplier, timers, instruction decoder, and the control logic required to manage instruction execution and EXU

data flow.

1.3.1.1 Execution Unit (EXU)

The EXU handles instruction fetching, decoding and execution, queue management, branch prediction, and branch folding. The instruction cache unit passes instructions to the queue in the EXU or, in the event of a cache miss, requests a fetch from external memory through the bus interface unit (BIU).

Data transfers to and from the EXU are handled through the bank of 32 GPRs, each 32 bits wide. Load and store instructions move data operands between the GPRs and the data cache unit, except in the cases of noncacheable data or cache misses. In such cases the DCU passes the address for the data read or write to the BIU. To minimize overhead in handling cache misses and noncacheable operands, a bypass is available from the BIU, which interfaces to the external memory being accessed, to the EXU.

In addition to 32 GPRs, the EXU contains status and special purpose registers that can be read or written by executing programs. Some registers are only accessible while the processor is in supervisor state, while others can be accessed in both user and supervisor states.

A robust set of timer facilities is integrated into the EXU. Four timer facilities are provided:

- A 64-bit time base register
- A 32-bit count-down programmable interval timer with auto-reload
- A fixed interval timer with four selectable intervals
- A watchdog timer with four selectable intervals and built-in reset

The frequency of the time base and other timer facilities is derived from a clock input which may be programmed to connect either to the processor clock (SysClk) or to an independent external timer-clock pin (TimerClk).

A simple memory protection mechanism in the EXU allows system software to manage two regions of memory where writing will be disallowed. Each region is one or more 4KB pages starting on a 4KB boundary. Once enabled, the protection mechanism generates a precise protection exception if a write to the region is attempted.

Dual-level exception prioritization logic in the EXU prioritizes exception sources. When an enabled exception is detected, an interrupt occurs and the processor suspends the current instruction stream and begins executing an exception handling routine.

Exceptions are categorized as either critical or noncritical. Critical exceptions have higher priority than noncritical exceptions, and are not automatically disabled when an interrupt due to a noncritical exception occurs. Critical exceptions include debug exceptions, machine checks, a critical-interrupt-pin input, and the watchdog timer exception. Noncritical exceptions include those caused by instruction execution, asynchronous external exceptions, and programmable and fixed interval timer exceptions.

Debug facilities in the PPC403GC are divided between the RISC core and the JTAG/debug unit external to the core. The JTAG/debug unit contains a standard JTAG state machine, together with boundary scan logic and other resources accessible through the external JTAG interface.

1.3.1.2 Memory Management Unit (MMU)

The PPC403GC MMU provides address translation, protection functions, and storage attribute control for embedded applications. The MMU supports demand paged virtual memory as well as a variety of other management schemes that depend on precise control of logical to physical address mapping and flexible memory protection. Together with appropriate system level software, the MMU provides the following functions:

- Translation of the 4GB logical address space into physical addresses
- Independent enable of Instruction and Data translation/protection
- Page level access control via the translation mechanism
- Software control of page replacement strategy
- Additional control over protection via zones
- Storage attributes for cache policy and speculative memory access control

The Translation Lookaside Buffer (TLB) is the hardware resource that controls translation and protection. It consists of 64 entries, each specifying a page to be translated. The TLB is fully associative, meaning that a given page entry can be placed anywhere in the TLB. The translation function of the MMU occurs pre-cache; therefore, PPC403GC cache tags and indexing use physical addresses.

The establishment and replacement of TLB entries is completely managed by software. This gives system software significant flexibility in implementing a custom page replacement strategy. For example, several entries in the TLB could be reserved via software for globally accessible static mappings, reducing TLB thrashing or translation delays. Several instructions are available for system software to manage TLB entries. These instructions are privileged and require the software to be executing in supervisor state. TLB instructions are provided to move TLB entry fields to and from GPRs.

The MMU divides logical storage into pages. Eight page sizes (1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M) are simultaneously supported, such that, at any given time, the TLB may contain entries for any combination of page sizes. In order for a logical to physical translation to exist, a valid entry for the page containing the logical address must be in the TLB. Addresses for which no TLB entry exists cause TLB-Miss exceptions.

As a performance enhancement, there are 4 instruction-side TLB entries kept in a shadow array managed by hardware. This array is intended to avoid TLB contention with load/store operations. Replacement and invalidation of these entries is managed completely by hardware. No system software action is required. The shadow array can be thought of as a

level 1 instruction-side TLB, with the main TLB serving as a level 2 instruction-side and a level 1 data-side TLB.

When address translation is enabled, the translation mechanism provides a basic level of protection. Physical addresses not mapped by a page entry are inaccessible when translation is enabled. Read access is implied by the existence of the valid entry in the TLB. The EX and WR bits in the TLB entry further define levels of access for the page, by permitting Execute and Write access, respectively. The Zone Protection Register (ZPR) adds additional flexibility by allowing the capability to override TLB access controls (for example, the ZPR provides a means of denying read access to application programs). This facility is used by system software to classify storage by type and easily change access by type without manipulation of individual TLB entries.

When translation is disabled, a simple memory protection mechanism in the MMU, referred to as the Protection Bounds mechanism, allows system software to manage two programmable regions of memory. Each region is specified as a multiple of aligned 4KB pages. Once enabled, the protection mechanism prevents write access to these regions, generating a precise protection exception if a write to the region is attempted.

1.3.1.3 Instruction Cache Unit (ICU)

The instruction cache is used to minimize access time for frequently executed instructions. Instruction lines from cacheable memory regions can be prefetched into the ICU. The ICU buffers a line of four 32-bit words from the bus interface unit, prior to placing the line into the cache during each fill.

The ICU contains a two-way set-associative 2KB cache memory. Each of the two sets is organized as 64 lines of 16 bytes each.

The ICU can send two instructions (eight bytes) per cycle to the execution unit, enabling branch and condition-register-logical instructions to execute in the same cycle with other instructions without emptying the instruction pipeline.

A separate bypass path is available to handle cache-inhibited instructions and to improve performance during line fill operations.

1.3.1.4 Data Cache Unit (DCU)

The data cache unit is used to minimize access latency for frequently used data in external memory. The cache features byte-writeability to improve the performance of byte and halfword store operations.

The DCU contains a two-way set-associative 1KB copy-back cache memory. Each of the two cache sets is organized as 32 lines of 16 bytes each.

The DCU manages data transfers between external memory and the general-purpose registers. DCU operations employ a copy-back (store-in) strategy to update cached data and maintain coherency with external memory. A copy-back cache updates only the data cache, not external memory, during store operations. A cache line is written to external

memory only if the line has been modified and is to be removed from the cache to make room for other data.

A separate bypass path is available to handle non-cacheable loads and to improve performance during line fill operations.

1.3.2 Bus Interface Unit (BIU)

The BIU provides the control functions for all data transfers between external memory or the internal On-Chip Peripheral Bus (OPB) and the processor core. In addition, the BIU arbitrates access for the DMA controller to the external bus and OPB bus for peripheral transfers. The BIU also supports attachment of an external bus master, allowing the external master to use the internal DRAM controller in the BIU to access DRAM.

1.3.2.1 External Interfaces to DRAM, SRAM, ROM, and I/O

The BIU provides a 32-bit external data bus, supporting direct connection of 8-, 16-, and 32-bit memory banks and I/O devices. A 24-bit external address bus is provided, plus four low-order byte-enables for a total of 64MB addressability per device or memory bank. In addition, eight decoded device-select signals are available, giving 512MB total addressability for a combination of DRAM, SRAM, ROM, and memory-mapped I/O devices. A maximum of four memory banks can be configured as DRAM. The other four configurable interfaces must be programmed as SRAM, ROM, or I/O devices.

Bank Registers are provided to configure the properties of each of the eight banks. These configurable properties include device width; setup, wait, and hold cycle timings; device-paced or programmed wait states; device size (1MB-64MB); DRAM refresh and precharge rates; DRAM page mode; and others. See Chapter 3 (Memory and Peripheral Interface) for a complete discussion of the external memory interfaces.

1.3.2.2 RISC Core Interface

The interface from the BIU to the RISC core includes a 32-bit data bus to the ICU and DCU for line fills, a 32-bit data bus from the DCU for line flushes, and separate 32-bit internal address buses from the ICU and DCU. Line fills and flushes are handled as burst transfers of 16 bytes, with four bytes transferred to or from the ICU or DCU per cycle. If the external device is less than 32 bits wide, data is packed or unpacked within the BIU so all data transfers between the BIU and the core are 32 bits wide (unless the request is for a byte or half-word).

It is selectable whether line fills occur target word first or occur sequentially. Target-word-first line fills allow the ICU or DCU to receive the required instruction or data as quickly as possible, and allow the instruction stream to move on with minimum probability of stalling the processor. The BIU reads words up to the end of the 16-byte line and then wraps back to the first word of the line, continuing until the line is filled.

Sequential line fill reads words sequentially into the 16-byte line, starting with the first word of the line, regardless of where the target address was on the line.

Halfword and word data transfer requests from the RISC core are address-aligned on the operand-size boundary. Unaligned data transfer requests from the executing program are detected and cause an alignment exception, thus allowing software to emulate the unaligned access.

1.3.2.3 DMA Interface

The interface between the BIU and the DMA controller consists of a 32-bit address bus and related control signals. The data flow for DMA transfers is handled by the BIU, which does data buffering and packing/unpacking if it is required during a DMA transfer.

1.3.2.4 On-Chip Peripheral Bus Interface

The On-chip Peripheral Bus (OPB) is an internal 32-bit address and 32-bit data bus for on-chip peripheral integration. In the PPC403GC, the serial port is the only device attached to it.

The OPB architecture supports direct attachment of 8-, 16-, and 32-bit devices, using a dynamic bus sizing scheme. All transfers are device-paced, with time-out detection handled within the BIU. The bus supports transfer rates of up to one transfer (four bytes) per cycle.

Transfers from the processor or cache are received by the BIU from the ICU or DCU; these result in transfers on the OPB when the addresses correspond to the OPB address space. In addition, DMA operations to devices on the OPB can be performed, with the device communicating either as a peripheral under control of the DMA controller or as a memory or MMIO device under control of the BIU.

1.3.2.5 External Bus Master Interface

The PPC403GC provides support for an external bus master to take control of the external bus from the BIU. While in this mode, the BIU monitors the external bus master interface for requests to the DRAM that is controlled by the DRAM controller internal to the BIU. If the external master makes such a transfer request, the BIU handles the control signals to the DRAM, such as the $\overline{\text{RAS}}$ / $\overline{\text{CAS}}$ lines and the output and write enables, leaving the address and data buses under control of the external master.

The BIU supports external DRAM transfers of byte, halfword, and word sizes, as well as burst transfers at the width of the memory device. Page crossing is detected internally and the BIU adds the appropriate precharge time and $\overline{\text{RAS}}$ cycle necessary to cross into the next page. Page crossing is detected only as the page boundary is approached sequentially from below (in steps of byte, half-word, or word size that match the programmed bus width). The BIU also handles DRAM refresh, holding off external master burst transfers until refresh is completed.

While an external master has control of the bus, the BIU does not monitor for requests to the SRAM that is controlled by the SRAM controller internal to the BIU. The BIU places the SRAM control lines in a high impedance state, so that external logic or the external master may drive those control lines.

1.3.3 DMA Controller

The DMA controller provides four independent channels, each of which can perform three types of data transfers. Buffered DMA transfers data between memory and a peripheral, passing the data to a buffer in the BIU and then back out. Fly-by DMA passes data between memory and a peripheral without passing through the BIU data buffer. Memory-to-memory transfers use the BIU data buffer, with the option of device-paced memory-to-memory DMA to interface between memories of varying access times. Fly-by and memory-to-memory transfers can operate in burst mode.

Each DMA channel has an associated control register, a source address register, a destination address register, a transfer count register, and a chained count register. Chaining, which allows uninterrupted transition from one DMA transfer to the next, is supported on each DMA channel. Peripheral set-up cycles, wait cycles, and hold cycles can be programmed into each DMA channel control register. The DMA status register holds the status of all four channels.

Each DMA channel uses three signals: $\overline{\text{DMAR}}$, $\overline{\text{DMAA}}$, and $\overline{\text{EOT/TC}}$. An external peripheral may request a DMA transaction by asserting $\overline{\text{DMAR}}$. If the DMA channel is enabled, the PPC403GC responds to the DMA request by asserting an active level on the $\overline{\text{DMAA}}$ pin when the DMA transfer begins. The PPC403GC DMA controller holds an active level on the $\overline{\text{DMAA}}$ pin while the transfer is in progress.

The signal $\overline{\text{DMADXFER}}$ is available to support burst-mode fly-by transfers between memory and peripheral. $\overline{\text{DMADXFER}}$ is active in the last cycle of each transfer (hence it is active continuously during single-cycle transfers). $\overline{\text{DMADXFER}}$, when ORed with the processor input clock SysClk, yields an appropriate signal to indicate that data has been latched (on writes to memory) or that data is available to be latched (on reads from memory).

If the DMA channel is operating in buffered mode, the PPC403GC reads data from a memory location or peripheral device, buffers the data, and then transfers the data to a peripheral device or memory location. If the DMA channel is operating in fly-by mode, the PPC403GC provides the address and control signals for the memory and $\overline{\text{DMAA}}$ is used as the read/write transfer strobe for the peripheral. When $\overline{\text{EOT/TC}}$ is programmed as an input, an external device may terminate the DMA transfer at any time by putting an active level on this pin. When programmed as an output, the $\overline{\text{EOT/TC}}$ pin is set to an active level by the PPC403GC to signify that the DMA transaction is in its last transfer cycle. The DMA control register is used to program the direction of the $\overline{\text{EOT/TC}}$ pins.

Software initiated memory-to-memory transfers are supported. If the memory has burst capability, this is supported by line-burst memory-to-memory mode, which transfers data in 16-byte bursts.

1.3.4 Asynchronous Interrupt Controller

The PPC403GC includes an on-chip interrupt controller. This controller accepts the asynchronous interrupt inputs and presents them to the core as a single interrupt signal. The sources of asynchronous interrupts are external signals, DMA channels, the serial port,

and the JTAG/debug unit.

Each of the five non-critical external interrupt inputs is individually configurable as negative or positive polarity, and as edge-triggered or level-sensitive. This configuration is programmed in the input/output configuration register (IOCR) in the BIU.

An external critical interrupt pin is also provided. This pin is always negative active, and edge triggered.

The interrupt controller provides an enable register to allow system software to enable or disable interrupts from each source, whether on- or off-chip. Each input from an interrupt source is represented in a status register and associated with the corresponding bit of an enable register. Any sources which are active and enabled are collected and sent to the RISC core as a single interrupt input. The interrupt mechanism within the core then prioritizes this asynchronous interrupt input with all other exception sources such as timer interrupts or program exceptions.

1.3.5 Serial Port

The PPC403GC serial port is capable of supporting RS232 standard serial communication, as well as high-speed execution (bit speed at a maximum of one-sixteenth of the SysClk processor clock rate). The clock which drives the serial port can be derived from SysClk or from an external clock source at the TimerClk pin (maximum of one-half the SysClk rate).

The PPC403GC serial port contains many features found only on advanced communications controllers, including the capability of being a peripheral for DMA transfers. An internal loopback mode supports diagnostic testing without requiring external hardware. An auto echo mode is included to retransmit received bits to the external device. Auto-resynchronization after a line break and false start bit detection are also provided, as well as operating modes that allow the serial port to react to handshaking line inputs or control handshaking line outputs without software interaction.

The serial port may also be programmed for use as a pattern generator. In this mode, the serial port transmitter may be used for pulse width modulation.

1.3.6 Debug Port

Debug is supported by the JTAG port. The IEEE 1149.1 Test Access Port, commonly called JTAG (Joint Test Action Group), is an architectural standard which is described in IEEE standards document 1149.1. The standard provides a method for accessing internal facilities on a chip using a four or five signal interface. The JTAG port was originally designed to support scan-based board testing. The JTAG boundary-scan register allows testing of circuitry external to the chip, primarily the board interconnect. Alternatively, the JTAG bypass register can be selected when no other test data register needs to be accessed during a board-level test operation.

The PPC403GC JTAG port has been enhanced to allow for the attachment of a debug tool such as the RISCWatch[™] 400 product from IBM Microelectronics. Through the JTAG test

access port, a debug workstation can single-step the processor and interrogate internal processor state to facilitate software debugging. The enhancements comply with the IEEE 1149.1 specification for vendor-specific extensions, and are therefore compatible with standard JTAG hardware for boundary-scan system testing.

1.3.7 Data Types

PPC403GC operands are bytes, halfwords, or words. Multiple words or strings of bytes can be transferred using the load/store multiple/string instructions. CPU instructions operate on signed and unsigned numbers.

The address of a multi-byte operand is always the lowest memory address occupied by that operand. Byte ordering may be selected to be either Big Endian (the lowest memory address of an operand contains its most significant byte) or Little Endian (the lowest memory address of an operand contains its least significant byte). Endian mode can be set to automatically change when entering and leaving an interrupt handler.

1.3.8 Register Set Summary

The PPC403GC contains general purpose registers (GPRs), special purpose registers (SPRs), the machine state register (MSR), the condition register (CR), and device control registers (DCRs). In addition, while not strictly considered registers, memory-mapped input/output (MMIO) is available for peripheral control. See Chapter 12 (Register Summary) for a detailed register listing.

1.3.8.1 General Purpose Registers

The PPC403GC contains 32 GPRs, each of 32 bits. The contents of these registers can be transferred from memory using load instructions and stored to memory using store instructions. GPRs are specified as operands in many PPC403GC instructions.

1.3.8.2 Special Purpose Registers

SPRs contain status and control for resources within the RISC core. Only the Time Base High User-mode (TBHU), the Time Base Low User-mode (TBLU), the Fixed-point Exception (XER), the Link (LR), and the Count (CTR) registers can be accessed by problem-state programs. Access to all other SPRs is privileged. SPRs are accessed using **mtspr** and **mfspr** instructions.

1.3.8.3 Machine State Register

The PPC403GC contains a 32-bit machine state register (MSR). The contents of a GPR can be written to the MSR using the **mtmsr** instruction, and the MSR contents can be read into a GPR using the **mfsr** instruction.

1.3.8.4 Condition Register

The PPC403GC contains a 32-bit condition register (CR). Instructions are provided to perform logical operations on CR bits and to test CR bits.

1.3.8.5 Device Control Registers

Device control registers exist outside the RISC core and contain status and controls for the BIU, DMA controller, and asynchronous interrupt controller. DCRs are accessed using **mtdcr** and **mfdcr** instructions. Access to all DCRs is restricted to supervisor-mode programs.

1.3.8.6 Memory Mapped Input/Output

Control registers associated with devices on the On-Chip Peripheral Bus are Memory Mapped I/O registers. On PPC403GC, the serial port is controlled by MMIO.

1.3.9 Addressing Modes

The addressing modes of the PPC403GC allow efficient retrieval and storage of data that is closely spaced in memory. These modes relieve the processor from repeatedly loading a GPR with an address for each piece of data regardless of the proximity of the data in memory.

In the base plus displacement addressing mode, the effective address is formed by adding a displacement to a base address contained in a GPR (or to an implied base of 0). The displacement is an immediate field in the instruction.

In the indexed addressing mode, the effective address is formed by adding an index contained in a GPR to a base address contained in a GPR (or to an implied base of 0).

The base plus displacement and the indexed addressing modes also have a “with update” mode. In the “with update” mode, the effective address calculated for the current operation is saved in the base GPR, and can be used as the base in the next operation.

Programming Model

2.1 Chapter Overview

This chapter covers a wide range of topics of potential interest to a programmer using the PPC403GC. These topics include:

- Memory organization, beginning on page 2-2.
- Commonly used registers, beginning on page 2-6. Other registers are covered in their respective topic chapters (for example, DMA registers in the DMA chapter). All registers are summarized in chapter 12.
- Data types and alignment, beginning on page 2-16.
- Little Endian mode, beginning on page 2-19.
- Instruction queue, beginning on page 2-25.
- Branching control, beginning on page 2-26.
- Speculative fetching, beginning on page 2-29.
- Privileged-mode operation, beginning on page 2-34.
- Context, execution, and storage synchronization, beginning on page 2-37.
- Instructions summarized by category, beginning on page 2-42. Also see chapter 11 (details of each instruction), appendix A (alphabetical short-form description of each instruction, and each extended mnemonic), and appendix B (short-form descriptions of instructions, by category).

2.2 Memory Organization and Addressing

2.2.1 Double-Mapping

The processor core of the PPC403GC has a 32 bit address bus, hence a 4 gigabyte (GB) address space. The processor interfaces to external memory and on-chip peripherals via a Bus Interface Unit (BIU). The BIU imposes addressing restrictions. Perhaps the most fundamental of these restrictions: the high-order address bit 0 is not presented to external memory, and also not decoded by the BIU for determining chip select usage (for SRAM) or RAS usage (for DRAM). Therefore, a given block of external memory can be addressed with bit 0 either set or cleared; there are two addresses available for every external memory location. Address bit 0 does participate in determining the storage attributes of any address (via the real-mode storage attribute registers such as the DCCR and the SGR, or via the TLB entries).

In virtual mode (address translation enabled), it is possible to set up multiple effective addresses, each with its own set of storage attributes, that all map to the same real address. Thus, the same region of real memory can be accessed in multiple fashions (cacheable and non-cacheable, for example) simply by setting up multiple entries in the TLB. Because of this, when in virtual mode, it is not necessary to rely on the dual-mapping that results from the BIU ignoring bit 0.

In real mode (address translation disabled), the storage attribute control registers (DCCR, ICCR, DCWR, and SGR) exercise memory attribute control on regions on 128 megabyte boundaries. Address bit 0 does participate in the selection of storage attributes via the storage attribute control registers. Therefore, there are exactly two effective addresses (in real mode) which can be used to access the same memory, specifically, a pair of addresses that differ only in bit 0. It is possible to program any of these registers such that its attribute is applied for one of these two addresses, and not for the other. Here is an example use of double-mapping with separate cacheability control based on the programming of the DCCR and ICCR:

Cacheability regions are on 128 megabyte boundaries. For this example, assume the region from 0x7000 0000 to 0x77FF FFFF, which would be external SRAM.

This region would also be addressed as 0xF000 0000 to 0xF7FF FFFF. The same external memory would be the target, but the cacheability need not be the same. Assume that the DCCR and the ICCR have been set up such that data accesses to 0x7000 0000 to 0x77FF FFFF are non-cacheable, while both data and instruction accesses to 0xF000 0000 to 0xF7FF FFFF are cacheable.

To access external memory hardware, one of the Bank Registers must be programmed. Suppose for this example that one megabyte of external SRAM memory has been defined to the PPC403GC at locations from 0x7000 0000 to 0x700F FFFF (and therefore also accessible as 0xF000 0000 to 0xF00F FFFF) by programming Bank Register

BR1 appropriately. That would produce a Chip Select signal ($\overline{CS1}$) on any **external** access to addresses in that one megabyte range. Note that accesses to these addresses may not produce Chip Select if the address is cacheable, because the access may be satisfied **internally** to the PPC403GC by the cache.

Suppose that only part of the one megabyte range is populated by normal program memory from which one would read instructions and read and write data. Cacheable access is correct and normal for such memory, so it would be accessed using addresses in the 0xF000 0000 to 0xF00F FFFF range.

Suppose further that part of the one megabyte range is occupied by memory-mapped hardware of some type, or by shared memory. In such cases, it is mandatory that Chip Select occurs, so that accesses reach the actual hardware, not a cache image of the hardware. Therefore, non-cacheable access is appropriate, using addresses in the 0x7000 0000 to 0x700F FFFF range.

The program can interleave accesses to the cacheable area of this example (instruction fetching, data reads or writes) with access to the non-cacheable area (data reads or writes) with zero time devoted to switching of the cacheability attributes. The access mode is determined solely by the address used.

2.2.2 Supported Memory

Up to 256 megabytes (MB) of external SRAM may be attached (ROM and MMIO are treated as SRAM). Simultaneously, up to 256 MB of DRAM may be attached. As shown in Figure 2-1 (PPC403GC Address Map) and as explained in Section 2.2.1 and in Section 3.6 (Address Bit Usage) on page 3-7, a 256 MB SRAM region and a 256 MB DRAM region are each double-mapped into the 4 GB memory space, consuming a total of 1 GB.

The remaining 3.0 GB is reserved. A portion of it has been set aside for use by on-chip peripherals. This processor family is intended to support custom ASICs which may make use of this large internal memory space. For the PPC403GC, the Serial Port controller is the only peripheral within this address space. Portions of the 3.0 GB may be made available for external use by future implementations with different external bus configurations.

2.2.3 Storage Attribute Regions

Storage attributes in general include cacheability, cache write-thru policy, guarding against speculative memory accesses, and memory coherency in multi-processor environments. The PPC403GC provides control mechanisms for each of these attributes (since PPC403GC does not support multi-processor environments, the support for memory coherency is without effect).

When the PPC403GC is operating in virtual mode (address translation is enabled), each of these attributes is controlled by the WIMG fields in the TLB entry for each memory page. W controls write-thru policy, I controls cacheability, M controls memory coherency, and G controls guarding against speculative accesses. The size of memory pages, and hence the size of storage attribute regions, may be any of eight choices (1K, 4K, 16K, 64K, 256K,

1M, 4M, or 16M). Multiple sizes may be in effect simultaneously, on different pages.

When the PPC403GC is operating in real mode (address translation is disabled), storage attributes are controlled by storage attribute control registers: DCWR (write-thru policy), DCCR (cacheability for loads and stores), ICCR (cacheability for fetches), and SGR (guarding against speculative accesses). In this mode, the size of storage attribute regions is fixed at 128M.

In real mode, the address map of the PPC403GC is divided into 32 storage attribute regions. Each region is 128 megabytes, defined by address bits A0:A4. Everywhere within a given 128 megabyte region, the storage attributes are the same. The attributes in each different 128 megabyte region are set independently.

2.2.4 Physical Address Map

The memory map of the PPC403GC is divided by the type of memory accessible. This is defined by address bits A1:A3. If A1:A3 = 0b000, the attached memory must be external DRAM. If A1:A3 = 0b111, the attached memory must be external SRAM (or equivalent, like ROM or memory-mapped hardware). As described in Section 2.2.1, each of these memory-type regions appears twice in the memory m0ap. Figure 2-1 shows that two pairs of DRAM regions (0, 1, and 16,17) physically overlap and that two pairs of SRAM regions (14,15 and 30, 31) physically overlap. The region numbering in Figure 2-1 is based upon 128M boundaries.

Four regions (0, 1, and 16,17) have been reserved for external DRAM devices. Within the DRAM regions a total of four banks of devices are supported (the total of DRAM and SRAM banks may not exceed eight). Each DRAM bank supports direct attachment of devices up to 64 MB. Each bank can be configured for 8, 16, or 32-bit devices. For individual DRAM banks, the bank size, the bank starting address, the number of wait states, the RAS to CAS timing, RAS precharge cycles, the use of an external address multiplexer (required for external bus masters), and the refresh rate are user programmable.

Four regions (14,15 and 30, 31) have been reserved for external SRAM devices. Within the SRAM regions a total of eight banks of devices are supported (the total of DRAM and SRAM banks may not exceed eight). Each SRAM bank supports direct attachment of devices up to 64 MB. Each bank can be configured for 8, 16, or 32-bit devices. For each SRAM bank, the bank size, the bank starting address, number of wait states, and timings of the chip selects, write enables, and output enables are all user programmable.

Writing to the DRAM and SRAM bank registers allows the user to change the characteristics of individual memory banks. Reading the contents of the SRAM and DRAM bank registers allows the user to examine the current configuration of each bank. The contents and use of the SRAM and DRAM bank registers are discussed in Chapter 3.

Addresses for which A1:A3 are neither 0b000 nor 0b111 are either internal to the PPC403GC (on the On-chip Peripheral Bus) or they are reserved. Twenty-four regions (2-13, and 18-29) are in this category.

Figure 2-1 shows the memory map for the PPC403GC and the device types supported in

each region. Each region in the figure is a storage attribute region, as described above.

ADDRESS	ADDRESS REGIONS	FUNCTION
0xFFFF FFFF 0xF000 0000	Regions 30 - 31	SRAM/ROM/PIA Access (double-mapping of 14-15)
0xEFFF FFFF 0x9000 0000	Regions 18 - 29	Reserved
0x8FFF FFFF 0x8000 0000	Regions 16 - 17	DRAM Access (double-mapping of 0-1)
0x7FFF FFFF 0x7000 0000	Regions 14 - 15	SRAM/ROM/PIA Access (double-mapping of 30-31)
0x6FFF FFFF 0x4800 0000	Regions 9 - 13	Reserved
0x47FF FFFF 0x4000 0000	Region 8	Reserved and Serial Port
0x3FFF FFFF 0x1000 0000	Regions 2 - 7	Reserved
0x0FFF FFFF 0x0000 0000	Regions 0 - 1	DRAM Access (double-mapping of 16-17)

Figure 2-1. PPC403GC Address Map

2.3 PPC403GC Register Set

With the exception of the serial port registers, all registers contained in the PPC403GC are architected as 32-bits. The registers can be grouped into categories based on their access mode: general purpose registers (GPR), device control registers (DCR), special purpose registers (SPR), the machine state register (MSR), the condition register (CR), and memory mapped input/output registers (MMIO). Some of the more commonly used registers are discussed in this chapter. Other registers are covered in their respective topic chapters (for example, DMA registers in the DMA chapter). All registers are summarized alphabetically in chapter 12, with cross-references to the pages where further discussion may be found.

For all registers with fields marked as **reserved**, the **reserved** fields should be written as **zero** and read as **undefined**. That is, when writing to a register with a **reserved** field, write a zero to that field. When reading from a register with a **reserved** field, ignore that field.

Good coding practice is to perform the initial write to a register with **reserved** fields as described in the preceding paragraph, and to perform all subsequent writes to the register using a read-modify-write strategy. That is, read the register, alter desired fields with logical instructions, and then write the register.

2.3.1 General Purpose Registers

The PPC403GC contains 32 General Purpose Registers (GPRs), each of 32 bits. The contents of these registers can be transferred from memory via load instructions and stored to memory via store instructions. GPRs are also referenced by most integer instructions. See Table 12-1 on page 12-2 for the numbering of the GPRs.

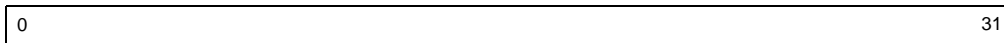


Figure 2-2. General Purpose Register (R0-R31)

0:31	General Purpose Register data
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2.3.2 Special Purpose Registers

Special Purpose Registers (SPRs) are on-chip registers that exist architecturally inside the processor core and are part of the PowerPC Embedded Architecture. They are accessed with the **mtspr** (move to special purpose register) and **mfspr** (move from special purpose register) instructions which are defined in Chapter 11.

Special purpose registers control the use of the debug facilities, the timers, the interrupts, the protection mechanism, real-mode storage attributes, the memory management unit, and other architected processor resources. Table 12-2 on page 12-2 shows the mnemonic,

name, and number for each SPR.

The only SPRs that are not privileged are the Time Base High User-mode (TBHU), the Time Base Low User-mode (TBLU), the Link Register (LR), the Count Register (CTR), and the Fixed-point Exception Register (XER). All other SPRs are privileged for both read and write. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion.

Table 2-1. Special Purpose Register (SPR) List

CDBCR				see Chapter 8
CTR				see Chapter 2
DAC1	DAC2	DBCR	DBSR	see Chapter 10
DCCR	DCWR			see Chapter 9
DEAR	ESR	EVPR		see Chapter 6
IAC1	IAC2			see Chapter 10
ICCR				see Chapter 9
ICDBDR				see Chapter 8
LR				see Chapter 2
PBL1	PBL2	PBU1	PBU2	see Chapter 9
PID				see Chapter 9
PIT				see Chapter 6
PVR				see Chapter 2
SGR	SMR			see Chapter 9
SPRG0	SPRG1	SPRG2	SPRG3	see Chapter 2
SRR0	SRR1	SRR2	SRR3	see Chapter 6
TBHI	TBHU	TBLO	TBLU	see Chapter 6
TCR	TSR			see Chapter 6
XER				see Chapter 2
ZPR				see Chapter 9

2.3.2.1 Count Register (CTR)

CTR is loaded via the **mtspr** instruction. After loading, the register may be used in two ways. The register contents may be a loop count, which can be automatically decremented and tested by certain branch instructions. This construct yields zero-overhead looping. Alternatively, the register contents may be a target address for the branch-to-counter instruction. This allows absolute-addressed branching to anywhere in the 4 GB memory space.

0	31
---	----

Figure 2-3. Count Register (CTR)

0:31	Count	(Count for branch conditional with decrement. Address for branch-to-counter instructions)
------	-------	--

2.3.2.2 Link Register (LR)

LR may be loaded via the **mtspr** instruction, or via any of the branch instructions which have the LK bit set to 1. These branch instructions load LR with the address of the instruction following the branch instruction (4 + address of the branch instruction), so that the LR contents may be used as a return address for a subroutine which was entered via the branch. In either case, the register contents may be a target address for the branch-to-link-register instruction. This allows absolute-addressed branching to anywhere in the 4 GB memory space.

In all cases where the contents of LR represent an instruction address, LR_{30:31} are ignored and assumed zero, since all instructions must be word-aligned. However, if LR is written using **mtspr** and then read using **mfspir**, all 32 bits will be returned as written.

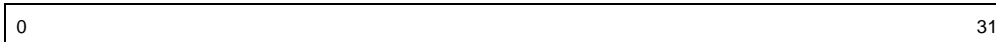


Figure 2-4. Link Register (LR)

0:31	Link Register Contents	If (LR) represents an instruction address, then LR _{30:31} should be zero.
------	------------------------	---

2.3.2.3 Processor Version Register (PVR)

The PVR is a read-only register which identifies the processor by Version and Revision numbers. Software may be written which has features that depend on an exact identification of the target processor. Such software can select the proper features dynamically by examining the PVR.

The 16-bit Version (comprised of the FAM and MEM fields) is assigned by the PowerPC Architecture process.

The 16-bit Revision (comprised of the CORE and CHIP fields) is assigned by the chip implementer.

The PVR may be read using the **mfspir** instruction. The PVR is privileged. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion.

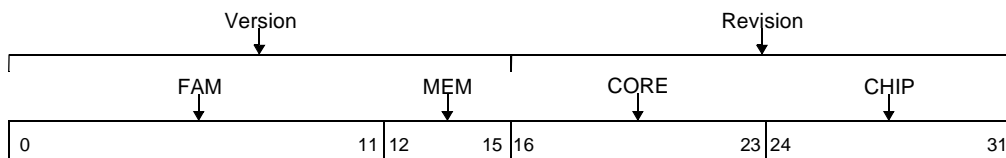


Figure 2-5. Processor Version Register (PVR)

0:11	FAM	Processor Family. Indicates a particular PowerPC family, such as 4xx or 6xx.	= 0x002 for the 4xx family.
12:15	MEM	Family Member. Indicates a specific family member, such as 403 or 601.	= 0 for PPC403GC
16:23	CORE	Core Revision. Identifies a specific implementation and revision of the processor core.	= 0x02 for PPC403GC
24:31	CHIP	Chip Revision. Identifies a specific configuration and revision of a chip that uses the processor core defined by the FAM/MEM/CORE fields.	= 0x00 for PPC403GC

2.3.2.4 Special Purpose Register General (SPRG0-SPRG3)

These four registers are provided as temporary storage locations. As an example, a supervisor routine may save the contents of a GPR to an SPRG, and later restore the GPR from it. This would be faster than the standard save/restore to a memory location. These registers are written using the **mtspr** instruction and read using the **mfspr** instruction.

The SPRGs are privileged for both read and write. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion.

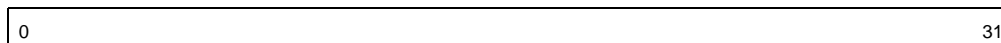


Figure 2-6. Special Purpose Register General (SPRG0-SPRG3)

0-31		General Data	(Privileged user-specified, no hardware usage.)
------	--	--------------	---

2.3.2.5 Fixed Point Exception Register (XER)

Overflow and carry conditions from arithmetic operations are recorded in the XER. The Summary Overflow (SO) field does not indicate that an overflow occurred on the most recent arithmetic operation, but that one occurred sometime in the past. The only ways to reset SO to zero are via the **mtspr** instruction or the **mcrxr** instruction. The TBC field may be loaded (using **mtspr**) with a byte count for load-string and store-string instructions.

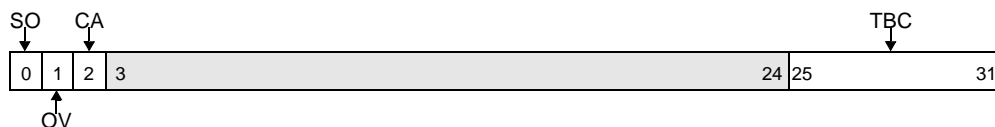


Figure 2-7. Fixed Point Exception Register (XER)

0	SO	Summary Overflow 0 - no overflow has occurred 1 - overflow has occurred	May be <u>set</u> by mtspr or by arithmetic instructions with the "OE" option (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr or by mcrxr .
1	OV	Overflow 0 - no overflow has occurred 1 - overflow has occurred	May be <u>set</u> by mtspr or by arithmetic instructions with the "OE" option (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr , by mcrxr , or by arithmetic instructions with the "OE" option.
2	CA	Carry 0 - carry has not occurred 1 - carry has occurred	May be <u>set</u> by mtspr or by arithmetic instructions that update CA (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr , by mcrxr , or by arithmetic instructions that update CA.
3:24		reserved	
25:31	TBC	Transfer Byte Count	Used by lswx and stswx . Written by mtspr specifying the XER.

Table 2-2. XER-Updating Arithmetic Instructions

Update XER[CA]		Update XER[OV] Set XER[SO]	
addc	subfc	addo	mullwo
addc.	subfc.	addo.	mullwo.
addco	subfco	addco	nego
addco.	subfco.	addco.	nego.
adde	subfe	addeo	subfo
adde.	subfe.	addeo.	subfo.
addeo	subfeo	addmeo	subfco
addeo.	subfeo.	addmeo.	subfco.
addic	subfic	addzeo	subfeo
addic.	subfme	addzeo.	subfeo.
addme	subfme.	divwo	subfmeo
addme.	subfmeo.	divwo.	subfmeo.
addmeo	subfmeo.	divwuo	subfzeo
addmeo.	subfze.	divwuo.	subfzeo.
addze	subfze.		
addze.	subfzeo		
addzeo	subfzeo.		
addzeo.			

There are numerous special cases associated with the use of the XER bits. The detailed discussion which follows should help clarify these:

XER[SO] Summary overflow; set to 1 when an instruction causes XER[OV] to be set to 1, except for **mtspr(XER)**, which sets XER[SO,OV] to the value of bit positions 0 and 1 in the source register, respectively. Once set, XER[SO] is not reset until an **mtspr(XER)** is executed with data that explicitly puts a 0 in the SO bit, or until an **mcrxr** instruction is executed.

XER[OV] Overflow; set to indicate whether or not an instruction that updates XER[OV] produces a result that “overflows” the 32-bit target register. XER[OV] = 1 indicates overflow. For arithmetic operations, this occurs when an operation has a carry-in to the high-order bit of the instruction result that does not equal the carry-out of the high-order bit (that is, the exclusive-or of the carry-in and the carry-out is 1).

The following instructions set XER[OV] differently. The specific behavior is indicated in the instruction descriptions.

- Move instructions
mcrxr, **mtspr(XER)**
- Multiply and divide instructions

XER[CA]

mullwo, mullwo., divwo, divwo., divwuo, divwuo.

Carry; set to indicate whether or not an instruction that updates XER[CA] produces a result that has a carry-out of the high-order bit. XER[CA] = 1 indicates a carry.

The following instructions set XER[CA] differently. The specific behavior is indicated in the instruction descriptions.

- Move instructions

mcrxr, mtspr(XER)

- Shift-algebraic operations

sraw, srawi

XER[TBC]

Transfer Byte Count.

This field provides a byte count for the **lswx** and **stswx** instructions.

This field is updated by **mtspr(XER)**.

2.3.3 Condition Register (CR)

The Condition Register (CR) is a 32-bit register that is broken into eight 4-bit fields as shown in Figure 2-8. The CR reflects the results of some operations (as indicated in the instruction descriptions in Chapter 11). The CR provides a mechanism for testing and conditional branching. Fields of the CR can be set in one of the following ways:

- Specified fields can be set by a move to the CR from a GPR (**mtcrf** instruction).
- A specified field can be set by a move to the CR from another CR field (**mcrf** instruction) or from the XER (**mcrxr** instruction).
- CR field 0 can be set as the implicit result of various fixed point instructions.
- A specified field can be set as the result of a Compare instruction.

In addition to the field-oriented instructions discussed above, instructions are provided to perform logical operations upon individual CR bits (the CR-logical instructions), and to test individual CR bits (the branch conditional instructions).

If any of the fields CR0-CR7 are set as the result of a Compare instruction, then the interpretation of the bits in that field will be as discussed in Section 2.3.3.1. Field CR0 is altered implicitly by numerous instructions, hence the interpretation of CR0 is discussed further in Section 2.3.3.2 below.

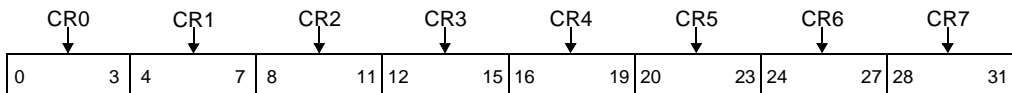


Figure 2-8. Condition Register (CR)

0:3	CR0	Condition Register Field 0
4:7	CR1	Condition Register Field 1
8:11	CR2	Condition Register Field 2
12:15	CR3	Condition Register Field 3
16:19	CR4	Condition Register Field 4
20:23	CR5	Condition Register Field 5
24:27	CR6	Condition Register Field 6
28:31	CR7	Condition Register Field 7

2.3.3.1 CR Fields after Compare Instructions

Compare instructions are used to compare the values of two 32-bit numbers. There are two types of compare instructions, **arithmetic** and **logical**, which are distinguished by the interpretation given to the 32-bit numbers. For **arithmetic** compares, the numbers are considered to be signed (two's complement, where 31 bits are significant; hi-order bit is a sign bit). For **logical** compares, the numbers are considered to be unsigned (all 32 bits are significant; no sign bit). As an example, consider the comparison of 0 with 0xFFFF FFFF. In an **arithmetic** compare, 0 is larger; in a **logical** compare, 0xFFFF FFFF is larger.

Compare instructions can direct the results of the comparison to any CR field, via the BF field (bits 6:8) of the instruction. The first data operand of a compare instruction is always the contents of a GPR. The second data operand can be the contents of a GPR, or can be immediate data derived from the IM field (bits 16:31) of the instruction. See the instruction descriptions (page 11-36 through page 11-39) for precise details. After a compare, the CR field specified by BF is updated and can be interpreted as follows:

LT (bit 0)	The first operand is less than the second operand.
GT (bit 1)	The first operand is greater than the second operand.
EQ (bit 2)	The first operand is equal to the second operand.
SO (bit 3)	Summary overflow; a copy of XER[SO].

2.3.3.2 The CR0 Field

After compare instructions with BF field of 0, the CR0 field is interpreted as shown in Section 2.3.3.1 above. The “dot” forms of arithmetic and logical instructions also alter CR0 (see Table C-2, CR Updating Instructions, on page C-10 for a list of instructions that alter the condition register). After most fixed-point instructions that update CR[CR0], the bits of CR0 are interpreted as follows:

LT (bit 0)	Less than 0; set if the high-order bit of the 32-bit result is 1.
GT (bit 1)	Greater than 0; set if the 32-bit result is non-zero and the high-order bit of the result is 0.
EQ (bit 2)	Equal to zero; set if the 32-bit result is 0.
SO (bit 3)	Summary overflow; a copy of XER[SO] at instruction completion.

The CR[CR0]_{LT, GT, EQ} subfields are set as the result of an algebraic comparison of the instruction result to 0, regardless of the type of instruction that sets CR[CR0]. If the instruction result is 0, the EQ subfield is set to 1. If the result is not 0, whether the LT subfield or the GT subfield is set depends on the value of the high order bit of the instruction result.

With respect to the updating of CR[CR0], the high-order bit of an instruction result is considered a sign bit, even for instructions that produce results that are not usually thought of as signed. For example, logical instructions such as **and.**, **or.**, and **nor.** update

CR[CR0]_{LT,GT,EQ} via this arithmetic comparison to 0, although the result of such a logical operation is often not actually an arithmetic result.

Note that if an arithmetic overflow occurs, the “sign” of an instruction result indicated by CR[CR0]_{LT,GT,EQ} may not represent the “true” (infinitely precise) algebraic result of the instruction that set CR0.

For example, if an **add.** instruction adds two large positive numbers and the magnitude of the result cannot be represented as a two’s-complement number in a 32-bit register, an overflow occurs and CR[CR0]_{LT,SO} are set, although the infinitely precise result of the add is positive.

Adding the largest 32-bit twos-complement negative number, x'80000000', to itself results in an arithmetic overflow and x'00000000' is recorded in the target register. CR[CR0]_{EQ,SO} is set, indicating a result of 0, but the infinitely precise result is negative.

The CR[CR0]_{SO} subfield is a copy of XER[SO]. Instructions that do not alter the XER[SO] bit cannot cause an overflow, but even for these instructions CR[CR0]_{SO} is a copy of XER[SO].

Some instructions set CR[CR0] differently or do not specifically set any of the subfields. These instructions include:

- Compare instructions

cmp, cmpi, cmpl, cmpli

- CR logical instructions

crand, crandc, creqv, crnand, crnor, cror, crorc, crxor, mcrf

- Move CR instructions

mtcrf, mcrxr

- **stwcx**

The instruction descriptions provide detailed information about how the listed instructions alter CR[CR0]. Table C-2 on page C-10 summarizes the operations that affect the CR.

2.3.4 Machine State Register

The PPC403GC contains one 32-bit Machine State Register (MSR). The contents of this register can be written from a GPR via the move to machine state register (**mtmsr**) instruction and read into a GPR via the move from machine state register (**mfmsr**) instruction. The MSR[EE] bit (External Interrupt Enable) may be set/cleared atomically using the **wrtee** or **wrteei** instructions. The MSR controls important chip functions such as the enabling/disabling of interrupts and debugging exceptions. Power management is possible through software control of the Wait State Enable bit within the MSR. The MSR contents are automatically saved, altered, and restored by the interrupt-handling mechanism. For further discussion, see Section 6.2 (Exception Handling Registers) on page 6-8.

2.3.5 Device Control Registers

Device Control Registers (DCRs) are on-chip registers that exist architecturally outside the processor core and thus are not actually part of the PowerPC Embedded Architecture. They are accessed with the **mtdcr** (move to device control register) and **mfdcr** (move from device control register) instructions which are defined in Chapter 11.

DCRs control the use of the DRAM/SRAM banks, the I/O configuration, and the DMA channels. They also hold status/address for bus errors. Table 12-3 on page 12-4 shows the mnemonic, name, and number for each DCR.

All DCRs are privileged for both read and write. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion.

Table 2-3. Device Control Register (DCR) List

BEAR	BESR			see Chapter 6
BR0	BR1	BR2	BR3	see Chapter 3
BR4	BR5	BR6	BR7	see Chapter 3
DMACC0	DMACC1	DMACC2	DMACC3	see Chapter 4
DMACR0	DMACR1	DMACR2	DMACR3	see Chapter 4
DMACT0	DMACT1	DMACT2	DMACT3	see Chapter 4
DMADA0	DMADA1	DMADA2	DMADA3	see Chapter 4
DMASA0	DMASA1	DMASA2	DMASA3	see Chapter 4
DMASR				see Chapter 4
EXISR	EXIER	IOCR		see Chapter 6

2.3.6 Memory Mapped Input/Output Registers

The registers associated with peripherals on the On-Chip Peripheral Bus (OPB) are Memory-Mapped I/O (MMIO) registers. The serial port on the PPC403GC is such a peripheral. Load and store instructions are used to access all MMIO registers. Table 12-4 on page 12-6 shows the mnemonic, name, and number (address) for each Memory Mapped I/O Register.

Table 2-4. Memory-Mapped I/O (MMIO) List

SPLS	SPHS	BRDH	BRDL	see Chapter 7
SPCTL				see Chapter 7
SPRC	SPTC	SPRB	SPTB	see Chapter 7

2.4 Data Types and Alignment

PPC403GC operands are bytes, halfwords, or words. Figure 2-9 shows the data types and their bit and byte definitions.

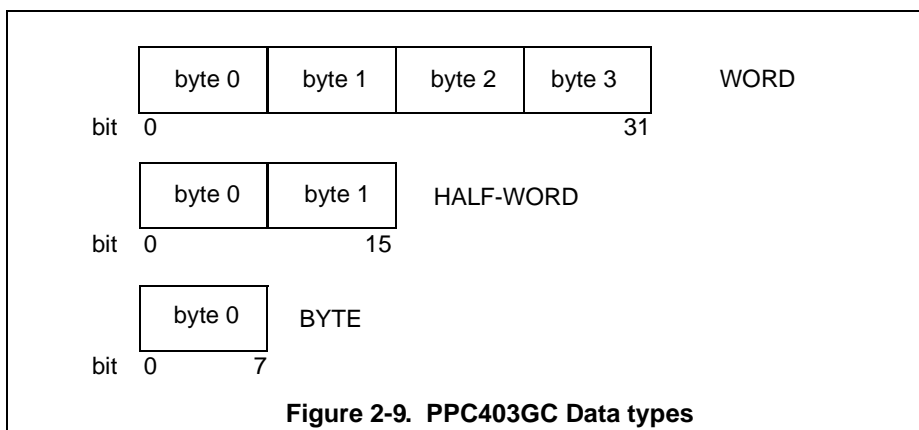
The address of a multi-byte operand is always the lowest memory address occupied by that operand. Byte ordering may be selected to be either Big Endian (the lowest memory

address of an operand contains its most significant byte) or Little Endian (the lowest memory address of an operand contains its least significant byte). See Section 2.5, Little Endian Mode, on page 2-19 for discussion of the related behavior of PowerPC processors.

All instructions are word objects, and are word-aligned (the byte address is divisible by 4).

Data at an operand location may be represented in two's complement notation or in unsigned integer format. This is independent of alignment issues.

The method of calculating the effective address (EA) for each of the Storage Reference and Cache Control instructions is detailed in the description of those instructions. See Chapter 11 (Instruction Set).



2.4.1 Alignment for Storage Reference Instructions

Data is moved to and from storage by the Storage Reference instructions (see page 2-43). All data operands referenced by the Storage Reference instructions (loads/stores) must be aligned on a corresponding operand-size boundary. In addition, the effective address calculated by each load/store instruction must also reference the corresponding operand-size boundary.

The data targets of instructions are of type and alignment that depend upon the instruction. Load-word and store-word instructions have word targets, word aligned. Load-multiple-word and store-multiple-word instructions may have multiple consecutive targets, each of which is a word, and word aligned.

Load-halfword and store-halfword instructions have halfword targets, halfword aligned.

Load-byte and store-byte instructions have byte targets, byte aligned (that is, any alignment). Load-string and store-string instructions may have multiple consecutive targets, each of which is a byte.

An alignment exception is taken for a Storage Reference instruction whenever the calculated EA does not match the required data alignment for that instruction, indicating either a coding error involving improper data alignment and/or address calculation, or the need for software emulation of the unaligned access in the exception handler.

When an attempt is made to perform any store-type access (including **dcbz** but not **dcbi** nor **dccci**) to a region where the write-thru data caching is indicated (either by the DCWR in real mode or by the W-bit of the TLB entry in virtual mode), an alignment exception will be taken. The PPC403GC data cache does not provide write-thru operation. The alignment exception provides the opportunity for system software to emulate the write-thru function.

2.4.2 Alignment for Cache Control Instructions

The Cache Control instructions (see page 2-46) also have EA's calculated during their execution. These instructions operate on cache lines, which are four words in length. For these instructions, the last four bits of the EA are ignored, so no alignment restrictions exist.

An alignment exception is taken when attempting to execute the **dcbz** instruction either to a non-cacheable area or to a write-thru area, in order to allow software to emulate the **dcbz** instruction semantics in the exception handler. This exception results from the non-cacheable or write-thru nature of the storage, not from the EA alignment.

2.5 Little Endian Mode

Objects may be loaded from or stored to memory in byte, halfword, word, or (for implementations that include hardware for double-precision floating point or for 64-bit instructions, but not PPC403GC) doubleword units. For a particular data length, the loading and storing operations are symmetric; a store followed by a load of the same data object will yield an unchanged value. There is no information in the process about the order in which the bytes which comprise the multi-byte data object are stored in memory.

If a stored multi-byte object is probed by reading its component bytes one at a time using load-byte instructions, then the storage order may be perceived. If such probing shows that the lowest memory address contains the most significant byte of the multi-byte scalar, the next higher sequential address the next least significant byte, and so on, then the multi-byte object is stored in **Big-Endian** form. Alternatively, if the probing shows that the lowest memory address contains the least significant byte of the multi-byte scalar, the next higher sequential address the next most significant byte, and so on, then the multi-byte object is stored in **Little-Endian** form.

To understand Endian handling in a PowerPC system, it is very important to keep in mind the probing concept discussed above. In PowerPC, the objective is for a processor to be able to run an Endian-sensitive program (one that tests its long data objects by probing them with shorter data objects) and have that program obtain its expected results. This is a processor-centric view. Memory, as perceived by the processor using its various load and store instructions, can be set to appear to be either Little-Endian or Big-Endian (under control of MSR bits that will be discussed in Section 2.5.2). If the PowerPC system is configured as Little-Endian, and the memory is probed by an external means (for example, a logic analyzer directly examining the memory), it will be seen that the memory is NOT organized as Little-Endian (nor as Big-Endian). This has consequences that will be discussed further when using memory-mapped hardware or when using external-master data transfers with other processors.

A PowerPC system can implement the appearance of Little-Endian behavior only within aligned doublewords (eight byte blocks whose lowest address is an integer multiple of eight). The memory location after a store of byte, halfword, word, or doubleword objects (using byte, halfword, word, or doubleword store instructions, respectively) is illustrated in the following example borrowed from the PowerPC Architecture reference. Note that the doubleword object is included here for reference only; the PPC403GC does not support doubleword operations.

Consider this C-language structure:

```
struct {
    int a;           /* 0x1112_1314 word */
    long long b;     /* 0x2122_2324_2526_2728 doubleword */
    char *c;         /* 0x3132_3334 word */
    char d[7];       /* 'A','B','C','D','E','F','G' array of bytes */
    short e;         /* 0x5152 halfword */
    int f;           /* 0x6162_6364 word */
} s;
```

In Big-Endian, which is the reset-default state of a PowerPC processor, memory looks as follows after the structure is stored (**in these tables, addresses are shaded, data is not**):

11	12	13	14				
00	01	02	03	04	05	06	07
21	22	23	24	25	26	27	28
08	09	0A	0B	0C	0D	0E	0F
31	32	33	34	'A'	'B'	'C'	'D'
10	11	12	13	14	15	16	17
'E'	'F'	'G'		51	52		
18	19	1A	1B	1C	1D	1E	1F
61	62	63	64				
20	21	22	23				

In a true Little-Endian memory system (NOT in the memory of a PowerPC processor in Little-Endian mode), memory looks as follows after the structure is stored:

14	13	12	11				
00	01	02	03	04	05	06	07
28	27	26	25	24	23	22	21
08	09	0A	0B	0C	0D	0E	0F

34	33	32	31	'A'	'B'	'C'	'D'
10	11	12	13	14	15	16	17
'E'	'F'	'G'		52	51		
18	19	1A	1B	1C	1D	1E	1F
64	63	62	61				
20	21	22	23				

With a PowerPC processor in Little-Endian mode, memory looks as follows after the structure is stored:

				11	12	13	14
00	01	02	03	04	05	06	07
21	22	23	24	25	26	27	28
08	09	0A	0B	0C	0D	0E	0F
'D'	'C'	'B'	'A'	31	32	33	34
10	11	12	13	14	15	16	17
		51	52		'G'	'F'	'E'
18	19	1A	1B	1C	1D	1E	1F
				61	62	63	64
20	21	22	23				

Note that, viewed from memory, the last case is neither Big-Endian nor Little-Endian. It will now be shown how this case was obtained, and how this case appears to be a Little-Endian memory, when viewed from the processor.

In the Little-Endian mode, the three low-order bits of the address are altered at the interface between the processor and the memory subsystem. The processor is “unaware” of these alterations; all address computation activities of the processor (incrementing of the Instruction Address Register, computation of Effective Address, computation of new address on Load-with-Update instructions, etc) proceed unchanged from the Big-Endian case. The alteration, described in Table 2-5, depends upon the size of data object being transferred.

Table 2-5. Address Alteration in Little-Endian Mode

Data length (bytes)	Address alteration	Type of load or store
1	XOR with 0b111	byte
2	XOR with 0b110	halfword
4	XOR with 0b100	word
8	no change	doubleword (for reference only)

Here is a verbal description of the behavior of the alteration, in all cases restricted to the bytes within an aligned doubleword:

- Words reverse position (within the doubleword) for all word, halfword, and byte accesses.
- Halfwords reverse position (within each word) for all halfword and byte accesses.
- Bytes reverse position (within each halfword) for all byte accesses.

That this results in a Little-Endian system as viewed from the processor will now be shown using the first word in the example structure for illustration. A word-store of 0x1112_1314 in a (true) Little-Endian system would produce the following in memory:

14	13	12	11
00	01	02	03

This may be probed with a word-load, two halfword-loads, or four byte-loads. These results would be produced:

Word-load from address 00	0x1112_1314
Halfword-load from address 00	0x1314
Halfword-load from address 02	0x1112
Byte-load from address 00	0x14
Byte-load from address 01	0x13
Byte-load from address 02	0x12
Byte-load from address 03	0x11

For the PowerPC Little-Endian mode to be considered equivalent to the true Little-Endian memory, the values returned to the processor must match those shown for the true Little-Endian case.

A word-store of 0x1112_1314 in a PowerPC system in Little-Endian mode would produce the following in memory:

11	12	13	14
04	05	06	07

This may be probed with a word-load, two halfword-loads, or four byte-loads. These results would be produced:

Word-load from (processor) address 00	hits memory address 04	0x1112_1314
Halfword-load from (processor) address 00	hits memory address 06	0x1314
Halfword-load from (processor) address 02	hits memory address 04	0x1112
Byte-load from (processor) address 00	hits memory address 07	0x14
Byte-load from (processor) address 01	hits memory address 06	0x13
Byte-load from (processor) address 02	hits memory address 05	0x12
Byte-load from (processor) address 03	hits memory address 04	0x11

This example shows that the processor sees precisely the correct results for a Little-Endian system. The processor is unaware that the data was stored in “unexpected” places in memory.

2.5.1 Non-processor Memory Access in Little-Endian

The system designer must be aware of this “unexpected” relocation of data in the memory system of a PowerPC processor in Little-Endian mode, if it is desired to equip the system with any feature which observes the memory directly (without going through the processor). As a specific example, suppose that it is desired to have a memory-mapped hardware device at address 00 in the Little-Endian system of our structure-storage example. The expected result would be

14	13	12	11				
00	01	02	03	04	05	06	07

The actual result would be

				11	12	13	14
00	01	02	03	04	05	06	07

If the device were physically connected at memory address 00, a word-store to address 00 would miss the device entirely. If the device were connected at memory address 04, then it would be accessed by a word-store to address 00, but the bytes would be in the wrong order. Anyone connecting directly to the memory system of a PowerPC processor in Little-Endian mode (not accessing the data via the processor) must keep such effects in mind.

Another class of example does not involve memory-mapped hardware. If code or data is brought into memory using either DMA or the External Bus Master, that information reaches memory directly, without application of Little Endian address processing by the PPC403GC. If the PPC403GC is to process that code or data as Little Endian, it is necessary that the information be pre-ordered at its source to take into account the PowerPC Little Endian address modifications that have been described in this section.

2.5.2 Control of Endian Mode

The selection of Endian mode in which the PPC403GC operates is controlled by two bits in the Machine State Register, MSR[LE] and MSR[ILE]. The current operational mode of the processor is described by MSR[LE]. If MSR[LE] = 1, the processor is executing in Little-Endian mode, otherwise it is in Big-Endian mode.

When the processor takes an interrupt, the MSR value prior to the interrupt is saved in either SRR1 or SRR3, depending on the type of interrupt. Then the contents of the Interrupt Little Endian bit, MSR[ILE], replaces the contents of the Little Endian mode bit, MSR[LE]. Therefore, the PPC403GC can automatically switch Endian modes when entering an interrupt handler. On leaving the interrupt handler, using an *rfi* or *rfci* instruction, as appropriate, the original value of MSR[LE] will be restored from SRR1 or SRR3. Hence, PPC403GC can also automatically switch Endian modes when leaving an interrupt handler. This mode-switching capability makes it reasonable for an operating system written in one Endian mode to support application programs written in the other mode.

The PPC403GC resets to Big-Endian mode, MSR[LE] = 0 and MSR[ILE] = 0.

2.6 Instruction Queue

Some of the discussion in this manual requires the definition of the elements of the PPC403GC instruction queue. See Figure 2-10. Instructions reach the queue via the Instruction Cache unit, regardless of cacheability. Instructions immediately drop to the lowest available queue location. If the queue was previously empty, an entering instruction will drop directly to decode (DCD). By convention, the passage of an instruction from DCD to one of the main execution units (EXE) is referred to as Dispatch.

Superscalar operation requires the presence of at least two instructions in the queue. If superscalar operation takes place, it occurs via the passage of the second instruction from the IQ1 stage to the limited-function execution unit (EXE*). This passage is conventionally referred to as Folding. PPC403GC requires in-order execution, therefore it is required that Dispatch of the predecessor instruction in DCD occur simultaneously with the Folding of the instruction in IQ1.

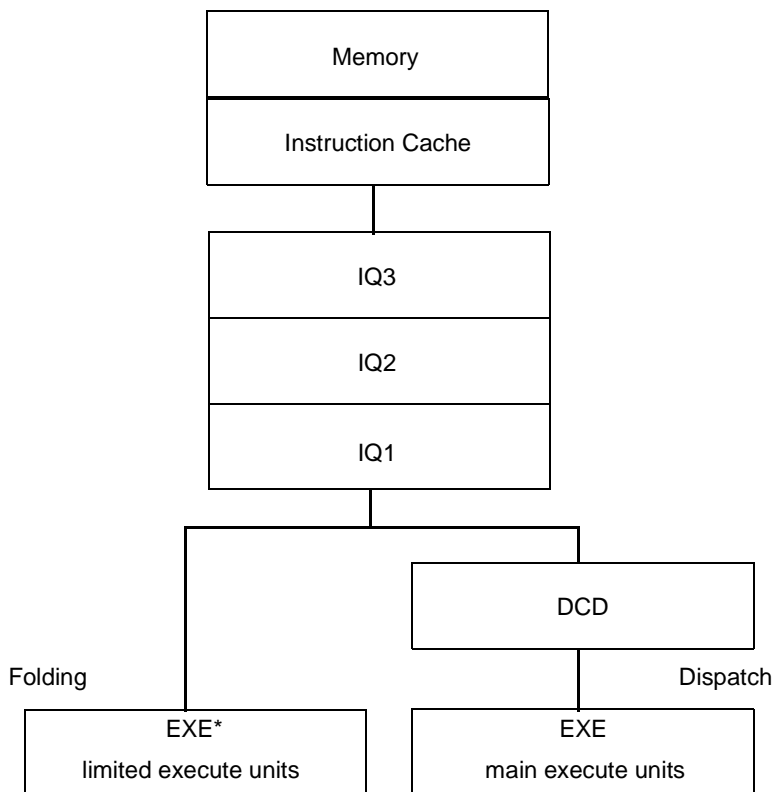


Figure 2-10. PPC403GC Instruction Queue

2.7 Branching Control

2.7.1 AA Field on Unconditional Branches

The unconditional branches (**b**, **ba**, **bl**, **bla**) carry the displacement to the branch target address as a 26 bit value (the 24 bit LI field right-extended with two zeroes). This displacement is always regarded as a signed 26-bit number, hence it covers a range of ± 32 megabytes. For the relative (AA=0) forms (**b**, **bl**), the target address is the Current Instruction Address (the address of the branch instruction) plus the (signed) displacement.

For the absolute (AA=1) forms (**ba**, **bla**), the target address is Zero plus the (signed) displacement. If the sign bit (LI[0]) is zero, the displacement is naturally interpreted as the actual target address. If the sign bit is one, the address is “below zero” (wraps to high memory). For example, if the displacement is 0x3FF FFFC (the 26-bit representation of negative four), the target address is 0xFFFF FFFC (zero minus four bytes, or four bytes from the top of memory).

2.7.2 AA Field on Conditional Branches

The conditional branches (**bc**, **bca**, **bcl**, **bcla**) carry the displacement to the branch target address as a 16 bit value (the 14 bit BD field right-extended with two zeroes). This displacement is always regarded as a signed 16-bit number, hence it covers a range of ± 32 kilobytes. For the relative (AA=0) forms (**bc**, **bcl**), the target address is the Current Instruction Address (the address of the branch instruction) plus the (signed) displacement.

For the absolute (AA=1) forms (**bca**, **bcla**), the target address is Zero plus the (signed) displacement. If the sign bit (BD[0]) is zero, the displacement is naturally interpreted as the actual target address. If the sign bit is one, the address is “below zero” (wraps to high memory). For example, if the displacement is 0xFFFFC (the 16-bit representation of negative four), the target address is 0xFFFF FFFC (zero minus four bytes, or four bytes from the top of memory).

2.7.3 BI Field on Conditional Branches

Conditional branch instructions may optionally test one bit of the Condition Register. The bit to be tested (bit 0-31) is specified by the value of the BI field. The content of the BI field is meaningless unless bit 0 of field BO is zero.

2.7.4 BO Field on Conditional Branches

Conditional branch instructions may optionally test one bit of the Condition Register. The option is selected if BO[0]=0; if BO[0]=1, the CR does not participate in the branch condition test. If selected, the condition is satisfied (branch can occur) if CR[BI]=BO[1].

Conditional branch instructions may optionally decrement the Count Register (CTR) by one, and after the decrement, test the CTR value. The option is selected if BO[2]=0. If selected, BO[3] specifies the condition that must be satisfied to allow a branch to occur. If BO[3]=0,

then CTR \neq 0 is required for a branch to occur. If BO[3]=1, then CTR=0 is required for a branch to occur.

If BO[2]=1, the contents of CTR are left unchanged, and the CTR does not participate in the branch condition test.

Table 2-6 summarizes the usage of the bits of the BO field. BO[4] will be further discussed in Section 2.7.5.

Table 2-6. Bits of the BO Field

BO Bit	Description
BO[0]	Condition Register Test Control 0 - test CR bit specified by BI field for value specified by BO[1] 1 - do not test CR
BO[1]	Condition Register Test Value 0 - if BO[0]=0, test for CR[BI]=0 1 - if BO[0]=0, test for CR[BI]=1
BO[2]	Counter Test Control 0 - decrement CTR by one, then test CTR for value specified by BO[3] 1 - do not change CTR, do not test CTR
BO[3]	Counter Test Value 0 - if BO[2]=0, test for CTR \neq 0 1 - if BO[2]=0, test for CTR=0
BO[4]	Branch Prediction Reversal 0 - apply standard branch prediction 1 - reverse the standard branch prediction

Table 2-7 lists specific BO field contents, and the resulting actions. In Table 2-7, “z” represents a mandatory value of zero, and “y” is a branch prediction option discussed in Section 2.7.5.

Table 2-7. Conditional Branch BO Field

BO Value	Description
0000y	Decrement the CTR, then branch if the decremented CTR \neq 0 and CR[BI]=0.
0001y	Decrement the CTR, then branch if the decremented CTR=0 and CR[BI]=0.
001zy	Branch if CR[BI]=0.
0100y	Decrement the CTR, then branch if the decremented CTR \neq 0 and CR[BI]=1.
0101y	Decrement the CTR, then branch if the decremented CTR=0 and CR[BI]=1.
011zy	Branch if CR[BI]=1.
1z00y	Decrement the CTR, then branch if the decremented CTR \neq 0.
1z01y	Decrement the CTR, then branch if the decremented CTR=0.
1z1zz	Branch always.

2.7.5 Branch Prediction

In the PPC403GC, the fetcher attempts to bring instructions from memory (which may be slow) into the instruction queue (where they are immediately available for use) in advance of actual need. Conditional branches present a problem to the fetcher; the branch may be taken, or the branch may simply fall through to the next sequential instruction. The fetcher must predict which will occur, in advance of the actual execution of the branch instruction. The fetcher's decision may be wrong, in which case time will be lost while the correct instruction is brought into the instruction queue. This section discusses how the fetcher's decision (called a **branch prediction**) is made, and how software may alter the prediction process.

The “standard” branch prediction is defined as follows:

Predict the branch to be taken if $((\text{BO}[0] \ \& \ \text{BO}[2]) \mid s) = 1$,

where “s” is bit 16 of the instruction (the sign bit of the displacement for all **bc** forms, and zero for all **bclr** and **bcctr** forms).

$(\text{BO}[0] \ \& \ \text{BO}[2]) = 1$ only when the conditional branch is in fact testing nothing (“branch always” condition). Obviously, the branch should be predicted taken for this case.

If the branch is testing anything, then $(\text{BO}[0] \ \& \ \text{BO}[2]) = 0$ and the standard prediction is controlled entirely by “s”. The standard prediction for this case derives from considering the relative form of **bc**, used at the end of a loop to control the number of times that the loop is executed. The branch is taken on all passes through the loop except the last one, so it is best if the branch is predicted taken. The branch target is the beginning of the loop, so the branch displacement is negative and $s=1$. Because this situation is so common, the standard prediction is that the branch is taken if $s=1$.

If branch displacements are positive, then $s=0$, and the branch is predicted not taken. If the branch instruction is any form of **bclr** or **bcctr** except the “branch always” form, then $s=0$, and the branch is predicted not taken.

There is a peculiar consequence of this prediction algorithm for the absolute forms of **bc** (**bca** and **bcla**). As discussed in Section 2.7.2, if $s=1$, the branch target is in high memory. If $s=0$, the branch target is in low memory. Since these are absolute-addressing forms, there is no reason to treat high and low memory differently. Nevertheless, for the high memory case the standard prediction is taken, and for the low memory case the standard prediction is not taken.

$\text{BO}[4]$ is the **prediction reversal** bit. If $\text{BO}[4]=0$, then the standard prediction will be applied. If $\text{BO}[4]=1$, then the reverse of the standard prediction will be applied. For those cases in Table 2-7 where $\text{BO}[4]=y$, it is permissible for software to reverse the standard prediction. This should only be done when the standard prediction is likely to be wrong. Note that for the “branch always” condition, reversal of the standard prediction is not allowed.

PowerPC Architecture specifies that PowerPC assemblers will provide a means for the programmer to conveniently control branch prediction. For any conditional branch mnemonic, a suffix may be added to the mnemonic to control prediction, as follows:

- + Predict branch to be taken
- Predict branch to be not taken

For example, **bcctr+** will cause BO[4] to be selected appropriately to force the branch to be predicted taken.

2.8 Speculative Fetching

The following is an explanation of the PPC403GC pre-fetching mechanism, and the situations which software needs to be aware of to protect against errant accesses to “sensitive” memory or I/O devices.

2.8.1 Architectural Overview of Speculative Accesses

PowerPC Architecture permits implementations to perform speculative accesses to memory, either for instruction fetching, or for data loads. A speculative access is defined as an access which is not required by a sequential execution model. For example, pre-fetching instructions beyond an unresolved conditional branch is a speculative fetch -- if the actual branch direction is in the opposite direction from the prediction, the actual program execution never needed the instructions from the predicted path. The same would be true for a super-scalar implementation that performs out-of-order execution, if it attempts to speculatively execute a load instruction that is past an unresolved branch.

PowerPC Architecture also defines the concept of “guarded” storage, from which speculative accesses are not allowed (actually, they are only allowed under certain circumstances, such as the storage is a “hit” in the cache).

The processor must determine the branch path that will be taken, prior to accessing guarded instructions or data beyond the branch. The specification of the “guarded” attribute of storage is typically controlled via the virtual memory mechanism (eg, a page table entry).

There are several situations in which it is necessary to protect the system from the processor making speculative accesses. The simplest example can be illustrated by considering a memory-mapped I/O device, with a status register that is automatically reset when it is read. Serial ports are an example, where reading the receive buffer auto-resets the RxRdy bit in the status register. In situations such as these, if the processor speculatively loads from these registers, when an intervening branch or interrupt may take the program flow away from the code containing the load instruction and then back again, upon return and re-reading the status register, the wrong result will be obtained. Similarly, if the program code itself exists in memory “right next to” the I/O device (say code goes from 0x0000 0000 to 0x0000 0FFF, and the I/O device is at 0x0000 1000), then pre-fetching past the end of the code can “hit” the I/O device.

Another example of a need for guarded storage: protection from pre-fetching past the “end” of memory. The fetcher will attempt to keep fetching past the last valid address, likely getting machine checks on the fetches to invalid addresses. While these machine checks do not actually get reported as an exception unless execution is attempted of the instruction at the

invalid address, some systems may still suffer from the attempt to access such an invalid address (eg, an external memory controller may log the error).

Thus, the PowerPC Architecture provides for a mechanism by which the system software can protect those areas of the address space that are mapped to sensitive devices, guarding them from accesses that are not actually required by the program flow. Note that for cachable storage, the Architecture specifically allows for the accessing of the entire cache block containing the referenced storage, even in guarded storage.

2.8.2 Speculative Accesses on PPC403GC

The PPC403GC does not perform out-of-order execution, thus speculative loads are never executed.

The PPC403GC provides means to control speculative instruction fetching. In real mode, speculative fetching may be disallowed on 128 megabyte regions by the Storage Guarded Register. When a region is guarded (speculative fetching disallowed) in real mode, pre-fetching is blocked until the pipeline is empty. The fetch request is completely resolved (no longer speculative) before it is issued. There is a considerable performance penalty for executing from guarded storage in real mode, so guarding should be used only when required. Note that, following a reset, the PPC403GC is operating in real mode with all of storage guarded.

In virtual mode, speculative fetching may be disallowed on memory page size regions, which can be as small as 1 kilobytes or as large as 16 megabytes, via the “G” bit in the TLB entry. When a region is guarded in virtual mode, pre-fetch to the region will cause an Instruction Storage Exception. Pre-fetch to unguarded regions will proceed normally.

It is possible for designers of system software and system hardware to avoid problems from speculative fetching, without using the Guarded Storage attributes described above. In order to guard against speculative instruction fetches to sensitive devices without using the Guarded attribute, the designers need to be aware of a number of details regarding the PPC403GC implementation.

2.8.2.1 Pre-Fetch Distance from an Unresolved Branch

The instruction pre-fetcher will speculatively fetch down the predicted branch path (either taken or sequential). The maximum distance down an unresolved branch path that the fetcher can access is 7 instructions (28 bytes). This corresponds to the unresolved branch in the DCD stage of the instruction queue (see Section 2.6 on page 2-25 for discussion of the instruction queue), with the next 3 instructions in IQ1-IQ3, and the Instruction Cache Unit (ICU) requesting the 4th subsequent instruction, which is at the start of a cache line containing the 4th-7th instructions, all of which get accessed if the address is cachable. If the address is non-cachable (as controlled by the ICCR), then only the 1st - 4th instructions get accessed.

2.8.2.2 Pre-Fetch of Branch to Count / Branch to Link

When predicting that a Branch to the CTR or a Branch to the LR (**bctr** / **blr**) instruction will be taken, the fetcher will not attempt to access the address contained in the CTR/LR if there is a CTR/LR updating instruction ahead of the branch in the instruction queue, up to DCD (see Section 2.6 for discussion of the instruction queue). In such a case, the fetcher recognizes that the CTR/LR contains “wrong” data, which could be some random value leftover from a previous use of the CTR/LR, and could likely be pointing to an invalid address or an I/O device. In these cases, the fetcher will wait for the CTR/LR updating instruction to enter EXE, at which time the “correct” CTR/LR contents are known, and the fetcher can use this value in the prediction. In this manner, the fetcher can be prevented from speculatively accessing a completely “random” address. The fetcher will only access up to 7 instructions down the sequential path past an unresolved branch or down the taken path of a relative or absolute branch, or at the contents of the CTR/LR when the CTR/LR contents are known to be correct.

2.8.2.3 Fetching Past an Interrupt-Causing / Returning Instruction

There is an exception to the rule regarding the branch to CTR/LR: if there is a **bctr** / **blr** instruction just past one of the interrupt-causing or interrupt-returning instructions **sc**, **rfi**, or **rftci**, the fetcher does not prevent speculatively fetching past these instructions. In other words, these interrupt-causing and interrupt-returning instructions are not considered by the fetcher when deciding whether to predict down a branch path. Instructions after an **rftci**, for example, are considered to be on the determined branch path. To understand the implications of this situation, consider the code sequence:

```

handler:  aaa
          bbb
          rfi

subroutine: bctr

```

When executing the interrupt handler, the fetcher doesn't recognize the **rftci** as a break in the program flow, and speculatively fetches the target of the **bctr**, which is really the first instruction of a subroutine that has not been called. Therefore, the CTR may contain an invalid pointer.

To protect against such a pre-fetch, the software should insert an unconditional branch hang (**b \$**) just after the **rftci**. This will prevent the hardware from pre-fetching the wrong “target” of the **bctr**.

Consider also the above code sequence, except the **rftci** instruction is replaced by an **sc** instruction. The purpose of the system call is to get the CTR initialized with the appropriate value for the **bctr** to branch to upon return from the system call. It is undesirable to use the same technique as **rftci**, since the **sc** handler is going to return to the instruction following the **sc**, which can't be a branch hang. Instead, software could put a **mtctr** just before the **sc**, putting a non-sensitive address in the CTR to be used as the prediction address prior to the

sc executing. An alternative would be to put a **mfctr/mtctr** between the **sc** and the **bctr**, with the **mtctr** again preventing the fetcher from speculatively accessing the address contained in the CTR prior to initialization.

2.8.2.4 Fetching Past **tw** or **twi** Instructions

The interrupt-causing instructions **tw** and **twi** do not require the special handling described in Section 2.8.2.3. These instructions are typically used by debuggers, which implement software breakpoints by substituting a trap instruction for whatever instruction was originally at the breakpoint address. In a code sequence **mtlr** followed by **blr** (or **mtctr** followed by **bctr**), replacement of **mtlr** (**mtctr**) by **tw** or **twi** would leave LR (CTR) uninitialized, so it would not be appropriate to fetch from the **blr** (**bctr**) target address. This situation is common, and the fetcher is designed to prevent the problem. No fetching to LR or CTR targets will occur while **tw** or **twi** is in the queue or in the EXE stage.

2.8.2.5 Fetching Past an Unconditional Branch

When an unconditional branch is in the pre-fetch queue, the fetcher will recognize that the sequential instructions following the branch are unnecessary. These sequential addresses will not be accessed from memory; instead, addresses at the branch target will be accessed.

Therefore, placing an unconditional branch just prior to the start of a sensitive address space (for example, at the “end” of a memory area that borders an I/O device) will guarantee that sequential fetching will not occur into that sensitive area.

2.8.2.6 Suggested Location of Memory-Mapped Hardware

The preferred method of protecting memory-mapped hardware from inadvertent access is to use virtual mode, with the hardware isolated to pages with $G = 1$. These pages may be as small as 1 KB. Code should never be included in these pages.

In real mode, the preferred protection method is to isolate memory-mapped hardware into regions which have been set as guarded via the SGR. Code should never be included in these regions. The disadvantage of this approach, compared to guarded pages in virtual mode, is that each real-mode guarded region consumes 128 MB of the address space.

Protection of memory-mapped hardware also can be achieved by proper positioning of code and hardware in the address space, as discussed below.

The dual-mapped SRAM regions of the PPC403GC operating in real mode (as discussed in Section 2.2.1) are illustrated in Table 2-8. The system designer has the option of mapping all of his I/O devices and all of his ROM and SRAM, anywhere into these regions. The BIU bank registers break the SRAM region into pieces ranging in size from 1MB to 64MB. All 8 BIU banks could be programmed as 1MB banks inside one 128MB region, or they can be mixed/matched as desired. Obviously, only two 64MB banks could be mapped into one of

the 128MB regions.

Table 2-8. SRAM Mapping

0x7000 0000 - 0x77FF FFFF (ICCR / DCCR / SGR bit 14)	128 Mbyte Region A
dual mapped as 0xF000 0000 - 0xF7FF FFFF (ICCR / DCCR / SGR bit 30)	
AND	
0x7800 0000 - 0x7FFF FFFF (ICCR / DCCR / SGR bit 15)	128 Mbyte Region B
dual mapped as 0xF800 0000 - 0xFFFF FFFF (ICCR / DCCR / SGR bit 31)	

One way to avoid the problem of cacheable instruction fetches colliding with I/O devices meant to be accessed as non-cacheable would be to put all ROM/SRAM code devices in the 128MB Region B, and put all I/O devices in the 128MB Region A. This allows for 128MB of actual SRAM (uses two BIU bank registers), and leaves six more BIU bank registers to select I/O devices in Region A.

If the system is setup in this way, addresses in Region A should only be used by load/store instructions accessing the I/O devices, so no speculative fetches should occur. Region A could be set as Guarded via the SGR; no performance penalty would result, since by design there is no possibility of pre-fetching from this region. Accesses in Region B would be for code and program data; speculative fetches in Region B can never hit addresses in Region A. Note that, using this hardware organization, the use of the SGR to protect Region A is completely redundant and optional.

The use of these regions may be reversed (code in Region A and I/O devices in Region B) if Region B is set as Guarded in the SGR. Pre-fetching from the top of Region A may attempt to speculatively access the bottom of Region B, but Guarding will prevent the pre-fetch from occurring. The performance penalty is slight, under the assumption that code infrequently executes near the top of Region A.

2.8.3 Summary

In summary, software needs to take the following actions to prevent speculative fetches from being made into sensitive data areas:

- Protect against “random” accesses to “bad” values in the LR/CTR on **blr** / **bctr** branches coming after **rfi/rfci/sc** instructions, putting an appropriate instruction(s) after the **rfi/rfci/sc** instruction. See 2.8.2.3 above.
- Protect against “running past” the end of memory into a bordering I/O device by putting an unconditional branch at the end of the memory area. See 2.8.2.5 above.

- Recognize that a maximum of 7 words (28 bytes) can be prefetched past an unresolved conditional branch, either down the target path or the sequential path. See 2.8.2.1 above.
- Of course, software should not code branches with known unsafe targets (either instruction-counter relative or LR/CTR based), on the assumption that they are “protected” by always guaranteeing that their direction is “not-taken”. The pre-fetcher is allowed to assume that if the branch “might” be taken, then it is safe to fetch down the target path.

2.9 Privileged Mode Operation

2.9.1 Background and Terminology

In the PowerPC architecture, there are a number of terms used to describe the concept of a “privileged” mode. The mode in which the processor is “privileged” to execute ALL instructions is referred to as both “Privileged Mode” and “Supervisor State”. The opposite state, in which the processor is NOT allowed to execute certain instructions, is called both “User Mode” and “Problem State”. These terms are used in pairs:

Privileged	Non-privileged
Privileged Mode	User Mode
Supervisor State	Problem State

The architecture uses the abbreviation “PR” for the MSR bit that controls the mode/state. When $MSR[PR] = 1$, the processor is in Problem State, and when $MSR[PR] = 0$, the processor is in Supervisor State.

2.9.2 MSR Bits and Exception Handling

The attempt to execute a privileged instruction while $MSR[PR] = 1$ will cause a privileged violation form of Program Exception (see Section 6.9 on page 6-32), and thus vector to offset 0x0700.

The current value of the $MSR[PR]$ bit is saved in the SRR1/SRR3 (along with all the other MSR bits) upon any interrupt, and the $MSR[PR]$ bit is then set to b'0', in all cases. This means that all exception handlers operate in Supervisor State, and can execute all instructions.

The Exception Syndrome Register (ESR) distinguishes different types of Program Exceptions. $ESR[PPR]$ is set when the exception was caused by a Privileged violation. Software is not required to clear this ESR bit.

2.9.3 Privileged Instructions

The following instructions are privileged instructions, and are not allowed to be executed when $MSR[PR] = 1$:

Table 2-9. Privileged Instructions

dcbi	
dccci	
dcread	
icbt	
iccci	
icread	
mfdcr	
mfmsr	
mfspr	For all SPRs except TBHU, TBLU, LR, CTR, and XER. See Section 2.9.4
mtdcr	
mtmsr	
mtspr	For all SPRs except LR, CTR, and XER. See Section 2.9.4
rfci	
rfi	
tlbia	
tlbre	
tlbsx	
tlbsx.	
tlbsync	
tlbwe	
wrtee	
wrteei	

2.9.4 Privileged SPRs

The only SPRs that are not privileged are the Time Base High User-mode (TBHU), the Time Base Low User-mode (TBLU), the Link Register (LR), Count Register (CTR), and the Fixed-point Exception Register (XER). TBHU and TBLU are valid only for read access. All other SPRs are privileged, for both read and write.

The PowerPC Architecture follows a convention that SPR numbers with the high-order bit of the 10-bit SPR number field being a b'1' are privileged. Because of the unusual coding of the SPR field in the machine code of the **mtspr** / **mfspr** instructions, this statement leaves room for confusion. The following example is intended to clarify the situation:

SPR number = 26 decimal, b'00000 11010', x'01A'

Assembler coding for this SPR: **mfspr r5,26**

The machine code for the instruction contains the following representation of the SPR number: b'11010 00000'. Note that the two 5-bit fields are reversed in the machine code, for compatibility with the earlier Power architecture.

Privileged SPRs are indicated by the high-order bit of the machine coding, which is actually the “middle” bit of the SPR number.

When considering the SPR number as a hexadecimal number, if the second digit of the three digit hex number is odd (ie, 1,3,5,7,9,B,D,F), then that SPR is privileged.

For the example above, the SPR number was x'01A'. The second hex digit ('1') is odd, therefore this SPR is privileged.

2.9.5 Privileged DCRs

The **mtdcr** / **mfdcr** instructions themselves are privileged, for all cases. Thus, all DCRs are privileged.

2.10 Context, Execution, and Storage Synchronization

The following is a discussion of synchronization in general, and of the supporting operations in the PPC403GC in particular. The reader is also referred to discussions in the PowerPC Architecture (section numbers refer to the First Edition of the PowerPC Architecture):

Section 5.7.1	Storage Access Ordering;
Section 7.2.1	Instruction Cache Instructions;
Section 7.3	Enforce In-order Execution of I/O Instruction;
Section 9.7	Synchronization;
Appendix L	Synchronization Requirements for Special Registers.

2.10.1 Context Synchronization

- 1) Context Synchronizing Operations in the PPC403GC include:

sc
rfi
rfci
exceptions in general (interrupts)
isync

- 2) Context synchronization requires that:

- A) All instructions prior to the context synch op complete in the context that existed prior to the context synch op; and
- B) All instructions after the context synch op complete in the context that exists after the context synch op.

- 3) “Context” as referred to above includes all processor context that is defined in the PowerPC Architecture. This includes the context of all architected registers, both GPRs and SPRs.

However, “context” specifically does not include memory contents. A context synch op does not guarantee that subsequent instructions “observe” the memory context established by previous instructions. To provide “memory-synchronization”, one must use either the **eiio** instruction (to guarantee memory access ordering on the processor issuing the **eiio**) or the **sync** instruction (to guarantee system memory ordering to all processors in a multiprocessor configuration). Note that on PPC403GC, **eiio** and **sync** are implemented identically. See Section 2.10.3 on page 2-40.

For PPC403GC and the PowerPC Embedded Controller family in general, the contents of DCRs (Device Control Registers, such as the DMA Control Registers and the Bank Registers) are not considered part of the processor “context” that is managed by a context synch op. DCRs belong to the peripherals of the processor, and as such can be considered analogous to memory-mapped registers, in that their context is managed in a manner similar to that of memory contents.

Finally, the architecture specifically allows for the Machine Check exception to be exempted from the context synchronization control. This means that it is possible for an instruction that is encountered prior in the instruction stream to the context synch op, to subsequently cause a Machine Check exception after the context synch op and additional instructions have completed.

- 4) Here are a few specific scenarios which illustrate the application of the caveats to the context synchronization requirements described in (3) above:

A) Instruction sequence:

STORE non-cachable to address XYZ

isync

XYZ instruction

In this sequence, the **isync** does not guarantee that the XYZ instruction will be fetched after the STORE has occurred to memory. Thus there is no guarantee which XYZ instruction will execute: the “old” version or the new (STORE’d) version.

B) Instruction sequence:

STORE non-cachable to address XYZ

isync

MTDCR to remove memory bank containing XYZ in BIU

In this sequence, there is no guarantee that the STORE will occur through the BIU prior to the **mtdcr** changing the BIU Bank Register. Thus, it is possible that the STORE may cause a machine-check due to a non-configured address error.

- 5) As an example of what context synchronization accomplishes, consider an interrupt that changes the PowerPC Endian mode. An interrupt is a context synchronizing operation. Any interrupt causes the MSR to be updated; its old value is saved in SRR1 or SRR3. The MSR[ILE] bit is copied to MSR[LE]. The MSR is part of the processor context; the context synchronizing operation guarantees that all instructions that precede the interrupt complete using the pre-interrupt value of the MSR[LE]; all instructions that follow the interrupt complete using the post-interrupt value.

Consider, on the other hand, some code that uses the **mtmsr** instruction to change the value of the MSR[LE] bit, which changes the PowerPC Endian mode. In this case, the bit is simply changed while the rest of the context remains the same. It's possible, for example, that pre-fetched instructions expect to access Big-Endian objects after the **mtmsr** has changed the Endian mode to PowerPC Little-Endian. This could cause problems. To prevent such problems, the code should execute a context synchronization operation, such as **isync**, immediately after the **mtmsr** instruction.

- 6) So, given the scenarios in (4) above, how does software ensure that memory/DCR contents get synchronized in the instruction stream? Through the use of the **eiemo** or **sync** instructions. These instructions guarantee “storage ordering”, such that all subsequent memory accesses “observe” the results of all previous memory accesses. Note that neither **eiemo** nor **sync** guarantee that instruction prefetching is done after the **eiemo/sync**. They do not cause the pre-fetch queues to be purged and instructions to be re-fetched. See Section 2.10.3 for further discussion of **sync** and **eiemo**. Instruction Cache state is considered part of the “context”, and thus requires a context synch op to guarantee ordering of I-cache accesses. Hence, the following sequence is required for self-modifying code:

STORE	to change D-cache contents
dcbst	to “flush” the new storage contents from D-cache to memory
sync	to guarantee the dcbst completes before the following instructions begin
icbi	“context-changing” op, invalidates I-cache contents.
isync	“context-synch” op, causes re-fetch using new I-cache context, and new memory context (due to previous sync).

In a similar manner, if software wishes to ensure that all storage accesses are complete prior to executing a **mtdcr** to change a Bank Register (example 4B above), software must issue a **sync** after all storage accesses and before the **mtdcr**. Likewise, if software wishes to ensure that all instruction fetches after the **mtdcr** use the new Bank Register contents, software must issue an **isync** after the **mtdcr**, and before the first instruction that should be fetched in the new context.

- 7) **isync** is used to guarantee all subsequent instructions are fetched and executed using the context established by all previous instructions. **isync** is context synchronizing. **isync** causes all pre-fetched instructions to be discarded and re-fetched. In addition to the self-modifying code sequence use of **isync** in (6), here is an example involving debug exceptions:

mtdbcr	setup IAC event
isync	wait for new DBCR context to be established

XYZ this instruction is at the IAC address; **isync** was necessary to guarantee the IAC event to happen at the execution of this instruction

2.10.2 Execution Synchronization

For completeness, consider the definition of “execution synchronizing” as it relates to “context synchronization”, as this concept is related to these scenarios.

Execution Synchronization is architecturally a subset of Context Synchronization. Execution synch specifically guarantees the rule described in 2A, but not the rule described in 2B, above. Execution synch ensures all prior instructions execute in the old context, but subsequent instructions may execute in the new or old context (indeterminate).

There are three execution synch ops in PPC403GC:

mtmsr

sync

eieio

Since **mtmsr** is itself execution synchronizing, it guarantees that prior instructions complete using the old MSR value (consider the example given in the second paragraph of (5) above). However, to guarantee that subsequent instructions use the new MSR value, we have to insert a Context synch op, such as **isync**.

Note that the architecture makes a “special” requirement that the MSR[EE] bit be, in effect, context synchronizing. This means that if a **mtmsr** turns on the EE bit, and an external interrupt is pending, the architecture requires that the exception be taken before the next instruction after the **mtmsr** is executed. PPC403GC meets this requirement by preventing any instructions from “folding” onto the **mtmsr** (see Section 2.23 for a definition and discussion of folding). The **mtmsr** is not in general context synchronizing however, so the PPC403GC does not, for example, discard prefetched instructions and re-fetch.

Finally, while **sync** and **eieio** are execution synchronizing, they are also more restrictive in their requirement of memory ordering. Stating that an op is execution synchronizing does not imply the storage ordering. This is an additional specific requirement of **sync/eieio**.

2.10.3 Storage Synchronization

sync is used to guarantee that all previous storage references are completed with respect to the PPC403GC, prior to letting the **sync** instruction complete (and hence, prior to any subsequent instructions beginning execution). **sync** is execution synchronizing.

An example of the use of **sync**:

stw (store to I/O device)

sync (wait for store to actually complete off chip)

mtbr7 (disable access to device)

eieio is used to guarantee the order of storage accesses. All storage accesses prior to **eieio** will complete prior to any storage accesses after the **eieio**. It may be necessary to force storage ordering on a processor that, for example, normally re-orders loads ahead of stores.

Example of the use of **eieio**:

stb X (store to I/O device, address X; this resets a status bit in the device)

eieio (Guarantee **stb** X completes before next instruction)

lbz Y (load from I/O device, address Y; this is the status reg that gets updated by the **stb** X. **eieio** was necessary, since the read/write addresses were different but in fact affected each other)

The PPC403GC implements both **sync** and **eieio** identically, in the manner described above for **sync**. In general, PowerPC architecture defines **sync** as able to function across all processors in a multiprocessor environment, and **eieio** to function only within its executing processor. The PPC403GC is designed as a uniprocessor; for this implementation, **sync** will not guarantee memory ordering across multiprocessors.

2.11 Instruction Set Summary

Table 2-10 summarizes the instruction categories in the PPC403GC instruction set. The instructions within each category are discussed in the subsequent sections. The Register Transfer Language descriptions of each instruction are contained in Chapter 11. Appendix A contains an alphabetical listing of all instructions, with short-form descriptions of syntax and function. Appendix B contains the same descriptions as Appendix A, but grouped by instruction categories as defined here.

In addition to the instruction mnemonics supported directly by hardware, the PowerPC Architecture defines a large number of **extended mnemonics**, which are intended to allow programs to be more readable. Each extended mnemonic translates directly into the mnemonic of some hardware instruction, typically with carefully specified operands. As an example, the PowerPC Architecture does not define a “shift right word immediate” instruction, because it is unnecessary. The desired result can be accomplished using the “rotate left word immediate then AND with mask” instruction (**rlwinm**). However, the operands required to do the job are not obvious, so an extended mnemonic is defined:

srwi RA,RS,n which is an extended mnemonic for **rlwinm RA,RS,32-n,n,31**

These extended mnemonics transfer the problem of remembering unusual operand combinations from the programmer to the assembler. They allow the use of mnemonics that properly reflect the programmer’s intentions, thus making the code more readable.

Extended mnemonics are documented in this manual in three places. In Chapter 11, under each hardware mnemonic are listed all extended mnemonics which translate into that hardware form. In Appendix A, extended mnemonics are listed alphabetically with the hardware mnemonics, not differentiating between the two. In Appendix B, all extended mnemonics are isolated in a single table (Table B-4 on page B-7).

Table 2-10. PPC403GC Instruction Set Summary

Instruction Category	Base Instructions
Storage Reference	load, store
Arithmetic / Logical	add, subtract, negate, multiply, divide, and, or, xor, nand, nor, xnor, sign extension, count leading zeros, andc, orc
Comparison	compare algebraic, compare logical, compare immediate
Branch	branch, branch conditional, branch to LR, branch to CTR
CR Logical	crand, crnor, crxnor, crxor, crandc, crorc, crnand, cror, cr move
Rotate/Shift	rotate and mask, rotate and insert, shift left, shift right
Cache Control	invalidate, touch, zero, flush, store, read
Interrupt Control	write to external interrupt enable bit, move to/from machine state register, return from interrupt, return from critical interrupt

Table 2-10. PPC403GC Instruction Set Summary (cont.)

Instruction Category	Base Instructions
TLB Management	invalidate, read entry, write entry, search, synchronize
Processor Management	system call, synchronize, trap, move to/from Device Control Registers, move to/from Special Purpose Registers, move to/from Condition Register, move to/from Machine State Register

2.11.1 Instructions Specific to PowerPC Embedded Controller

In order to facilitate functions required of processors used in embedded real-time applications, the PowerPC Embedded Controller family defines instructions beyond those found in the PowerPC Architecture. Table 2-11 summarizes all such instructions which are present in the PPC403GC.

Table 2-11. Instructions Specific to PowerPC Embedded Controller

dccci	mfdcr
dcread	mtdcr
icbt	rfci
iccci	tlbre
icread	tlbsx
	tlbsx.
	tlbwe
	wrtree
	wrttee

2.11.2 Storage Reference Instructions

The PPC403GC uses load and store instructions to transfer data between memory and the general purpose registers. Load and store instructions operate on byte, halfword and word data. The Storage Reference instructions also support loading or storing multiple registers, character strings, and byte-reversed data. Table 2-12 shows the Storage Reference instructions available for use in the PPC403GC.

Table 2-12. Storage Reference Instructions

LOADS					STORES			
Byte	Halfword Algebraic	Halfword	Multiple and String	Word	Byte	Halfword	Multiple and String	Word
lbz	lha	lbrx	lmw	lwarx	stb	sth	stmw	stw
lbzu	lhau	lhz	lswi	lwbrx	stbu	sthbrx	stswi	stwbrx
lbzux	lhaux	lhzu	lswx	lwz	stbux	sthux	stswx	stwu
lbzx	lhax	lhzux		lwzu	stbx	sthux		stwux
		lhzx		lwzux		sthx		stwx
				lwzx				stwcx.

2.11.3 Arithmetic and Logical Instructions

Table 2-13 shows the set of arithmetic and logical instructions supported by the PPC403GC. Arithmetic operations are performed on integer or ordinal operands stored in registers. Instructions using two operands are defined in a three operand format where the operation is performed on the operands stored in two registers and the result is placed in a third register. Instructions using one operand are defined in a two operand format where the operation is performed on the operand in one register and the result is placed in another register. Several instructions also have immediate formats in which one operand is coded as part of the instruction itself. Most arithmetic and logical Instructions offer the programmer the ability to optionally set the condition code register based on the outcome of the instruction. The instructions whose mnemonics end in "." (for example, add.) are the forms which will set the condition register.

Table 2-13. Arithmetic and Logical Instructions

ARITHMETIC						LOGICAL		
add	addi	divw	mulhw	subf	subfc	and	eqv	nor
add.	addic	divw.	mulhw.	subf.	subme	and.	eqv.	nor.
addo	addic.	divwo	mulhwu	subfo	subme.	andc		
addo.	addis	divwo.	mulhwu.	subfo.	submeo	andc.	extsb	or
addc	addme	divwu	mulli	subfc	submeo.	andi.	extsb.	or.
addc.	addme.	divwu.	mullw	subfc.	subfze	andis.		orc
addco	addmeo	divwuo	mullw.	subfco	subfze.		extsh	orc.
addco.	addmeo.	divwuo.	mullwo	subfco.	subfzeo	cntlzw	extsh.	ori
adde	addze		mullwo.	subfe	subfzeo.	cntlzw.		oris
adde.	addze.			subfe.			nand	
addeo	addzeo		neg	subfeo			nand.	xor
addeo.	addzeo.		neg.	subfeo.				xor.
			nego					xori
			nego.					xoris

2.11.4 Comparison Instructions

Comparison instructions perform arithmetic or logical comparisons between two operands and set one of the eight condition code register fields (see Section 2.3.3 on page 2-13) based on the outcome of the comparison. Table 2-14 shows the comparison instructions supported by the PPC403GC.

Table 2-14. Comparison Instructions

cmp cmpi cmpl cmpli

2.11.5 Branch Instructions

The architecture provides conditional and unconditional branches to any storage location. The conditional branch instructions provide a capability to test the condition codes set by a prior instruction and branch accordingly. In addition, conditional branch instructions may also decrement and test the Count Register as part of determination of the branch condition and may save the return address in the link register. The target address for a branch may be a displacement from the current instruction's address, or may be contained in the link or count registers, or may be an absolute address.

Table 2-15. Branch Instructions

UNCONDITIONAL	CONDITIONAL
b	bc
ba	bca
bl	bcl
bla	bcla
	bcctr
	bcctrl
	bclr
	bclrl

2.11.6 Condition Register Logical Instructions

Condition Register Logical instructions allow the user to combine the results of several comparisons without incurring the overhead of conditional branching. These instructions may significantly improve code performance if multiple conditions are tested prior to making a branch decision. Table 2-16 summarizes the Condition Register Logical Instructions.

Table 2-16. Condition Register Logical Instructions

crand	crnor
crandc	cror
creqv	crorc
crnand	crxor
	mcrf

2.11.7 Rotate and Shift Instructions

Rotate and shift instructions rotate and shift operands which are stored in the general purpose registers. Rotate instructions also include the capability to mask rotated operands.

Table 2-17 shows the rotate and shift instructions available for the PPC403GC.

Table 2-17. Rotate and Shift Instructions

ROTATE	SHIFT
rlwimi	slw
rlwimi.	slw.
rlwinm	sraw
rlwinm.	sraw.
rlwnm	srawi
rlwnm.	srawi.
	srw
	srw.

2.11.8 Cache Control Instructions

Cache control instructions allow the user to indirectly control the contents of the data and instruction caches. The user may fill, flush, invalidate and zero blocks (16-byte lines) in the data cache. The user may also invalidate congruence classes in both caches and invalidate and fill individual lines in the instruction cache.

Table 2-18. Cache Control Instructions

DCACHE	ICACHE
dcbf	icbi
dcbi	icbt
dcbst	iccci
dcbt	icread
dcbtst	
dcbz	
dccci	
dcread	

2.11.9 Interrupt Control Instructions

The interrupt control instructions allow the user to move data between general purpose registers and the machine state register, return from interrupts and enable or disable maskable external interrupts. Table 2-19 shows the Interrupt control instruction set.

Table 2-19. Interrupt Control Instructions

mfmsr
mtmsr
rfi
rfci
wrtee
wrteei

2.11.10 TLB Management Instructions

The TLB management instructions read and write entries of the TLB array in the MMU, search the TLB array for an entry which will translate a given address, invalidate all TLB entries, and synchronize TLB updates with other processors.

Table 2-20. TLB Management Instructions

tlbia
tlbre
tlbsx
tlbsx.
tlbsync
tlbwe

2.11.11 Processor Management Instructions

The processor management instructions are used to move data between the general purpose registers and special control registers in the PPC403GC and also provide traps, system calls and synchronization controls to the user.

Table 2-21. Processor Management Instructions

eieio	mcrxr	mtcrf
isync	mfcrr	mtdcr
sync	mfddcr	mtsrr
	mfssrr	sc
		tw
		twi

The PPC403GC memory and peripheral interface provides direct processor bus attachments for most memory and peripheral devices. The interface minimizes the amount of external glue logic needed to communicate with memory and peripheral devices, reducing the embedded system device count, circuit board area, and cost.

For example, to eliminate off-chip address decoding for chip selects, the PPC403GC provides eight programmable chip selects that enable system designers to relocate memory and peripherals in the PPC403GC memory map. Chip select timing and associated control signals are programmable, as are setup, wait and hold times.

The Bus Interface Unit (BIU) is the internal structure controlling the interface between the PPC403GC and memory and peripherals. The BIU controls the interfaces between storage (both addresses which are external to the PPC403GC and addresses which are internal on the On-chip Peripheral Bus) and users of that storage (the processor core, the internal DMA controller, an external bus master). The BIU interfaces to main storage and peripherals and the OPB interface to internal peripherals are discussed in this chapter.

Together, the structure of the BIU and the manner in which the caches are controlled by the DCCR and ICCR determine the nature of the memory map of the PPC403GC. See Section 2.2 (Memory Organization and Addressing) on page 2-2 for a discussion of the memory map.

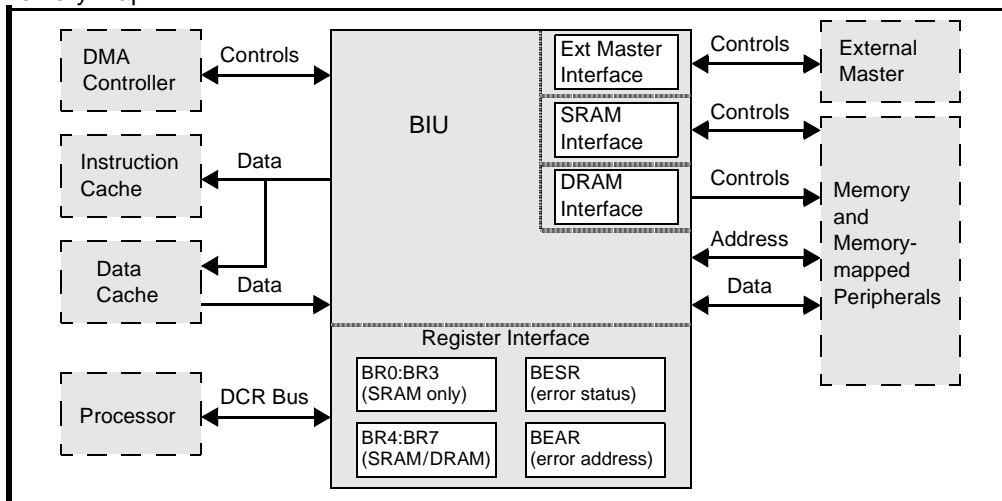


Figure 3-1. BIU Interfaces

3.1 Memory Interface Signals

Figure 3-2 shows that external signals from the PPC403GC can be grouped within categories. Because the physical interface to static random access memory (SRAM), read only memory (ROM) and memory-mapped I/O are similar, one group of BIU signals attaches these devices to the PPC403GC (the SRAM interface). Another group of signals supports direct attachment of dynamic random access memory (DRAM) devices. The groups share several common signals.

Some signals have different meanings, depending on whether the PPC403GC is the bus master. The signals shown in Figure 3-2 assume that the PPC403GC is the bus master. See Section 3.10 (External Bus Master Interface) and Figure 3-24 for signal usage when an external master is involved.

Block data movement under the control of the PPC403GC DMA Controller still utilizes the BIU, with the PPC403GC as bus master. Chapter 4 (DMA Operations) and Figure 4-2 describe the DMA signals, and show their relation to the BIU and its signals.

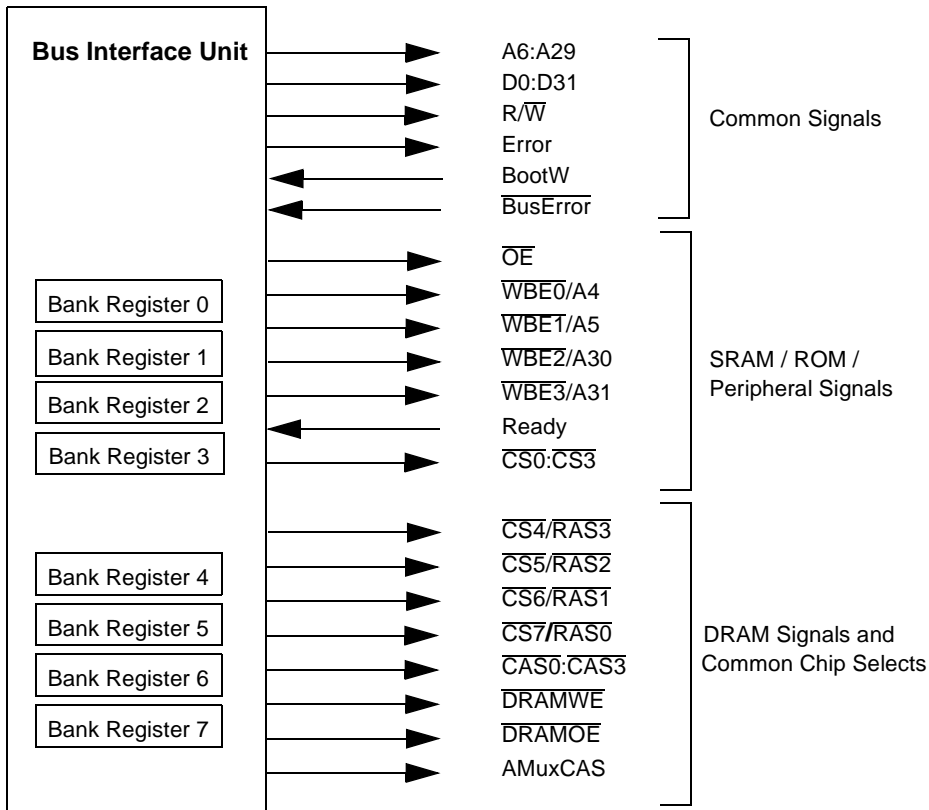


Figure 3-2. Grouping of External BIU Signals

3.1.1 Address Bus When Idle

When the Address Bus goes idle, its behavior is determined by the Address Tri-state Control Bit (IOCR[ATC]). If IOCR[ATC] = 0, when the Address Bus goes idle, it goes to a hi-impedance state (tri-state). If IOCR[ATC] = 1, when the Address Bus goes idle, it:

- Holds the last value in all non-Bus Master operations.
- For Bus Master operations, goes hi-impedance 1 cycle before HoldAck to 1 cycle after HoldAck.
- Byte Enables behave the same as the address bus, except that Byte Enables go to inactive state instead of last state.

3.2 Access Priorities

The BIU is the single pathway to external memory for a number of potentially competing memory requests. For example: the fetcher, via the instruction cache (ICU), may be attempting to read instructions from memory while the data cache (DCU) is attempting to store data into memory. While both of these things are occurring, the DRAM controller of the BIU may need to perform refresh of a DRAM bank, to maintain the validity of data there. The BIU performs arbitration among such requests.

The arbitration priority for access to BIU resources is, from highest to lowest:

- 1) DRAM Refresh.

Note that DRAM Refresh may overlap with any SRAM access and will occur without any performance impact to the SRAM access. Any DRAM access will wait for the Refresh to finish before gaining access to the bus.

- 2) External Bus Master high-priority.

- 3) DMA high-priority.

- 4) Cache-inhibited DCU read; cache-inhibited DCU write; DCU line fill.

Note that only one data-side request may be presented to the BIU at any given time.

- 5) Cache-inhibited ICU read; ICU line fill.

Note that only one instruction-side request may be presented to the BIU at any given time.

- 6) DCU line flush.

- 7) DMA low-priority.

- 8) External Bus Master low-priority.

3.3 Function During Processor Wait State

If the PPC403GC is in Wait State ($MSR[WE] = 1$), the processor is not executing instructions, hence it is not generating bus requests to the BIU. However, the BIU is still fully operational. In particular, note the following:

- The DRAM controller will continue to generate DRAM refresh normally.
- DMA operations (based on DMA channel setup that occurred prior to entering Wait State) will function normally.
- If an External Master wishes to take the bus while the PPC403GC is in Wait State, the BIU will support that request.

3.4 Memory Banks Supported

The PPC403GC memory interface supports up to eight external RAM/ROM banks and peripheral devices in non-overlapping addresses. Four of the banks have dedicated chip select logic (SRAM interface). Another four banks have multiplexed chip select/row address select (\overline{CS}/RAS) lines; these banks are shared by the SRAM and the DRAM controllers.

The minimum size of memory region which can be defined for a bank is 1MB. The maximum size is 64MB.

Table 3-1 shows the possible combinations of supported devices. Note that up to four DRAM banks are supported in the DRAM regions. If no DRAM is used, all eight chip selects can be programmed into the SRAM region.

Table 3-1. SRAM And DRAM Banks Supported

Number of SRAM Banks	Number of DRAM Banks
4	4
5	3
6	2
7	1
8	0

The BIU contains eight bank registers, as shown in Figure 3-2. Each bank register controls a \overline{CS} or \overline{CS}/RAS signal. For example, bank register 0 controls $\overline{CS0}$, bank register 6 controls the shared signal $\overline{CS6}/RAS1$, and bank register 7 controls the shared signal $\overline{CS7}/RAS0$. Bank registers 0-3 can control SRAM only. Bank registers 4-7 can control DRAM, in addition to controlling SRAM. For bank registers 4-7, the setting of bit 31 in each bank register

determines which type of memory is configured.

3.5 Attachment to the Bus

Byte-wide, halfword-wide, and word-wide devices can all be attached to the data bus. Regardless of which bank register controls the devices, and regardless of whether the devices are SRAM or DRAM, the devices share the same address and data bus. Different bank registers activate different control lines (SRAM or DRAM). These control lines, which differentiate among separate devices and among types of devices, may informally be considered to be a separate control bus.

As shown in Figure 3-3, devices of different widths attached to the data bus are “left justified” toward the byte 0 side of the bus. Byte devices always are attached to byte 0, halfword devices to byte 0 and byte 1, while word devices use the entire data bus.

On byte or halfword write operations, the unused bytes of the data bus are in Hi-Z state.

3.5.1 Bus Width after Reset

In general, the configuration of bank registers to allow the PPC403GC to support various device widths is a software task. At reset, however, enough configuration must be defined by hardware to allow boot code to run (normally from a small ROM in high memory). A default configuration is defined for bank register BR0, which supports slowest possible ROM/SRAM. The device width for this default configuration is determined at reset by the BootW input signal.

BootW is sampled while the $\overline{\text{Reset}}$ signal is active and again after $\overline{\text{Reset}}$ is deactivated to determine the width of the boot ROM. For an 8-bit boot ROM width, the BootW pin should be tied to 0. For a 32-bit boot ROM width, this pin should be tied to 1. For a 16-bit boot ROM width, the BootW pin should be tied to the $\overline{\text{Reset}}$ pin.

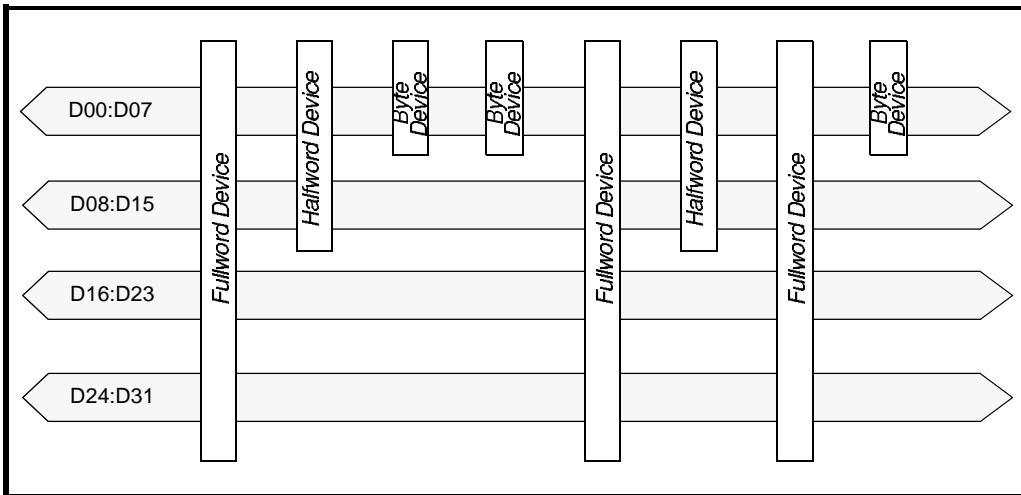


Figure 3-3. Attachment of Devices of Various Widths to the PPC403GC Data Bus

3.5.2 Alternative Bus Attachment

Devices are “left justified” on the bus under the assumption that the PPC403GC is the sole source of control signals to the devices. That assumption is consistent with the PPC403GC design, which attempts to minimize the number of external components required. However, if a large number of byte and halfword devices are attached to the system, the capacitive loading on byte 0 (and byte 1, if many halfword devices are used) will be much larger than the loading on byte 3, possibly resulting in unacceptable timing performance on byte 0 or byte 1.

If a bank register is configured as word-wide, then byte-wide devices may be attached to the bus in any byte lane (and accessed using byte loads and stores). External logic may be required to develop additional control signals if the data bus is to be utilized in this manner.

Similarly, if a bank register is configured as word-wide, then halfword-wide devices may be attached to the bus in the byte 0 / byte 1 lane, or in the byte 2 / byte 3 lane, and accessed using halfword loads and stores. Again, external logic may be required to develop additional control signals if the data bus is to be utilized in this manner.

3.6 Address Bit Usage

Note from Figure 3-2 that, although the PPC403GC address bus is 32 bits as defined by the PowerPC Architecture, only 24 address bits (A6:29) are presented externally on the PPC403GC. The 24 address bits, combined with the four decoded low-order write-byte enables and eight chip selects, can address 512MB of main storage.

Figure 3-4 illustrates the relationship between portions of the 32-bit address and several memory-controlling registers.

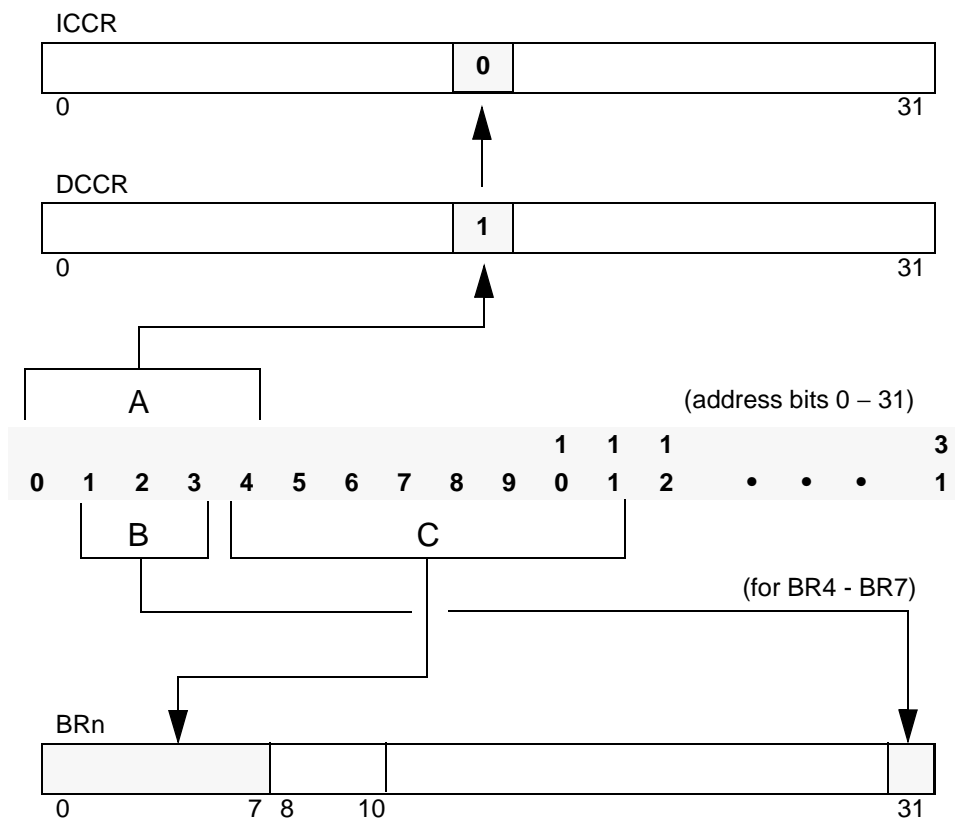


Figure 3-4. Usage of Address Bits

3.6.1 Storage Attribute Control

The 4 gigabyte total address space (32 bits) is divided into 32 regions of 128 megabytes each for purposes of storage attribute control in real mode (address translation disabled). The storage attributes available on PPC403GC are cacheability (controlled by the DCCR and ICCR), write-through (controlled by the DCWR), and speculative access (controlled by the SGR).

The 32 values (0-31) of address bits 0:4 (labelled “A” in Figure 3-4) are the region numbers. Each value of “A” has associated with it one bit in each storage attribute control register. The value of the associated bit determines the storage attribute for that 128 megabyte region. See Section 2.2.4 (Physical Address Map) on page 2-4 for further discussion of the regions, and see Section 9.5.1 (Storage Attribute Control Registers) on page 9-22 for details of the registers.

3.6.2 SRAM / DRAM / OPB Addresses

Access to external memory of the PPC403GC occurs via the Bus Interface Unit (BIU). The BIU is a memory controller providing numerous services (examples include wait-state generation and DRAM refresh). The BIU also imposes some addressing restrictions:

- 1) All SRAM (and devices such as PROM that use similar control signals) must have address[1:3]=b'111'.
- 2) All DRAM must have address[1:3]=b'000'.
- 3) Any address for which address[1:3] is neither b'000' nor b'111' is reserved, on the On-Chip Peripheral Bus (OPB).

To inform the BIU of the characteristics of the attached external devices, one or more Bank Registers must be programmed. The PPC403GC contains eight Bank Registers, BR0-BR7. Four of these (BR0 - BR3) can control only SRAM-like devices. The other four (BR4 - BR7) can control either SRAM or DRAM devices.

BR0-3 can control only memory with address[1:3] = b'111', which must be SRAM-like devices. BR4-7 can control memory with either address[1:3] = b'111' (SRAM-like devices) or address[1:3] = b'000' (DRAM devices), depending on the setting of BRn[31]. Addresses with address[1:3] not equal to either b'111' or b'000' cannot be controlled by any Bank Register.

Let BRn refer to the particular Bank Register programmed for an address range. The following must be true:

- 1) If the bank register is any of BR0 - BR3, only SRAM is supported.
It must be true that address[1:3]=b'111'.
For BR0 - BR3, BRn[31] is Reserved. If read, it will return 0 regardless of what value was written to it.
- 2) If the bank register is any of BR4 - BR7, the following apply:
 - A) If address[1:3]=b'111' (the SRAM case), then must have BRn[31]=1.
 - B) If address[1:3]=b'000' (the DRAM case), then must have BRn[31]=0.
- 3) If address[1:3] is neither b'000' nor b'111', then it is not appropriate to program a Bank Register for this address. This address is reserved for internal use, and Bank Registers are only for external addresses. Neither the SRAM nor the DRAM controller will be activated by this address, and a machine check exception will be generated (by the timeout error) if there is no device on the OPB at that address.

In Figure 3-4, the field "B" depicts the dependence of BRn[31] on address[1:3] for BR4 - BR7.

3.6.3 External Memory Location

Each Bank Register controls the characteristics of one contiguous block of external memory, where only address bits 1:31 are considered. Address[0] is not presented externally by the PPC403GC, but address[0] may influence storage attributes (see Section 3.6.1 on page 3-8). Address[1:3] will be b'000' or b'111', and (for BR4 - BR7) BRn[31] will reflect this selection (see Section 3.6.2 on page 3-9). Address[4:11] of the starting (lowest) address of the contiguous block is reflected in BRn[0:7], as described below. This is represented by field "C" of Figure 3-4.

The contiguous block of memory that is described by the Bank Register must be selected to be one of the seven sizes shown in Table 3-2. The starting address of the block must be aligned on a boundary that is an integer multiple of the selected size. Bits of A[4:11] shown as "0" in Table 3-2 must be zero in the starting address.

Table 3-2 illustrates field BRn[0:7], which is used to specify the starting address of the block controlled by the bank. Bits shown as "v" are bits which are permitted to be non-zero in A[4:11] of the block starting address. Bits of BRn[0:7] shown as "v" are compared to the bits shown as "v" in A[4:11] to determine whether or not a given address is controlled by Bank Register BRn. Bits of BRn[0:7] shown as "X" are ignored in the comparison.

Table 3-2. Restrictions on Bank Starting Address

Size (megabytes)	Size Select BRn[8:10]	Bank Addr Sel BRn[0:7]	Bank Starting Address A[4:11]
1	b'000'	b'vvvv vv vv'	b'vvvv vv vv'
2	b'001'	b'vvvv vv vX'	b'vvvv vv v0'
4	b'010'	b'vvvv vv XX'	b'vvvv vv 00'
8	b'011'	b'vvvv v XXX'	b'vvvv v 000'
16	b'100'	b'vvvv XXXX'	b'vvvv 0000'
32	b'101'	b'vvvX XXXX'	b'vvv0 0000'
64	b'110'	b'vvXX XXXX'	b'vv00 0000'

More than one Bank Register is used only when multiple blocks of memory must be described. This could occur because the blocks are not contiguous or because the blocks (even if contiguous) require different memory characteristics (for example, one block is fast memory and another is slow memory). It is an error to have more than one Bank Register describe the same address.

3.7 The SRAM Interface

The SRAM interface provides control signals for the direct attachment of SRAM, ROM, and peripherals which have an SRAM-like interface.

3.7.1 Signals

Five sets of signals are dedicated to the SRAM interface:

$\overline{CS0}:\overline{CS7}$	Chip selects
R/\overline{W}	Read/not write
\overline{OE}	Output enable
$\overline{WBE0}:\overline{WBE3}$	Write byte enables
Ready	An input to allow an external source to control SRAM wait timing

The timings of the occurrence of \overline{CS} , \overline{OE} , and \overline{WBE} signals are programmable via the Bank Registers, as follows:

- \overline{CS} may become active either 0 or 1 clock cycles (CSon) after the address becomes valid.
- \overline{OE} may become active either 0 or 1 clock cycles (OEon) after \overline{CS} becomes active.
- The Data Bus may be driven with valid data either 0 or 1 clock cycles (OEon) after \overline{CS} becomes active on write operations.
- \overline{WBE} may become active either 0 or 1 clock cycles (WBEon) after \overline{CS} becomes active.
- \overline{WBE} may become inactive either 0 or 1 clock cycles (WBEoff) before \overline{CS} becomes inactive.
- For non-burst accesses, \overline{CS} becomes inactive $1 + \text{TWT}$ cycles after the address becomes valid, where $0 \leq \text{TWT} \leq 63$.

For burst accesses, on the first transfer of the burst, \overline{CS} becomes inactive $1 + \text{FWT}$ cycles after the address becomes valid, where $0 \leq \text{FWT} \leq 15$. On all transfers beyond the first, \overline{CS} becomes inactive $1 + \text{BWT}$ cycles after the address becomes valid, where $0 \leq \text{BWT} \leq 3$.

- TWT, FWT, BWT, CSon, OEon, WBEon, and WBEoff are not independent. Let $\text{DLYon} = 1$ if $\text{OEon} = 1$ or $\text{WBEon} = 1$, otherwise $\text{DLYon} = 0$. Then it is required that $(\text{TWT} \geq \text{CSon} + \text{DLYon} + \text{WBEoff})$ for non-burst transfers, and that $(\text{FWT} \geq \text{CSon} + \text{DLYon} + \text{WBEoff})$ and $(\text{BWT} \geq \text{WBEoff})$ for burst transfers.

- Hold time may be programmed from 0 to 7 cycles. During Hold time, the address bus is driven and all control signals are inactive. The data bus is driven for the Hold time if the operation is a write.
- If the PPC403GC is bus master and the bus is idle, then SRAM control signals \overline{CS} , \overline{OE} , and \overline{WE} will be held inactive.

The relationship of these control signals, and the parameters controlling them, are illustrated in Figure 3-5 for single transfers and in Figure 3-6 for burst transfers.

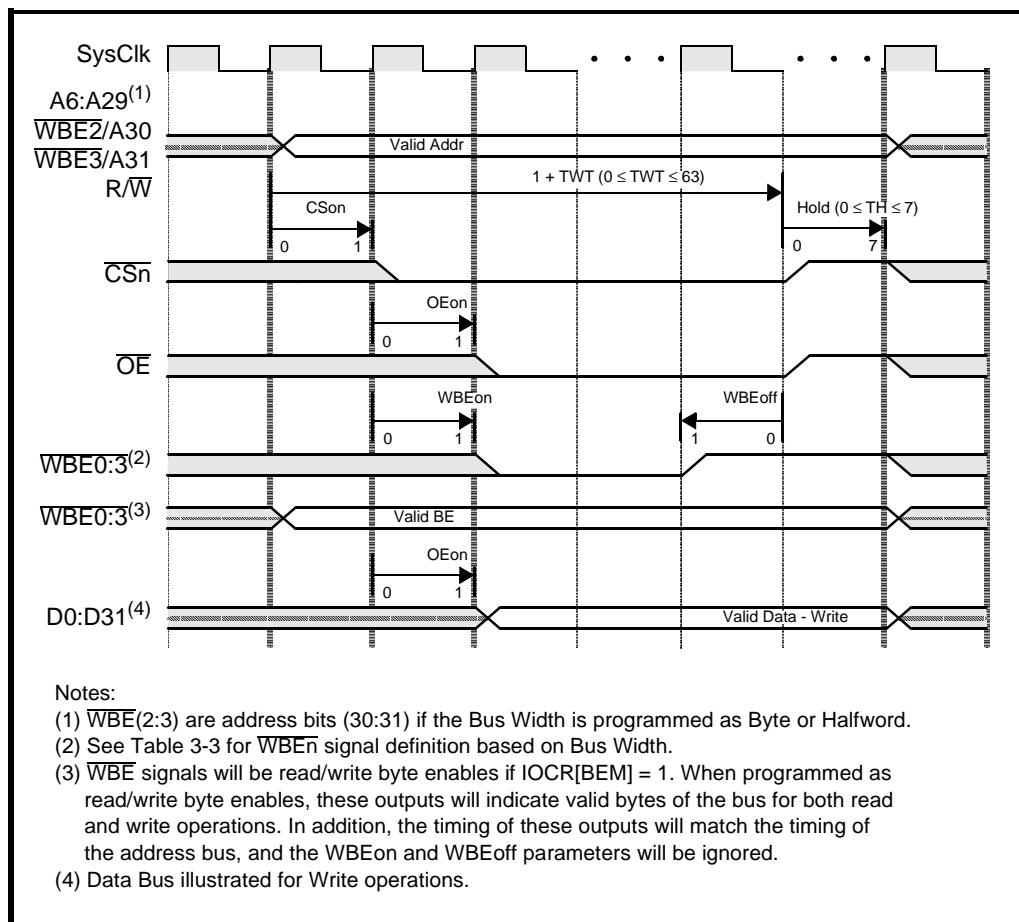


Figure 3-5. Parameter Definitions — SRAM Single Transfer

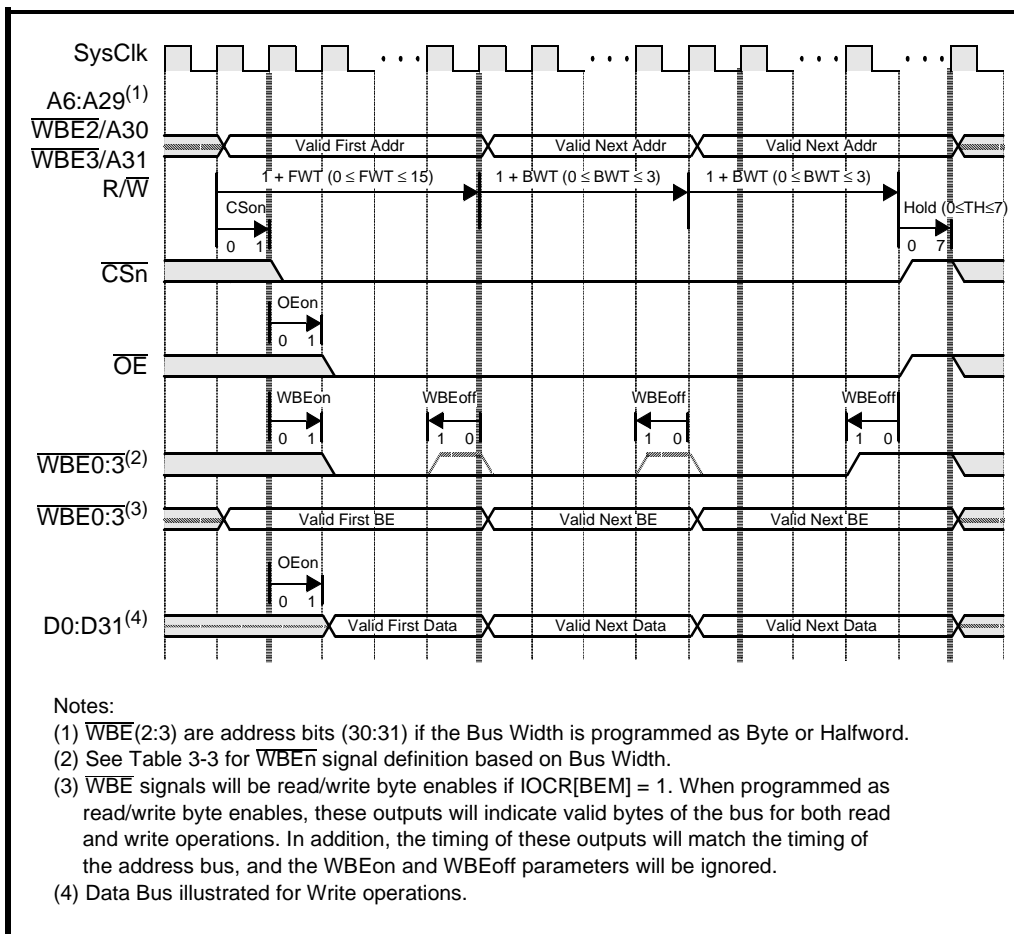


Figure 3-6. Parameter Definitions — SRAM Burst Mode

3.7.1.1 SRAM Read Example

Figure 3-7 shows the timing of chip select, output enable, write-byte enables, the address bus and the data bus relative to the system clock (SysClk) for a read cycle from SRAM, ROM, or peripheral devices. Two different accesses are illustrated, each with different timing parameters. This results from the sharing of the bus by devices defined in different bank registers.

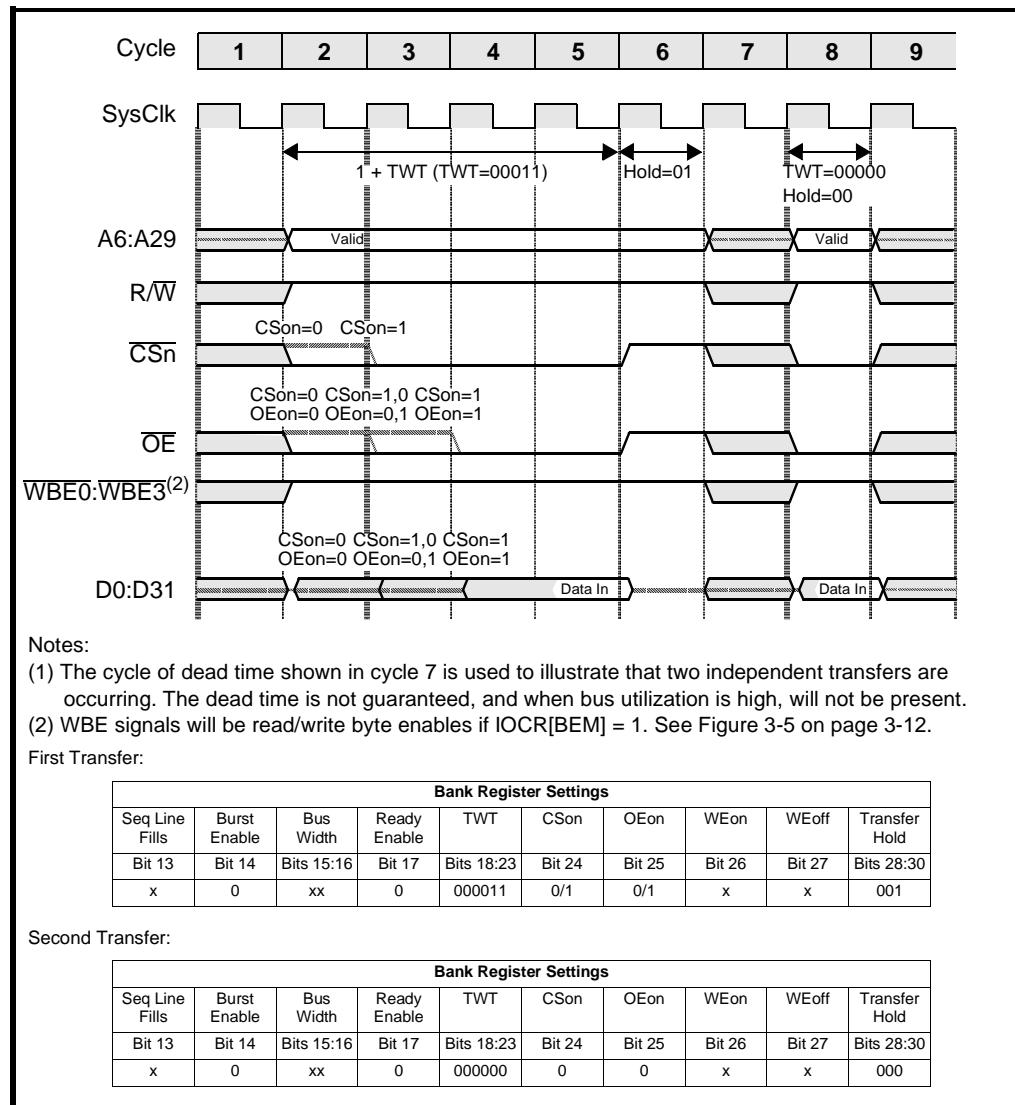


Figure 3-7. SRAM Read

3.7.1.2 SRAM Write Example

Figure 3-8 shows the timing of chip select, output enable, write-byte enables, the address bus and the data bus relative to the system clock (SysClk) for a write cycle to SRAM or peripheral. Two different accesses are illustrated, each with different timing parameters. This results from the sharing of the bus by devices defined in different bank registers.

- Note that the cycle when the data bus turns on is determined by the OEon parameter.

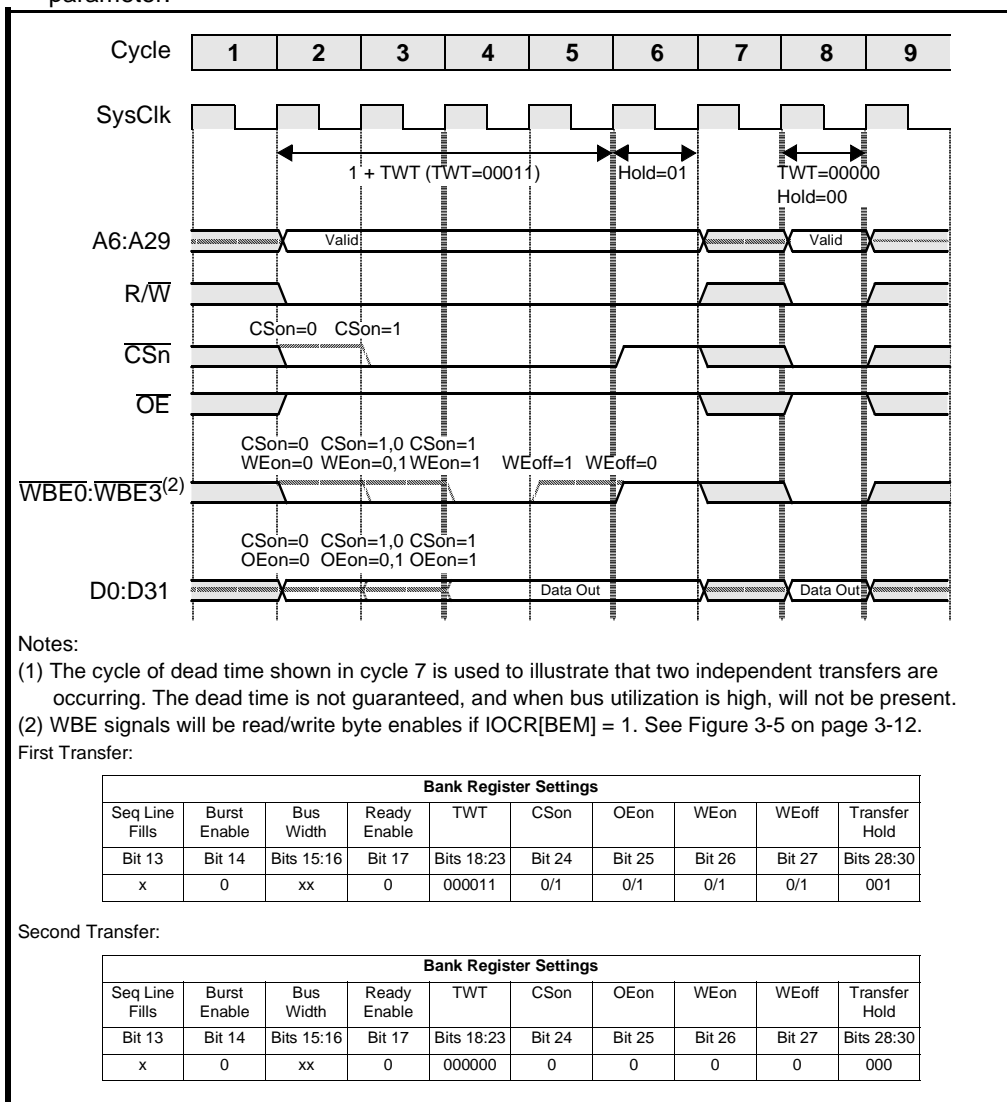


Figure 3-8. SRAM Write

3.7.1.3 $\overline{\text{WBE}}$ Signal Usage

The byte write enable outputs, $\overline{\text{WBE0}}:\overline{\text{WBE3}}$, select the bytes to be written in a memory write access. The usage of these lines varies, controlled by the bus width programmed into the bank register describing the memory region.

Table 3-3. Usage of $\overline{\text{WBE0}}:\overline{\text{WBE3}}$ vs Bus Width

Bus Width (bytes)	$\overline{\text{WBE0}}$ Usage	$\overline{\text{WBE1}}$ Usage	$\overline{\text{WBE2}}$ Usage	$\overline{\text{WBE3}}$ Usage
1	write byte enable	1 (inactive)	A30	A31
2	hi-byte write enable	lo-byte write enable	A30	A31
4	byte 0 write enable	byte 1 write enable	byte 2 write enable	byte 3 write enable

- For memory regions defined as eight-bit regions, $\overline{\text{WBE2}}$ and $\overline{\text{WBE3}}$ are address bits A30 and A31 and $\overline{\text{WBE0}}$ is the write enable line.
- For memory regions defined as 16-bit regions, $\overline{\text{WBE2}}$ is address bit A30, $\overline{\text{WBE3}}$ is address bit A31, and $\overline{\text{WBE0}}$ and $\overline{\text{WBE1}}$ are the high byte and low byte write enables.
- For memory regions defined as 32-bit regions, $\overline{\text{WBE0}}$ through $\overline{\text{WBE3}}$ are the write byte enables corresponding to bytes 0 through 3 on the data bus, respectively.
- $\overline{\text{WBE}}$ signals will be read/write byte enables if $\text{IOCR}[\text{BEM}] = 1$. When programmed as read/write byte enables, these outputs will indicate valid bytes of the bus for both read and write operations. In addition, the timing of these outputs will match the timing of the address bus, and the WBEon and WBEoff parameters will be ignored.

3.7.2 Device-Paced Transfers

The ready signal (Ready) is an input which allows the insertion of externally generated (device-paced) wait states. Ready is monitored only when the Bank Register is programmed with Ready Enable = 1. Note:

- If Wait = 0, Ready Enable and the Ready input are ignored, and single-cycle transfers will occur.
- For non-burst transfers, sampling of the Ready input starts TWT cycles after the beginning of the transfer. Sampling continues once per cycle until either Ready is high when sampled or a timeout occurs (see below). For examples, see Figure 3-9 (SRAM Read Extended with Ready) on page 3-18 and Figure 3-10 (SRAM Write Extended with Ready) on page 3-19.

For burst transfers, sampling of the Ready input starts FWT cycles after the beginning of the first transfer of a burst, and starts BWT cycles after the beginning of subsequent transfers of a burst. Sampling continues once per cycle until either Ready is high when sampled or a timeout occurs (see below).

- The Ready input can be synchronous or asynchronous.
 - If IOCR[ARE] = 0, then Ready is synchronous. Data is latched one cycle after Ready is sampled high, and there are setup time requirements on the Ready signal with respect to SysClk.
 - If IOCR[ARE] = 1, then Ready is asynchronous. Data is latched three cycles after Ready is sampled high, and the setup time requirements are removed.
- The PPC403GC may be programmed to wait only a limited time for the Ready signal to arrive, or it may be programmed for unlimited wait.
 - If IOCR[PTD] = 0 and 128 cycles elapse from the start of the device-paced transfer without the PPC403GC receiving the Ready response from the device, a Bus Timeout error will occur. Depending on the nature of the bus access, this will be either an Instruction Machine Check (see Section 6.4.2 on page 6-18) or a Data Machine Check (see Section 6.4.3 on page 6-20).
 - IF IOCR[PTD] = 1, no Bus Timeout occurs on external accesses.

3.7.2.1 SRAM Device-Paced Read Example

Figure 3-9 shows the timing of chip select, output enable, write-byte enables, the address bus and the data bus relative to the system clock (SysClk) for a read cycle from SRAM, ROM, or peripheral device, extended by Ready.

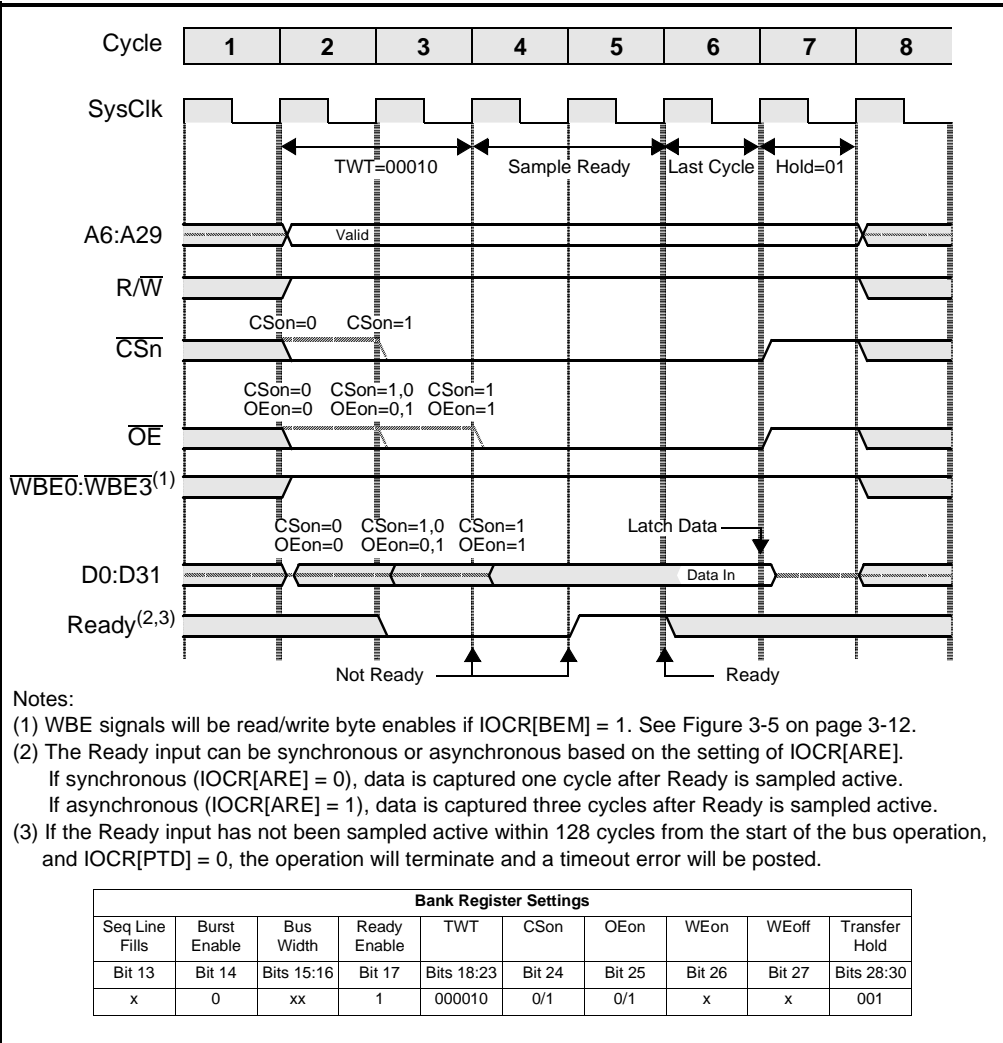


Figure 3-9. SRAM Read Extended with Ready

3.7.2.2 SRAM Device-Paced Write Example

Figure 3-10 shows the timing of chip select, output enable, write-byte enables, the address bus and the data bus relative to the system clock (SysClk) for a write cycle to SRAM or peripheral device, extended by Ready.

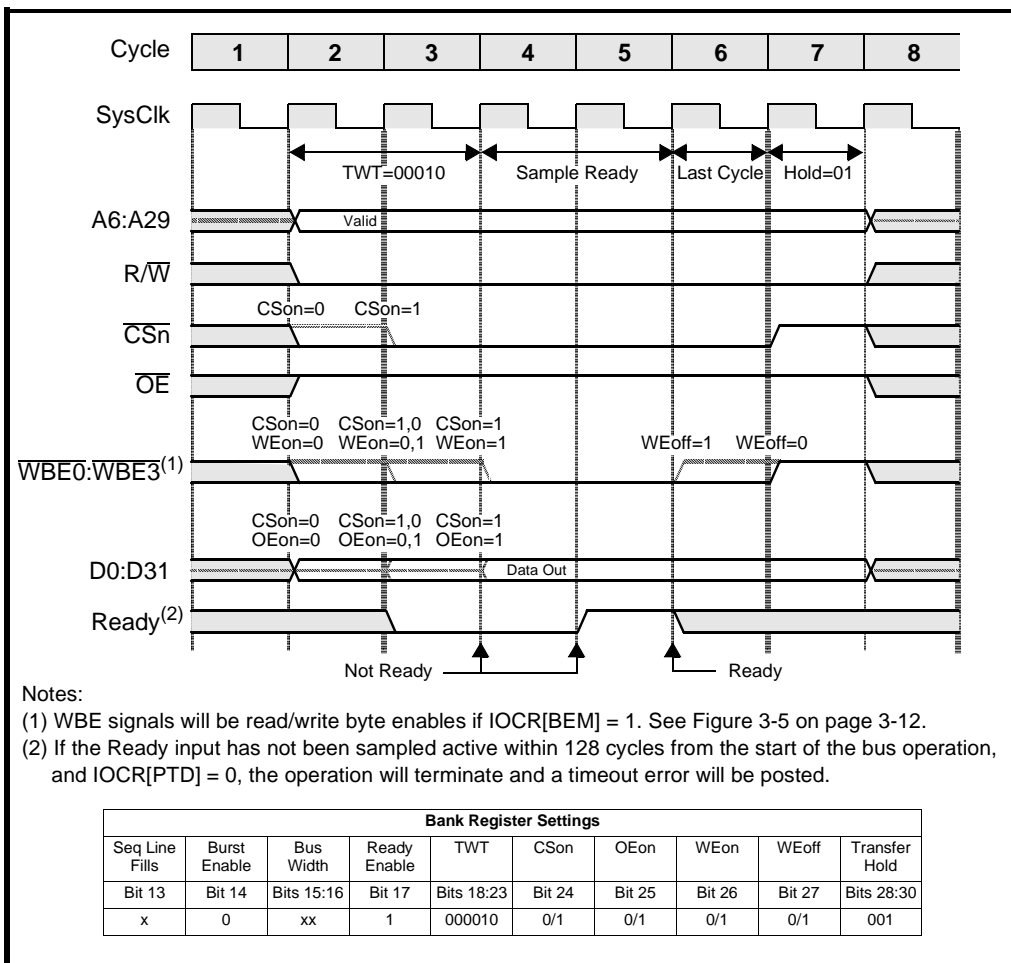


Figure 3-10. SRAM Write Extended with Ready

3.7.3 SRAM Burst Mode

SRAM Burst Mode is controlled by the Burst Mode Enable bit of the SRAM bank registers. When enabled, this mode will activate bursting for all cache line fills and flushes, bus master burst operations, DMA flyby burst and DMA memory-to-memory line burst operations, and all packing and unpacking operations. Some important information about SRAM Burst Mode:

- On the first transfer of the burst, \overline{CS} becomes inactive $1 + FWT$ cycles after the address becomes valid, where $0 \leq FWT \leq 15$.
On all transfers beyond the first, \overline{CS} becomes inactive $1 + BWT$ cycles after the address becomes valid, where $0 \leq BWT \leq 3$.
- FWT , BWT , C_{Son} , O_{Eon} , W_{BEon} , and W_{BEoff} are not independent. Let $DLY_{on} = 1$ if $O_{Eon} = 1$ or $W_{BEon} = 1$, otherwise $DLY_{on} = 0$. Then it is required that $(FWT \geq C_{Son} + DLY_{on} + W_{BEoff})$ and $(BWT \geq W_{BEoff})$.
 C_{Son} , O_{Eon} , W_{BEon} parameters apply only to the first transfer of a burst. W_{BEoff} applies to all transfers of a burst.
- Hold time may be programmed from 0 to 7 cycles. During Hold time, the address bus is driven and all control signals are inactive. The data bus is driven for the Hold time if the operation is a write.
- Non-Burst transfers with burst mode enabled will use the FWT parameter and will follow each transfer with the programmed Hold time.
- Burst Write operations are possible using the same wait timing parameters as a Burst Read. For the first transfer of a write operation, the data bus is driven based on the parameters C_{Son} and O_{Eon} . After the first transfer, the data bus is immediately driven with the next data to be bursted.
- Bursting of back-to-back sequential BIU requests (treating sequential requests as one request for which continual bursting is possible) is not supported.
- Sampling of the Ready input starts FWT cycles after the beginning of the first transfer of a burst, and starts BWT cycles after the beginning of subsequent transfers of a burst. Sampling continues once per cycle until either Ready is high when sampled or a timeout occurs (see below).

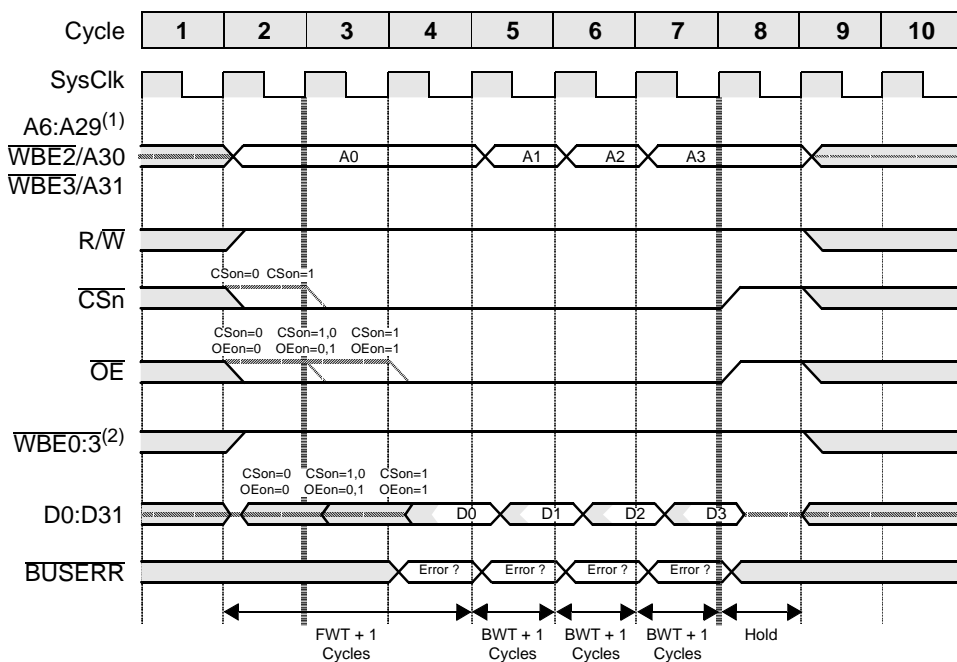
The Ready input can be synchronous or asynchronous.

- If $IOCR[ARE] = 0$, then Ready is synchronous. Data is latched one cycle after Ready is sampled high, and there are setup time requirements on the Ready signal with respect to $SysClk$.
- If $IOCR[ARE] = 1$, then Ready is asynchronous. Data is latched three cycles after Ready is sampled high, and the setup time requirements are removed.

- The PPC403GC may be programmed to wait only a limited time for the Ready signal to arrive, or it may be programmed for unlimited wait.
- If IOCR[PTD] = 0 and 128 cycles elapse from the start of the device-paced transfer without the PPC403GC receiving the Ready response from the device, a Bus Timeout error will occur. Depending on the nature of the bus access, this will be either an Instruction Machine Check (see Section 6.4.2 on page 6-18) or a Data Machine Check (see Section 6.4.3 on page 6-20).
- IF IOCR[PTD] = 1, no Bus Timeout occurs on external accesses.

3.7.3.1 SRAM Burst Read Example

An example of SRAM burst mode read is shown in Figure 3-11.



Notes:

- (1) WBE(2:3) are address bits (30:31) if the Bus Width is programmed as Byte or Halfword.
- (2) See Table 3-3 for WBE_n signal definition based on Bus Width. IOCR[BEM] = 0 for this example.
- (3) Must have FWT ≥ CSon + OEon. All signals will retain the values shown in cycle 4 until the wait interval has elapsed.
- (4) If Hold is programmed ≥ 001 then all signals will retain the values shown in cycle 8 until the hold interval has elapsed.

Bank Register Settings										
Seq Line Fills	Burst Enable	Bus Width	Ready Enable	FWT	BWT	CSon	OEon	WEon	WEoff	Transfer Hold
Bit 13	Bit 14	Bits 15:16	Bit 17	Bits 18:21	Bits 22:23	Bit 24	Bit 25	Bit 26	Bit 27	Bits 28:30
1	1	xx	0	0002	00	0/1	0/1	x	x	001

Figure 3-11. SRAM Burst Read

3.7.3.2 SRAM Burst Write Example

An example of SRAM burst mode write is shown in Figure 3-12.

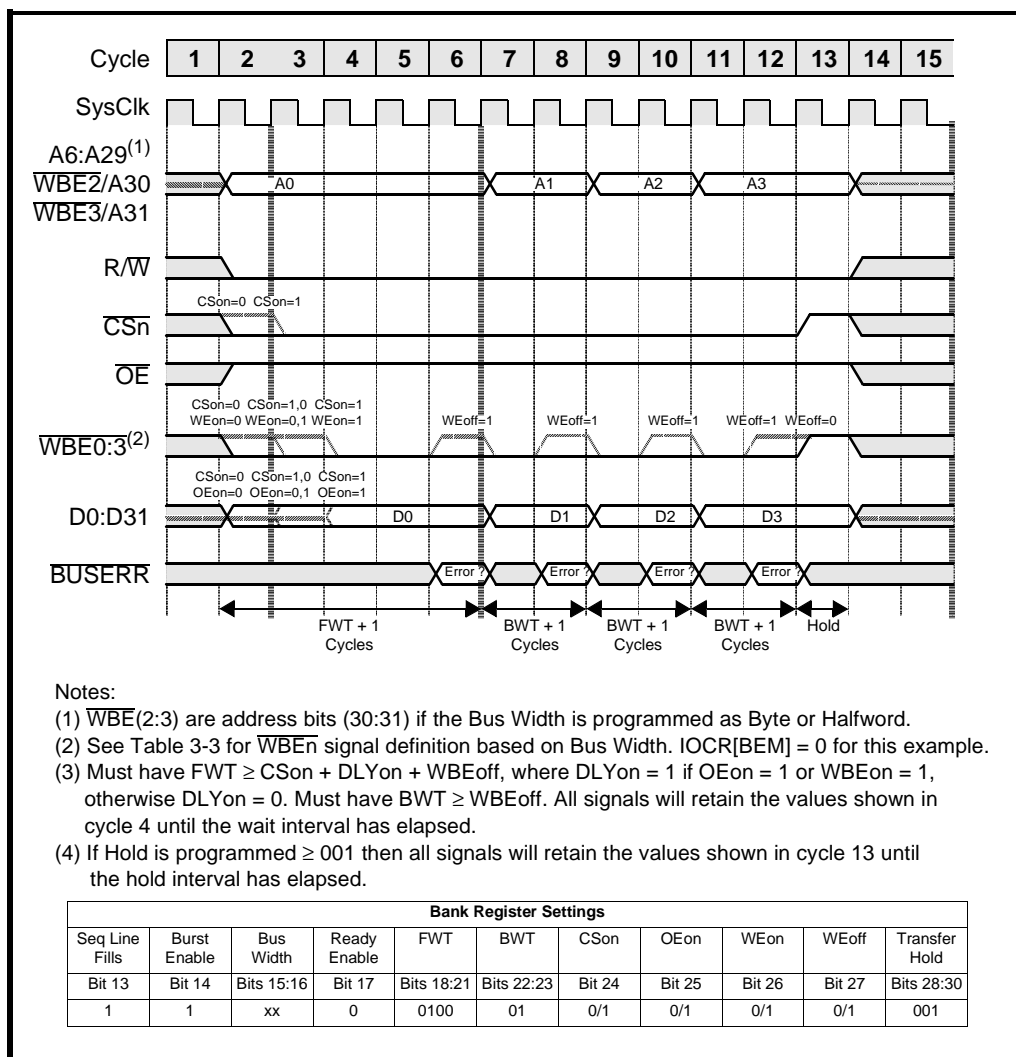


Figure 3-12. SRAM Burst Write

3.7.4 Bank Registers for SRAM Devices

Four bank registers (BR0 through BR3) control SRAM devices only; four bank registers (BR4 through BR7) can control either SRAM or DRAM devices. When configured to control SRAM-like devices, BR0-BR7 control chip selects $\overline{CS0}:\overline{CS7}$, respectively.

Figure 3-13 shows the fields of BR0 - BR3 (which control only SRAM-like devices), and also shows the fields of BR4 - BR7 when these registers are configured to control SRAM-like devices. Section 3.8.2 will describe the usage of BR4 - BR7 for DRAM devices.

Bits 0:13,15:16 of the bank register have the same usage, whether for SRAM or DRAM. For BR4 - BR7, bit 31 controls the interpretation of bits 14,17:30. If bit 31 has value 1, then the SRAM definition is used. If bit 31 has value 0, then the DRAM definition is used.

On power up, BR0 is initialized for valid SRAM devices at addresses 0xFFFF0 0000 - 0xFFFF FFFF (equivalent to 0x7FF0 0000 - 0x7FFF FFFF; see Section 2.2.1, Double-Mapping, on page 2-2). BR1-BR7 are initialized to invalid SRAM devices, so they must be further set up by software before use. The system then attempts to boot from a ROM at address 0xFFFF FFFC. Chapter 5 (Reset and Initialization) contains detailed information about register parameters at reset and at power-up.

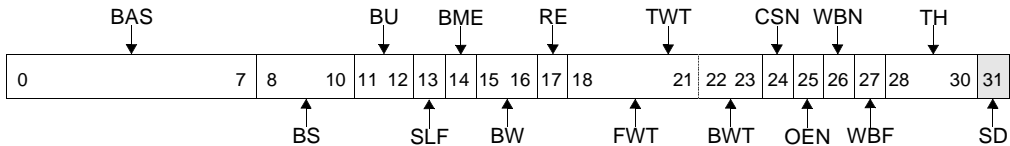


Figure 3-13. Bank Registers - SRAM Configuration (BR0-BR7)

0: 7	BAS	Base Address Select	Specifies the starting address of the SRAM bank.
8:10	BS	Bank Size 000 - 1 MB bank 001 - 2 MB bank 010 - 4 MB bank 011 - 8 MB bank 100 - 16 MB bank 101 - 32 MB bank 110 - 64 MB bank 111 - Reserved	
11:12	BU	Bank Usage 00 - Disabled, invalid, or unused bank 01 - Bank is valid for read only (RO) 10 - Bank is valid for write only (WO) 11 - Bank is valid for read/write (R/W)	

Figure 3-13. Bank Registers - SRAM Configuration (BR0-BR7) (cont.)

13	SLF	Sequential Line Fills 0 - Line fills are Target Word First 1 - Line fills are Sequential	
14	BME	Burst Mode Enable 0 - Bursting is disabled 1 - Bursting is enabled	For cache line fills and flushes, bus master burst operations, DMA flyby burst and DMA memory-to-memory line burst operations, and all packing and unpacking operations
15:16	BW	Bus Width 00 - 8-bit bus 01 - 16-bit bus 10 - 32-bit bus 11 - Reserved	
17	RE	Ready Enable 0 - Ready pin input is disabled 1 - Ready pin input is enabled	
18:23	TWT	Transfer Wait	Wait states on all non-burst transfers. Used if field BME=0.
18:21	FWT	First Wait	Wait states on first tranfer of a burst. Used if field BME=1.
22:23	BWT	Burst Wait	Wait states on non-first transfers of a burst. Used if field BME=1.
24	CSN	Chip Select On Timing 0 - Chip select is valid when address is valid 1 - Chip select is valid one SysClk cycle after address is valid	
25	OEN	Output Enable On Timing 0 - Output Enable is valid when chip select is valid 1 - Output Enable is valid one SysClk cycle after chip select is valid	Controls when the data bus goes active, for writes as well as reads.
26	WBN	Write Byte Enable On Timing 0 - Write byte enables are valid when Chip Select is valid 1 - Write byte enables are valid one SysClk cycle after chip select is valid	
27	WBF	Write Byte Enable Off Timing 0 - Write byte enables become inactive when chip select becomes inactive 1 - Write byte enables become inactive one SysClk cycle before chip select becomes inactive	
28:30	TH	Transfer Hold	Contains the number of hold cycles inserted at the end of a transfer. Hold cycles insert idle bus cycles between transfers to enable slow peripherals to remove data from the data bus before the next transfer begins.

Figure 3-13. Bank Registers - SRAM Configuration (BR0-BR7) (cont.)

31		reserved, for BR0-BR3	(For BR0-BR3, on a write, this bit is ignored; on a read, a zero is returned.)
	SD	SRAM - DRAM Selection, for BR4-BR7 0 - DRAM usage. 1 - SRAM usage.	(For BR4-BR7 in SRAM configuration, this bit must be 1.)

- **The BAS field (bits 0:7)** sets the base address for a SRAM device. The BAS field is compared to bits 4:11 of the effective address. If the effective address is within the range of a BAS field, the associated bank is enabled for the transaction. Fields BS and BAS are not independent. See Section 3.6.3 on page 3-10, including Table 3-2 (Restrictions on Bank Starting Address).

Multiple bank registers inadvertently may be programmed with the same base address or as overlapping banks. An attempt to use such overlapping banks is reported as a Non-Configured error to the Data Cache, Instruction Cache, or DMA Controller (whichever originated the access). No external access will be attempted. This error may result in a Machine Check exception. See Section 6.4.2 (Instruction Machine Check Handling) on page 6-18 and Section 6.4.3 (Data Machine Check Handling) on page 6-20. If the error occurred during a DMA access, an External Interrupt may result. See Section 4.2.11 (Errors) on page 4-31.

- **The BS field (bits 8:10)** sets the number of bytes which the bank may access, beginning with the base address set in the BAS field. Fields BS and BAS are not independent. See Section 3.6.3 on page 3-10, including Table 3-2 (Restrictions on Bank Starting Address).
- **The BU field (bits 11:12)** specify unused chip selects and protect banks of physical devices from read or write accesses.

When any access is attempted to an address within the range of the BAS field, and the bank is designated as invalid in the BU field, and there is no other bank with BU marked as valid which matches the address, then a Non-configured Error occurs. (A Non-configured Error also occurs if there is no bank that matches the address, regardless of BU field values.) When a write access is attempted to an address within the range of the BAS field, and the bank is designated as Read-Only, a BIU protection error occurs. Also, when a read access is attempted to an address within the range of the BAS field, and the bank is designated as Write-Only, a BIU protection error occurs. If the transaction is an instruction fetch, an Instruction Machine Check exception may occur (see Section 6.4.2, Instruction Machine Check Handling, on page 6-18). If the transaction is a data access, a Data Machine Check exception will occur (see Section 6.4.3, Data Machine Check Handling, on page 6-20). If the error occurred during a DMA access, an External Interrupt may result. See Section 4.2.11 (Errors) on page 4-31.

- **The SLF field (bit 13)** controls incoming data order on line fills. If “1”, then all line fills will be in sequential order (first word transferred is the first word of the cache line, whether or not the target address is the first word of the cache line). If “0”, then all fills will be in target-word-first order (first word transferred is the word at the target address, then the following sequential addresses to the highest address in the cache line, then sequentially from the first word of the cache line, until the entire line is transferred).

Line flushes are always transferred in sequential order, regardless of the state of the SLF field. All packing and unpacking of bytes or halfwords within a word are always transferred in sequential order, regardless of the state of the SLF field.

- **The BME field (bit 14)** controls bursting for cache line fills and flushes, bus master burst operations, DMA flyby burst and DMA memory-to-memory line burst operations, and all packing and unpacking operations. If “1”, then bursting is enabled. When bursting is enabled, the parameters Chip Select On (CST), Output Enable On (OET), and Write Byte Enable On (WBN) are valid only for the first transfer cycle. First Wait (FWT) applies during the first transfer of the burst, while Burst Wait (BWT) applies during all remaining transfers of the burst. If Burst Wait is programmed ≥ 1 cycle, then it is valid to program Write Byte Enable Off (WBF) to one. If $WBF = 1$, then the Write Byte Enable signals will turn off during the last cycle of each transfer (first transfer as well as each burst transfer).
- **The BW field (bits 15:16)** controls the width of bank accesses. If the BW field is b'00', the bank is assumed to have an 8-bit data bus; b'01' indicates a 16-bit data bus; b'10' indicates a 32-bit data bus. Figure 3-3 shows how devices of various widths are attached to the PPC403GC data bus.
- **The RE field (bit 17)** controls the use of the Ready input signal. If the field is 0, the Ready input is ignored; no additional wait states are inserted into bus transactions. If the field is 1, the Ready input is examined after the wait period expires; additional wait states are inserted if the Ready input is 0. The number of wait states in each transaction is determined by the TW field in the register and activation of the Ready input.
- **The TWT field (bits 18:23)** specifies the number of wait states to be taken by each transfer to the SRAM bank. The number of cycles from address valid to the deassertion of \overline{CS} is $(1 + TWT)$, where $0 \leq TWT \leq 63$. This field is used for non-burst transfers (field BME = 0).
- **The FWT field (bits 18:21)** specifies the number of wait states to be taken by the first access to the SRAM bank during a burst transfer (field BME = 1). The number of cycles from address valid to address invalid on the first access is $(1 + FWT)$, where $0 \leq FWT \leq 15$. See Section 3.7.3 on page 3-20 for further discussion of SRAM/ROM burst mode.

- **The BWT field (bits 22:23)** specifies the number of wait states to be taken by accesses beyond the first to the SRAM bank during a burst transfer (field BME = 1). On burst accesses except for the last, the number of cycles from address valid to the next valid address on each burst access is $(1 + \text{BWT})$, where $0 \leq \text{BWT} \leq 3$. On the last burst access, the number of cycles from address valid to the deassertion of $\overline{\text{CS}}$ is $(1 + \text{BWT})$, where $0 \leq \text{BWT} \leq 3$. See Section 3.7.3 on page 3-20 for further discussion of SRAM/ROM burst mode.
- **The CSN field (bit 24)** specifies the chip select turn on delay (**CSon**). The chip select signal may turn on coincident with the address or be delayed by 1 clock cycle.
- **The OEN field (bit 25)** specifies the output enable turn on delay (**OEon**), which is when the output enable signal should be asserted for read operations relative to the chip select signal. If 0, the signal will be asserted coincident with the chip select. If 1, the OE signal will be delayed by 1 clock cycle. This signal is also used on write operations to control the turn-on of the data bus. If 0, the data bus will be driven coincident with the chip select. If 1, the data bus will be driven 1 clock cycle after the chip select is activated.
- **The WBN field (bit 26)** specifies the write enable turn on delay (**WBEon**), which is when the write byte enables should be asserted relative to the chip select signal. If 0, then the $\overline{\text{WBE}}$ signal will turn on coincident with the chip select. If 1, then the $\overline{\text{WBE}}$ signal will be delayed 1 clock cycle from the chip select.
- **The WBF field (bit 27)** specifies the write enable turn off time (**WBEoff**), which is when the write byte enables are deasserted, relative to the deassertion of the chip select signal. If the bit is 0, then $\overline{\text{WBE}}$ will turn off coincident with the chip select signal. If the bit is 1, then $\overline{\text{WBE}}$ will turn off one cycle before the turn-off of the chip select signal. It is invalid to set the WBF = 1 if the Wait parameter is equal to 0.
- **The TH field (bits 28:30)** specify the number of SysClk cycles (0 through 7) that the bus is held after the deassertion of $\overline{\text{CS}}$. During these cycles, the address bus and data bus are active and $\text{R}/\overline{\text{W}}$ is valid during the Hold time; chip select, output enable, and write byte enables are inactive.
- **The SD field (bit 31)** specifies the usage (SRAM or DRAM) of the bank register, for bank registers BR4-BR7, which have dual usage. For those registers, SD = 1 indicates SRAM and SD = 0 indicates DRAM. For BR0-BR3, only SRAM usage is defined, and field SD is reserved (always 0).

3.8 The DRAM Interface

3.8.1 Signals

Five sets of signals are dedicated to the DRAM interface:

$\overline{\text{RAS0}}:\overline{\text{RAS3}}$	Row address selects for each DRAM bank
$\overline{\text{CAS0}}:\overline{\text{CAS3}}$	Column address selects for bytes 0 through 3 of all DRAM banks
$\overline{\text{DRAMOE}}$	DRAM output enable for all DRAM banks
$\overline{\text{DRAMWE}}$	DRAM write enable for all DRAM banks
AMuxCAS	An output used to control column address selection by an external mux

Many of the timing parameters associated with these signals are programmable. The following discussion details the relations among these signals and the programmable options that are available:

- $\overline{\text{RAS}}$ becomes active approximately 1/2 clock cycle after the address becomes valid.
 - Early RAS Mode activates the $\overline{\text{RAS}}$ line slightly earlier than normal (approximately 1/4 cycle after the address becomes valid), under control of BRn[ERM]. Using Early RAS Mode will reduce the available address setup time, but will allow more DRAM access time. Early RAS Mode applies to both read and write operations, and in page mode as well as non-page mode. Early RAS Mode will not affect the RAS output during refresh cycles. Early RAS Mode is illustrated in Figure 3-15 and Figure 3-16.

Caution for users of Early RAS Mode:

- If a DRAM bank is programmed to use the Early RAS Mode feature (DRAM bank register bit 14 is set to 1), no access to this bank may occur within 700 nsec from any of the following:
 - the deactivation of Reset;
 - any change of SysClk frequency, including the restart of SysClk from a stopped state (change of SysClk duty cycle does not require access restrictions);
 - enabling normal-power operation by clearing IOCR[SPD] to 0.

- No use of Early RAS Mode may occur while the chip is in the power-reduced mode set by IOCR[SPD] = 1. This power-reduced mode is intended for achieving minimum chip power dissipation in a clock-stopped state; it is not intended for use during normal chip operation.

- $\overline{\text{CAS}}$ activation is programmable; $\overline{\text{CAS}}$ may be activated either 1 or 2 clock cycles after $\overline{\text{RAS}}$ becomes valid. During page mode transfers, $\overline{\text{CAS}}$ becomes active 1/2 cycle after the address becomes valid.

$\overline{\text{CAS}}$ becomes inactive when $\overline{\text{RAS}}$ becomes inactive, on a single transfer or on the last transfer of a burst. $\overline{\text{CAS}}$ becomes inactive when the address changes for burst transfers other than the last.

- On DRAM read only, the PPC403GC may be programmed to latch data from the data bus either on the rise of SysClk (normal operation) or on the rising edge of $\overline{\text{CAS}}$. Latching data on the rising edge of $\overline{\text{CAS}}$ (DRAM Read on CAS) provides more time for the memory to present the data to the PPC403GC. The DRAM Read on CAS feature is under the control of IOCR bit 26.
- $\overline{\text{DRAMOE}}$, $\overline{\text{DRAMWE}}$, and $\overline{\text{AMuxCAS}}$ are activated at the beginning of the cycle in which $\overline{\text{CAS}}$ is activated. $\overline{\text{DRAMOE}}$, $\overline{\text{DRAMWE}}$, and $\overline{\text{AMuxCAS}}$ are deactivated coincident with the deactivation of $\overline{\text{RAS}}$.
- $\overline{\text{RAS}}$ Precharge is the interval from the deassertion of $\overline{\text{RAS}}$ to the earliest time when $\overline{\text{RAS}}$ may be again asserted. Precharge is selectable as either 1.5 or 2.5 cycles.

Note that using Early RAS Mode will reduce the available precharge time by 1/4 cycle.

If the PPC403GC is the bus master, then the column address lines and $\overline{\text{R}/\overline{\text{W}}}$ are maintained valid for either 1 or 2 cycles following the deassertion of $\overline{\text{RAS}}$.

- If the PPC403GC is bus master and the bus is idle, then $\overline{CS4}/RAS3$ - $\overline{CS7}/RAS0$, $\overline{CAS0}$ - $\overline{CAS3}$, \overline{DRAMOE} , \overline{DRAMWE} , and $\overline{AMuxCAS}$ will be held inactive.

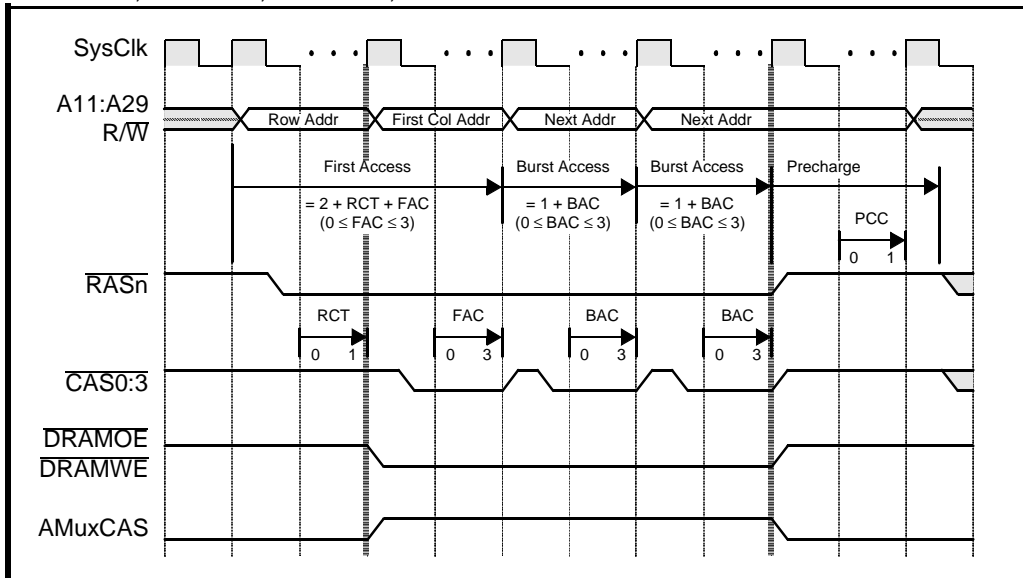


Figure 3-14. Parameter Definitions — DRAM

3.8.1.1 DRAM Read Example

The following figure illustrates the timing of a single (non-burst) DRAM read.

Note that the Early RAS Mode and DRAM Read on CAS features are illustrated here. DRAM Read on CAS only applies to DRAM read operations.

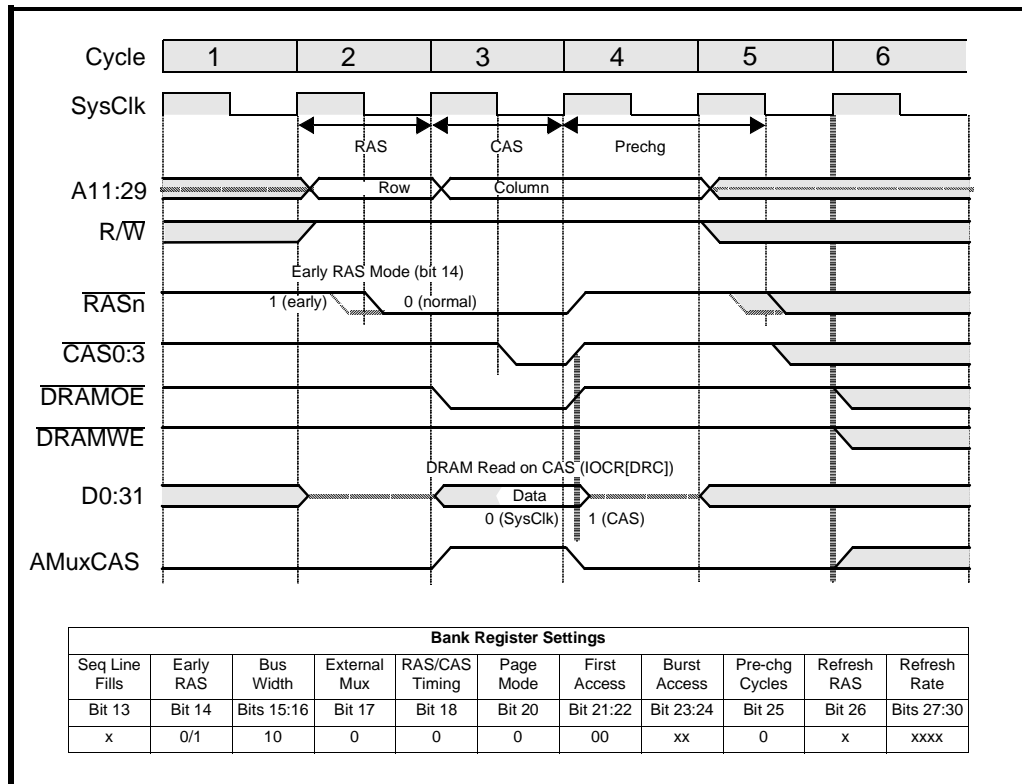


Figure 3-15. DRAM Single Transfer Read

3.8.1.2 DRAM Write Example

The following figure illustrates the timing of a single (non-burst) DRAM write.

Note that the Early RAS Mode feature is illustrated here.

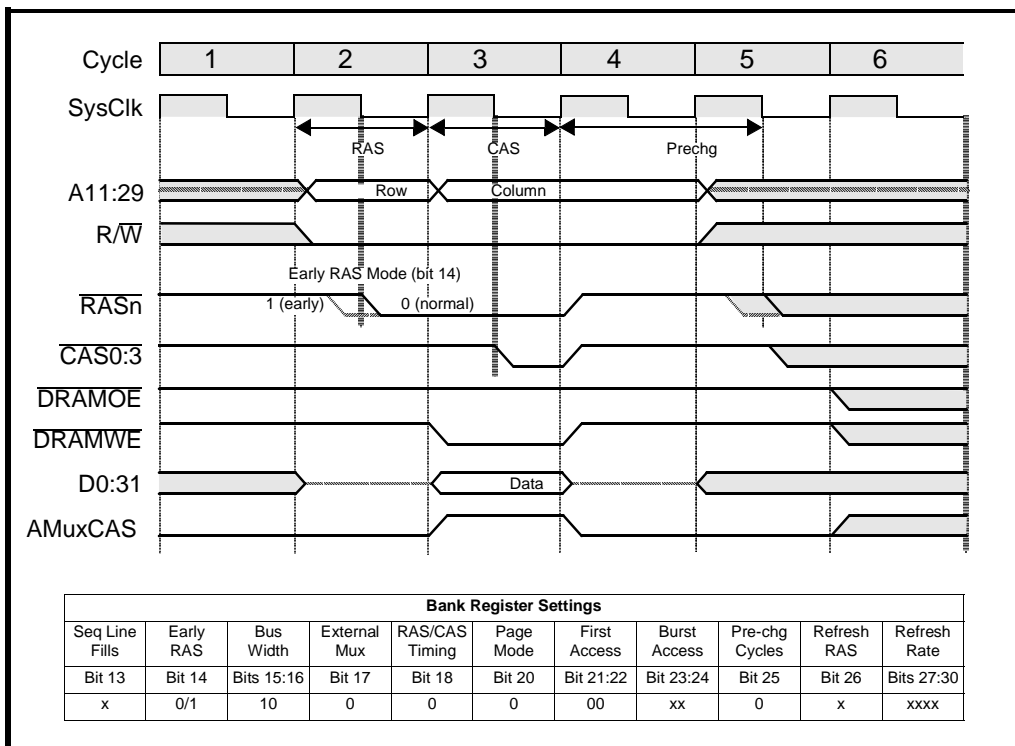


Figure 3-16. DRAM Single Transfer Write

3.8.1.3 DRAM Page Mode Read Example

The following figure illustrates the timing of a 3-2-2-2 burst DRAM read.

Early RAS Mode and DRAM Read on CAS features are not illustrated here, but they may be used if desired. DRAM Read on CAS only applies to DRAM read operations.

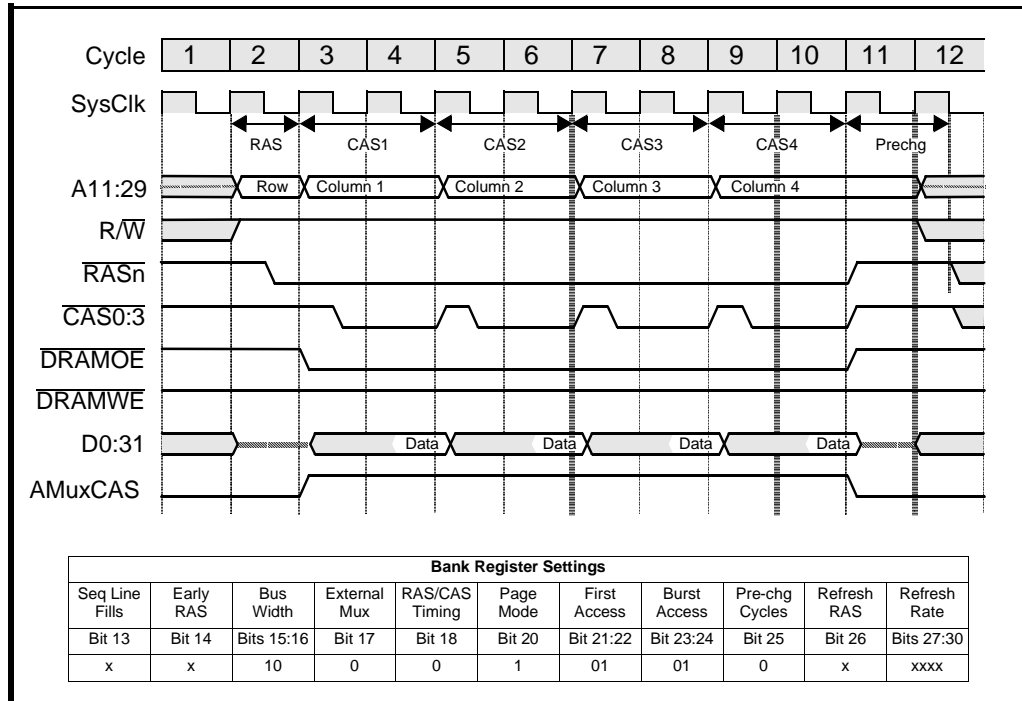


Figure 3-17. DRAM 3-2-2-2 Page Mode Read

The following figure illustrates the timing of a 2-1-1-1 burst DRAM read.

Note that the Early RAS Mode and DRAM Read on CAS features are illustrated here. DRAM Read on CAS only applies to DRAM read operations.

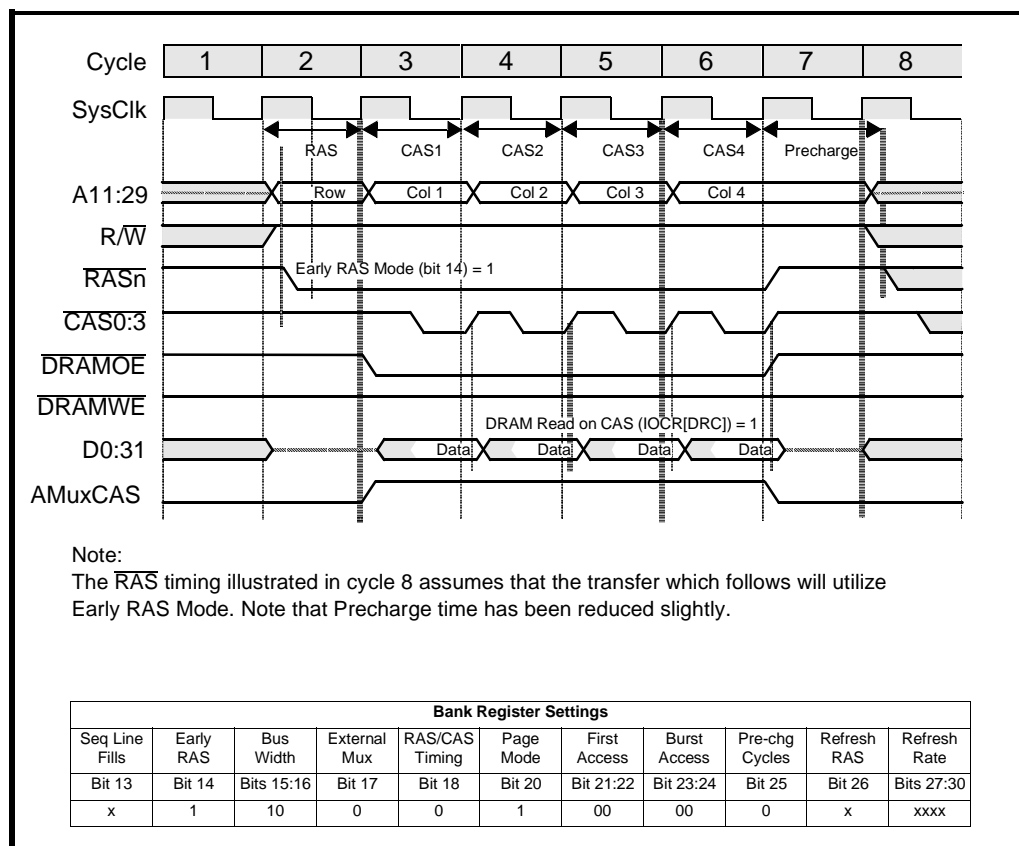


Figure 3-18. DRAM 2-1-1-1 Page Mode Read

3.8.1.4 DRAM Page Mode Write Example

The following figure illustrates the timing of a 3-2-2-2 burst DRAM write.

The Early RAS Mode feature is not illustrated here, but it may be used if desired.

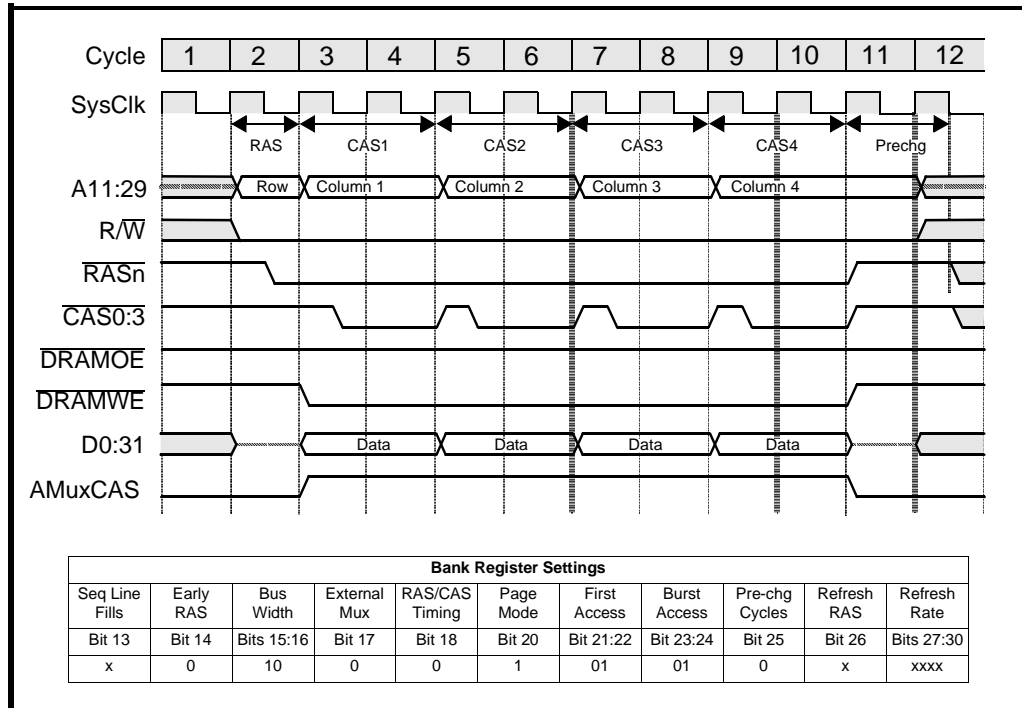


Figure 3-19. DRAM 3-2-2-2 Page Mode Write

The following figure illustrates the timing of a 2-1-1-1 burst DRAM write.

Note that the Early RAS Mode feature is illustrated here.

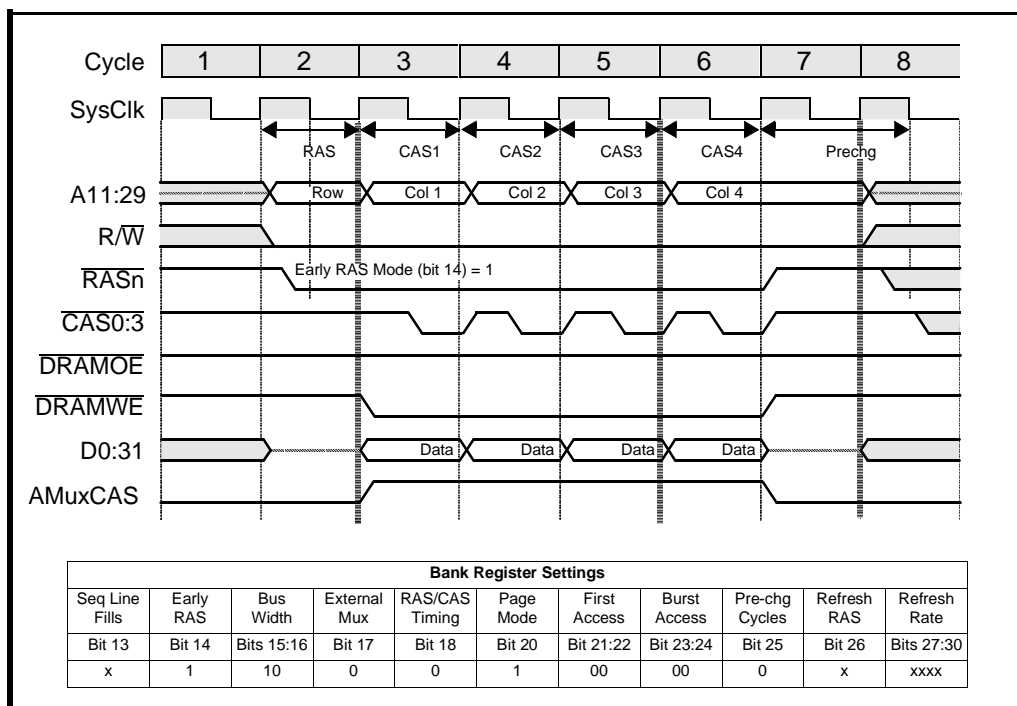


Figure 3-20. DRAM 2-1-1-1 Page Mode Write

3.8.1.5 DRAM $\overline{\text{CAS}}$ Before $\overline{\text{RAS}}$ Refresh Example

The following figure illustrates $\overline{\text{CAS}}$ -before- $\overline{\text{RAS}}$ refresh. See page 3-43 for a discussion of the controls for this mode of refresh.

Note:

Early RAS Mode does not affect the activation of $\overline{\text{RAS}}$ during refresh. $\overline{\text{RAS}}$ is always activated 1 cycle following the activation of $\overline{\text{CAS}}$ during a refresh operation.

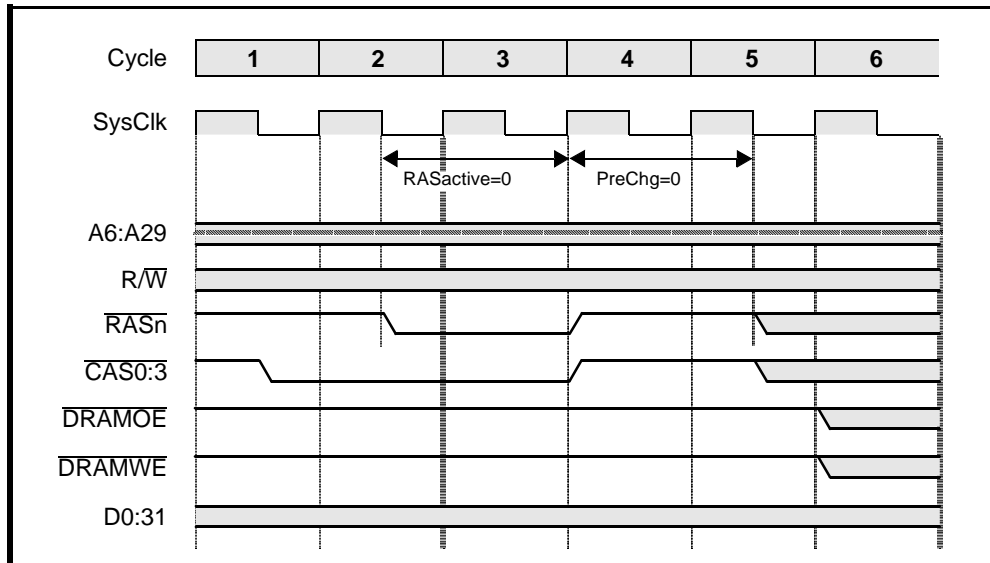


Figure 3-21. DRAM Refresh Timing, $\overline{\text{CAS}}$ Before $\overline{\text{RAS}}$, 1 Bank

3.8.2 Bank Registers for DRAM Devices

Four bank registers (BR4 through BR7) can control either SRAM or DRAM devices. When configured to control DRAM devices, BR4 - BR7 control row address select (RAS) lines $\overline{\text{RAS3}}$ through $\overline{\text{RAS0}}$, respectively.

Figure 3-22 shows the fields of BR4 - BR7 when these registers are configured to control DRAM-like devices. Section 3.7.4 describes the usage of BR4 - BR7 for SRAM devices.

Bits 0:13,15:16 of the bank register have the same usage, whether for SRAM or DRAM. For BR4 - BR7, bit 31 controls the interpretation of bits 14,17:30. If bit 31 has value 1, then the SRAM definition is used. If bit 31 has value 0, then the DRAM definition is used.

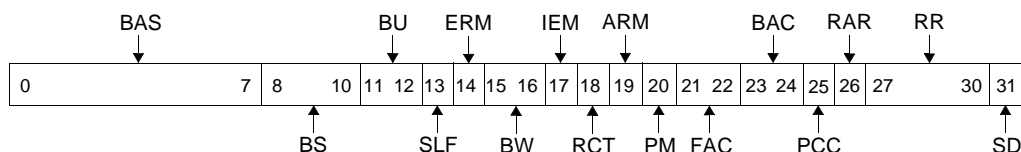


Figure 3-22. Bank Registers - DRAM Configuration (BR4-BR7)

0: 7	BAS	Base Address Select	Specifies the starting address of the DRAM bank.
8:10	BS	Bank Size 000 - 1 MB bank 001 - 2 MB bank 010 - 4 MB bank 011 - 8 MB bank 100 - 16 MB bank 101 - 32 MB bank 110 - 64 MB bank 111 - Reserved	
11:12	BU	Bank Usage 00 - Disabled, invalid, or unused bank 01 - Bank is valid for read only (RO) 10 - Bank is valid for write only (WO) 11 - Bank is valid for read/write (R/W)	
13	SLF	Sequential Line Fills 0 - Line fills are Target Word First 1 - Line fills are Sequential	
14	ERM	Early RAS Mode 0 - normal RAS activation (approximately 1/2 cycle following address valid) 1 - early RAS activation (approximately 1/4 cycle following address valid)	
15:16	BW	Bus Width 00 - 8-bit bus 01 - 16-bit bus 10 - 32-bit bus 11 - Reserved	

Figure 3-22. Bank Registers - DRAM Configuration (BR4-BR7) (cont.)

17	IEM	Internal / External Multiplex 0 - Address bus multiplexed internally 1 - Address bus multiplexed externally	If an external bus master is used, an external multiplexer must also be used.
18	RCT	RAS Active to CAS Active Timing 0 - CAS becomes active one SysClk cycle after RAS becomes active 1 - CAS becomes active two SysClk cycles after RAS becomes active	
19	ARM	Alternate Refresh Mode 0 - Normal refresh 1 - Immediate or Self refresh	(Use alternate values of field RR.)
20	PM	Page Mode 0 - Single accesses only, Page Mode not supported 1 - Page Mode burst access supported	
21:22	FAC	First Access Timing 00 - First Wait = 0 SysClk cycles 01 - First Wait = 1 SysClk cycles 10 - First Wait = 2 SysClk cycles 11 - First Wait = 3 SysClk cycles	First Access time is 2 + FAC if RCT = 0. First Access time is 3 + FAC if RCT = 1.
23:24	BAC	Burst Access Timing 00 - Burst Wait = 0 SysClk cycles 01 - Burst Wait = 1 SysClk cycles 10 - Burst Wait = 2 SysClk cycles 11 - Burst Wait = 3 SysClk cycles	Burst Access time is 1 + BAC. Note: if FAC = 0, BAC is ignored and treated as 0.
25	PCC	Precharge Cycles 0 - One and one-half SysClk cycles 1 - Two and one-half SysClk cycles	
26	RAR	RAS Active During Refresh 0 - One and one-half SysClk cycles 1 - Two and one-half SysClk cycles	
27:30	RR	Refresh Interval	See Table 3-4 for bit values assigned to various refresh intervals. If field ARM=1, use Table 3-5.
31	SD	SRAM - DRAM Selection 0 - DRAM usage. 1 - SRAM usage.	Must be 0 for DRAM configuration.

- **The BAS field (bits 0:7)** select the address for the DRAM bank. These bits are compared to bits 4:11 of an effective address in the DRAM address region. Address bits A1:A3 must contain 0 for DRAM accesses. Address bits A0:A4 determine the cacheability of the memory region. Fields BS and BAS are not independent. See Section 3.6.3 on page 3-10, including Table 3-2 (Restrictions on Bank Starting Address).

Multiple bank registers inadvertently may be programmed with the same base address or as overlapping banks. An attempt to use such overlapping banks is reported as a Non-Configured error to the Data Cache, Instruction Cache, or DMA Controller (whichever originated the access). No external access will be attempted. This error may result in a Machine Check exception. See Section 6.4.2 (Instruction Machine Check Handling) on page 6-18 and Section 6.4.3 (Data Machine Check Handling) on page 6-20. If the error occurred during a DMA access, an External Interrupt may result. See Section 4.2.11 (Errors) on page 4-31.

- **The BS field (bits 8:10)** sets the number of bytes which the bank may access, beginning with the base address set in the BAS field. Fields BS and BAS are not independent. See Section 3.6.3 on page 3-10, including Table 3-2 (Restrictions on Bank Starting Address).

- **The BU field (bits 11:12)** specify unused chip selects and protect banks of physical devices from read or write accesses.

When any access is attempted to an address within the range of the BAS field, and the bank is designated as invalid in the BU field, and there is no other bank with BU marked as valid which matches the address, then a Non-configured Error occurs. (A Non-configured Error also occurs if there is no bank that matches the address, regardless of BU field values.) When a write access is attempted to an address within the range of the BAS field, and the bank is designated as Read-Only, a BIU protection error occurs. Also, when a read access is attempted to an address within the range of the BAS field, and the bank is designated as Write-Only, a BIU protection error occurs. If the transaction is an instruction fetch, an Instruction Machine Check exception may occur (see Section 6.4.2, Instruction Machine Check Handling, on page 6-18). If the transaction is a data access, a Data Machine Check exception will occur (see Section 6.4.3, Data Machine Check Handling, on page 6-20). If the error occurred during a DMA access, an External Interrupt may result. See Section 4.2.11 (Errors) on page 4-31.

- **The SLF field (bit 13)** controls incoming data order on line fills. If “1”, then all line fills will be in sequential order (first word transferred is the first word of the cache line, whether or not the target address is the first word of the cache line). If “0”, then all fills will be in target-word-first order (first word transferred is the word at the target address, then the following sequential addresses to the highest address in the cache line, then sequentially from the first word of the cache line, until the entire line is transferred).

Line flushes are always transferred in sequential order, regardless of the state of the SLF field. All packing and unpacking of bytes or halfwords within a word are always transferred in sequential order, regardless of the state of the SLF field.

- **The ERM field (bit 14)** alters the timing of when $\overline{\text{RASn}}$ becomes active. In Early RAS Mode (ERM = 1), $\overline{\text{RASn}}$ becomes active approximately 1/4 cycle after address valid, while in the standard (ERM = 0) mode, $\overline{\text{RASn}}$ becomes active approximately 1/2 cycle after address valid. Early RAS Mode provides more row address access time for the DRAM device, to enable the first transfer of a DRAM burst.

Related to the ERM field usage is the usage of IOCR[DRC] (bit 26 of the IOCR). If DRC = 1, values from the data bus are latched on the rise of $\overline{\text{CAS}}$, which provides a longer access time than the standard (DRC = 0) mode. This provides more time for data to arrive from memory on every transfer (first and all burst transfers) of a read. Both of these timing enhancements are used to provide maximum DRAM access time.

The use of these enhancements is illustrated for single transfers in Figure 3-15 on page 3-32 and in Figure 3-16 on page 3-33, and for burst transfers in Figure 3-17 on page 3-34 and in Figure 3-17 on page 3-34.

- **The BW field (bits 15:16)** controls the width of bank accesses. If the BW field is b'00', the bank is assumed to have an 8-bit data bus; b'01' indicates a 16-bit data bus; b'10' indicates a 32-bit data bus. Figure 3-3 shows how devices of various widths are attached to the PPC403GC data bus.
- **The IEM field (bit 17)** allows system designers to configure an external address multiplexer to allow external bus masters to access DRAM.
- **The RCT field (bit 18)** controls the time from $\overline{\text{RAS}}$ activation to $\overline{\text{CAS}}$ activation during an access. If RCT = 0, the time will be 1 system clock period. If RCT = 1, the time will be 2 system clock periods.

RCT = 1 extends the time that the row address is presented to the DRAM.

- **The ARM field (bit 19)** enables refresh modes other than the standard automatic refresh based on elapsed cycles (see the discussion of the RR field on page 3-43 and the discussion of Alternate Refresh Mode in Section 3.8.3 on page 3-45). If ARM = 0, then standard automatic DRAM refresh is in effect.
- **The PM field (bit 20)** controls burst DRAM operation, where on accesses beyond the first, the row address is not re-specified. When PM = 1, burst access is allowed under the Page Mode DRAM protocol (in Page Mode, each new column addresses is latched at the falling edge of CAS). When PM = 0, all accesses are single transfers (both row and column addresses supplied for each transfer).
- **The FAC field (bits 21:22)** specifies first access wait time. This parameter is in effect on any access in which the row address is specified (single transfer, or first transfer of a burst). The period where $\overline{\text{CAS}}$ is active will be extended by a number of cycles equal to the FAC field. The access time is (2 + FAC) if field RCT = 0, or (3 + FAC) if field RCT = 1.
- **The BAC field (bits 23:24)** specifies burst access wait time. This parameter is in effect on any access in which the row address is not specified (transfers other than the first while in page mode, field PM = 1). The period where $\overline{\text{CAS}}$ is active will be extended by a number of cycles equal to the BAC field. The access time is (1 + BAC).

ACCESS CYCLE RESTRICTIONS:

If the first-access field $FAC = b'00'$, then the burst-access field BAC will be ignored and treated as $b'00'$. This prevents the use of DRAM specifications where the first access time is 2 cycles and the burst access times are ≥ 2 cycles. For example 2-1-1-1 DRAM specification is allowed, but 2-2-2-2 and 2-3-3-3 are not.

- **The PCC field (bit 25)** controls \overline{RAS} pre-charge, which is the minimum time which must be allowed between the deactivation of \overline{RAS} on one access and the activation of \overline{RAS} on the next access to the DRAM device. When the pre-charge parameter is set to '0' the pre-charge time is 1.5 cycle, and when set to '1' the pre-charge will be 2.5 cycles. These times are measured from the deassertion of \overline{RAS} until the earliest time when \overline{RAS} may be reasserted.

Note that using Early RAS Mode ($ERM = 1$) will reduce the pre-charge time by 1/4 cycle.

- **The RAR field (bit 26)** controls the RAS active time during CAS-before-RAS refresh operation. $RAR = 0$ results in RAS active time of 1.5 system cycles, and $RAR = 1$ results in RAS active time of 2.5 cycles. This parameter allows flexibility in optimizing system performance.
- **The RR field (bits 27:30)** selects the \overline{CAS} before \overline{RAS} refresh rate. DRAM refresh is transparent to the user. Refresh rates are selectable from 64 SysClk cycles to 6144 SysClk cycles, as shown in Table 3-4. A refresh completes in four clock cycles (if $RAR = 0$) or five clock cycles (if $RAR = 1$).

If field $ARM=1$ (Alternate Refresh Mode selected), use Table 3-5 to define the RR field values used with the alternate refresh action. See Section 3.8.3 on page 3-45 for a full discussion of Alternate Refresh Mode.

- **The SD field (bit 31)** specifies the usage (SRAM or DRAM) of the bank register, for bank registers BR4-BR7, which have dual usage. For those registers, $SD = 1$ indicates SRAM and $SD = 0$ indicates DRAM. For BR0-BR3, only SRAM usage is defined, and field SD is reserved (always 0).

Table 3-4. RR Field for Normal Refresh Mode

Value	Interval	Refresh Period (μ sec)	Refresh Period (μ sec)
		SysClk=33 MHz	SysClk=25 MHz
0000	No refresh		
0001	Reserved		
0010	64 SysClk cycles	1.92	2.56
0011	96 SysClk cycles	2.88	3.84
0100	128 SysClk cycles	3.84	5.12
0101	192 SysClk cycles	5.76	7.68
0110	256 SysClk cycles	7.68	10.24
0111	384 SysClk cycles	11.52	15.36
1000	512 SysClk cycles	15.36	20.48
1001	768 SysClk cycles	23.04	30.72
1010	1024 SysClk cycles	30.72	40.96
1011	1536 SysClk cycles	46.08	61.44
1100	2048 SysClk cycles	61.44	81.92
1101	3072 SysClk cycles	92.16	122.88
1110	4096 SysClk cycles	122.88	163.84
1111	6144 SysClk cycles	184.32	245.76

Table 3-5. RR Field for Alternate Refresh Mode

Value	Action
0001	Immediate Refresh
0010	Self Refresh -- Hold RAS
0100	Self Refresh -- Hold CAS
0110	Self Refresh -- Hold RAS and CAS

3.8.3 Alternate Refresh Mode

BRn[ARM] is the Alternate Refresh Mode bit. When ARM = 0, refresh for this bank is done normally at the rate programmed in the DRAM Refresh Rate field of the bank register.

When ARM = 1, Alternate Refresh Mode is enabled. In Alternate Refresh Mode, the DRAM Refresh Rate field now indicates either Immediate Refresh or Self Refresh.

While in the Alternate Refresh mode, the internal refresh request generator will be ignored and it is up to the software to either put the device in Self Refresh mode, or use the Immediate Refresh to meet the refresh requirements of the device.

Software must ensure that there are no DRAM accesses while any bank is in the Alternate Refresh Mode. If the Alternate Refresh mode bit is set and a DRAM access is attempted, a Non-Configured error will occur.

3.8.3.1 Immediate Refresh

Immediate Refresh is a means of using the refresh controller internal to the PPC403GC to perform DRAM refresh, with the time of refresh occurrence determined by software rather than determined automatically by the BIU. In Alternate Refresh mode, refresh will not occur at all unless activated by software. Once the Immediate Refresh mode is activated, refreshes will continue until the Alternate Refresh Mode bit is reset by software. Immediate Refresh behaves according to the following rules:

- Each cycle that the Alternate Refresh Mode bit is set, and the Refresh Rate field is programmed to 0001, the DRAM control register will continue to set the refresh request latch in the DRAM controller. Thus, if this bit is set for at least one cycle, the DRAM controller will guarantee that at least one refresh occurs. If the mode is set for more than one cycle, then one or more refreshes may occur and will continue to occur until the Alternate Refresh Mode bit is reset. Since the Immediate Refresh mode is setting the refresh request latch in the DRAM controller, there may be one additional refresh done after exiting the Alternate Refresh mode.
- If more than one refresh request is active, BR7 has the highest priority, followed by BR6, then BR5, and finally BR4. If BR7's Immediate Refresh mode remains active for a long period of time, then no other bank will be refreshed during this time. To avoid this problem, the bank which requires Immediate Refresh mode should be programmed on one of the lower priority banks so that the other bank of DRAM will have higher priority and will continue to get refreshed at the rate programmed.

3.8.3.2 Self Refresh Mode

Several DRAMs available today provide support for self-refresh mode. In this mode the RAS and CAS signals are held active and the DRAM device will perform the row refreshes internally. No data accesses are allowed during this time and the output of the device

remains HiZ. The advantage of using self refresh mode is that the power dissipation of the DRAM device is 30 to 40 times less than when the device is in the active mode. Thus, for those applications which run on battery power and have long intervals where the DRAM's are not accessed, the power requirement of the system can be significantly reduced.

- Self Refresh Mode is supported by providing the code the ability to activate the RAS and CAS signals and hold them on for extended periods of time. To accomplish this, the Alternate Refresh mode bit is set in the DRAM bank control register and one of the following codes is set into the Refresh Rate field of the same bank control register:

0010 - This code will cause the RAS signal for that bank of DRAM to be activated and remain active until either the Refresh Rate field is changed or the Alternate refresh mode bit is reset.

0100 - This code will cause all 4 CAS signals to be activated and remain active until either the Refresh Rate field is changed or the Alternate Refresh mode bit is reset.

0110 - This code will cause the RAS signal for that bank of DRAM to be activated as well as all 4 CAS signals. These signals will remain active until either the Refresh Rate field is changed or the Alternate refresh mode bit is reset.

- These three operations will activate the RAS or CAS signals regardless of any DRAM access that are in progress or pending. It is up to the code to ensure that no DRAM accesses occur to any DRAM bank if any one bank is in the self refresh mode. If a DRAM access does occur while in the Alternate Refresh mode then a Non-Configured error will occur.
- Other DRAM banks that are active while one bank is in Self Refresh mode may be attempting to perform refresh cycles. These refresh attempts will occur normally except that the RAS and CAS signals that are being held active for Self Refresh will continue to be held active without regard for the refresh attempt by the other DRAM bank.

For a discussion of the behavior of the DRAM control signals during reset, and the effect of Self Refresh during reset, see Section 5.5 on page 5-8.

3.8.4 Example of DRAM Connection

The following example shows the connections for three banks of DRAM. In the example, BR7 has been configured as a 32 bit DRAM composed of byte devices. BR6 has been configured as 8 bit DRAM. BR5 has been configured as 16 bit DRAM composed of byte devices. Figure 3-23 illustrates the use of RAS, CAS, and Data Bus lines necessary to achieve this configuration.

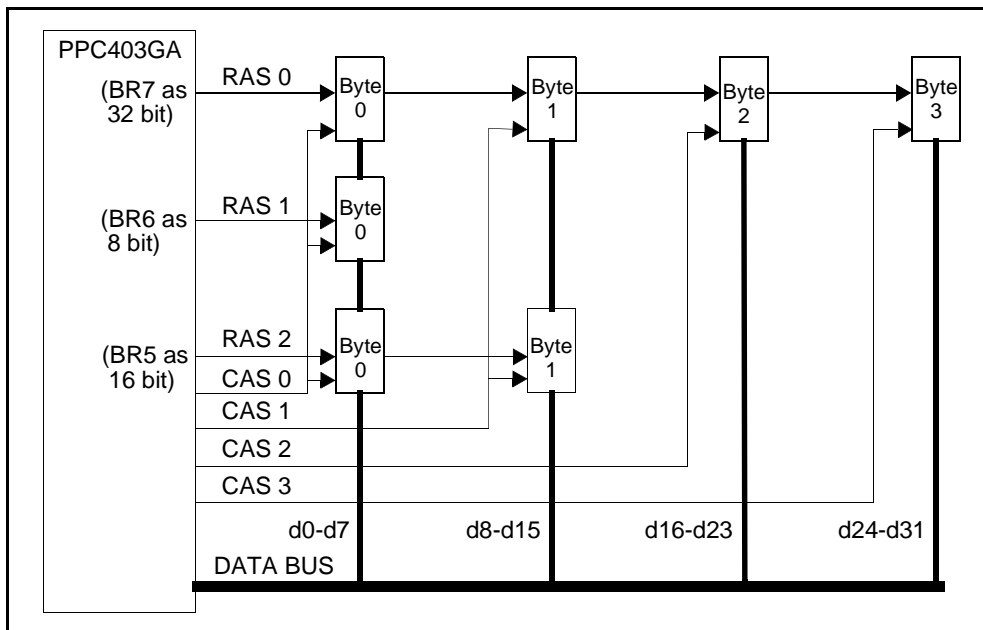


Figure 3-23. Example of DRAM Connection

3.8.4.1 Note about SIMMs

It is common for DRAM to be supplied in SIMM packages, which may be either one-sided or two-sided. Comment is required about two-sided SIMMs. An 8MB SIMM will be used for illustration.

A SIMM carrying 8MB of DRAM will be labelled as an 8MB SIMM, regardless of whether it is one-sided or two-sided. However, the two-sided SIMM will actually be two nearly separate 4MB memories. While the two sides will share many bus pins, for simplicity of connection, each side will have a separate $\overline{\text{RAS}}$ pin. The separate $\overline{\text{RAS}}$ pin forces each side to be connected to a separate PPC403GC DRAM bank (at 4MB per bank), just as if the sides were entirely separate packages. The one-sided SIMM will have only one $\overline{\text{RAS}}$ pin, so that all 8MB can be accessed using only one bank, instead of two.

3.8.5 Address Bus Multiplex for DRAM

Addresses are presented to DRAM in two sequential transfers. The first portion of the address is presented with the $\overline{\text{RAS}}$ strobe, then the second portion with the $\overline{\text{CAS}}$ strobe. It is not, in general, required for the same number of address bits to be transferred in each portion.

Assuming that the Bank Register of the PPC403GC has been configured for Internal Multiplex (field IEM=0), the PPC403GC will multiplex the internal address bits a6-a31 onto the external address pins A11-A29 as shown in Table 3-6.

Table 3-6. Multiplexed Address Outputs

PPC403GC Pin Name	Logical Addr During $\overline{\text{RAS}}$	Logical Addr During $\overline{\text{CAS}}$
A29	a22	a31
A28	a21	a30
A27	a20	a29
A26	a19	a28
A25	a18	a27
A24	a17	a26
A23	a16	a25
A22	a15	a24
A21	a14	a23
A20	a13	a22
A19	a12	a21
A18	a13	a12
A17	a12	a11
A16	a11	a10
A15	a10	a9
A14	a9	a8
A13	a8	a7
A12	a7	a6
A11	a6	xx

The above information has been combined with bus width and DRAM size to produce Table 3-7 through Table 3-9, which explicitly define how to connect the PPC403GC to a wide variety of DRAMs. The tables show the external address pins of the PPC403GC, the pins of the memory device to which they should be wired, and the logical address bit carried on each line in both the $\overline{\text{RAS}}$ and $\overline{\text{CAS}}$ cycles. There are separate tables for 8 bit, 16 bit, and 32 bit bus width (as defined in Bank Register field BW).

Table 3-7. DRAM Multiplex for 8 bit Bus

PPC403GC Pin Name	DRAM Addr Pin Name	Logical Addr During $\overline{\text{RAS}}$	Logical Addr During $\overline{\text{CAS}}$	Meg 1	Meg 2,4	Meg 8,16	Meg 32, 64			
A29	p0	a22	a31							
A28	p1	a21	a30							
A27	p2	a20	a29							
A26	p3	a19	a28							
A25	p4	a18	a27							
A24	p5	a17	a26							
A23	p6	a16	a25							
A22	p7	a15	a24							
A21	p8	a14	a23							
A18	p9	a13	a12							
A16	p10	a11	a10 XX for 2 meg							
A14	p11	a9	a8 XX for 8 meg							
A12	p12	a7	a6 XX for 32 meg							
XX This position is a DON'T CARE since the DRAM will take only the ROW address for this pin.										

Table 3-8. DRAM Multiplex for 16 bit Bus

PPC403GC Pin Name	DRAM Addr Pin Name	Logical Addr During \overline{RAS}	Logical Addr During \overline{CAS}	Meg 1,2	Meg 4,8	Meg 16, 32	Meg 64			
A28	p0	a21	a30							
A27	p1	a20	a29							
A26	p2	a19	a28							
A25	p3	a18	a27							
A24	p4	a17	a26							
A23	p5	a16	a25							
A22	p6	a15	a24							
A21	p7	a14	a23							
A20	p8	a13	a22							
A17	p9	a12	a11 XX for 1 meg							
A15	p10	a10	a9 XX for 4 meg							
A13	p11	a8	a7 xx for 16 meg							
A11	p12	a6	XX for 64 meg							
XX This position is a DON'T CARE since the DRAM will take only the ROW address for this pin.										

Table 3-9. DRAM Multiplex for 32 bit Bus

PPC403GC Pin Name	DRAM Addr Pin Name	Logical Addr During \overline{RAS}	Logical Addr During \overline{CAS}	Meg 1	Meg 2,4	Meg 8,16	Meg 32, 64
A27	p0	a20	a29				
A26	p1	a19	a28				
A25	p2	a18	a27				
A24	p3	a17	a26				
A23	p4	a16	a25				
A22	p5	a15	a24				
A21	p6	a14	a23				
A20	p7	a13	a22				
A19	p8	a12	a21				
A16	p9	a11	a10 XX for 2 meg				
A14	p10	a9	a8 XX for 8 meg				
A12	p11	a7	a6 XX for 32 meg				
XX This position is a DON'T CARE since the DRAM will take only the ROW address for this pin.							

3.9 The On-Chip Peripheral Bus Interface

The PPC403GC OPB is a synchronous device-paced bus that attaches on-chip peripherals to the processor core. The OPB comprises a 32-bit data bus, a 32-bit address bus, and control signals. The bus can support single-cycle data transfers between on-chip peripherals and the core.

The OPB is connected to the BIU, which is always the bus master of the OPB. Requests for data transfers on the OPB can originate from the instruction cache, the data cache, or DMA, and are arbitrated by the BIU. The BIU controls all handshaking and data movement required to complete a transfer accepted by the BIU.

3.10 External Bus Master Interface

The PPC403GC supports a shared bus protocol which allows external bus masters to take control of the PPC403GC external buses and SRAM control signals. Furthermore, the PPC403GC provides support for external bus masters to access the local DRAM, using the DRAM controller internal to the PPC403GC.

Figure 3-24 shows a sample interconnection among a PPC403GC, one DRAM bank and one external bus master. Only one DRAM bank is shown, but the bus master could access as many as four DRAM banks local to the PPC403GC. Also, with the appropriate arbitration logic, multiple bus masters may be used in a PPC403GC system.

The internal/external multiplexer bit (bit 17) in the bank register for this DRAM bank must be set for an external multiplexer. Also, as shown in Figure 3-24, the system designer must provide a multiplexer to generate the DRAM row and column address from the address output by the external master. The multiplexer is controlled by the AMuxCAS output from the PPC403GC. Signals for external bus arbitration are described in the next section.

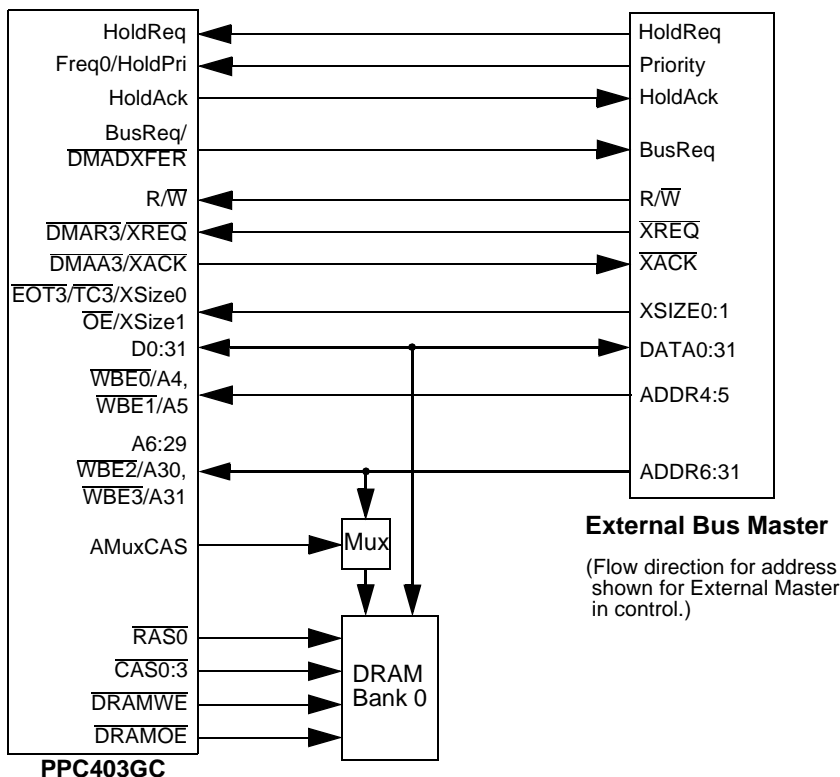


Figure 3-24. Sample PPC403GC / External Bus Master System

3.10.1 External Bus Arbitration

To gain control of the bus from the PPC403GC, the external bus master requests the bus by placing an active level on the PPC403GC HoldReq input. The PPC403GC indicates that it has relinquished the bus to the external bus master by placing an active level on the HoldAck output.

The priority signal HoldPri is used to control bus master HoldReq priority. When the HoldPri input is low, the bus master HoldReq has the highest priority in arbitration over a load, store, instruction fetch, or DMA request (the PPC403GC completes any bus operations currently in progress prior to processing this request). When the HoldPri input is high, the bus master HoldReq has the lowest priority. A low priority HoldReq will not gain control of the bus if any of the following is true:

- 1) Any other valid request is pending. See Section 3.2 (Access Priorities) on page 3-3 for the list of possible requests.
- 2) Any bus transfer is in progress.
- 3) Within 3 cycles following a previous operation. (The 3 cycle blockage is designed to allow successive line fills to continue uninterrupted.)

While the external bus master has control of the bus, if the PPC403GC has a bus operation pending, the PPC403GC will request to regain control of the bus by activating the BusReq pin.

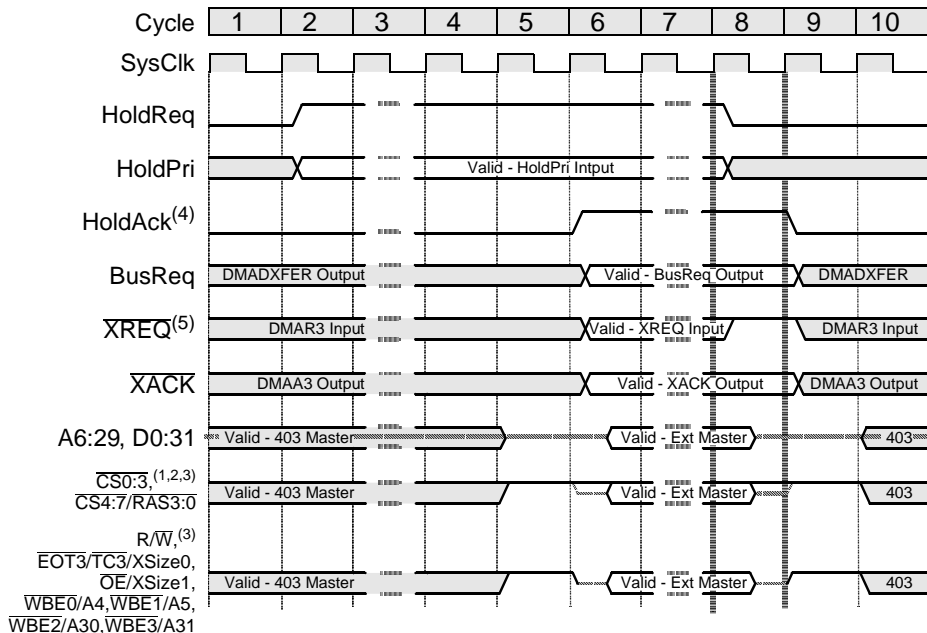
To relinquish the bus, the external bus master places an inactive level on the HoldReq input.

All of the external bus master mode signals are qualified with the HoldAck output signal. When HoldAck is active, multiplexed PPC403GC signals such as $\overline{EOT3}/TC3/XSize0$, $\overline{OE}/XSize1$, $\overline{DMAR3}/XREQ$, and $\overline{DMAA3}/XACK$ support external bus master access to PPC403GC DRAM. The following outputs are placed in high impedance during HoldAck: the data bus D0:31, the address bus A6:29, R/\overline{W} , $\overline{WBE0:3}$, \overline{OE} , $\overline{CS0:3}$, and $\overline{CS4:7}$ unless programmed as $\overline{RAS3:0}$.

Note:

The bus master interface is a **synchronous interface**. Signals must be presented with timing that is appropriate with respect to the system clock (SysClk) that is input to the PPC403GC. See the PPC403GC Data Sheet for the pertinent setup and hold times.

Figure 3-25 shows the timing for the HoldReq/HoldAck signals:



Notes:

- (1) CS0:3 and CS4:7/RAS3:0 which are programmed as ROM, SRAM, or I/O require an external pull-up to hold the signals inactive during cycles 6 and 8.
- (2) CS4:7/RAS3:0 will continue to be driven by the processor during the HoldAck state if that bank control register is programmed as DRAM.
- (3) These signals are driven inactive by the processor one cycle before HoldAck is activated and one cycle after HoldAck is deactivated.
- (4) If HoldPri = 0:
HoldAck is activated by the processor when HoldReq is active and the previous processor bus access has been completed.
If HoldPri = 1:
HoldAck is activated by the processor when HoldReq is active and no other request is pending within 3 cycles from the previous PPC403GC-initiated transfer.
- (5) XREQ must be driven inactive by the external bus master in cycle 8 until the HoldAck signal is deactivated by the processor.

Figure 3-25. HoldReq/HoldAck Bus Arbitration

The following table summarizes the states of signals on output pins when HoldAck is active.

Table 3-10. Signal States During Hold Acknowledge

Signal Names	State When HoldAck Active
A6:29	Floating (set to input mode)
AMuxCAS	Operable (see note 1)
BusReq	Operable (see note 1)
$\overline{\text{CAS0:3}}$	Operable (see note 1)
$\overline{\text{CS0:3}}$	Floating
$\overline{\text{CS4:7/RAS3:0}}$	$\overline{\text{CS}}$ floating, $\overline{\text{RAS}}$ operable (see note 1)
D0:31	Floating (external master drives bus)
$\overline{\text{DMAA0:2}}$	Inactive (high)
$\overline{\text{DMAA3/XAck}}$	Operable (see note 1)
$\overline{\text{DRAMOE}}$	Operable (see note 1)
$\overline{\text{DRAMWE}}$	Operable (see note 1)
$\overline{\text{DTR/RTS}}$	Operable (see note 1)
Error	Operable (see note 1)
HoldAck	Active
$\overline{\text{OE}}$	Floating (input for XSize1)
$\overline{\text{Reset}}$	Floating unless initiating system reset
$\overline{\text{R/W}}$	Floating (set to input)
$\overline{\text{TC0:2}}$	Inactive (high)
$\overline{\text{TC3}}$	Floating (input for XSize0)
TDO	Operable (see note 1)
TS0:6	Operable (see note 1)
$\overline{\text{WBE0:3}}$	Operable (inputs for A4:5, A30:31)
XmitD	Operable (see note 1)

Note:

1. Signal may be active while HoldAck is asserted, depending on the operation being performed by the PPC403GC.

3.10.2 DRAM Accesses by the External Bus Master

In a typical system design, the PPC403GC DRAM controller will remain responsible for system DRAM, to maintain consistency of DRAM refresh, even when the external master controls the bus. In that case, a method is needed for the external master to transfer data to and from DRAM which is under control of the PPC403GC. That method is provided by the \overline{XREQ} / \overline{XACK} protocol described in this section. Since this protocol only applies to DRAM, the high-order address bits which identify the DRAM address space are assumed, and not transferred.

A **valid request cycle** is defined as any cycle in which \overline{XREQ} is active and the BIU is idle or in the last cycle of a previous bus master request (last cycle of precharge for single transfers; last cycle of \overline{CAS} for burst transfers). Transfer direction (R/\overline{W}), transfer size ($XSize0:1$), and transfer address are communicated from the External Master to the PPC403GC during valid request cycles, as described in the following paragraphs.

While the external bus is in the HoldAck state, the R/\overline{W} input signal is sampled by the PPC403GC during any valid request cycle. The R/\overline{W} signal is used by the PPC403GC to determine the direction of the transfer and whether to activate \overline{DRAMOE} or \overline{DRAMWE} .

The $\overline{EOT3}[TC3][XSize0]$ and $\overline{OE}[XSize1]$ input signals are also sampled by the PPC403GC during any valid request cycle. These signals are used by the PPC403GC to determine the size of the transfer and whether the request is for a single transfer or a burst transfer. Table 3-11 describes the $XSize0:1$ definitions, along with the Bus Width bit settings in the corresponding bank register:

Table 3-11. $XSize0:1$ Bit Definitions

$XSize0:1$	Bus Width	Operation
00	00, 01, or 10	Byte Transfer
01	00, 01, or 10	Halfword Transfer
10	00, 01, or 10	Fullword Transfer
11	00	Burst Byte Transfer
11	01	Burst Halfword Transfer
11	10	Burst Fullword Transfer

For single transfers, any width (byte, halfword, or word) of external data may be exchanged with any width of memory device; if the transfer size is greater than the bus width, the PPC403GC will initiate a burst transfer at the bus width, returning an \overline{XACK} for each transaction. For burst transfers, the width of the external data must be the same as the width of the memory device.

When the external bus is in the HoldAck state, a set of input signals including $\overline{WBE0}[A4]$, $\overline{WBE1}[A5]$, $A6:A11$, $A22:A29$, $\overline{WBE2}[A30]$, $\overline{WBE3}[A31]$, are sampled by the PPC403GC during any valid request cycle. Address bus bits 4:11 are compared to the bank control registers bits 0:7, to determine which DRAM bank the external request will use. The address

is always assumed to be in the DRAM region, so bits 0:3 are unnecessary. When a burst transfer is in progress, address bits 22:31 are used to detect a page crossing. Bits 30:31 are used to select the proper $\overline{\text{CAS}}$ signals.

While HoldAck is active, $\overline{\text{XACK}}$ (the $\overline{\text{DMAA3}}[\overline{\text{XACK}}]$ output) indicates to the external bus master that this cycle is a data transfer cycle. In the case of a read operation, this indicates that data is available for the external bus master to latch. In the case of a write operation, this indicates that the data will be written into the DRAM at the end of the current cycle.

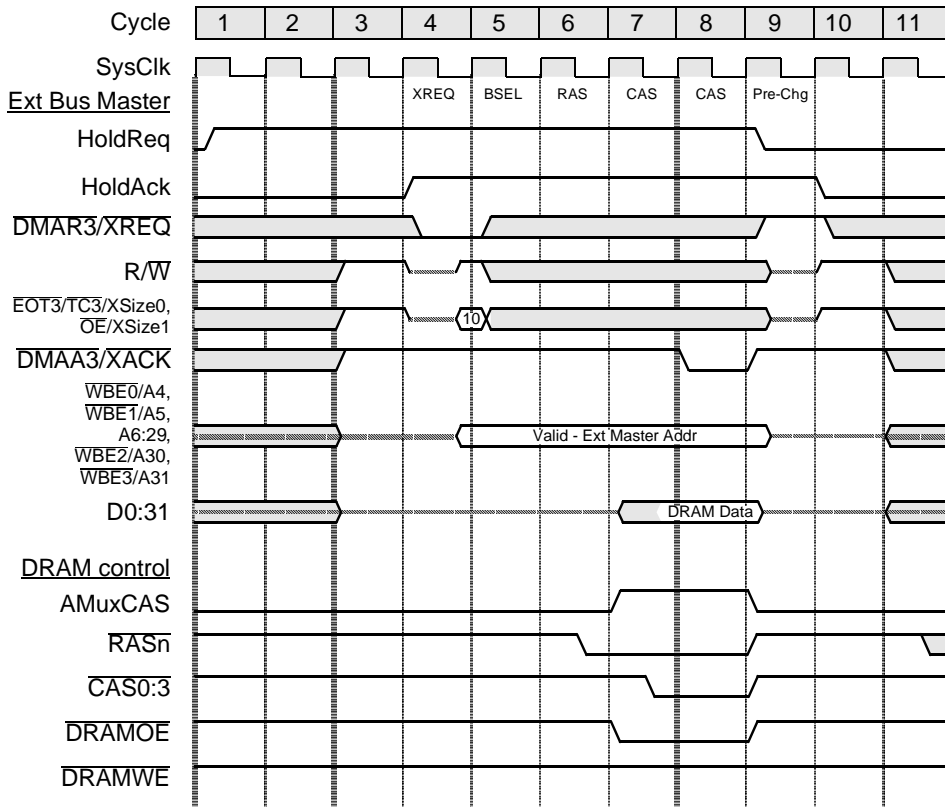
3.10.2.1 External Master Single Transfers

To request a transfer, the external bus master places an active level on the PPC403GC transfer request ($\overline{\text{XREQ}}$) input and provides the full address (A4-31) of the memory location on the address bus, the direction of the transfer (R/W), and the transfer size (XSize0:1).

The PPC403GC receives the address from the external bus master and compares the address to the contents of the bank registers to determine which bank will be accessed. With this information and the direction of the transfer, the PPC403GC can begin the DRAM transfer.

The PPC403GC responds with $\overline{\text{XACK}}$ during the last cycle of the transfer to indicate that the data is available to be latched in the case of a read, or that the DRAM has captured the data in the case of a write.

The following figure illustrates an external master single-transfer read (data flows from DRAM to the external master).



Notes:

(1) For multiple transfers, the next valid request is cycle 9.

Bank Register Settings										
Seq Line Fills	Early RAS	Bus Width	External Mux	RAS/CAS Timing	Page Mode	First Access	Burst Access	Pre-chg Cycles	Refresh RAS	Refresh Rate
Bit 13	Bit 14	Bits 15:16	Bit 17	Bit 18	Bit 20	Bit 21:22	Bit 23:24	Bit 25	Bit 26	Bits 27:30
x	x	10	1	0	0	01	xx	0	x	xxxx

Figure 3-26. External Bus Master Read Using the Internal DRAM Controller

3.10.2.2 External Master Burst Transfers

To request the first transfer of the burst, the external bus master places an active level on the PPC403GC transfer request (\overline{XREQ}) input and provides the full address (A4-31) of the memory location on the address bus, the direction of the transfer (R/W), and XSize0:1. The burst transfer is indicated XSize0:1 = b'11', which conveys no information about the transfer size. For burst transfers, the transfer size is required to be the same as the bus width defined in the bank register associated with the transfer address.

The PPC403GC receives the address from the external bus master and compares the address to the contents of the bank registers to determine which bank will be accessed. With this information and the direction of the transfer, the PPC403GC can begin the DRAM transfer.

During a burst transfer, \overline{XACK} goes active during each transfer to indicate that the data is available to be latched in the case of a read, or that the DRAM has captured the data in the case of a write. For transfers beyond the first, the External Master presents the new address (and for writes, the new data) on the rise of SysClk when $\overline{XACK} = 0$.

For subsequent transfers of the burst, the PPC403GC examines \overline{XREQ} and XSize0:1 during the valid request cycle, the last cycle of \overline{CAS} active. If \overline{XREQ} is found to be active with XSize0:1 = b'11', the next transfer of the burst will begin. The valid request cycle during \overline{CAS} active which finds \overline{XREQ} to be inactive or which finds XSize0:1 \neq b'11' will begin the last transfer of the burst. The number of transfers during the burst will be one plus the number of valid request cycles in which \overline{XREQ} is active and XSize0:1 = b'11'.

Address bits A22:31 for each burst transfer are latched in the BIU so that the BIU can determine whether a page boundary has been crossed during the transfer. Page cross detection is done only for sequentially incrementing addresses. Refresh requests will be delayed by 16 data transfers before interrupting a burst, to insure that line fills are not interrupted. To a bus master, a page cross or a refresh will appear as an extended delay between \overline{XACK} occurrences; a bus master does not need to have explicit knowledge of these events.

The following figure illustrates an external master burst write (data flows from the external master to DRAM).

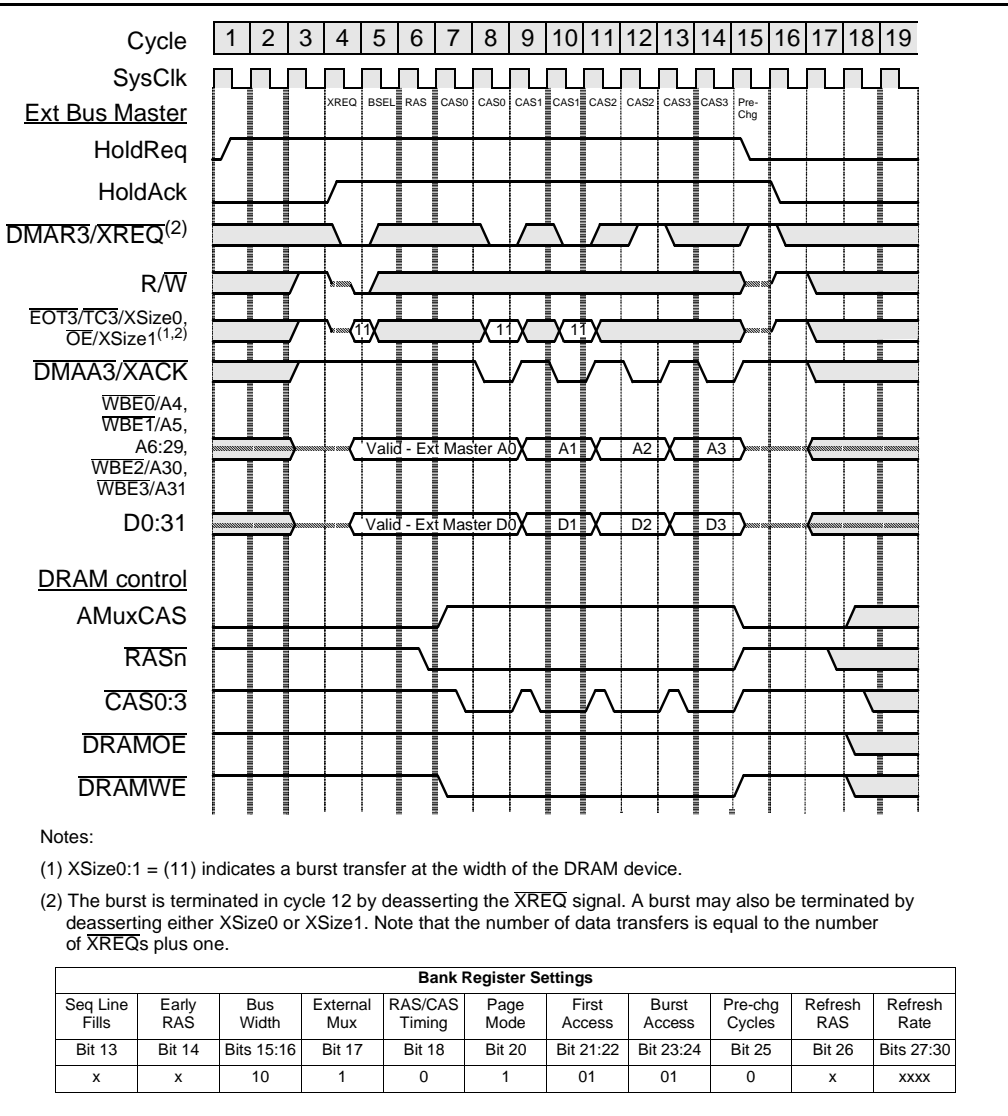


Figure 3-27. Burst Write to 3-2-2-2 Page Mode DRAM

Direct Memory Access (DMA) allows faster data transfer between memory and peripherals than that which is possible under program control. Using DMA leaves the processor core free to execute instructions, with no contention for the bus if the core is executing from cache. DMA is useful when the overhead associated with the DMA controller setup is minimal when compared to the time it would take to move the data using load and store instructions executing under program control.

This chapter presents an overview of the DMA features of the PPC403GC, followed by detailed discussions of DMA operations, signals, and registers.

4.1 Overview

The PPC403GC contains a four-channel DMA controller which handles data transfers between memory and peripherals and from memory to memory. The DMA controller is tightly integrated with the BIU, using dataflow elements of the BIU to perform buffering, memory access control, and packing/unpacking.

Each channel is an independent controller (hardware sequencer) containing a set of registers needed for a data transfer operation. Each channel contains a control register, a source address register, a destination address register, and a transfer count register. Each channel supports chained DMA operations; therefore, it contains a chained count register, and its source address register functions as the chained address register. All DMA channels report their status to the single DMA Status Register, as shown in Figure 4-1.

Each DMA Channel Control Register is used to initialize the DMA channel and enable DMA transfers and interrupts. The DMA Count Register is initialized with the number of transfers in the DMA transaction. The DMA Destination Address Register is used to specify the address of the memory in buffered and fly-by mode DMA transfers. Once the channel's registers are configured and the channel is enabled, the DMA channel may begin transferring data.

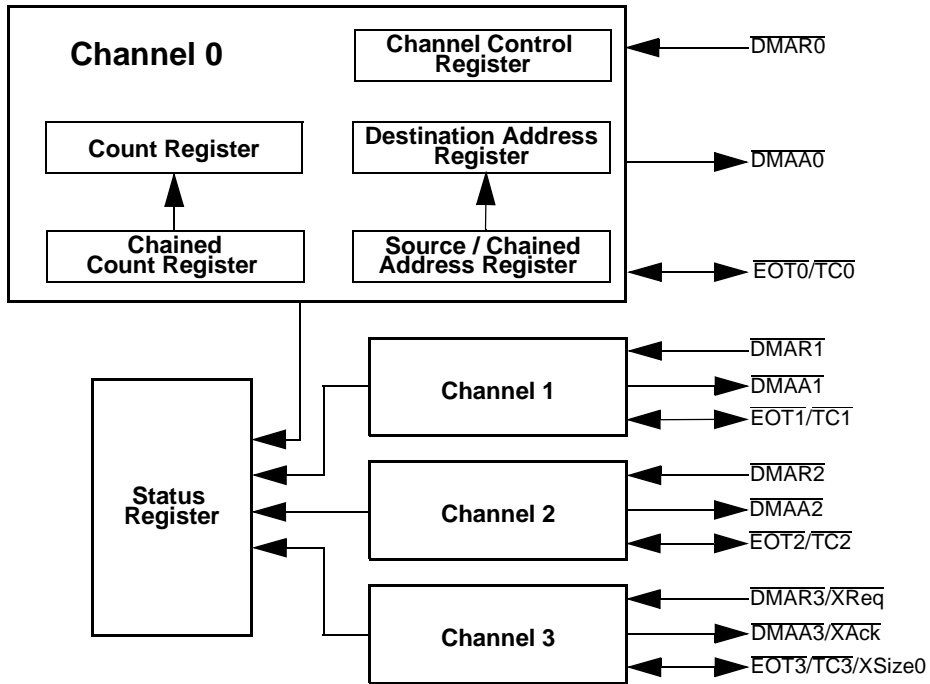


Figure 4-1. DMA Controller Block Diagram

4.2 DMA Operations

The DMA controller operates in three modes: buffered, fly-by, and memory-to-memory.

- Buffered
 - Each channel supports data transfers between memory and peripherals where the peripherals may be internal or external to the PPC403GC.
 - PPC403GC latches data in the BIU and re-drives.
 - Allows for different width/speed memory and peripheral.
 - PPC403GC will pack/unpack to meet memory/peripheral width requirements.
- Fly-by
 - Each channel supports transfers between memory and external peripherals.
 - PPC403GC provides address & controls; data driven directly by peripheral/memory.
 - Data “flies by” the PPC403GC without intervention.
 - Fastest possible transfer (no buffering latency).
 - Devices/memory must be of equal width.
- Memory-to-memory
 - Each channel supports data transfers between memory locations which may be located in different memory banks.
 - Can be initiated by software or hardware.
 - Data is buffered in the BIU of the PPC403GC.

The PPC403GC serial port unit (SPU) can also be used either as source or destination for DMA transfers. DMA transfers to or from the SPU are discussed in the chapter on serial port operations.

4.2.1 DMA Signals

The DMA controller uses both dedicated DMA signals and the external memory and peripheral controls in the bus interface unit (BIU), as shown in Figure 4-2.

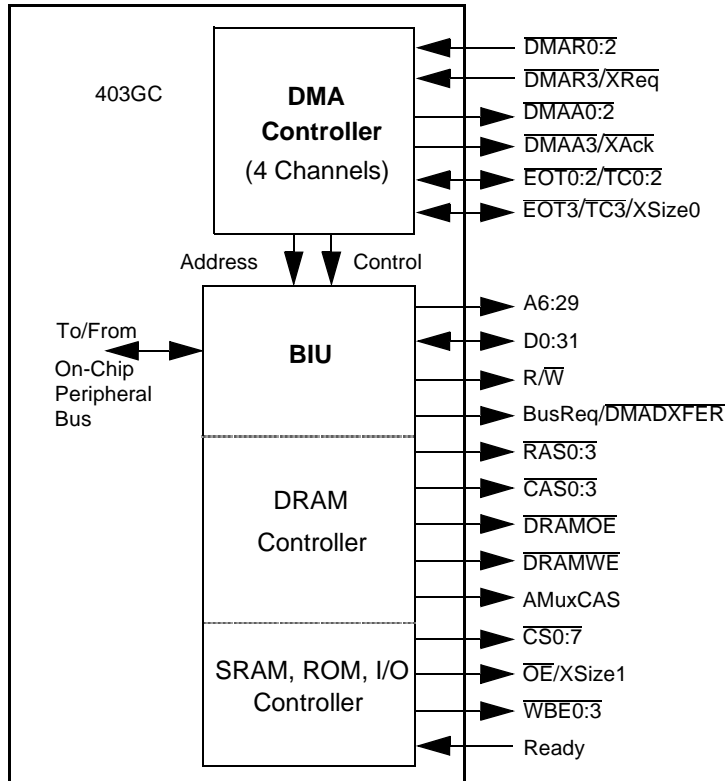


Figure 4-2. PPC403GC DMA Controller Interfaces

Figure 4-1 shows the individual DMA channels and their associated signals. Note that the Channel 3 signals are multiplexed; their function depends on whether the PPC403GC is bus master (the signal HoldAck is inactive) or another device is the bus master (HoldAck is active). If HoldAck is active, the signals function as bus master signals. At all other times, they function as DMA channel 3 control signals.

When the PPC403GC is the bus master, the three signals $\overline{\text{DMAR}}$, $\overline{\text{DMAA}}$, and $\overline{\text{EOT/TC}}$ are used with each DMA channel. An external device or internal peripheral may request a DMA transaction by placing a 0 on a channel's DMA request pin, $\overline{\text{DMAR}}$. If the DMA channel is enabled via the channel control register, the PPC403GC responds to the DMA request by asserting an active level on the $\overline{\text{DMAA}}$ pin when the DMA transfer begins. The PPC403GC DMA controller holds an active level on the $\overline{\text{DMAA}}$ pin while the transfer is in progress.

The DMA Request input ($\overline{\text{DMAR}}$) is double-latched for metastability protection on detecting

an activation of request. (Turn-off of $\overline{\text{DMAR}}$ is recognized in the first cycle following deactivation.) Observe that due to the metastability protection, $\overline{\text{DMAR}}$ must be held active for a minimum of two cycles in order for the BIU to arbitrate and initiate the memory-transfer portion of the DMA cycle.

Arbitration by the BIU determines when a DMA Request will be honored. The general rule of BIU arbitration is this: the BIU arbitrates in the last cycle of a data transfer in order to determine the operation which will begin in the following cycle. (Keep in mind the 2-cycle latency in the BIU recognition of the activation of $\overline{\text{DMAR}}$.)

To prevent a second transfer from taking place, the peripheral must deassert the $\overline{\text{DMAR}}$ line during the Acknowledge cycle. In buffered memory-to-peripheral transfers, if wait and hold times are set to zero, one hold cycle is added to give the peripheral time to deactivate $\overline{\text{DMAR}}$.

When programmed as the terminal count output, the $\overline{\text{EOT/TC}}$ pin will be lowered to a 0 by the PPC403GC to signify that the DMA transaction transfer count has reached 0. When the $\overline{\text{EOT/TC}}$ is programmed as an end-of-transfer input, an external device may terminate the DMA transfer at any time by placing an active level on the $\overline{\text{EOT/TC}}$ pin. The direction of the DMA channel's end-of-transfer/terminal count $\overline{\text{EOT/TC}}$ pin is programmable via the DMA Channel Control Register.

If the DMA channel is operating in fly-by mode, the PPC403GC provides the address and control signals for the memory and $\overline{\text{DMAA}}$ is used as the read/write transfer strobe for the peripheral.

When HoldAck is not active, the signal $\overline{\text{DMADXFER}}$ is defined. $\overline{\text{DMADXFER}}$ controls burst-mode fly-by DMA transfers between memory and peripherals. $\overline{\text{DMADXFER}}$ is not meaningful unless a DMA Acknowledge signal (DMAA0:DMAA31) is active. For transfer rates slower than one transfer per cycle, $\overline{\text{DMADXFER}}$ is active for one cycle when one transfer is complete and the next one starts. For transfer rates of one transfer per cycle, $\overline{\text{DMADXFER}}$ remains active throughout the transfer.

4.2.2 DMA Timing Parameters

Timing on the memory-access portion of DMA transfers is dictated by the parameters of the BIU bank register associated with the memory address. The DMA Channel Control Registers provide the following additional timing parameters:

- Setup, DMACRn[PSC], valid for buffered and fly-by modes:

Setup is the delay between the time that the DMA channel is granted control of the bus by the BIU (an internal control path on the PPC403GC) and the time that the channel activates DMA Acknowledge to the peripheral. DMACRn[PSC] SysClk cycles of setup time will be inserted between the time $\overline{\text{DMAR}}$ is accepted (on a peripheral read) or the data bus is driven (on a peripheral write) and $\overline{\text{DMAA}}$ is asserted for the peripheral part of the transfer.

A practical use of the Setup parameter is to prevent bus collisions in scenarios in which other bus devices may be late in removing their data from the bus. A typical system can manage potential collisions between memory and other SRAM-like devices by programming OEn=1 in the BIU bank register. (DRAM has an inherent delay analogous to OEn due to the time it takes the DRAM controller to activate DRAMOE.) When DMA transfers are intermixed with these other bus operations, Setup delay can be used to provide a delay analogous to that provided by OEn in SRAM operations.

- Wait, DMACRn[PWC], valid for buffered mode only:

Wait simply lengthens the duration of the active DMA Acknowledge signal. $\overline{\text{DMAA}}$ stays active for (DMACRn[PWC] + 1) SysClk cycles.

- Hold, DMACRn[PHC], valid for buffered mode only:

Hold prevents subsequent BIU operations from starting on the cycle following the peripheral transfer cycle (the cycle following the deactivation of DMA Acknowledge). This applies for DMA writes to the memory access portion of the DMA transfer, and for DMA reads to the initiation of the next outstanding BIU bus operation following the end of the DMA transfer.

There will be DMACRn[PHC] SysClk cycles between the time that $\overline{\text{DMAA}}$ becomes inactive until the bus is available for the next bus access. During this period, the address bus, the data bus, and the control signals remain active.

4.2.3 Buffered Mode Transfers

All four channels support buffered mode transfers and chained transfers in this mode. Figure 4-3 shows that, in buffered mode, the PPC403GC buffers the data during transfers between memory and a peripheral. The numbers in Figure 4-3 refer to the sequence of operations, not necessarily to the bus cycles of a DMA transfer.

The diagram illustrates that the PPC403GC BIU latches the data during the first half of the DMA transfer, then turns the data bus around and drives the data during the second half of the transfer.

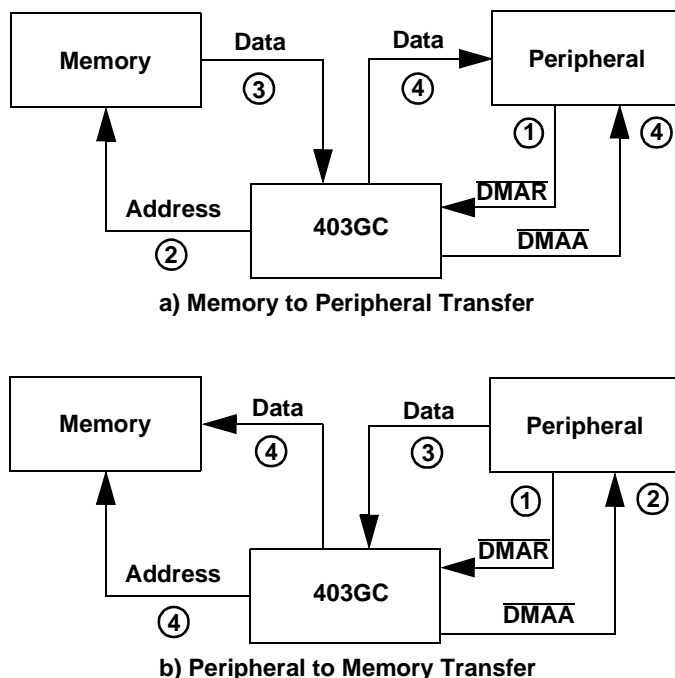


Figure 4-3. Overview of Buffered Mode Transfers

The transfer width of the peripheral portion of the DMA transfer is dependent on the programming of the `DMACRn[PW]` field. The transfer size programmed into `DMACRn[PW]` must match the width of the peripheral. (The DMA controller does not pack/unpack during transfers to/from the peripheral.)

The transfer width during the memory portion of the DMA transfer is dependent on the programming of the associated BIU bank register `BRx[BW]`. (This is the setting normally used by the BIU for all memory operations to that memory location - whether initiated by DMA operations or loads/stores, etc.)

If the peripheral and the memory use data transfers of different widths, the PPC403GC performs the necessary packing and unpacking of data during the memory portion of the transaction. The transfer size must be programmed to be equal to the peripheral width (packing and unpacking is only performed during the memory portion of the transfer). For example, a byte peripheral transfer to word memory would cause the BIU to perform a byte access to the word-wide memory. A word-wide peripheral transfer to byte-wide memory would cause the BIU to perform four byte memory accesses in order to perform the packing/

unpacking (the BIU would perform this operation as a burst if the memory bank was set up to allow it).

The value programmed in the DMA count register is interpreted as the number of transfers of the bus width specified in DMACRn[PW], not the total number of bytes. The maximum number of bytes that can be transferred in a single programming (non-chained mode) of a DMA channel is (4 bytes/transfer X 64K transfers) = 256K bytes.

4

Prior to transferring any data, the DMA channel must be configured and enabled for buffered mode and the transfer characteristics of the peripheral must be programmed in the DMA Channel Control Register. Also, the DMA Count Register must be initialized with the number of transfers in the DMA transaction and the DMA Destination Address Register for the channel must be written with the address where the data will be transferred. If chaining is desired for a channel, there are optional methods for programming the DMA Chained Count Register and the DMA Source/Chained Address Register; see Section 4.2.8 (Chained Operations) on page 4-26.

4.2.3.1 Buffered Transfer from Memory to Peripheral

In this example, the memory access is from a 32-bit wide, 2-1-1-1 access DRAM bank and the PPC403GC provides the necessary signals to the DRAM bank. The timing parameters used for the DRAM bank are programmed in the corresponding DRAM bank register. If the width of the memory is smaller than the width of the peripheral, the PPC403GC will read the necessary bytes from the memory, pack them into one peripheral-sized data item and transfer that item to the peripheral.

The DMA channel control register determines the buffered operation to be performed, width and direction of the transfer, and other configuration settings. Figure 4-4 presents the bit settings for a buffered read from a 32-bit memory, followed by a write to a 32-bit peripheral with no setup, hold, or wait cycle requirements:

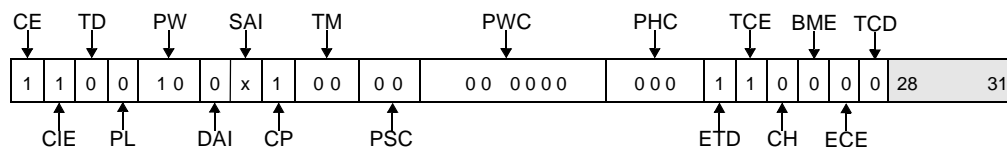


Figure 4-4. DMACR Setting for Buffered DRAM Read, Peripheral Write Reserved

Table 4-1 describes the bit settings used in this example of a buffered transfer:

Table 4-1. Sample DMACR Settings for Buffered Transfer

Bit	Name	Description
0	CE	Channel Enable 1 - Channel is enabled for DMA operation
1	CIE	Channel Interrupt Enable 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode) 0 - Transfers are from memory to peripheral
3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC
4:5	PW	Peripheral Width 10 - Word (32-bits) Transfer Width is the same as Peripheral Width.
6	DAI	Destination Address Increment 0 - Hold the destination address (do not increment)
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes).
8	CP	Channel Priority 1 - Channel has high priority for the external or internal bus

Table 4-1. Sample DMACR Settings for Buffered Transfer (cont.)

Bit	Name	Description
9:10	TM	Transfer Mode 00 - Buffered mode DMA
11:12	PSC	Peripheral Setup Cycles (in this example, zero)
13:18	PWC	Peripheral Wait Cycles (in this example, zero)
19:21	PHC	Peripheral Hold Cycles (in this example, zero)
22	ETD	End-of-Transfer / Terminal Count (EOT/TC) Pin Direction 1 - The EOT/TC pin is programmed as a terminal count (TC) output. When programmed as TC and the terminal count is reached, this signal will go active the cycle after $\overline{\text{DMAA}}$ goes inactive.
23	TCE	Terminal Count Enable 1 - Channel stops when terminal count reached.
24	CH	Chaining Enable 0 - DMA Chaining is disabled
25	BME	Burst Mode Enable 0 - Channel does not burst to memory. (In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. (ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero.
28:31		reserved

To complete channel configuration, the count register is loaded with the transfer count and the beginning address is loaded in the destination address register. Full descriptions of the DMA channel control, count, and destination address registers are presented in Section 4.3 on page 4-32.

Once the DMA channel is configured, the peripheral initiates a transfer by placing a 0 on the $\overline{\text{DMAR}}$ pin for that channel. The $\overline{\text{DMAR}}$ signal is double latched inside the PPC403GC for metastability protection. For that reason the DMA read from memory begins two cycles after the request is placed on $\overline{\text{DMAR}}$.

When the transfer is from a memory to a peripheral as shown in Figure 4-3a, the PPC403GC first reads in a data item from memory. Then the PPC403GC begins the peripheral transfer cycle by writing that data to the peripheral, using the $\overline{\text{DMAA}}$ pin as the transfer strobe. Figure 4-5 shows the best case timing for a buffered mode transfer from DRAM to a peripheral.

The $\text{R}/\overline{\text{W}}$ signal is active throughout this cycle and, because no hold time has been programmed for this peripheral, so is $\overline{\text{DMAA}}$. Note that the address bus is placed in high impedance during the peripheral transfer cycle.

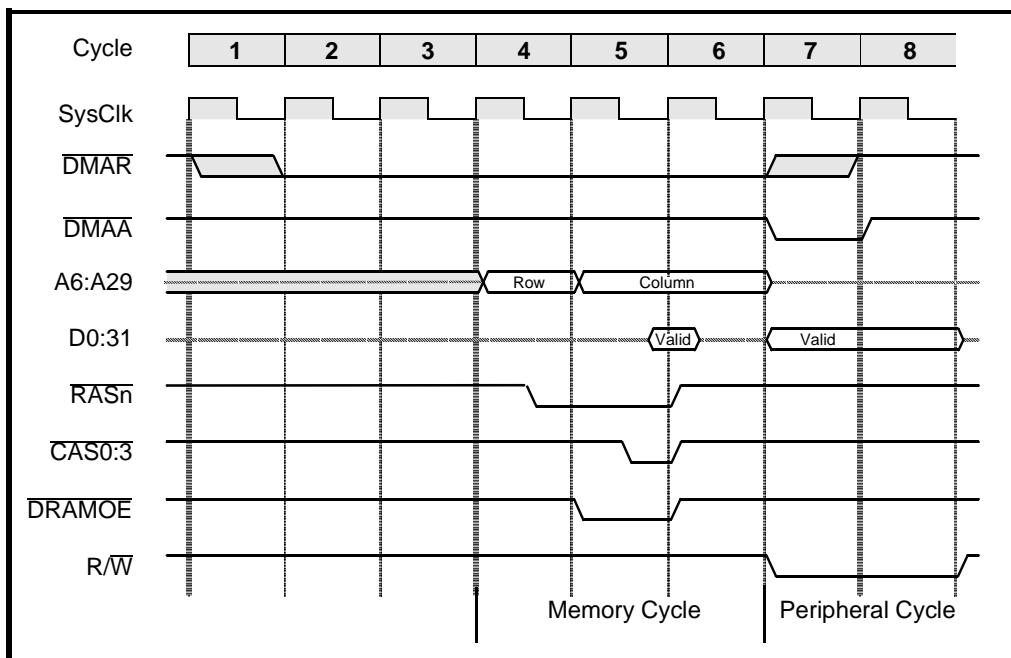


Figure 4-5. Buffered Mode Transfer from a 32-bit 2-1-1-1 DRAM to a 32-bit Peripheral

To prevent a second transfer from taking place, the peripheral must deassert the **DMAR** pin during the **DMAA** cycle. The timing for removing the **DMAR** signal is governed by the programming of the wait and transfer hold bits in the DMA Control Register.

In Buffered Memory to Peripheral transfers, if the Wait and Hold times are zero, one Hold cycle is added to give the peripheral time to deactivate **DMAR**.

4.2.3.2 Buffered Transfer from Peripheral to Memory

To set up a transfer from peripheral to memory, assuming the same device widths and timings, the TD field must be set to 1 in the channel control register. Other bit settings remain unchanged, and the DMACR is loaded with the revised configuration. Again, the count and destination address registers must be loaded with the transfer count and the beginning memory address, respectively.

Figure 4-6 shows the timing for a buffered mode transfer from a peripheral to DRAM. The peripheral initiates the transfer by placing a 0 on $\overline{\text{DMAR}}$. The PPC403GC places a 0 on the $\overline{\text{DMAA}}$ pin to request data from the peripheral. The peripheral responds by placing data on the data bus.

In this example, no hold or wait cycles have been programmed into the peripheral, so the peripheral must remove the data after one SysClk cycle. The R/W is active throughout this cycle and since no hold time has been programmed for this peripheral, so is $\overline{\text{DMAA}}$. The PPC403GC then writes the data to a 32-bit, 2-1-1-1 access DRAM bank, and the PPC403GC provides the necessary signals to the DRAM bank.

Note that the address bus is placed in high impedance during the peripheral cycle of the transfer. To prevent a second transfer from taking place, the peripheral must deassert the $\overline{\text{DMAR}}$ pin as shown in Figure 4-6.

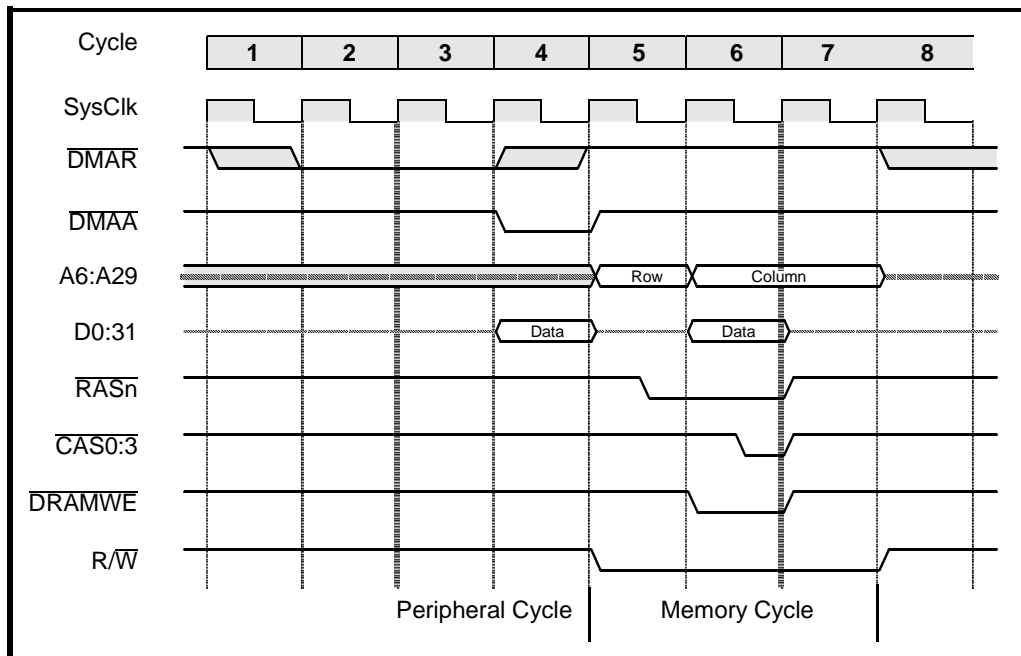


Figure 4-6. Buffered Mode Transfer from a 32-bit Peripheral to a 32-bit DRAM

4.2.4 Fly-By Mode Transfers

All four channels support fly-by mode transfers and chained transfers in this mode. Figure 4-7 shows that, in fly-by mode, the PPC403GC does not buffer the data during transfers between memory and a peripheral. The numbers in Figure 4-7 refer to the sequence of operations, not necessarily to the bus cycles of a DMA transfer.

The diagram illustrates that the PPC403GC BIU does not latch the data during the DMA transfer, but the data is driven directly by the memory and latched by the peripheral, or driven directly by the peripheral and latched by the memory, depending on the direction of transfer. Unlike buffered mode transactions where the PPC403GC must read and then write the data, the PPC403GC data bus off-chip drivers are tri-stated during the entire fly-by transaction.

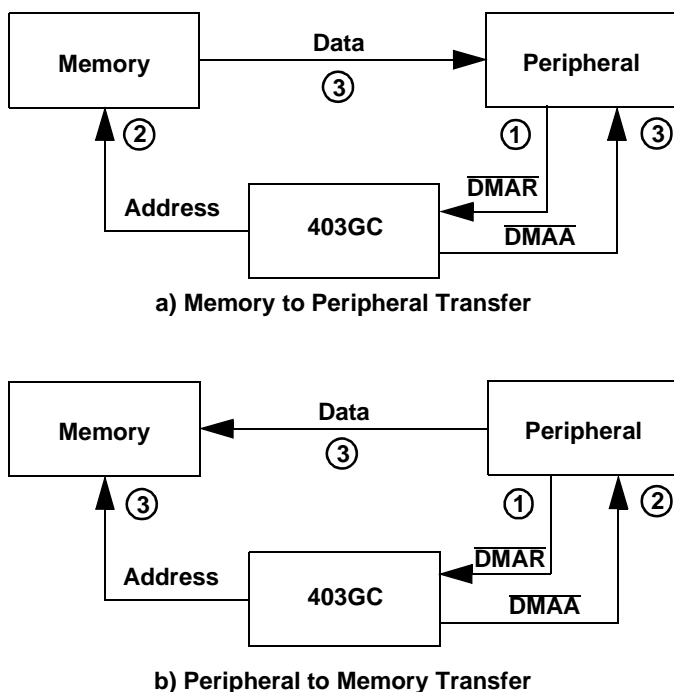


Figure 4-7. Overview of Fly-by Mode DMA Transfer

In fly-by mode transfers from memory to a peripheral, the PPC403GC provides address and control signals to the memory and a control signal to the peripheral. The PPC403GC enables the output from the memory and when the valid data is on the data bus, the

PPC403GC signals the peripheral to accept the data.

During fly-by mode transfers from a peripheral to memory, the PPC403GC signals to the peripheral when to place data on the data bus and the PPC403GC provides the address and control signals to write the data to the correct memory address.

The transfer width of the peripheral portion of the DMA transfer is dependent on the programming of the DMACRn[PW] field. The transfer size programmed into DMACRn[PW] must match the width of the peripheral. The bus width for the memory portion of the transfer is described by the associated BIU bank register BRx[BW]. Since data is not packed or unpacked during fly-by transfers, the bus width of the memory must equal the peripheral width.

The value programmed in the DMA count register is interpreted as the number of transfers of the bus width specified in DMACRn[PW], not the total number of bytes. The maximum number of bytes that can be transferred in a single programming (non-chained mode) of a DMA channel is (4 bytes/transfer X 64K transfers) = 256K bytes.

Prior to transferring any data, the DMA channel must be configured and enabled for fly-by mode and the transfer characteristics of the peripheral must be programmed in the DMA Channel Control Register. Also, the DMA Count Register must be initialized with the number of transfers in the DMA transaction and the DMA Destination Address Register for the channel must be written with the address where the data will be transferred. If chaining is desired for a channel, there are optional methods for programming the DMA Chained Count Register and the DMA Source/Chained Address Register; see Section 4.2.8 (Chained Operations) on page 4-26.

4.2.4.1 Fly-by Transfer from Memory to Peripheral

In this example, the PPC403GC performs a DMA Fly-By transfer from a 32-bit 3-cycle DRAM memory to a 32-bit peripheral. Figure 4-10 shows the channel control register settings for this transfer:

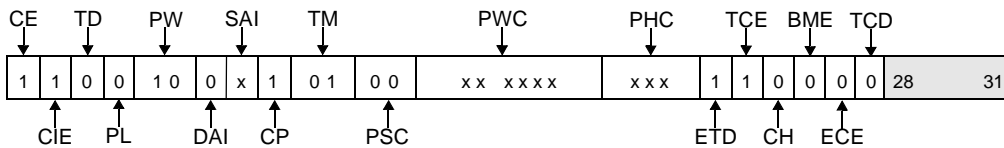


Figure 4-8. DMACR Setting for Fly-By Memory Read, Peripheral Write Reserved

Table 4-2 describes the bit settings for each field in this DMACR:

Table 4-2. Sample DMACR Settings for Fly-By Transfer

Bit	Name	Description
0	CE	Channel Enable 1 - Channel is enabled for DMA operation
1	CIE	Channel Interrupt Enable 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode) 0 - Transfers are from memory to peripheral
3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC
4:5	PW	Peripheral Width 10 - Word (32-bits) Transfer Width is the same as Peripheral Width.
6	DAI	Destination Address Increment 0 - Hold the destination address (do not increment)
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes).
8	CP	Channel Priority 1 - Channel has high priority for the external or internal bus
9:10	TM	Transfer Mode 01 - Fly-by mode DMA
11:12	PSC	Peripheral Setup Cycles (in this example, zero)
13:18	PWC	Peripheral Wait Cycles (don't care, not used in fly-by mode)
19:21	PHC	Peripheral Hold Cycles (don't care, not used in fly-by mode)
22	ETD	End-of-Transfer / Terminal Count (EOT/TC) Pin Direction 1 - The EOT/TC pin is programmed as a terminal count (TC) output. When programmed as TC and the terminal count is reached, this signal will go active the cycle after DMAA goes inactive.
23	TCE	Terminal Count Enable 1 - Channel stops when terminal count reached.
24	CH	Chaining Enable 0 - DMA Chaining is disabled
25	BME	Burst Mode Enable 0 - Channel does not burst to memory. (In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. (ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero.
28:31		reserved

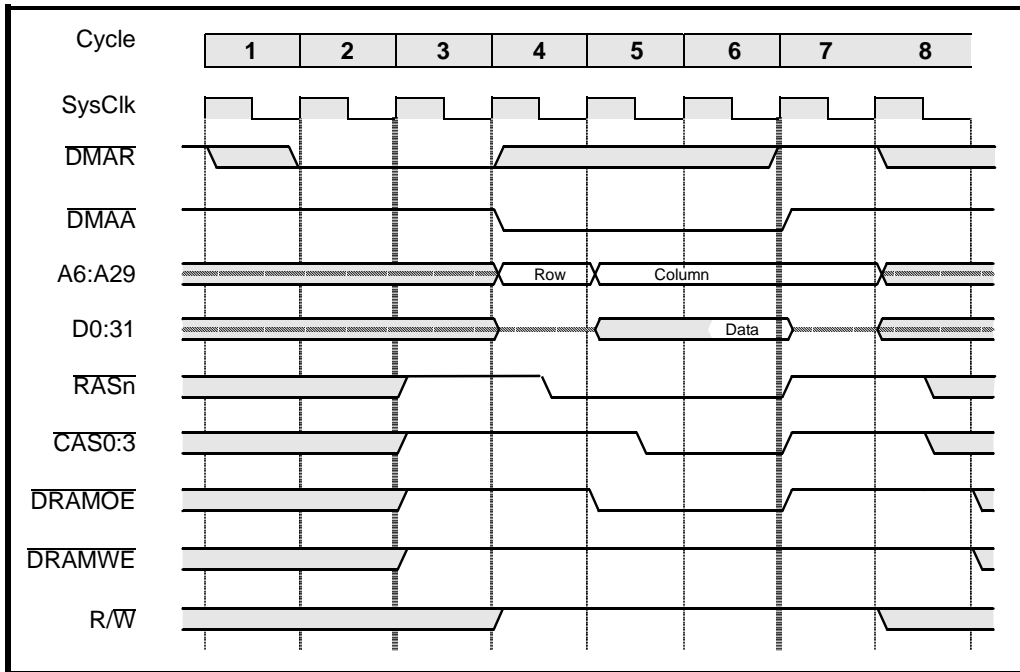


Figure 4-9. Fly-By Transfer from 3-cycle DRAM to a 32-bit Peripheral

Once the DMA channel is configured, the peripheral initiates a transfer by placing a 0 on the PPC403GC $\overline{\text{DMAR}}$ pin. When the transfer is from a memory to a peripheral as shown in Figure 4-7a on page 4-13, the PPC403GC outputs the correct control signals to the memory so that the memory can output one data item. The PPC403GC places a 0 on the $\overline{\text{DMAA}}$ pin while the memory access is in progress; the peripheral captures the data on the rise of $\overline{\text{DMAA}}$.

When the transfer is from peripheral to memory, the peripheral drives the data bus while $\overline{\text{DMAA}}$ is low.

4.2.5 Fly-By Burst

Fly-By Burst transfers allow the DMA channel to use the burst capability of a memory device. In Fly-By Burst Mode transfers, the PPC403GC provides addresses and control signals to the memory and control signals to the peripheral.

Once the DMA channel is configured, the peripheral initiates a transfer by placing a “0” on the $\overline{\text{DMAR}}$ pin for that channel. The PPC403GC accesses the memory using the parameters in the BIU Bank Register corresponding to the DMA memory address. The PPC403GC signals the peripheral to accept/place data on the bus using $\overline{\text{DMAA}}$ and $\overline{\text{DMADXFER}}$. If the memory is capable and $\overline{\text{DMAR}}$ remains active, the subsequent transfers to/from memory will be accessed using the memory burst parameters. Transfers continue in burst mode until $\overline{\text{DMAR}}$ is deasserted or until there is a higher priority request.

The features of Fly-By Burst Mode are summarized in the following:

- Continuous burst, up to 64k words.
- Additional peripheral signal $\overline{\text{DMADXFER}}$ for burst transfers. The output $\overline{\text{DMADXFER}}$ is multiplexed with the BusReq output signal. If the HoldAck signal is active the BusReq signal is gated to the output. If the HoldAck signal is inactive, then the $\overline{\text{DMADXFER}}$ signal is gated to the output.

$\overline{\text{DMADXFER}}$ is active in the last cycle of each transfer (hence it is active continuously during single-cycle transfers). $\overline{\text{DMADXFER}}$ must be qualified with the $\overline{\text{DMAA}}$ signal by the external peripheral, since $\overline{\text{DMADXFER}}$ will be activated in the last cycle of all transfers, not just DMA transfers. $\overline{\text{DMADXFER}}$, when ORed with the processor input clock SysClk, yields an appropriate signal to indicate that data has been latched (on writes to memory) or that data is available to be latched (on reads from memory).

- Transfers from Peripheral to Memory:
 - Peripheral drives data bus while $\overline{\text{DMAA}}$ is active. $\overline{\text{DMAA}}$ can remain active for multiple transfers.
 - $\overline{\text{DMADXFER}}$ (ORed with SysClk) is active during one cycle to indicate to the peripheral when one transfer is complete and the next one starts. The peripheral provides new data for the next transfer in the following cycle if $\overline{\text{DMAA}}$ is still active.
 - $\overline{\text{DMADXFER}}$ can remain active to indicate a new transfer every cycle.
- Transfers from Memory to Peripheral:
 - Peripheral is selected when $\overline{\text{DMAA}}$ is active. $\overline{\text{DMAA}}$ can remain active for multiple transfers.
 - $\overline{\text{DMADXFER}}$ (ORed with SysClk) is active during one cycle to indicate to the peripheral when one transfer is complete and the next one starts. The peripheral latches data when at the end of the cycle when $\overline{\text{DMADXFER}}$ (ORed with SysClk) is active.
 - $\overline{\text{DMADXFER}}$ can remain active to indicate a new transfer every cycle.

4.2.5.1 Fly-By Burst, Memory to Peripheral

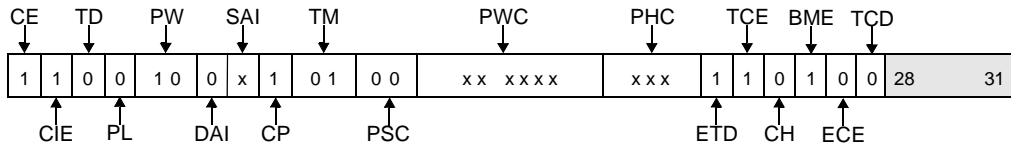


Figure 4-10. DMACR Setting for Fly-By Burst, Peripheral Write

Reserved

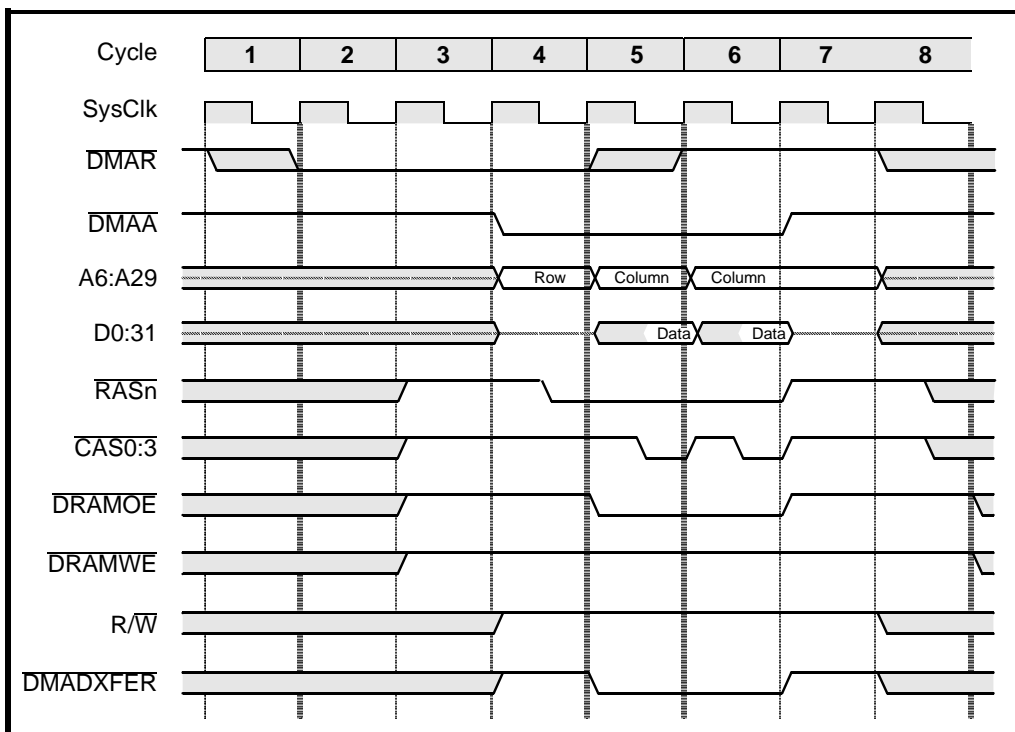
Table 4-2 describes the bit settings for each field in this DMACR:

Table 4-3. Sample DMACR Settings for Fly-By Burst

Bit	Name	Description
0	CE	Channel Enable 1 - Channel is enabled for DMA operation
1	CIE	Channel Interrupt Enable 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode) 0 - Transfers are from memory to peripheral
3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC
4:5	PW	Peripheral Width 10 - Word (32-bits) Transfer Width is the same as Peripheral Width.
6	DAI	Destination Address Increment 0 - Hold the destination address (do not increment)
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes).
8	CP	Channel Priority 1 - Channel has high priority for the external or internal bus
9:10	TM	Transfer Mode 01 - Fly-by mode DMA
11:12	PSC	Peripheral Setup Cycles (in this example, zero)
13:18	PWC	Peripheral Wait Cycles (don't care, not used in fly-by mode)
19:21	PHC	Peripheral Hold Cycles (don't care, not used in fly-by mode)
22	ETD	End-of-Transfer / Terminal Count (EOT/TC) Pin Direction 1 - The EOT/TC pin is programmed as a terminal count (TC) output. When programmed as TC and the terminal count is reached, this signal will go active the cycle after DMAA goes inactive.

Table 4-3. Sample DMACR Settings for Fly-By Burst (cont.)

Bit	Name	Description
23	TCE	Terminal Count Enable 1 - Channel stops when terminal count reached.
24	CH	Chaining Enable 0 - DMA Chaining is disabled
25	BME	Burst Mode Enable 1 - Channel will burst to memory. (In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. (ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero.
28:31		reserved

**Figure 4-11. DMA Fly-by Burst; 2-1-1-1 DRAM; 2 Transfers**

4.2.5.2 Fly-By Burst, Peripheral to Memory

The following example is a DMA Fly-By Burst from the peripheral to the memory. This is the opposite transfer direction from the previous example, hence $\text{DMACR}[\text{TD}] = 1$ for this example. All other DMACR fields are unchanged.

For this example, the memory speed is 3-2-2-2 (instead of the 2-1-1-1 of the previous example). The difference of memory speeds is handled entirely in BIU bank register settings, not in DMA controls.

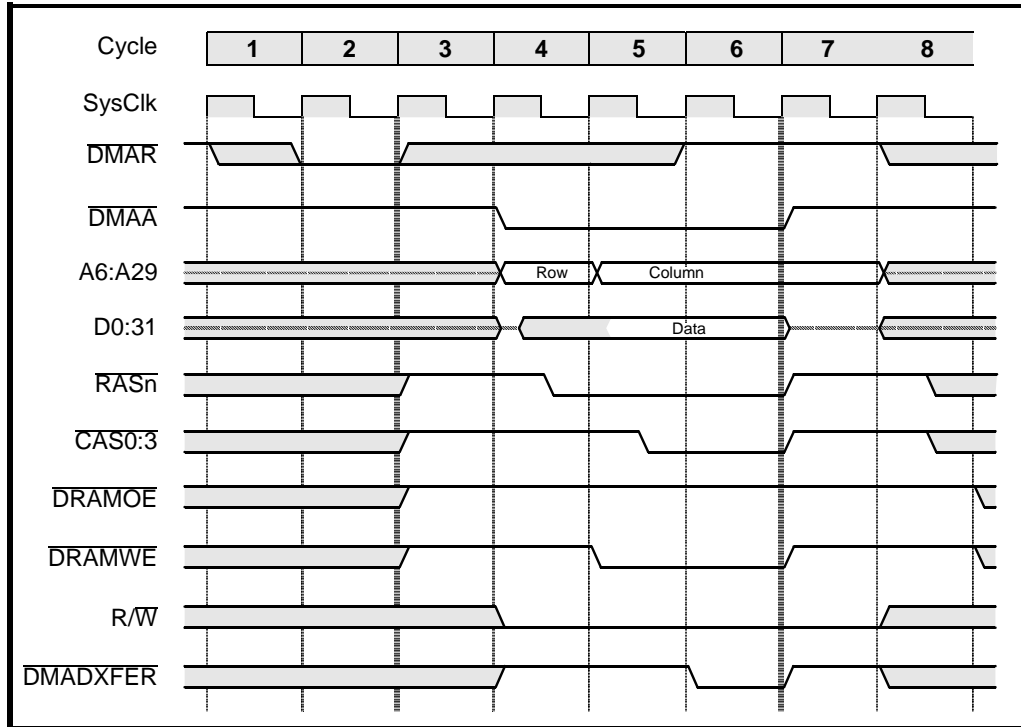


Figure 4-12. DMA Fly-by Burst; 3-2-2-2 DRAM; Single Transfers

4.2.6 Memory-to-Memory Mode Transfers

All four channels support memory-to-memory mode transfers. Chained transfers are not allowed in this mode. Figure 4-13 shows that, in memory-to-memory mode, the PPC403GC buffers the data during transfers between one area of memory and another. The numbers in Figure 4-13 refer to the sequence of operations, not necessarily to the bus cycles of a DMA transfer.

The diagram illustrates that the PPC403GC BIU latches the data during the first half of the DMA transfer, then turns the data bus around and drives the data during the second half of the transfer.

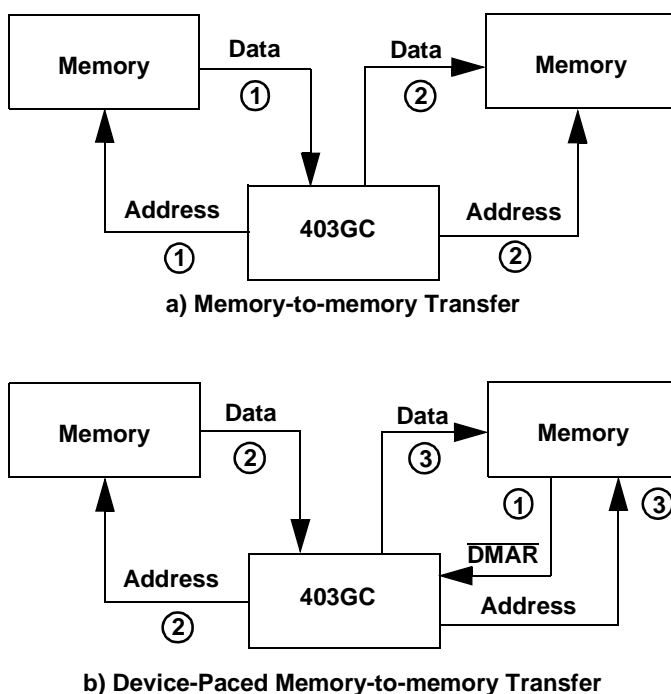


Figure 4-13. Overview of Memory-to-memory Mode DMA Transfer

Memory-to-memory moves can be initiated either by software or by an external device. If initiated via software, the transfer will begin as soon as the channel is configured and enabled for memory-to-memory move. If memory-to-memory moves are initiated by hardware (also known as device-paced memory-to-memory move), the user configures the channel for memory-to-memory move and transfers begin when an external device places

an active request on the channel request line. For memory-to-memory transfers, one block of data is read from the source memory address and it is written to the destination address.

The transfer width is set by the programming of the DMACRn[PW] field. The bus width during each portion (source or destination) of the DMA transfer is set by the programming of the associated BIU bank register BRx[BW] for that memory address. If the setting of DMACRn[PW] and the memory bus width are not identical, the PPC403GC performs the necessary packing and unpacking of data. For example, a byte transfer to word memory would cause the BIU to perform a byte access to the word-wide memory. A word-wide transfer to byte-wide memory would cause the BIU to perform four byte memory accesses in order to perform the packing/unpacking (the BIU would perform this operation as a burst if the memory bank was set up to allow it).

The value programmed in the DMA count register is interpreted as the number of transfers of the width specified in DMACRn[PW], not the total number of bytes. The maximum number of bytes that can be transferred in a single programming of a DMA channel (for memory-to-memory modes other than the software-initiated memory-to-memory line mode) is (4 bytes/transfer X 64K transfers) = 256K bytes. For memory-to-memory line mode, the maximum is (4 words/transfer X 64K transfers) = 256K words.

Prior to transferring any data, the DMA channel must be configured and enabled for memory-to-memory mode and the transfer characteristics must be programmed in the DMA Channel Control Register. The DMA Count Register must be initialized with the number of transfers in the DMA transaction and the DMA Destination Address Register for the channel must be written with the address where the data will be transferred. The DMA Source/Chained Address Register must be written with the source memory address for the transfer.

4.2.6.1 Memory-to-Memory Transfers Initiated by Software

The DMA channel must be configured for memory-to-memory mode via programming the DMA Channel Control Register. Also, the DMA Count and the DMA Destination Address Registers must be initialized. Chaining is not allowed for Memory-to-Memory transfers.

DMACRn[PW] may be programmed for byte, halfword, word, or line transfers. See Section 4.2.6.3 (Memory-to-Memory Line Burst Mode) on page 4-25 for additional information on line transfers.

Memory-to-memory transfers initiated by software do not require $\overline{\text{DMAR}}$ and $\overline{\text{DMAA}}$. This example presents transfers of 32-bit blocks between two memories, which may be either DRAM or SRAM. The memory interfaces are configured in the respective BIU bank registers, not in the DMA registers.

Figure 4-14 shows the channel control register settings for this transfer:

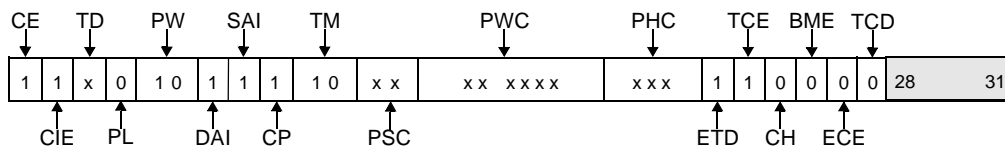


Figure 4-14. DMACR Setting for Memory-to-Memory Transfer

Reserved

Table 4-4 describes the bit settings for each field in this DMACR:

Table 4-4. Sample DMACR Settings for Memory-to-Memory Transfer

Bit	Name	Description
0	CE	Channel Enable 1 - Channel is enabled for DMA operation
1	CIE	Channel Interrupt Enable 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode)
3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC
4:5	PW	Peripheral Width 10 - Word (32-bits) Transfer Width is the same as Peripheral Width.
6	DAI	Destination Address Increment 1 - Increment the destination address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes) 1 - Increment the source address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.
8	CP	Channel Priority 1 - Channel has high priority for the external or internal bus
9:10	TM	Transfer Mode 10 - Software initiated memory-to-memory mode DMA
11:12	PSC	Peripheral Setup Cycles (don't care)
13:18	PWC	Peripheral Wait Cycles (don't care)
19:21	PHC	Peripheral Hold Cycles (don't care)

Table 4-4. Sample DMACR Settings for Memory-to-Memory Transfer (cont.)

Bit	Name	Description
22	ETD	End-of-Transfer / Terminal Count ($\overline{EOT/TC}$) Pin Direction
23	TCE	Terminal Count Enable
24	CH	Chaining Enable 0 - DMA Chaining is disabled
25	BME	Burst Mode Enable 0 - Channel does not burst to memory. (In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. (ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero.
28:31		reserved

4.2.6.2 Device-Paced Memory-to-Memory Transfers

A device-paced transfer between memories is performed at the request of an external processor or bus master. This transfer mode is similar to the software-initiated memory-to-memory transfer except for the TM field setting (TM = 11). The transfer count, destination address, and source address registers must also be initialized.

DMACRn[PW] = b'11' (transfer width is a line), which is permissible for software-initiated memory-to-memory transfers, is not allowed for Device-Paced Memory-to-Memory transfers. Device-Paced Memory-to-Memory is specifically designed to transfer data between a memory-mapped peripheral and memory. Therefore, only word, halfword, or byte transfers are allowed.

Once the DMA channel is configured for this mode, the external device initiates a transfer by placing a 0 on the PPC403GC \overline{DMAR} pin. The PPC403GC outputs the correct control signals to the source memory so that the memory can output data. The PPC403GC buffers and then outputs the data to the destination memory address.

Note that as long as the controlling device places an active signal on \overline{DMAR} , transfers will continue. To terminate a device paced memory-to-memory transfer, the controlling device must deassert \overline{DMAR} one SysClk cycle before the last cycle in the current transfer. Packing and/or unpacking of data is completed if the widths of the memory devices are not equal.

4.2.6.3 Memory-to-Memory Line Burst Mode

Memory-to-memory (M2M) burst allows the DMA channel to use the burst capability of a memory device. In M2M Line Burst transfers, 16 bytes of data starting at the source address are read into the PPC403GC buffer and then written out to the destination memory address. The PPC403GC accesses the memory using the parameters in the BIU Bank Register corresponding to the memory address. If the memory device has a bus width of a word, 4 words will be accessed in burst mode. If the memory device has a bus width of a halfword, 8 halfwords will be accessed in burst mode. If the memory device has a bus width of a byte, 16 bytes will be accessed in burst mode. The PPC403GC handles packing and/or unpacking of data if the widths of the memory devices are not equal.

M2M Line Burst is only supported for M2M transfers initiated by software (no Device Paced transfers).

The features of M2M Line Burst mode are summarized in the following:

- Line burst only. Each transfer request is for 4 words, 8 halfwords, or 16 bytes.
- Maximum transfer count 64K lines, 256K words.
- Addresses must be quadword aligned.
- BIU handles packing/unpacking.

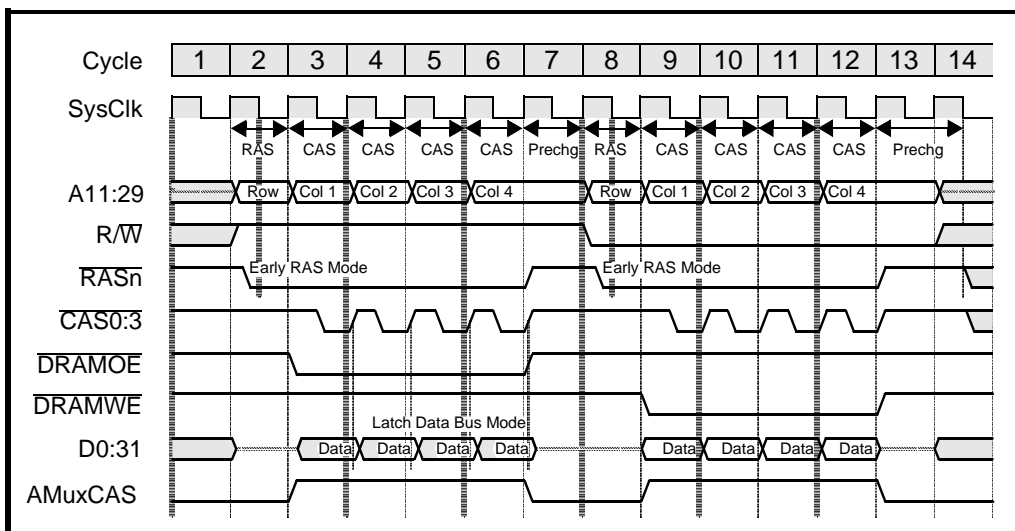


Figure 4-15. Memory-to-Memory Line Burst, 2-1-1-1 DRAM

4.2.7 Packing and Unpacking of Data

In transfers between a peripheral and memory, the width of the peripheral is considered inviolate. The transfer width to the peripheral will be the Peripheral Width (byte, halfword, or word), as specified in DMACR[PW]. The DMA controller of the PPC403GC allows this data to be successfully transferred to memory of width different from the peripheral width. This is accomplished by packing or unpacking the data while it is in transit (packing and unpacking is only supported on the memory side of the transfer). Table 4-5 shows the packing / unpacking options that are supported.

Table 4-5. Packing / Unpacking Support

Memory Size	Peripheral Width	Transfer Size	Pack / Unpack
Byte	Byte	Byte	Not required.
Halfword	Byte	Byte	Allowed if memory is Byte writeable.
Word	Byte	Byte	Allowed if memory is Byte writeable.
Byte	Halfword	Halfword	Packing / Unpacking occurs. Data in memory must be halfword aligned.
Halfword	Halfword	Halfword	Not required.
Word	Halfword	Halfword	Allowed if memory is Byte or Halfword writeable. Data in memory must be halfword aligned.
Byte	Word	Word	Packing / Unpacking occurs. Data in memory must be word aligned.
Halfword	Word	Word	Packing / Unpacking occurs. Data in memory must be word aligned.
Word	Word	Word	Not required.

4.2.8 Chained Operations

The DMA channels also support DMA data chaining. Data chaining can only be used with buffered and fly-by mode transfers. In either mode, the PPC403GC will begin transferring data between the memory and the peripheral until one of these **Chaining Conditions** is detected:

- The channel will chain when the Transfer Count reaches zero AND Chaining is enabled AND TC Chain Mode is enabled.
- The channel will chain when EOT is active AND EOT Chain Mode is enabled AND Chaining is enabled.

Immediately upon completion of the transfers, the count register is reloaded with a new count value (from the DMACC) and the address register is reloaded with the a new address (from the DMA SA). Transfers then continue uninterrupted.

Chaining will stop when any of these **Terminating Conditions** are detected:

- The channel will stop when the Transfer Count reaches zero AND (Terminal Count is enabled AND Chaining is disabled OR Terminal Count is enabled AND TC Chain mode is disabled).

The channel always sets Terminal Count status whenever TC=0 and the channel does not chain.

- The channel will stop when the EOT is active AND EOT Chain Mode is disabled AND EOT/TC Direction is set for EOT.

The following **Special Conditions** should be noted:

- Channel does not chain when the Transfer Count = 0.
If DMACR(27)=1, TC Chain Mode Disable, the channel will not chain when TC=0.
- Channel does not stop when the Transfer Count = 0.
If DMACR(23)=0, TC Enable control bit, Terminal Count is disabled and the channel will not stop when the Transfer Count = 0. The channel will continue to transfer data and the Transfer Count will wrap past zero.
- Channel does not chain when EOT is active.
If the Chaining Enable bit is not set and the channel is configured to chain when EOT is active the channel will not chain. The channel will continue to transfer data until some other condition is met.

4.2.8.1 Chaining Example -- Quick Start of Transfer

In this example, a normal DMA transfer is initiated, and then the chaining operation is set up while the first transfer is in progress. This approach minimizes the time required to get data moving. If the first block is short, then this approach would run the risk that the first transfer would complete before the chained transfer could be set up.

- Start a normal DMA operation.
 - 1) Status register has been cleared.
 - 2) Load the DMADA with the memory address of the transfer.
 - 3) Load the DMACT with the transfer count.
 - 4) Enable the channel by **mtdc** DMACR. The Chaining Enable in the DMACR does not need to be, and should not be set.
 - 5) Load the DMASA with the chained memory address.

- 6) Load the DMACC with the chained transfer count. This will set the Chaining Enable in the DMACR.
- 7) When a Chaining Condition is detected, the DMACT is loaded with the DMACC and the DMADA is loaded with the DMASA. The Chaining Status bit is set in the DMASR.
- 8) The Chaining Status bit will cause an interrupt if interrupts are enabled.
- 9) If the software wants to continue the chain, the Chain Status bit in the DMASR must be reset. The sequence can then be repeated starting at step 5 above.

4.2.8.2 Chaining Example -- No Setup Race

In this example, both the first and second transfers are set up before the first transfer begins. This guarantees proper function regardless of the length of the first block, at the cost of slightly longer time before any data moves.

- 1) Status register has been cleared.
- 2) Load the DMADA with the memory address of the transfer.
- 3) Load the DMACT with the transfer count.
- 4) Load the DMASA with the chained memory address.
- 5) Load the DMACC with the chained transfer count.
- 6) Enable the channel by **mtdcr** DMACR. The Chaining Enable in the DMACR should be set by the word that was written to the DMACR. Go to Step 9 below.
- 7) Load the DMASA with the chained memory address.
- 8) Load the DMACC with the chained transfer count. This will set the Chaining Enable in the DMACR.
- 9) When a Chaining Condition is detected, the DMACT is loaded with the DMACC and the DMADA is loaded with the DMASA. The Chaining Status bit is set in the DMASR.
- 10) The Chaining Status bit will cause an interrupt if interrupts are enabled.
- 11) If the software wants to continue the chain, the Chain Status bit in the DMASR must be reset. The sequence can then be repeated starting at step 7 above.

4.2.9 DMA Transfer Priorities

Two priority rankings determine the functional priority of the DMA channels and the transfers they perform. The first ranking depends on the setting of the channel priority (CP) field in the DMACR. A transfer on a high-priority channel takes precedence over a low-priority transfer. Transfers of the same priority are ranked in order by channel number, channel 0 having highest priority.

The BIU recognizes the DMA channel priority (either high or low priority). A high-priority DMA transfer executes at a higher priority than a data or instruction cache operation, while cache operations take precedence over low-priority DMA transfers. See Section 3.2 (Access Priorities) on page 3-3 for a full listing of BIU arbitration priorities.

The BIU arbitrates in the last cycle of a data transfer in order to determine the operation which will begin in the following cycle. DMA transactions are “interruptable” every time the BIU re-arbitrates. The progress of a given DMA transfer is decided dynamically, depending on other pending BIU operations first, and then on ranking of the channels within the DMA controller.

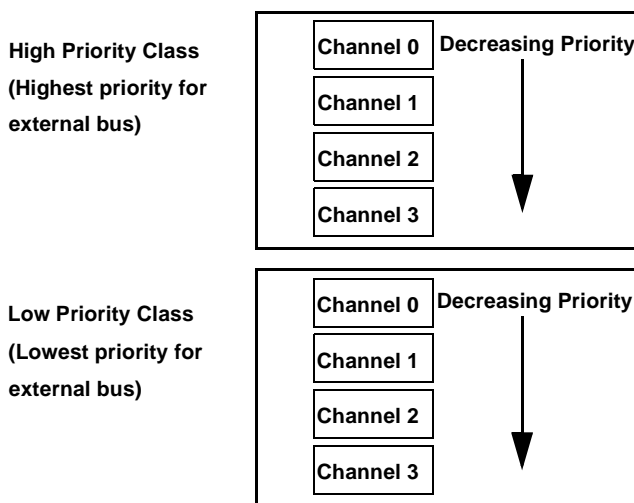


Figure 4-16. DMA Transfer Priorities

4.2.10 Interrupts

For each DMA channel, the DMA Channel Control Register (DMACR) is used to initialize the DMA channel and enable DMA interrupts. As shown in Figure 4-17 below, $DMACR_n[CIE] = 1$ will enable DMA interrupts for DMA channel “n”. Each channel enabled in its DMACR can generate interrupts for end-of-transfer, terminal-count, errors, or chaining.

For any DMA channel for which interrupts are enabled, interrupts will occur in the following circumstances:

- Channels with chaining

```
Channel_X_Interrupt = Channel_X_Interrupt_Enable &
                      ((TC_Enable & Transfer_Count=0)
                       OR
                       (EOT(Active) & EOT_Chain_Mode(Disabled))
                       OR
                       Channel_X_Error
                       OR
                       Channel_X_Chaining_Status);
```

- Channels without chaining

```
Channel_X_Interrupt = Channel_X_Interrupt_Enable &
                      ((TC_Enable & Transfer_Count=0)
                       OR
                       (EOT(Active) & EOT_Chain_Mode(Disabled))
                       OR
                       Channel_X_Error);
```

All DMA interrupts are presented to the processor as EXTERNAL interrupts. As such, they also must be enabled by the processor’s control mechanisms for external interrupts, in addition to enabling them at the source via the DMACR. In chapter 6, see the discussion of the External Interrupt Enable Register (EXIER), fields D0IE:D3IE. Also in chapter 6, see the discussion of the Machine State Register (MSR), field EE.

4.2.11 Errors

If an error occurs during a DMA transfer on channel “n”, the channel will be disabled and the error will be recorded in the DMASR Error Status bit for this channel (DMASR[RIn]). If the DMA Control Register for this channel has been programmed to present interrupts to the processor (DMACRn[CIE] = 1) and if the External Interrupt Enable Register has been programmed to enable DMA interrupts from this channel (EXIER[DnIE] = 1), then an External Interrupt will occur.

Whether or not interrupts are enabled, errors during DMA transfers are recorded in the Error Status bits (RI0:RI3) of the DMASR. The error may have been posted from the BIU (bus protection errors, non-configured bank errors, the bus error input pin, and bus timeout errors), or from the DMA controller (unaligned address errors). To determine the type of error, examine BESR[DMES], the DMA Error Status bit of the Bus Error Syndrome Register. If no subsequent bus error has occurred between the time of the original DMA error and the time when the BESR is examined, then the following is true:

- If BESR[DMES] = 0, then the error is an Unaligned Address error posted by the DMA controller.
- If BESR[DMES] = 1, then a bus error has occurred. The bus error is more fully specified by the RWS and ET fields of the BESR. The address of the bus error is recorded in the BEAR.

If an additional bus error occurs following the DMA error but prior to the examination of the BESR by the DMA error handling routine, it may not be possible to identify the cause of the original error. Any error which is posted to the BESR clears all bits set by previous errors. The first Data Machine Check error (which is an error on a D-cache transaction) will lock the BESR and BEAR to preserve information about that error. However, Instruction Machine Check errors (which are errors on I-cache transactions) and DMA errors do not lock the BESR. Therefore, information which details the cause of a DMA error can be overwritten.

4.3 DMA Registers

All DMA registers are device control registers and are accessed via move to/from device control register (**mtdcr/mfdcr**) instructions. The detailed functions of each register are discussed in the following subsections.

4.3.1 DMA Channel Control Register (DMACR0-DMACR3)

The DMA Channel Control Registers, DMACR0-3, are four 32-bit registers (one for each DMA channel) which set up and enable their respective DMA channels. Prior to executing DMA transfers, each Channel Control Register must be initialized and enabled. This is accomplished via a move to device control register (**mtdcr**) instruction. The contents of the DMA Channel Control Register may also be read into a general purpose register by using a move from device control register (**mfdcr**) instruction.

The DMA channels are enabled and the transfer mode, direction, width and the peripheral location (internal or external) are all programmed via the Channel Control Register. Also, transfer parameters such as peripheral set-up, wait and hold times are programmed in the Channel Control Register. Figure 4-17 shows the DMACR bit definitions.

Conditions which dictate stopping a channel (see Section 4.2.8 on page 4-26) will cause the Channel Enable bit (DMACRn[CE]) to be cleared by hardware.

When chaining occurs, the Chaining Enable bit (DMACRn[CH]) will be cleared by hardware. When the Chained Count Register (DMACCN) is written, the Chaining Enable bit will be set by hardware.

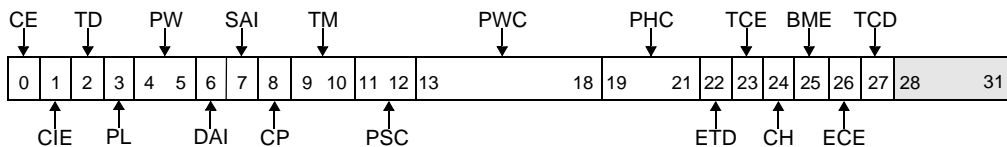


Figure 4-17. DMA Channel Control Registers (DMACR0-DMACR3)

0	CE	Channel Enable 0 - Channel is disabled 1 - Channel is enabled for DMA operation (Hardware clears this bit when channel stopping conditions are satisfied.)
1	CIE	Channel Interrupt Enable 0 - Disable DMA interrupts from this channel to the processor 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode) 0 - Transfers are from memory to peripheral 1 - Transfers are from peripheral to memory

Figure 4-17. DMA Channel Control Registers (DMACR0-DMACR3) (cont.)

3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC 1 - Peripheral is internal to PPC403GC (internal peripherals are those on the OPB)
4:5	PW	Peripheral Width 00 - Byte (8-bits) 01 - Halfword (16-bits) 10 - Word (32-bits) 11 - M2M line (16 bytes) Transfer Width is the same as Peripheral Width. M2M transfer initiated by software only.
6	DAI	Destination Address Increment 0 - Hold the destination address (do not increment) 1 - Increment the destination address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes) 0 - Hold the source address (do not increment) 1 - Increment the source address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.
8	CP	Channel Priority 0 - Channel has low priority for the external or internal bus 1 - Channel has high priority for the external or internal bus
9:10	TM	Transfer Mode 00 - Buffered mode DMA 01 - Fly-by mode DMA 10 - Software initiated memory-to-memory mode DMA 11 - Hardware initiated (device paced) memory-to-memory mode DMA
11:12	PSC	Peripheral Setup Cycles 00 - No cycles for setup time will be inserted during DMA transfers 01 - One SysClk cycle of setup time will be inserted between the time $\overline{\text{DMAA}}$ is accepted (on a peripheral read) or the data bus is driven (on a peripheral write) and $\overline{\text{DMAA}}$ is asserted for the peripheral part of the transfer in buffered and fly-by modes. 10 - Two SysClk cycles of setup time are inserted 11 - Three SysClk cycles of setup time are inserted
13:18	PWC	Peripheral Wait Cycles The value (0-63) of the PWC bits determines the number of SysClk cycles that $\overline{\text{DMAA}}$ stays active after the first full SysClk cycle $\overline{\text{DMAA}}$ is active. For instance, the PWC bits have a value of 5, then $\overline{\text{DMAA}}$ is active for six SysClk cycles.
19:21	PHC	Peripheral Hold Cycles The value (0-7) of these bits determines the number of SysClk cycles between the time that $\overline{\text{DMAA}}$ becomes inactive until the bus is available for the next bus access. During this period, the address bus, the data bus and control signals remain active.
22	ETD	End-of-Transfer / Terminal Count ($\overline{\text{EOT/TC}}$) Pin Direction 0 - The $\overline{\text{EOT/TC}}$ pin is programmed as an end-of-transfer ($\overline{\text{EOT}}$) input. 1 - The $\overline{\text{EOT/TC}}$ pin is programmed as a terminal count ($\overline{\text{TC}}$) output. When programmed as $\overline{\text{TC}}$ and the terminal count is reached, this signal will go active the cycle after $\overline{\text{DMAA}}$ goes inactive.

Figure 4-17. DMA Channel Control Registers (DMACR0-DMACR3) (cont.)

23	TCE	Terminal Count Enable 0 - Channel does not stop when terminal count reached. 1 - Channel stops when terminal count reached.	
24	CH	Chaining Enable 0 - DMA Chaining is disabled 1 - DMA chaining is enabled for this channel	(Hardware clears this bit when chaining occurs. Hardware sets this bit when DMACC is written.)
25	BME	Burst Mode Enable 0 - Channel does not burst to memory. 1 - Channel will burst to memory.	(In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. 1 - If Chaining is enabled, channel will chain when EOT is active.	(ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero. 1 - Channel will not chain when TC reaches zero.	
28:31		reserved	

4.3.2 DMA Status Register (DMASR)

The DMA Status Register is a 32-bit register which contains the status of terminal count, EOT, bus errors, and internal or external DMA requests for all DMA channels.

Status registers are normally considered to be set via hardware, and read and cleared via software. Reading DMASR is done using the **mfdcr** instruction. Clearing is done by writing a word to DMASR using **mtdcr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

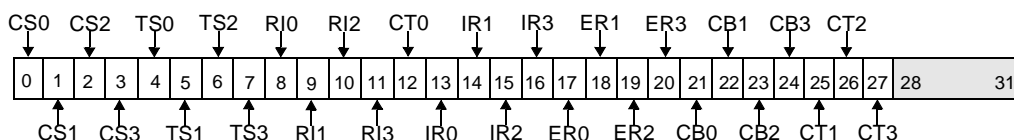


Figure 4-18. DMA Status Register (DMASR)

0:3	CS0: CS3	Channel 0-3 Terminal Count Status 0 - Terminal count has not been reached in the Transfer Count Register for channels 0-3, respectively. 1 - Terminal count has been reached in the Transfer Count Register for channels 0-, respectively.	TC will be set whenever the Transfer Count reaches 0 and the channel does not chain.
4:7	TS0: TS3	Channel 0-3 End-Of-Transfer Status (Valid only if $\overline{\text{EOT}}/\text{TC}$ has been programmed for the $\overline{\text{EOT}}$ function) 0 - End of transfer has not been requested for channels 0-3, respectively. 1 - End of transfer has been requested for channels 0-3, respectively.	
8:11	RI0: RI3	Channel 0-3 Error Status 0 - No error. 1 - Error.	BIU errors: - Bus Protection. - Non-configured Bank. - Bus Error Input. - Time-out Check. DMA errors: - Unaligned Address.
12	CT0	Chained Transfer on Channel 0. 0 - No chained transfer has occurred. 1 - Chaining has occurred.	
13:16	IR0: IR3	Internal DMA Request 0 - No internal DMA request pending 1 - A DMA request from an internal device is pending	
17:20	ER0: ER3	External DMA Request 0 - No external DMA request pending 1 - A DMA request from an external device is pending	

Figure 4-18. DMA Status Register (DMASR) (cont.)

21:24	CB0: CB3	Channel Busy 0 - Channel not currently active 1 - Channel currently active
25:27	CT1: CT3	Chained Transfer on Channel 1-3. 0 - No chained transfer has occurred. 1 - Chaining has occurred.
28:31		reserved

4.3.3 DMA Destination Address Register (DMADA0-DMADA3)

The DMA Destination Address Register is a 32-bit register which contains the memory address for buffered or fly-by mode transfers. For memory-to-memory mode transfers, the DMA Destination Address Register contains the memory destination address. When a channel is operating in chained mode, the DMA Destination Address Register initially contains the memory transfer address. Figure 4-1 shows that when the transfer count reaches zero, the DMA Destination Address register is loaded with the contents of the Source/Chained Address Register. Figure 4-19 shows the DMADA bit definitions.

In all DMA modes, if DMACR[DAI] = 1, the DMADA is incremented by 1, 2, or 4, depending on the Transfer Width (Peripheral Width). If the Transfer Width is Byte, the address is always incremented by 1. If the Transfer Width is Halfword and the starting address is halfword aligned, the address is incremented by 2. If the Transfer Width is Halfword and the starting address is NOT halfword aligned, the Error bit is set for that channel and no transfer occurs. If the Transfer Width is Word and the starting address is word aligned, the address is incremented by 4. If the Transfer Width is Word and the starting address is NOT word aligned, the Error bit is set for that channel and no transfer occurs.

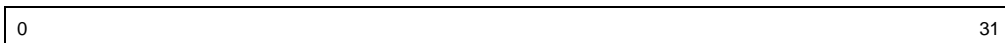


Figure 4-19. DMA Destination Address Registers (DMADA0-DMADA3)

0:31	Memory address for transfers between memory and peripheral. Destination address for memory-to-memory transfers.
------	--

The contents of the DMA Destination Address Register can be accessed via the move to/from device control register (**mtdcr/mfdcr**) instructions.

4.3.4 DMA Source/Chained Address Register (DMASA0-DMASA3)

The DMA Source/Chained Address Register is a 32-bit register which is only used in memory-to-memory move mode for any channel or when chaining has been enabled in buffered or fly-by mode. In memory-to-memory move mode, the DMA Source/Chained Address Register contains the source memory address for the next transfer. If chaining is enabled (via the chaining enable bit in DMA Channel Control Register), the DMA Source/Chained Address Register contains the address which is written into the DMA Destination Address register when the terminal count is reached.

In memory-to-memory mode, if $DMACR[SAI] = 1$, the DMASA is incremented by 1, 2, or 4, depending on the Transfer Width (Peripheral Width). If the Transfer Width is Byte, the address is always incremented by 1. If the Transfer Width is Halfword and the starting address is halfword aligned, the address is incremented by 2. If the Transfer Width is Halfword and the starting address is NOT halfword aligned, the Error bit is set for that channel and no transfer occurs. If the Transfer Width is Word and the starting address is word aligned, the address is incremented by 4. If the Transfer Width is Word and the starting address is NOT word aligned, the Error bit is set for that channel and no transfer occurs.

The DMA Source/Chained Address Register can be accessed via move to/from device control register (**mtdcr/mfdcr**) instructions with the appropriate DCR number. Figure 4-20 shows the DMASA bit definitions.

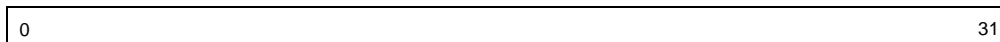


Figure 4-20. DMA Source Address Registers (DMASA0-DMASA3)

0:31		Source address for memory-to-memory transfers. Replacement contents for Destination Address for chained transfers.
------	--	---

4.3.5 DMA Count Register (DMACT0-DMACT3)

The DMA Count Register is a 32-bit register of which only 16 bits are implemented. The DMA Count Register contains the number of transfers left in the DMA transaction for its respective channel. The maximum number of transfers is 64K and each transfer can be 1, 2, or 4 bytes as programmed in the DMA Channel Control Register. The maximum count of 64K transfers is programmed by writing a value of 0 to the DMACT. The DMA Count Register can be accessed via move to/from device control register (**mtdcr/mfdcr**) instructions using the appropriate DCR number. Figure 4-21 shows the DMA Count Register bit definitions.

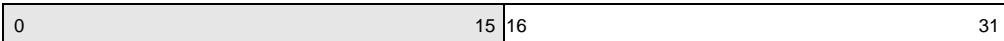


Figure 4-21. DMA Count Registers (DMACT0-DMACT3)

0:15		reserved
16:31		Number of Transfers remaining.

4.3.6 DMA Chained Count Register (DMACC0-DMACC3)

When chaining is enabled for Channel 0:3, the DMA Chained Count Register contains the number of transfers in the next DMA transaction for Channel 0:3. When the current DMA transaction is complete, the contents of the Channel 0:3 Count Register are loaded with the contents of DMACC0:3. When chaining is disabled for Channel 0:3, the DMA Chained Count Register is not used. The DMA Chained Count Register can be accessed via move to/from device control register (**mtdcr/mfdcr**) instructions. The Chaining Enable bit of the DMA Control Register (DMACR0:3[24]) is set when the DMACC0:3 is written via **mtdcr**. Figure 4-22 shows the DMACC bit definitions.

0	15	16	31
---	----	----	----

Figure 4-22. DMA Chained Count Registers (DMACC0-DMACC3)

0:15		reserved
16:31		Chained Count.

Reset and Initialization

This chapter describes the three types of processor resets, the initial state of the processor after each type of reset, and the minimum initialization code required to begin executing application code. Initialization of external system components or system-specific chip facilities may need to be performed in addition to the basic initialization code described in this chapter.

5.1 Core, Chip, and System Resets

The PPC403GC has three reset modes: core reset, chip reset and system reset. A core reset affects the resources within the core but not most peripherals outside the core. A core reset is the only reset which preserves the contents of the bank registers. A chip reset affects all resources contained in the chip but does not drive the reset pin on the PPC403GC. A system reset is similar to a chip reset, however, the reset pin is driven active to initiate a reset of components external to the PPC403GC.

Each type of reset may be generated internal to the chip by a debug tool or other code utilizing the Debug Control Register, or by the second expiration of the Watchdog Timer if it is enabled in the Timer Control Register. Each type of reset may be generated externally by a JTAG-based debug tool. System Reset may also be initiated external to the chip via the Reset signal.

For all reset modes, the MSR[CE,EE,ME,DE,PE] bits are all cleared to 0 to disable exceptions until reset processing is complete. MSR[DR,IR] are cleared to 0 to disable address translation. MSR[PR] is cleared to 0 to place the processor in supervisor state. The processor begins execution at address 0xFFFF FFFC.

Section 5.3 (Register Contents After A Reset) on page 5-4 details the register bits affected by each type of reset. Each reset mode is further described in the following subsections.

5.1.1 Core Reset

Resets the processor core, including the data and instruction caches.

The reset does not alter the DMA Controller, Bus Interface Unit, or Serial Port configurations. The BIU state machine is reset, the DMA channels are placed in an inactive state, and the Data Side Machine Check status bit in the BESR is cleared.

The contents of external DRAM is preserved since refreshes continue during the reset.

5.1.2 Chip Reset

Resets the entire chip including the core, caches, DMA Controller, Bus Interface Unit, and Serial Port.

The contents of external DRAM is not preserved since refreshes stop during and after the reset.

5.1.3 System Reset

Resets the entire chip with the same effect as Chip Reset.

If the system reset is generated internal to the chip, the $\overline{\text{Reset}}$ signal is driven active for a minimum of 2048 clock cycles. Logic external to the chip is required to maintain the active level on the $\overline{\text{Reset}}$ pin for a total of at least 2048 clock cycles at POR.

5.1.3.1 Behavior of the $\overline{\text{Reset}}$ Line

System Reset behavior of the PPC403GC is as follows:

- 1) Upon recognizing a system reset, initiated by either software or the falling edge of the externally asserted $\overline{\text{Reset}}$ line, the processor will drive the $\overline{\text{Reset}}$ line active for 2048 clocks (61.4 μs @ 33.33 MHz).
- 2) The processor will stop driving the $\overline{\text{Reset}}$ output after 2048 cycles and will then wait until the $\overline{\text{Reset}}$ line rises to its inactive state. The processor will retain the value of the boot width pin (BootW) from two clocks before the $\overline{\text{Reset}}$ is sensed as inactive.
- 3) Once the external $\overline{\text{Reset}}$ line is inactive (as seen by the PPC403GC), the processor will wait 32 more clocks before activating the core logic for the first instruction fetch from address 0xFFFF FFFC. This time will allow 960 ns (@ 33.33 Mhz) for other receivers on the $\overline{\text{Reset}}$ line to react to the removal of $\overline{\text{Reset}}$. BootW will be sampled by the processor for the second time during this interval.

Some things to consider:

- Systems must still provide a power-on reset (POR) function to activate $\overline{\text{Reset}}$. During POR, the number of cycles that the processor will drive the $\overline{\text{Reset}}$ line varies (from 1 to 2048).
- $\overline{\text{Reset}}$ is an open-drain line with an external pullup resistor that can be over-driven by the processor's pull-down driver. Systems with circuits that control the $\overline{\text{Reset}}$ line external to the processor should not drive the $\overline{\text{Reset}}$ line inactive within the first 2048 clocks of a reset sequence or they will be contending with the processor on the $\overline{\text{Reset}}$ line.

5.2 Processor State After Reset

Table 5-1 describes the processor configuration after a core, chip or system reset.

Table 5-1. Processor Configuration After a Reset

Chip Resource	Core Reset Configuration	Chip Reset or System Reset Configuration
Bus Behavior Address Tri-state Byte Enable Mode Device-Paced Timeout Asynchronous Ready DRAM Read	Unchanged Unchanged Unchanged Unchanged Unchanged	Tri-state when bus idle WBE pins are Write Byte Enables Timeout is possible Data latched the cycle after Ready detected Latch data on rise of SysClk
Caches	Disabled	Disabled
DMA	Channels Disabled	Channels Disabled EOT/TC Configured as EOT
Guarded Storage Attribute	All storage is guarded	All storage is guarded
Interrupts (External & Critical)	Disabled	Disabled
Memory Bank 0 Bank Address Bank Size Bus Width Ready Transfer Wait Chip Select Output Enable Write Byte Enable Write Byte Enable Transfer Hold Line Fills Burst Mode Bank Usage Memory Type	Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged Unchanged	0xFF 1MB Set by BootW signal during most recent System Reset Disabled 64 cycles 1 Cycle Turn-On Delay 1 Cycle Turn-On Delay 1 Cycle Turn-On Delay 1 Cycle Advance Turn-off 7 Cycles Target Word First Disabled Read and Write SRAM
Memory Banks 1 - 7	Unchanged	Disabled
Power Dissipation	Unchanged	Normal
Processor Mode	Supervisor Mode	Supervisor Mode
Protection / Translation	Disabled	Disabled
Real-Time Debug Mode	Unchanged	Trace Status outputs disabled

Table 5-1. Processor Configuration After a Reset

Chip Resource	Core Reset Configuration	Chip Reset or System Reset Configuration
Serial Port		
Receive Buffer Status	Unchanged	Empty
Transmit Buffer Status	Unchanged	Empty
Transmit Shifter Status	Unchanged	Empty
Loopback	Unchanged	Unchanged
Auto-echo	Unchanged	Disabled
Data Terminal Ready	Unchanged	Inactive
Request to Send	Unchanged	Inactive
Receiver	Unchanged	Disabled
Transmitter	Unchanged	Disabled
Serial Clock	Unchanged	System Clock
Timer Clock Source	Unchanged	System Clock
Wait State	Disabled	Disabled
Watchdog Timer Reset	Disabled	Disabled

5.3 Register Contents After A Reset

The initial processor state is controlled by the register contents after a reset. The initial register contents varies with the type of reset that has occurred.

In general, the contents of SPRs are undefined after a core, chip, or system reset. The contents of DCRs and MMIO Registers are unchanged after a core reset and undefined after a chip or system reset. The exceptions to these rules are shown in the following tables.

Table 5-2. Contents of Machine State Register After Reset

Register	Bits	Core Reset	Chip Reset	System Reset	Comment
MSR	13 – WE	0	0	0	Wait State Disabled
	14 – CE	0	0	0	Critical Interrupts Disabled
	15 – ILE	0	0	0	Interrupt Little Endian
	16 – EE	0	0	0	External Interrupts Disabled
	17 – PR	0	0	0	Supervisor Mode
	19 – ME	0	0	0	Machine Check Interrupt Disabled
	22 – DE	0	0	0	Debug Interrupts Disabled
	26 – IR	0	0	0	Instruction Translation Disabled
	27 – DR	0	0	0	Data Translation Disabled
	28 – PE	0	0	0	Protection Disabled
	29 – PX	0	0	0	Protection Inclusive
	31 – LE	0	0	0	Little Endian

Table 5-3. Contents of Special Purpose Registers After Reset

Register	Bits	Core Reset	Chip Reset	System Reset	Comment
DBCR	0 : 31	0	0	0	
DBSR	22 : 23	01	10	11	Most recent reset.
DCCR	0 : 31	0x00000000	0x00000000	0x00000000	Data Cache disabled
ESR	0 : 31	0x00000000	0x00000000	0x00000000	No exception syndromes
ICCR	0 : 31	0x00000000	0x00000000	0x00000000	Instruction Cache disabled
PVR	0 : 31	0x00200200	0x00200200	0x00200200	Processor version. The Minor Change Level field (last hex digit of the PVR value) may change due to minor processor updates. Except for the value of this field, such changes do not impact this document.
SGR	0 : 31	0xFFFFFFFF	0xFFFFFFFF	0xFFFFFFFF	Real-mode storage is guarded.
TCR	2 : 3 9	00 0	00 0	00 0	Watchdog Timer reset disabled Auto-Reload of PIT disabled
TSR	2 : 3	Copy of TCR bits 2:3	Copy of TCR bits 2:3	Copy of TCR bits 2:3	If Reset Caused by Watchdog Timer
		Undefined	Undefined	Undefined	After Power-up
		Unchanged	Unchanged	Unchanged	If Reset not caused by Watchdog Timer

Table 5-4. Contents of Serial Port Registers After Reset

Register	Bits	Core Reset	Chip Reset	System Reset	Comment
SPLS	0	Unchanged	0	0	Receive Buffer Not Full
	5	Unchanged	1	1	Transmitter Buffer Empty
	6	Unchanged	1	1	Transmitter Shifter Empty
SPCTL	0	Unchanged	0	0	Auto-echo Disabled
	1	Unchanged	Unchanged	Unchanged	Loop Back Mode Unchanged
	2	Unchanged	0	0	Data Terminal Ready Inactive
	3	Unchanged	0	0	Request To Send Inactive
SPRC	0	Unchanged	0	0	Disable Receiver
SPTC	0	Unchanged	0	0	Disable Transmitter
	7	Unchanged	0	0	Disable Pattern Generation Mode

Table 5-5. Contents of Device Control Registers After Reset

Register	Bits	Core Reset	Chip Reset	System Reset	Comment
BESR	0	0	0	0	No Data Bus Error
BR0	0 : 31	Unchanged	0xFF183FFE	0xFF183FFE	If Byte Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF18BFFE	0xFF18BFFE	If Half-word Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF193FFE	0xFF193FFE	If Full-word Boot Width at the time of the most recent System Reset.
BR1 - 3	0 : 31	Unchanged	0xFF003FFE	0xFF003FFE	If Byte Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF00BFFE	0xFF00BFFE	If Half-word Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF013FFE	0xFF013FFE	If Full-word Boot Width at the time of the most recent System Reset.
BR4 - 7	0 : 31	Unchanged	0xFF003FFF	0xFF003FFF	If Byte Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF00BFFF	0xFF00BFFF	If Half-word Boot Width at the time of the most recent System Reset.
		Unchanged	0xFF013FFF	0xFF013FFF	If Full-word Boot Width at the time of the most recent System Reset.
DMACR 0-3	0	0	0	0	DMA Channels Disabled
	22	Unchanged	0	0	Configure EOT/TC as EOT.
IOCR	18	Unchanged	0	0	Tri-state bus when idle
	19	Unchanged	0	0	Normal power operation
	20	Unchanged	0	0	WBE pins are Write Byte Enables
	21	Unchanged	0	0	Timeout possible on device-paced access
	24	Unchanged	0	0	Data latched cycle after Ready detected
	26	Unchanged	0	0	Latch Data Bus on SysClk
	27 : 28	Unchanged	0	0	Trace Status outputs disabled
	29	Unchanged	0	0	Timer Clock Source = SysClk
	30	Unchanged	0	0	Serial Port Clock Source = SysClk

5.4 Signal States During Reset

The following table summarizes the states of signals on output pins when $\overline{\text{Reset}}$ is active.

Table 5-6. Signal States During Reset

Signal Names	State When $\overline{\text{Reset}}$ Active
A6:29	Floating
AMuxCAS	Inactive (low)
BusReq	Inactive (low)
CAS0:3	Inactive (high)
$\overline{\text{CS0:3}}$	Floating
$\overline{\text{CS4:7/RAS3:0}}$	Floating
D0:31	Floating
$\overline{\text{DMAA0:2}}$	Inactive (high)
$\overline{\text{DMAA3/XAck}}$	Inactive (high)
$\overline{\text{DRAMOE}}$	Inactive (high)
$\overline{\text{DRAMWE}}$	Inactive (high)
$\overline{\text{DTR/RTS}}$	Inactive (high)
Error	Inactive (low)
HoldAck	Inactive (low)
$\overline{\text{OE}}$	Floating
$\overline{\text{Reset}}$	Floating unless initiating system reset
R/W	Floating
$\overline{\text{TC0:2}}$	Floating (set to input)
$\overline{\text{TC3}}$	Floating (set to input)
TDO	Floating
TS0:6	Inactive (low)
$\overline{\text{WBE0:3}}$	Floating
XmitD	Inactive (high)

The assertion of $\overline{\text{Reset}}$ with the SysClk non-switching will put all of the I/O's in the state defined in Table 5-6 above. As long as the SysClk remains non-switching, the chip will not enter the system reset state with the exception of the JTAG interface logic which will go the reset or idle state even though the SysClk remains off.

By stopping the switching of the SysClk input and activating the $\overline{\text{Reset}}$ input, the chip will dissipate the minimum amount of power.

5.5 DRAM Controller Behavior During Reset

If the $\overline{\text{Reset}}$ input to the chip is asserted with the SysClk input operating, the chip will enter the system reset state. While the $\overline{\text{Reset}}$ input is asserted, the RAS signals will be HiZ and the CAS signals will go to the inactive state. After the $\overline{\text{Reset}}$ input is deasserted, the CAS signals will remain inactive, and the RAS signals will change from HiZ to Inactive.

If the $\overline{\text{Reset}}$ input to the chip is asserted with the SysClk input in either the '1' or '0' state and not switching, the RAS signals will switch from the previous state, either logic '1' or '0' to the HiZ state. The CAS signals will remain unchanged and will continue to drive either a '1' or '0' as controlled by whatever operation was in progress when the clock stopped. If the SysClk remains non-switching and the $\overline{\text{Reset}}$ input is deasserted, the RAS signals will switch from the HiZ state back to the previous state before the $\overline{\text{Reset}}$ input was activated. The CAS signals will remain unchanged and will continue to drive either logic '0' or '1' as defined by the bank register.

By stopping the switching of the SysClk input and activating the $\overline{\text{Reset}}$ input, the chip will dissipate the minimum amount of power. If it is desired to continue to keep the DRAM device in the Self Refresh mode while in this state, a pull-down will be required on the RAS output for the DRAM bank. This will hold the RAS signal active while the $\overline{\text{Reset}}$ input is active. Note that this will also activate the RAS signal during normal system reset and therefore an active pull-down may be required by the system.

Caution for users of Early RAS Mode:

- If a DRAM bank is programmed to use the Early RAS Mode feature (DRAM bank register bit 14 is set to 1), no access to this bank may occur within 700 nsec from any of the following:
 - the deactivation of Reset;
 - any change of SysClk frequency, including the restart of SysClk from a stopped state (change of SysClk duty cycle does not require access restrictions);
 - enabling normal-power operation by clearing IOCR[SPD] to 0.
- No use of Early RAS Mode may occur while the chip is in the power-reduced mode set by IOCR[SPD] = 1. This power-reduced mode is intended for achieving minimum chip power dissipation in a clock-stopped state; it is not intended for use during normal chip operation.

5.6 Effect of Reset on the TLB

- No access to the TLB may occur within 700 nsec from any of the following:
 - the deactivation of Reset;
 - any change of SysClk frequency, including the restart of SysClk from a stopped state (change of SysClk duty cycle does not require access restrictions);
 - enabling normal-power operation by clearing IOCR[SPD] to 0.
- No access to the TLB may occur while the chip is in the power-reduced mode set by IOCR[SPD] = 1. This power-reduced mode is intended for achieving minimum chip power dissipation in a clock-stopped state; it is not intended for use during normal chip operation.

5.7 Initial Processor Sequencing

After any type of reset, the processor begins by fetching the word at address 0xFFFF FFFC and attempting to execute it. Since the only memory configured immediately after reset is the upper 1MB bank (0xFFF00000 - 0xFFFFFFFF) the instruction at 0xFFFFFFFFC must be a branch instruction. The branch must be to initialization code in the upper 1MB bank.

The system must provide memory in the upper 1MB bank region which must be either non-volatile or initialized by some mechanism, external to the processor, prior to a reset. The upper 1MB bank configuration after reset is 64 wait states, one cycle of address to chip select delay, one cycle of chip select to output enable delay, and seven cycles of hold time. The bus width (8-, 16-, or 32-bit) is controlled by the BootW signal.

There are no processor restrictions on when the initial bank configurations can be modified after the reset has occurred. There may, however, be restrictions due to the memory devices in the system.

5.8 Initialization Requirements

When a reset is performed, the processor is initialized to a minimum configuration to start executing initialization code. Initialization code is necessary to complete the processor and system configuration. The initialization code described in this section is the minimum recommended for configuring the processor to run application code.

Initialization code should configure the following processor resources.

- Enable Bus Status Mode if logic analyzer debug is required. See Section 10.2.4 (Bus Status Debug Mode) on page 10-3 for more detail.
- Initialize DCWR to non-write-thru, to avoid alignment exceptions on store operations (must be done before first store).
- Program all memory and I/O bank configuration registers.
- Invalidate the i-cache and d-cache.
- Enable cacheability for appropriate memory regions.
- Turn off guarded attribute (SGR) as appropriate for memory regions.
- Initialize system memory as required by the operating system or application code.
- Initialize processor registers as needed by the system.
- Initialize off-chip system facilities.
- Dispatch the operating system or application code.

5.8.1 Notes on Bank Register Initialization

As shown in Table 5-1, hardware initializes Bank Register 0 for slow memory, and initializes the other bank registers in a disabled state. For optimum performance, the initialization code should reprogram the bank configuration register for the high memory bank as soon as possible. In some systems, the high memory bank devices may allow for the bank register configuration to change while the memory is being accessed. In this case, the initialization code can reprogram the high memory bank immediately. There are cases where the memory devices cannot be reprogrammed while they are being accessed. In these cases, the code to perform the bank reconfiguration must either be contained entirely within the instruction cache or in another configured bank.

- An example where special precautions are not required:

If software is reprogramming between valid states of a given bank register (for example, if the hardware is fast ROM on BR1, both slow and fast bank register settings are valid), then no special precautions are required.

- An example where special precautions are required:

Suppose that the processor is running from one memory (say slow PROM from BR0) and that it is desired to switch to an entirely separate memory that covers the same (or larger) memory address range (say SRAM on BR3). If program was being fetched via BR0, then the code must allow for a time interval when both BR0 and BR3 are invalid (since a machine check would result if both were valid on the same accessed address at the same time). A probable way to accomplish this would be for the code to cache itself, then disable BR0, and then enable BR3 with appropriate settings. During the time when both BR0 and BR3 were disabled, all required memory addresses must already be valid in the cache.

5.8.2 Initialization Code Example

This section presents an example of initialization code to illustrate the steps that should be taken to initialize the processor before the operating system or user programs are executed. It is presented in pseudo-code with function calls similar to PPC403GC mnemonics. Specific implementations may require different ordering of these sections to ensure proper operation.

```

/* _____ */
/*               PPC 403 GC Initialization Pseudo Code           */
/* _____ */
@0xFFFFFFFFFC:          /* Initial instruction fetch from 0xFFFFFFFFFC */
    ba(init_code);       /* branch from initial fetch address to init_code */

@init_code:              /* Start of initialization psuedo code */

/* _____ */
/* Enable bus status mode now if logic analyzer trace of boot code is desired. */
/* _____ */

    mtdcr(IOCR, 8);       /* may omit if boot-code trace not needed. */

/* _____ */
/* Clear DCWR to avoid alignment exceptions on stores.           */
/* _____ */

    mtspr(DCWR, 0);

/* _____ */
/* Configure system memory.                                     */
/* _____ */
/* _____ */
/* NOTE :                                                         */
/* _____ */
/* If bank 0 memory can be configured while being accessed then start by */
/* reconfiguring bank 0 then configure banks 1-7 as necessary.           */
/* _____ */
/* If bank 0 memory cannot be configured while being accessed,           */
/* then start by configuring banks 1-7 as required,                       */
/* and then configure bank 0. Bank 0 can be configured by                 */
/* executing bank 0 configuration code in one of the other configured     */
/* banks or by executing bank 0 configuration code that is guarenteed to be in the */
/* cache. The example shown below uses another bank to reconfigure bank 0. */
/* _____ */
/* _____ */

/* _____ */
/* Reconfigure bank 0 if allowed                                         */
/* _____ */

if (configuring bank 0 while accessing bank 0 is allowed)
{
    mtdcr(BR0, bank_0_configuration);
}

```

```

/* _____ */
/* configure banks 1-7 if they exist */
/* _____ */

if (bank_1_exists)
    mtdcr(BR1, bank_1_configuration);
if (bank_2_exists)
    mtdcr(BR2, bank_2_configuration);
if (bank_3_exists)
    mtdcr(BR3, bank_3_configuration);
if (bank_4_exists)
    mtdcr(BR4, bank_4_configuration);
if (bank_5_exists)
    mtdcr(BR5, bank_5_configuration);
if (bank_6_exists)
    mtdcr(BR6, bank_6_configuration);
if (bank_7_exists)
    mtdcr(BR7, bank_7_configuration);

/* _____ */
/* Reconfigure bank 0 if necessary */
/* _____ */

if (configuring bank 0 while accessing bank 0 is NOT allowed)
{
    move_code(&another_bank, ( mtdcr(BR0, bank_0_configuration) ));
    move_code(&another_bank + 4, ( blr);
    bla(&another_bank);          /* branch to bank 0 configuration code and save */
                                /* the return point */
}

/* _____ */
/* Invalidate both caches and enable cacheability */
/* _____ */

/* _____ */
/* Invalidate the instruction cache */
/* _____ */

address = 0;          /* start at first line */
for (line = 0; line < 64; line++) /* the i-cache has 64 congruence classes */
{
    iccci(address);    /* iccci instruction invalidates congruence class */
    address += 16;     /* point to the next congruence class */
}

```

```

/*_____ */
/* Invalidate the data cache */
/*_____ */

address = 0; /* start at first line */
for (line = 0; line < 32; line++) /* the d-cache has 32 congruence classes */
{
    dccci(address); /* dccci instruction invalidates congruence class */
    address += 16; /* point to the next congruence class */
}

/*_____ */
/* Enable cacheability */
/*_____ */

mtspr(DCCR, d_cache_cacheability); /* enable d-cache */
mtspr(ICCR, i_cache_cacheability); /* enable i-cache */

/*_____ */
/* Clear guarded attribute for max performance. */
/* Can do as early as desired (e.g., before caches invalidated). */
/*_____ */

    mtspr(SGR, 0);

/*_____ */
/* Load operating system and/or application code, including exception handlers, */
/* into memory. */
/*_____ */
/* The example assumes that the system and/or application code is loaded */
/* immediately after the cache is initialized. */
/* The example assumes that the source and destination regions do not overlap. */
/*_____ */

while (not_done) /* repeat until all code has been loaded. */
{
    lmw(4, &code); /* load 4 word into 4 registers */
    stmw(4, &new_location); /* store 4 words to d-cache */
    dcbst(&new_location); /* store cache block to physical memory */
    icbi(&new_location); /* clear any obsolete code from i-cache */
    inc(&code); /* increment the code address by 4 words */
    inc(&new_location); /* increment the new_location addr by 4 words */
}
sync(); /* allow all stores to complete */

```

```

/* _____ */
/* Store the last block (may have been unaligned) */
/* _____ */

dcbst(&new_location);          /* store cache block to physical memory */
sync();                        /* allow store to complete */
icbi(&new_location);          /* clear any obsolete code from i-cache */
isync();                       /* clear any obsolete code from queue */

/* _____ */
/* Establish machine state and on-chip facilities. This order MUST be followed. */
/* _____ */

/* Configure :                watchdog timer */
/*                          serial port clocks */
/*                          external interrupt polarity */
/*                          external interrupt edge/level sensitivity */
/*                          serial port pin assignments */

mtdcr(IOCR,io_configuration);  /* configure I/O */

/* _____ */
/* Initialize and configure the Serial Port */
/* _____ */

stb(BRDH_addr, 0);             /* clear Serial Port baud rate divisor high */
stb(BRDL_addr, 0);             /* clear Serial Port baud rate divisor low */
stb(SPLS_addr, 0x78);          /* clear error bits in Serial Port line status */
stb(SPHS_addr, 0xff);          /* clear error bits in Serial Port handshake status */
stb(SPCTL_addr, 0);            /* clear Serial Port control register */
stb(SPRC_addr, 0);             /* clear Serial Port receiver command register */
stb(SPTC_addr, 0);             /* clear Serial Port transmitter command register */
stb(BRDH_addr, baud_rate_high); /* program desired baud rate divisor, high */
stb(BRDL_addr, baud_rate_low); /* program desired baud rate divisor, low */
stb(SPCTL_addr, serial_port_config); /* configure serial port */
/*                          transmitter and receiver may be */
/*                          enabled any time after a interrupt service */
/*                          routine is available */

```

```

/*_____ */
/* Initialize and configure DMA facilities */
/*_____ */

mtdcr(DMASR,0xFFFFFFFF); /* clear DMA status register */

if (channel 0 used)
{
    if (memory-to-memory mode)
    {
        mtdcr(DMASA0, &source_addr); /* initialize source memory address */
        mtdcr(DMADA0, &source_addr); /* initialize destination address */
        mtdcr(DMACT0, transfer_count); /* initialize transfer count */
    }
    else if ( (buffered mode || fly-by mode) && chaining enabled)
    {
        mtdcr(DMASA0, &count_addr); /* initialize chaining terminal count address */
        mtdcr(DMACC0, chained_count); /* initialize chained transfer count */
        mtdcr(DMADA0, &source_addr); /* initialize memory transfer address */
        mtdcr(DMACT0, transfer_count); /* initialize transfer count */
    }
    else if ( (buffered mode || fly-by mode) && !chaining enabled)
    {
        mtdcr(DMADA0, &source_addr); /* initialize memory address */
        mtdcr(DMACT0, transfer_count); /* initialize transfer count */
    }
}

mtdcr(DMACR0, channel_control); /* initialize channel control */
}

```



```

if (channel 1 used)
{
    if (memory-to-memory mode)
    {
        mtdcr(DMASA1, &source_addr); /* initialize source memory address */
        mtdcr(DMADA1, &source_addr); /* initialize destination address */
        mtdcr(DMACT1, transfer_count); /* initialize transfer count */
    }
    else if ( (buffered mode || fly-by mode) && !chaining enabled)
    {
        mtdcr(DMADA1, &source_addr); /* initialize memory address */
        mtdcr(DMACT1, transfer_count); /* initialize transfer count */
    }

    mtdcr(DMACR1, channel_control); /* initialize channel control */
}

if (channel 2 used)
    Repeat steps in channel 1 for channel 2

if (channel 3 used)
    Repeat steps in channel 1 for channel 3

/* _____ */
/*Initialize and configure external interrupts */
/* _____ */

mtdcr(EXISR, 0xFFFFFFFF); /* clear external interrupt status register */
mtdcr(EXIER, external_interrupt_configuration); /* enable external interrupts */

/* _____ */
/* set the exception vector prefix */
/* _____ */

mtdcr(EVPR, prefix_addr); /* initialize exception vector prefix */

```

```

/*_____ */
/* initialize and configure timer facilities */
/*_____ */

mtspr(TBLO, 0); /* reset time base low first to avoid ripple */
mtspr(PIT, 0); /* clear pit so no pit indication after TSR cleared */
mtspr(TSR, 0xFFFFFFFF); /* clear timer status register */
mtspr(TCR, timer_enable); /* enable desired timers */
mtspr(TBHI, time_base_h); /* set time base, hi first to catch possible ripple */
mtspr(TBLO, time_base_l); /* set time base, low */
mtspr(PIT, pit_count); /* set desired pit count */

/*_____ */
/* Initialize Exceptions in the Machine State Register */
/*_____ */
/* Exceptions must be enabled immediately after timer */
/* facilities to avoid missing a timer exception. */
/*_____ */
/* The MSR also controls the user/supervisor mode, */
/* protection mode, translation, and the wait state. */
/* These modes must be initialized by the operating */
/* system or application code. */
/*_____ */
/* If enabling translation, code must initialize the TLB. */
/*_____ */
/*_____ */

mtmsr(machine_state);

/*_____ */
/* initialization of non-processor facilities should be performed at this time */
/*_____ */

/*_____ */
/* branch to operating system or application code */
/*_____ */
ba(&code_load_address);

```

Interrupts, Exceptions, and Timers

PPC403GC exceptions are generated by signals from internal and external peripherals, instructions, the internal timer facility, debug events, or error conditions. Six external interrupt pins are provided on the PPC403GC; one critical interrupt and five general purpose, individually maskable interrupts.

This chapter begins by defining the terminology of exceptions in Section 6.1 (Interrupts and Exceptions) on page 6-2.

Table 6-2 (Exception Vector Offsets) on page 6-7 lists the various exceptions which may be handled by the PPC403GC in the order of their exception vector offsets. This chapter provides detailed discussion of each exception in that same order. Table 6-2 may be used as an index to the detailed discussions.

Finally, the timer facilities of the PPC403GC are detailed in Section 6.17 (Timer Architecture) on page 6-40.

Many registers are associated with exception handling and control. Discussion of these registers is distributed through the chapter. The general-use exception handling registers MSR, SRR0-3, EVPR, ESR, and DEAR are discussed in Section 6.2 (Exception Handling Registers) on page 6-8. The machine-check handling registers BESR and BEAR are discussed in Section 6.4.1 (Bus Error Reporting) on page 6-16. The external-interrupt and configuration registers EXIER, EXISR, and IOCR are discussed in Section 6.7.1 (External Interrupt Control) on page 6-24. The timer handling registers TSR and TCR are discussed in Section 6.17 (Timer Architecture) on page 6-40.

6.1 Interrupts and Exceptions

An **interrupt** is the action in which the processor saves its old context (MSR and instruction pointer) and begins execution at a pre-determined interrupt-handler address, with a modified MSR. **Exceptions** are the events which will, if enabled, cause the processor to take an interrupt.

6.1.1 Architectural Definitions and Behavior

Precise interrupts are those for which the instruction pointer saved by the interrupt must be either the address of the excepting instruction or the address of the next sequential instruction. **Imprecise** interrupts are those for which it is possible (not required, just possible) for the saved instruction pointer to be something else, possibly prohibiting guaranteed software recovery.

Note that precise and imprecise are defined under the assumption that the interrupts are unmasked (enabled to occur) at the time of the occurrence of the exception. Consider an exception that would cause a precise interrupt, if the interrupt were enabled at the time of the exception, but which occurs while the interrupt is masked. Some exceptions of this type can cause the interrupt to occur later, immediately upon enabling. In such a case, the interrupt would not be considered precise with respect to the enabling instruction, but imprecise ("delayed precise") with respect to the cause of the exception.

Asynchronous interrupts are caused by events which are independent of instruction execution. All asynchronous interrupts are precise, and the following rules apply:

- 1) All instructions prior to the one whose address is reported to the exception handling routine (in the save/restore register) have completed execution. However, some storage accesses generated by these preceding instructions may not have completed.
- 2) No subsequent instruction has begun execution, including the instruction whose address is reported to the exception handling routine.

Synchronous interrupts are those which are caused directly by the execution (or attempted execution) of instructions. Synchronous interrupts may be either precise or imprecise.

For synchronous precise interrupts, the following rules apply:

- 1) The save/restore register addresses either the instruction causing the exception or the immediately following instruction. Which instruction is addressed can be determined from the interrupt type and status bits.
- 2) All instructions preceding the instruction causing the exception have completed execution. However, some storage accesses generated by these preceding instructions may not have completed.

- 3) The instruction causing the exception may appear not to have begun execution (except for causing the exception), may have partially completed, or may have completed, depending on the interrupt type.
- 4) No subsequent instruction has begun execution.

Imprecise interrupts are all synchronous and the following rules apply:

- 1) The save/restore register addresses either the instruction that caused the exception or some instruction following the instruction that caused the exception.
- 2) All instructions preceding the instruction addressed by the save/restore register have completed execution.
- 3) If an instruction (the “interrupt-forcing” instruction) causes an exception which generates an interrupt (for example, an alignment exception), the context synchronizing mechanism is required to force the handling of imprecise interrupts from prior instructions, before handling the interrupt from the interrupt-forcing instruction. On entrance to the handler for such an imprecise interrupt, the save/restore register addresses the interrupt-forcing instruction (not the instruction which caused the imprecise interrupt). The interrupt-forcing instruction may have been partially executed, but it will not have completed.
- 4) If an execution synchronizing instruction other than **sync** or **isync** is executed, the execution synchronizing mechanism is required to force the handling of imprecise interrupts from prior instructions, before completing the execution synchronizing instruction. On entrance to the handler for such an imprecise interrupt, the save/restore register addresses the execution synchronizing instruction (not the instruction which caused the imprecise interrupt). The execution synchronizing instruction appears not to have begun execution (except for its forcing the imprecise interrupt).

If the execution synchronizing instruction was either **sync** or **isync**, then the save/restore register may address either the **sync** or **isync** instruction or the following instruction.
- 5) If the imprecise interrupt is not forced by either the context synchronizing mechanism or the execution synchronizing mechanism, then the instruction addressed by the save/restore register has not begun execution, if it is not the excepting instruction.
- 6) No instruction following the instruction addressed by the save/restore register has begun execution.

Machine Check interrupts are a special case. They are typically caused by some kind of hardware or storage subsystem failure, or by an attempt to access an invalid address. A machine check may be caused indirectly by the execution of an instruction, but not be recognized and/or reported until long after the processor has executed past the instruction which caused the machine check. As such, machine check interrupts cannot properly be

thought as synchronous, nor as precise or imprecise. They are handled as critical class interrupts (see Section 6.1.2.1 on page 6-6). In the case of machine check, the following general rules apply:

- 1) No instruction after the one whose address is reported to the machine check handler in the save/restore register has begun execution.
- 2) The instruction whose address is reported to the machine check handler in the save/restore register, and all prior instructions, may or may not have completed successfully. All the prior instructions which are ever going to complete have done so already, and have done so within the context existing prior to the machine check interrupt. No further interrupt (other than possible additional machine checks) will occur as a result of those instructions.

6

6.1.2 Behavior of the PPC403GC Implementation

Except for machine checks, all PPC403GC exceptions are handled precisely. Precise handling implies that the address of the excepting instruction (synchronous exceptions other than System Call) or the address of the next instruction to be executed (asynchronous exceptions and the System Call synchronous exception) is passed to the exception handling routine. Precise handling also implies that all instructions prior to the instruction whose address is reported to the exception-handling routine have completed execution and that no subsequent instruction has begun execution. The specific instruction whose address is reported may not have begun execution or may have partially completed, as specified for each exception type. Asynchronous imprecise exceptions include data-side machine checks. Synchronous precise exceptions include most debug exceptions, program exceptions, protection bounds violations, data storage exceptions, TLB-miss exceptions, system calls, alignment exceptions, and instruction-side machine checks. Asynchronous precise exceptions include the critical interrupt exception, external interrupts, internal peripherals, internal timer facility exceptions, and some debug events.

Instruction Machine Checks (an error while attempting to fetch an instruction from external memory) require further explanation. The fetch request, if it is to cacheable memory and if it misses in the instruction cache, will cause an instruction cache line fill (four words). Any words of the line that are specifically requested by the fetcher, and passed to it prior to the word upon which the error occurs, will execute without causing an exception. Any words from that line which are provided including and after the word upon which the error was reported, will cause an exception upon attempted execution. After the four words of the instruction cache line have been received from memory, if any of the words were in error, the entire cache line is discarded (words for which an error are reported are not maintained in the instruction cache).

It would be improper to declare an exception at the time that an erroneous word is passed to the fetcher, because the address is possibly the result of an incorrect speculation by the fetcher. It is quite possible that no attempt will actually be made to execute an instruction from the erroneous address. If execution is attempted, an exception will occur at that time. The exception will be a machine check, but it will be precise (with respect to the attempted

execution). The execution will be suppressed, SRR2 will contain the erroneous address, and the ESR will indicate the type of Instruction Machine Check. This exception is clearly asynchronous to the actual erroneous memory access; it is handled as synchronous with respect to the attempted execution from the erroneous address.

In the PPC403GC, only one exception is handled at any one time. If multiple exceptions occur simultaneously, they are handled in the priority order shown in Table 6-1.

Table 6-1. PPC403GC Exception Priorities

Priority	Exception Type	Causing Conditions
1	Machine Check — D-side	External bus error, non-configured memory error, bank protection violation, or time-out during data-side access
2	Debug — IAC	IAC Debug Event when in Internal Debug Mode
3	Machine Check — I-side	Attempted execution of instruction for which external bus error, non-configured memory error, bank protection violation, or time-out occurred during fetch
4	Debug — UDE, EXC	UDE or EXC Debug Event when in Internal Debug Mode
5	Critical Interrupt Pin	Interrupt from the CINT pin
6	Watchdog Timer — First Timeout	Posting of an enabled first time-out of the watchdog timer in the TSR
7	ITLB Miss	Attempted execution of an instruction at an address and process ID for which a valid matching entry was not found in the TLB.
8	Instruction Storage Exception — (ZPR-field) = 0	Instruction translation is active, execution access to the translated address is not permitted because ZPR[ZSEL] = 0 in user mode, and an attempt is made to execute the instruction
9	Instruction Storage Exception — EX = 0	Instruction translation is active, execution access to the translated address is not permitted because EX = 0, and an attempt is made to execute the instruction
	Instruction Storage Exception — G = 1	Instruction translation is active, the page is marked Guarded, and an attempt is made to execute the instruction
10	Program Exception	Attempted execution of illegal instructions, TRAP instruction, or privileged instruction in problem state
	System Call	Execution of the system call (sc) instruction
11	DTLB Miss	Valid matching entry for the effective address and process ID of an attempted data access is not found in the TLB
	Data Storage Exception — Protection Bounds	Data translation is not active and violation of the addresses defined by the protection bound registers occurs
12	Data Storage Exception — (ZPR-field) = 0	Data translation is active and data-side access to the translated address is not permitted because ZPR[ZSEL] = 0 in user mode
13	Data Storage Exception — WR = 0	Data translation is active and write access to the translated address is not permitted because WR = 0

Table 6-1. PPC403GC Exception Priorities (cont.)

14	Alignment Exception	Misaligned data accesses and dcbz to non-cacheable addresses. Any string or multiple instruction in Little Endian mode. Any store access to write-thru storage (including dcbz , but not dcbi or dccci).
15	Debug — IC, BT, TIE, DAC	IC, BT, TIE, or DAC Debug Event when in Internal Debug Mode
16	External Interrupt Input	Interrupts from the DMA channels, serial port, JTAG port, and external interrupt pins
17	Fixed Interval Timer	Posting of an enabled Fixed Interval Timer interrupt in the TSR
18	Programmable Interval Timer	Posting of an enabled Programmable Interval Timer interrupt in the TSR

6**6.1.2.1 Critical and Non-Critical Exceptions**

The PPC403GC processes exceptions as non-critical and critical. Four exceptions are defined as **critical**: machine check exceptions, debug exceptions, exceptions caused by an active level on the critical interrupt pin and the first time-out from the watchdog timer. For clarity, exception handling for critical interrupts is discussed after the following discussion of non-critical exception handling.

When a **non-critical** exception is taken, Save/Restore Register 0 (SRR0) is written with the address of the excepting instruction (most synchronous exceptions) or the next sequential instruction to be processed (asynchronous exceptions and system call). If the PPC403GC was executing a multi-cycle instruction (load/store multiple, load/store string, multiply or divide), the instruction is terminated and its address written in SRR0. When load multiple and load string instructions are terminated, the addressing registers are not updated; this is to ensure that the instructions can be restarted (if the addressing registers were in the range of registers to be loaded, this would be an invalid form in any event). Some of the target registers of the load multiple or load string may have been written; when the instruction is restarted, they will simply be written again. Similarly, some of the target memory of store multiple or store string may have been written, and will be rewritten when the instruction is restarted. Save/Restore Register 1 (SRR1) is written with the contents of the Machine State Register (MSR). The MSR is then updated to reflect the new context of the machine. The new MSR contents take effect beginning with the first instruction of the exception handling routine.

Exception handling routine instructions are fetched at an address determined by the exception type. The address of the exception handling routine is formed from the concatenation of the high-order 16-bits of the Exception Vector Prefix Register (EVPR) and the exception vector offset. The contents of the EVPR are indeterminate on power-up and must be initialized by the user via the move to special purpose register (**mtspr**) instruction. Table 6-2 shows the exception vector offsets for different exception types. Note that there may be multiple sources of the same exception type; exceptions of the same type are mapped to the same exception vector, regardless of source. In these cases, the exception handling routine must examine specific status registers to determine the exact source of the exception.

At the end of the exception handling routine, execution of a return from interrupt (**rfi**) instruction forces the contents of SRR0 and SRR1 to be written into the program counter and the MSR, respectively. Execution then begins at the address in the program counter.

The four **critical** exceptions are processed in a similar manner. When a critical exception is taken, SRR2 and SRR3 hold the next sequential address to be processed when returning from the exception, and the contents of the MSR, respectively. At the end of the critical exception handling routine, execution of the return from critical interrupt (**rfci**) forces the contents of SRR2 and SRR3 to be written into the program counter and the MSR, respectively.

Table 6-2. Exception Vector Offsets

Offset (hex)	Exception Type	Exception Class	Category	Page
0100	Critical Interrupt Pin	Asynchronous Precise	Critical	6-15
0200	Machine Check — D-side	Machine Check, Imprecise	Critical	6-16
	Machine Check — I-side	Machine Check, Precise	Critical	
0300	Data Storage Exception — Protection Bounds (MSR[DR]=0)	Synchronous Precise	Non-critical	6-21
	Data Storage Exception — (ZPR-field) = 0 or WR = 0 (MSR[DR]=1)	Synchronous Precise	Non-critical	
0400	Instruction Storage Exception	Synchronous Precise	Non-critical	6-23
0500	External Interrupt	Asynchronous Precise	Non-critical	6-24
0600	Alignment Exception	Synchronous Precise	Non-critical	6-31
0700	Program	Synchronous Precise	Non-critical	6-32
0C00	System Call	Synchronous Precise	Non-critical	6-33
1000	Programmable Interval Timer	Asynchronous Precise	Non-critical	6-34
1010	Fixed Interval Timer	Asynchronous Precise	Non-critical	6-35
1020	Watchdog Timer	Asynchronous Precise	Critical	6-35
1100	Data TLB Miss	Synchronous Precise	Non-critical	6-36
1200	Instruction TLB Miss	Synchronous Precise	Non-critical	6-37
2000	Debug Exception — IC, BT, TIE, IA1, IA2, DR1, DW1, DR2, DW2	Synchronous Precise	Critical	6-38
	Debug Exception — UDE, EXC	Asynchronous Precise	Critical	

6.2 Exception Handling Registers

Several registers which are routinely involved in exception handling are discussed in this section. These registers are:

- the Machine State Register (MSR), which carries the active machine state information;
- the Save/Restore Registers (SRR0-SRR3), which preserve the machine state on entering the handler;
- the Exception Vector Prefix Register (EVPR), which participates in defining the location of the handler;
- the Exception Syndrome Register (ESR), which helps specify the cause of synchronous exceptions;
- the Data Exception Address Register (DEAR), which carries the operand address of certain synchronous exceptions.

6.2.1 Machine State Register (MSR)

The Machine State Register (MSR) is a 32-bit register that holds the current context of the PPC403GC. If a non-critical interrupt is taken, the contents of the MSR are automatically written in Save/Restore Register 1 (SRR1). If a critical interrupt is taken, the contents of the MSR are written in Save/Restore Register3 (SRR3). When a return from interrupt (**rfi**) or return from critical interrupt (**rfci**) instruction is executed, the contents of the MSR are restored from SRR1 or SRR3, respectively. Figure 6-1 shows the MSR bit definitions and describes the function of each MSR bit.

The contents of the MSR can be read into general purpose registers via the move from machine state register (**mfmsr**) instruction. The contents of a general purpose register can be written to the MSR via the move to machine state register (**mtmsr**) instruction. The MSR(EE) bit (External Interrupt Enable) may be set/cleared atomically using the **wrtee** or **wrteei** instructions.

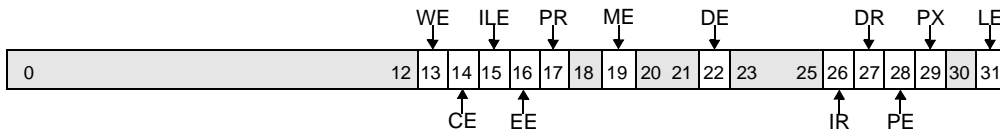


Figure 6-1. Machine State Register (MSR)

0:12		reserved
13	WE	Wait State Enable 0 - The processor is not in the wait state and continues processing. 1 - The processor enters the wait state and remains in the wait state until an exception is taken or the PPC403GC is reset or an external debug tool clears the WE bit.

Figure 6-1. Machine State Register (MSR) (cont.)

14	CE	Critical Interrupt Enable 0 - Critical exceptions are disabled. 1 - Critical exceptions are enabled.	CE controls these interrupts: critical interrupt pin, watchdog timer first time-out.
15	ILE	Interrupt Little Endian 0 - Interrupt handlers execute in Big-Endian mode. 1 - Interrupt handlers execute in Little-Endian mode.	MSR(ILE) is copied to MSR(LE) when an interrupt is taken.
16	EE	External Interrupt Enable 0 - Asynchronous exceptions are disabled. 1 - Asynchronous exceptions are enabled.	EE controls these interrupts: non-critical external, DMA, serial port, JTAG serial port, programmable interval timer, fixed interval timer.
17	PR	Problem State 0 - Supervisor State — all instructions allowed. 1 - Problem State — privileged instructions disallowed.	
18		reserved	
19	ME	Machine Check Enable 0 - Machine check exceptions are disabled 1 - Machine check exceptions are enabled	
20:21		reserved	
22	DE	Debug Exception Enable 0 - Debug exceptions are disabled 1 - Debug exceptions are enabled	
23:25		reserved	
26	IR	Instruction Relocate 0 - Instruction address translation is off 1 - Instruction address translation is on	
27	DR	Data Relocate 0 - Data address translation is off 1 - Data address translation is on	
28	PE	Protection Enable 0 - Protection exceptions are disabled 1 - Protection exceptions are enabled — treated as 0 if MSR[DR] = 1	
29	PX	Protection Exclusive Mode 0 - Protection mode is inclusive as defined in Section 9.4.2 on page 9-18 1 - Protection mode is exclusive as defined in Section 9.4.2 on page 9-18	
30		reserved	
31	LE	Little Endian 0 - Processor executes in Big-Endian mode. 1 - Processor executes in Little-Endian mode.	

6.2.2 Save/Restore Register 0 and 1 (SRR0 - SRR1)

Save/Restore Registers 0 and 1 are two 32-bit registers which hold the interrupted context of the machine when a non-critical interrupt is processed. Save/Restore Register 0 (SRR0) is written with the 32-bit effective address of the instruction which was to be executed next at the time the exception occurred. Save/Restore Register 1 (SRR1) is written with the contents of the Machine State Register. At the end of the exception processing routine, executing a return from interrupt (**rfi**) instruction restores the program counter and the machine state register from SRR0 and SRR1, respectively. Figure 6-2 shows the bit definitions for SRR0.

Figure 6-2. Save / Restore Register 0 (SRR0)

Figure 6-3 shows the bit definitions for SRR1

Figure 6-3. Save / Restore Register 1 (SRR1)

The contents of SRR0 and SRR1 can be written into general purpose registers via the move from special purpose register (**mfsprr**) instruction. The contents of general purpose registers can be written to SRR0 and SRR1 via the move to special purpose register (**mtsprr**) instruction.

6.2.3 Save/Restore Register 2 and 3 (SRR2 - SRR3)

SRR2 and SRR3 are two 32-bit registers which hold the interrupted context of the machine when a critical interrupt occurs. Save/Restore Register 2 (SRR2) is written with the 32-bit effective address of the instruction which was to be executed next at the time the exception occurred. Save/Restore Register 3 (SRR3) is written with the contents of the Machine State Register. At the end of the exception processing routine, executing a return from critical interrupt (**rfci**) instruction restores the program counter and the machine state register from SRR2 and SRR3, respectively. Figure 6-4 shows the SRR2 bit definitions.

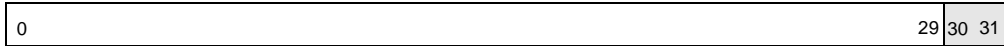


Figure 6-4. Save / Restore Register 2 (SRR2)

0:29	SRR2 receives an instruction address when a critical interrupt is taken; the Program Counter is restored from SRR2 when rfci is executed.
30:31	reserved

Figure 6-5 shows the bit definitions for SRR3

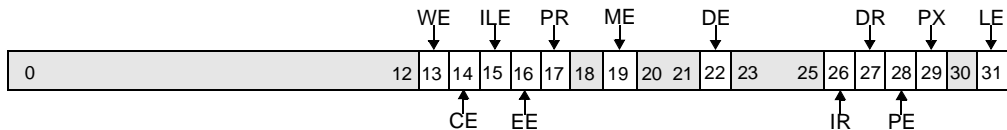


Figure 6-5. Save / Restore Register 3 (SRR3)

0:31	SRR3 receives a copy of the MSR when a critical interrupt is taken; MSR is restored from SRR3 when rfci is executed.
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The contents of SRR2 and SRR3 can be written into general purpose registers via the move from special purpose register (**mfspr**) instruction. The contents of general purpose registers can be written to SRR2 and SRR3 via the move to special purpose register (**mtspr**) instruction.

6.2.4 Exception Vector Prefix Register (EVPR)

The EVPR is a 32-bit register whose high-order 16 bits contain the prefix for the address of the exception processing routines. The 16-bit exception vector offsets (shown in Table 6-2 on page 6-7) are concatenated to the right of the high-order 16-bits of the EVPR to form the 32-bit address of the exception processing routine. Figure 6-6 shows the EVPR bit definitions.

0	15	16	31
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Figure 6-6. Exception Vector Prefix Register (EVPR)

0:15		Exception Vector Prefix
16:31		reserved

The contents of the EVPR can be written into a general purpose register via the move from special purpose register (**mfspir**) instruction. The contents of a general purpose register can be written to the EVPR via the move to special purpose register (**mtspir**) instruction.

6.2.5 Exception Syndrome Register (ESR)

The ESR is a 32-bit register whose bits help to specify the exact cause of various synchronous exceptions. These exceptions include Instruction Machine Checks, Program Exceptions, Data Storage Exceptions, Instruction Storage Exceptions, and Data TLB Miss Exceptions. See Section 6.4.2 on page 6-18 and for a discussion of Instruction Machine Checks. See Section 6.9 on page 6-32 for a discussion of Program Exceptions. The ESR does not need to be reset by exception-handling software; however, it is recommended to reset ESR in Instruction Machine Check handlers (see Section 6.4.2 on page 6-18 for discussion).

The contents of the ESR can be written into a general purpose register via the move from special purpose register (**mfspir**) instruction. Figure 6-7 shows the ESR bit definitions.

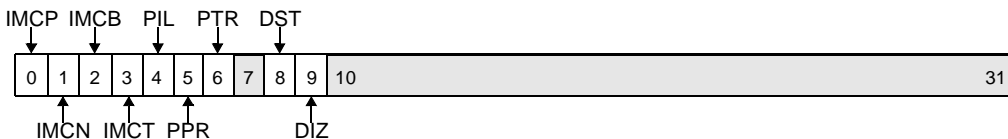


Figure 6-7. Exception Syndrome Register (ESR)

0	IMCP	Instruction Machine Check - Protection 0 - BIU Bank Protection Error did not occur. 1 - BIU Bank Protection Error occurred.
1	IMCN	Instruction Machine Check - Non-configured 0 - BIU Non-configured Error did not occur. 1 - BIU Non-configured Error occurred.
2	IMCB	Instruction Machine Check - Bus Error 0 - BIU Bus Error did not occur. 1 - BIU Bus Error occurred.

Figure 6-7. Exception Syndrome Register (ESR) (cont.)

3	IMCT	Instruction Machine Check - Timeout 0 - BIU Timeout Error did not occur. 1 - BIU Timeout Error occurred.
4	PIL	Program Exception - Illegal 0 - Illegal Instruction Program Exception did not occur. 1 - Illegal Instruction Program Exception occurred.
5	PPR	Program Exception - Privileged 0 - Privileged Instruction Program Exception did not occur. 1 - Privileged Instruction Program Exception occurred.
6	PTR	Program Exception - Trap 0 - Trap Program Exception did not occur. 1 - Trap Program Exception occurred.
7		reserved
8	DST	Data Storage Exception / D-Miss — Store Operations 0 - Excepting instruction was not a store. (also 0 for Protection Bounds exception) 1 - Excepting instruction was a store (includes dcbz , dcbi , dccci).
9	DIZ	Data / Instruction Storage Exception — Zone Fault 0 - Excepting condition was not a zone fault. 1 - Excepting condition was a zone fault (any user-mode storage access instruction, except dcibt or dcibtst , executed in user mode with translation enabled and with (ZPR field) = 00).
10:31		reserved

In general, the ESR bits are set to indicate the kind of precise interrupt that occurred, with other bits being cleared. The exceptions to this are the I-side Machine Check (IMC) bits. Since IMCs can occur without the interrupt being taken ($MSR[ME] = 0$), these bits are “accumulated” even when other ESR-setting exceptions (Data Storage, Program, DTLB-miss) are occurring. Thus, Data Storage and Program exceptions leave the IMC bits alone, but clear the Data Storage and Program bits that are not associated with the specific Data Storage or Program interrupt that is occurring. Likewise, enabled IMC ($MSR[ME] = 1$) will set the appropriate IMC bit, clear the other IMC bits, and clear the Data Storage and Program bits. If the IMC occurs but is disabled ($MSR[ME] = 0$), then it sets the appropriate IMC bits but leaves the Data Storage and Program bits alone. If an IMC occurs while $MSR[ME]=0$, and the instruction upon which an IMC is occurring also is some other kind of ESR-setting instruction (Program, Data Storage, DTLB-miss, or Instruction Storage exception), then the IMC bits of the ESR will be set to indicate the type of IMC, and the other ESR bits will be set/cleared to indicate the kind of other exception. These scenarios are summarized in Table 6-3.

Table 6-3. ESR Alteration by Various Exceptions

Scenario	ESR[0:3]	ESR[4:6]	ESR[8:9]
Program exception w/o IMC	left alone	set to type	cleared
DSE/D-miss/ISE w/o IMC	left alone	cleared	set to type
Enabled IMC	set to type	cleared	cleared
Disabled IMC, no others	set to type	left alone	left alone
Disabled IMC + Program exception/DSE/D-miss/ISE	set to type	set to type	cleared
Disabled IMC + DSE/D-miss/ISE	set to type	cleared	set to type

If a particular instruction causes both a Program exception and one of DSE/D-miss/ISE (eg, **dcbi** privileged exception + DSE Zone error), then the architected prioritization occurs (program exception wins) and this indicates which situation to look for in Table 6-3. Likewise, an enabled IMC occurring in combination with any of the other exceptions always wins the prioritization, and thus the third entry in Table 6-3 above would apply.

6.2.6 Data Exception Address Register (DEAR)

The Data Exception Address Register (DEAR) is a 32-bit register which contains the address of the access where one of the following synchronous precise exceptions occurred: alignment exception, data TLB miss, or data storage exception. Figure 6-8 shows the DEAR bit definitions.

**Figure 6-8. Data Exception Address Register (DEAR)**

0:31		Address of Data Exception (synchronous)
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The contents of the DEAR can be written into a general purpose register via the move from special purpose register (**mf spr**) instruction. The DEAR is read only and can not be written via a move to special purpose register (**mt spr**) instruction.

6.3 Critical Interrupt Pin Exception

An external source requests a Critical Interrupt by creating a negative transition on the Critical Interrupt pin ($\overline{\text{CINT}}$). Prior to the transition, $\overline{\text{CINT}}$ must be at a high level for at least one SysClk cycle. Then $\overline{\text{CINT}}$ must be driven low for at least one SysClk cycle. When the processor detects that a negative transition has occurred on $\overline{\text{CINT}}$, the bit EXISR[CIS] is set. The critical exception will be recognized if enabled by MSR[CE] and by EXIER[CIE].

Note: MSR[CE] also enables the Watchdog Timer (WDT) first-time-out exception. However, after the occurrence of the WDT interrupt, control is passed to a different exception vector than for the critical pin interrupt. See Section 6.13 on page 6-35.

Because the Critical Interrupt Pin is enabled via EXIER[CIE] in addition to MSR[CE], the Critical Interrupt Pin may be disabled temporarily (via EXIER), without disabling the Watchdog Interrupt. Since only privileged operating system code can change the EXIER, application code may not disable any external interrupts, including the Critical Interrupt Pin.

Because the status of the Critical Interrupt Pin is maintained in EXISR[CIS], code that runs with MSR[CE] disabled (typically Machine Check, Watchdog, Debug, and Critical Interrupt Pin handlers) may poll EXISR[CIS] to see if an event has occurred.

After detecting a Critical Interrupt and if no synchronous precise exceptions are outstanding, the PPC403GC immediately takes the Critical Interrupt Exception and stores the address of the next instruction to be executed in SRR2. Simultaneously, the current contents of the MSR are saved in SRR3. The MSR Critical Interrupt Enable bit (MSR[CE]) is reset to 0 to disable another Critical interrupt or the Watchdog Timer first time-out from interrupting the critical interrupt exception handler before SRR2 and SRR3 have been saved. The MSR Debug Exception Enable bit (MSR[DE]) is reset to 0 to disable debug exceptions during the critical interrupt exception handler. The MSR is also written with the other values shown in Table 6-4. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0100. Exception processing begins at the address in the program counter.

Once inside the exception handling routine and after saving the contents of SRR2/SRR3, Critical Interrupts may be re-enabled by setting the MSR[CE] = 1. The critical interrupt handler must explicitly clear EXISR[CIS] prior to re-enabling MSR[CE]. Clearing is done by writing a word to EXISR using **mtdcr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Executing the return from critical interrupt instruction (**rfci**) restores the contents of the program counter and the MSR from SRR2 and SRR3, respectively and the PPC403GC resumes execution at the address contained in the program counter.

Table 6-4. Register Settings during Critical Interrupt Exceptions

SRR2	Written with the address of the next instruction to be executed
SRR3	Written with the contents of the MSR

Table 6-4. Register Settings during Critical Interrupt Exceptions (cont.)

MSR	WE, PR, CE, EE, DE, PE \leftarrow 0 ME, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0100
EXISR	CIS \leftarrow 1

6.4 Machine Check Exceptions

When an external bus error, timeout, BIU non-configured error, or BIU protection error occurs on an instruction fetch, and execution of that instruction is subsequently attempted, an Instruction Machine Check (IMC) exception will occur.

When an external bus error, timeout, BIU non-configured error, or BIU protection error occurs while attempting data accesses, a Data Machine Check (DMC) exception will occur. When a data access causes the machine check, the address which caused the machine check is written into the Bus Error Address Register (BEAR).

6.4.1 Bus Error Reporting

6.4.1.1 Bus Error Syndrome Register (BESR)

The BESR is a 32-bit register whose bits identify machine check errors on data operations and the type of error. See Section 6.4.3 (Data Machine Check Handling) on page 6-20 for further discussion on data-side machine checks. Software should clear the BESR before executing the return from critical interrupt (**rfci**).

- On data-side bus errors, the address of the error will be placed in the BEAR and the description of the error will be placed in the BESR (assuming that these registers are not locked by the prior occurrence of a Data Machine Check). This information will be locked (cannot be overwritten by subsequent error events) until BESR is cleared by software.
- On instruction-fetching errors and DMA errors, the address of the error will be placed in the BEAR and the description of the error will be placed in the BESR (assuming that these registers are not locked by the prior occurrence of a Data Machine Check). However, information placed in the BEAR and BESR because of errors during instruction fetching or during DMA transactions is not locked in those registers, and will be overwritten if any subsequent error occurs.

The contents of the BESR can be written into a general purpose register via the move from device control register (**mfdcr**) instruction. Figure 6-9 shows the BESR bit definitions.

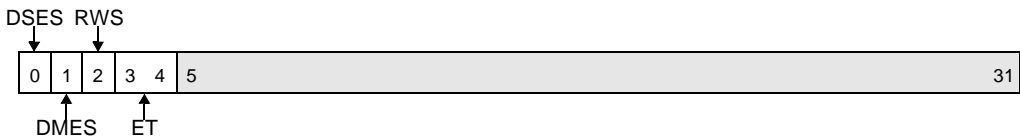


Figure 6-9. Bus Error Syndrome Register (BESR)

0	DSES	Data-Side Error Status 0 - No data-side error 1 - Data-side error
1	DMES	DMA Error Status 0 - No DMA operation error 1 - DMA operation error
2	RWS	Read/Write Status 0 - Error operation was a Write 1 - Error operation was a Read
3:4	ET	Error Type 00 - Protection violation (write to Read-Only bank, or read from Write-Only bank) 01 - Access to a non-configured bank 10 - Active level on bus error input pin 11 - Bus time-out
5:31		reserved

6.4.1.2 Bus Error Address Register (BEAR)

The Bus Error Address register is a 32-bit register which contains the address of the access where a data access bus error occurred. The BEAR is written the first time a data access bus error occurs and its contents are locked until the Bus Error Syndrome Register (BESR) is cleared. Figure 6-10 shows the BEAR bit definitions.

- On data-side bus errors, the address of the error will be placed in the BEAR and the description of the error will be placed in the BESR (assuming that these registers are not locked by the prior occurrence of a Data Machine Check). This information will be locked (cannot be overwritten by subsequent error events) until BESR is cleared by software.
- On instruction-fetching errors and DMA errors, the address of the error will be placed in the BEAR and the description of the error will be placed in the BESR (assuming that these registers are not locked by the prior occurrence of a Data Machine Check). However, information placed in the BEAR and BESR because of errors during instruction fetching or during DMA transactions is not locked in those registers, and will be overwritten if any subsequent error occurs.

The BEAR is a device control register and its contents can be written into a general purpose register via the move from device control register (**mfdcr**) instruction.

0	31
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Figure 6-10. Bus Error Address Register (BEAR)

0:31	Address of Bus Error (asynchronous)
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6

6.4.2 Instruction Machine Check Handling

When a machine check occurs on an instruction fetch, and execution of that instruction is subsequently attempted, an Instruction Machine Check (IMC) exception will occur. If enabled by MSR[ME], the processor will report the IMC by vectoring to the Machine Check handler (offset 0x0200), and setting a bit in the Exception Syndrome Register (ESR) to differentiate IMC from Data Machine Check, and to indicate the cause of the IMC. Taking the vector automatically clears the MSR[ME] bit.

The address of the error will be placed in the BEAR and the cause of the error will be placed in the BESR (assuming that these registers are not locked by the prior occurrence of a Data Machine Check). However, information placed in the BEAR and BESR because of errors during instruction fetching is not locked in those registers, and will be overwritten if any subsequent error occurs.

Note that it would be improper to declare an Instruction Machine Check exception at the time of occurrence of the error at the BIU, because the address is possibly the result of an incorrect speculation by the fetcher. It is possible that no attempt will actually be made to execute an instruction from the erroneous address. If execution is attempted, an exception will occur at that time.

When a machine check occurs on an instruction fetch, the erroneous instruction is never written to the I-cache. The fetch request, if it is to cacheable memory and if it misses in the instruction cache, will cause an instruction cache line fill (four words). Any words of the line that are specifically requested by the fetcher, and passed to it prior to the word upon which the error occurs, will execute without causing an exception. Any words from that line which are provided including and after the word upon which the error was reported, will cause an exception upon attempted execution. After the four words of the instruction cache line have been received from memory, if any of the words were in error, the entire cache line is discarded.

The bits of the ESR which differentiate various causes of IMC are shown in Table 6-5. The ESR does not need to be reset by the IMC interrupt handler, but it is recommended to reset

the ESR to avoid confusion. This is discussed further below. In addition, the Error output from the PPC403GC will be active when any of the bits ESR[0:3] are set, or when BESR[DSES] is set. To reset the Error output, all these bits must be cleared.

Table 6-5. ESR Usage for Instruction Machine Checks

Bit	Mnemonic	Exception Cause
ESR[0]	IMCP	Protection
ESR[1]	IMCN	Non-configured
ESR[2]	IMCB	Bus Error
ESR[3]	IMCT	Timeout

The Instruction Machine Check bits in the ESR will be set, even if the MSR[ME] = 0. This means that if Instruction Machine Checks are occurring while running in code that has MSR[ME] disabled, then the type of IMC will be recorded in the ESR, but no interrupt will occur. Software running with MSR[ME] disabled can sample the ESR to determine if IMCs have occurred during the disabled execution.

When MSR[ME] is re-enabled, if a new IMC exception occurs, then its type will be recorded in the ESR and the Machine Check interrupt will be invoked. However, re-enabling MSR[ME] will not cause a Machine Check interrupt to occur simply due to the presence of the ESR bit indicating the type of the IMC that occurred while MSR[ME] was disabled. The IMC must occur while MSR[ME] is enabled for the Machine Check interrupt to be taken. Software should, in general, clear the ESR bits prior to returning from a Machine Check interrupt, to avoid any ambiguity when handling subsequent Machine Check or Program exceptions.

See Section 6.2.5 on page 6-12 for a discussion of ESR handling when other synchronous exceptions occur in combination with either enabled or disabled IMC.

When a Instruction Machine Check exception occurs (even if disabled by MSR[ME] = 0), the PPC403GC places an active signal on the PPC403GC Error pin. This pin will remain active until ESR[0:3] are cleared (note also that the pin will be activated by Data Machine Check, controlled by BESR[DSES]).

When an Instruction Machine Check interrupt occurs, the PPC403GC stores the address of the excepting instruction in SRR2. Simultaneously, the current contents of the MSR are written into SRR3.

The MSR Machine Check Enable bit (MSR[ME]) is reset to 0 to disable another machine check from interrupting the machine check exception handling routine. The other MSR bits are written with the values shown in Table 6-6. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0200. Exception processing begins at the new address in the program counter. Executing the return from critical interrupt instruction (**rfci**) restores

the contents of the program counter and the MSR from SRR2 and SRR3, respectively.

Table 6-6. Register Settings during Instruction Machine Check

SRR2	Written with the address that caused the machine check.
SRR3	Written with the contents of the MSR
MSR	WE, PR, CE, EE, ME, DE, PE \leftarrow 0 PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0200
ESR	Written with cause of Instruction Machine Check.

6.4.3 Data Machine Check Handling

When a machine check occurs while attempting data accesses, a Data Machine Check (DMC) exception will occur. When a data access causes the machine check, the address which caused the machine check is written into the Bus Error Address Register (BEAR). The first data-side error locks its address into the BEAR; if further data-side errors occur before the first is handled, their addresses are lost. The cause of a data-side check is recorded in the Bus Error Syndrome Register (BESR). The BEAR remains locked until the BESR is cleared. If enabled by MSR[ME], the processor will report the DMC by vectoring to the Machine Check handler (EVPR[0:15] || 0x0200). Taking the vector automatically clears the MSR[ME] bit. BESR[DSES] is the actual source of the DMC; it must be cleared by software before executing the return from critical interrupt (**rfci**) or before otherwise re-enabling MSR[ME].

There is a significant difference between instruction-side and data-side error handling which must be appreciated in order to write a successful interrupt handler for data-side machine checks. On the instruction-side, a valid/invalid flag accompanies the instruction which has been fetched from memory. If an IMC occurred while obtaining that instruction, then an (erroneous) instruction will enter the processor (pre-fetch queue), but at all times it will be recognized as invalid. On the data-side, there is no valid/invalid flag associated with data items. If a DMC occurs, invalid data can enter the data cache, and not be recognizable as invalid data. The interrupt handler for the DMC must take corrective action (such as invalidating the cache line) to protect against the use of invalid data.

When a Data Machine Check exception occurs (even if disabled by MSR[ME] = 0), the PPC403GC places an active signal on the PPC403GC Error pin. This pin will remain active until BESR[DSES] is cleared (note also that the pin will be activated by Instruction Machine Check, controlled by ESR[0:3]).

When a Machine Check interrupt occurs, the PPC403GC stores the address of the next sequential instruction in SRR2. Simultaneously, the current contents of the MSR are written into SRR3.

The MSR Machine Check Enable bit (MSR[ME]) is reset to 0 to disable another machine check from interrupting the machine check exception handling routine. The other MSR bits are written with the values shown in Table 6-7. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0200. Exception processing begins at the new address in the program counter. Executing the return from critical interrupt instruction (**rfci**) restores the contents of the program counter and the MSR from SRR2 and SRR3, respectively.

Table 6-7. Register Settings during Data Machine Check

SRR2	Written with the address of the next sequential instruction.
SRR3	Written with the contents of the MSR
MSR	WE, PR, CE, EE, ME, DE, PE ← 0 PX ← unchanged DR, IR ← 0 ILE ← unchanged LE ← ILE
PC	EVPR[0:15] 0x0200
BEAR	Written with the address that caused the Machine Check.
BESR	Written with type of machine check.

6.5 Data Storage Exception

The Data Storage exception is generated when the desired access to the effective address is not permitted for any of the following reasons:

- In Problem State with data translation enabled
 - A zone fault, which is any user-mode storage access (data load, store, **icbi**, **dcbz**, **dcbst**, or **dcbf**) with an effective address with (ZPR field) = 00. (**dcbt** and **dcbtst** will no-op in this situation, rather than cause an exception. The instructions **dcbi**, **dccci**, **icbt**, and **iccci**, being privileged, cannot cause zone fault Data Storage exceptions.)
 - Data store or **dcbz** to an effective address with the WR bit clear and (ZPR field) ≠ 11. (The privileged instructions **dcbi** and **dccci** are treated as “stores”, but will cause privileged Program exceptions, rather than Data Storage exceptions.)
- In Supervisor State with data translation enabled
 - Data store, **dcbi**, **dcbz**, or **dccci** to an effective address with the WR bit clear and (ZPR field) other than 11 or 10.
- In either Problem or Supervisor State with data translation disabled and MSR[PE] = 1, a Protection Bounds error is detected.

A Protection Bounds error occurs when a “store” access is attempted to an address in a protected region. These include data cache operations **dcbz** and **dcbi**, but not **dccci**. Protected regions are defined by the two pairs of Protection Bound Upper and Lower registers and the Protection Exclusive Mode bit MSR[PX]. Protection is enabled by the MSR[PE] bit. A Protection Bounds error can only occur when data translation is disabled (MSR[DR]=0). If data translation is enabled, then the Protection Bounds mechanism is disabled, regardless of the state of MSR[PE].

See Section 9.4.2 (Real-mode Access Protection) on page 9-18 for a detailed discussion.

Programming Note:

The **icbi**, **icbt**, and **iccci** instructions are treated as loads from the addressed byte with respect to address translation and protection. Instruction cache ops use MSR[DR], not MSR[IR], to determine translation of their operands. Instruction Storage Exceptions and Instruction-side TLB Miss Exceptions are associated with the fetching of instructions, not with the execution of instructions. Data Storage Exceptions and Data TLB Miss Exceptions are associated with the execution of instruction cache ops.

When a data storage exception is detected, the PPC403GC suppresses the instruction causing the exception and writes the instruction address in SRR0. The Data Exception Address Register (DEAR) is written with the data address that caused the access violation. Exception Syndrome Register (ESR) bits are written as shown in Table 6-8 to provide further information about the error. The current contents of the MSR are written into SRR1, and MSR bits are then written with the values shown in Table 6-8.

The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0300. Exception processing begins at the new address in the program counter. Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1, respectively, and the PPC403GC resumes execution at the new program counter address.

For instructions that can simultaneously generate Program Exceptions (privileged instructions executed in Problem State) and Data Storage Exceptions, the Program Exception has priority.

The following registers will be modified to the specified values:

Table 6-8. Register Settings during Data Storage Exceptions

SRR0	Set to the effective address of the instruction causing the data storage exception
SRR1	Set to the value of the MSR at the time of the exception
MSR	WE, PR, EE, PE ← 0 CE, ME, DE, PX ← unchanged DR, IR ← 0 ILE ← unchanged LE ← ILE
PC	EVPR[0:15] 0x0300

Table 6-8. Register Settings during Data Storage Exceptions (cont.)

DEAR	Set to the effective address of the failed access
ESR	$DST \leftarrow 1$ if excepting operation is a store operation (includes dcbi , dcbz , and dccci). Not set for Protection Bounds exception. $DIZ \leftarrow 1$ if access failure due to a zone protection fault (ZPR field value of 00 in User State) $DST, DIZ \leftarrow 0$ for Protection Bounds exception. See Section 6.2.5 on page 6-12 for details of ESR operation.

6.6 Instruction Storage Exception

The Instruction Storage Exception is generated when instruction translation is active and execution is attempted for an instruction whose fetch access to the effective address is not permitted for any of the following reasons:

- In Problem State
 - Instruction fetch from an effective address with (ZPR field) = 00.
 - Instruction fetch from an effective address with the EX bit clear and (ZPR field) \neq 11.
 - Instruction fetch from an effective address contained within a Guarded region (G=1).
- In Supervisor State
 - Instruction fetch from an effective address with the EX bit clear and (ZPR field) other than 11 or 10.
 - Instruction fetch from an effective address contained within a Guarded region (G=1).

The SRR0 register will save the address of the instruction causing the Instruction Storage exception.

The Exception Syndrome Register (ESR) will be set to indicate the following conditions:

- If $ESR[DIZ] = 1$, then the excepting condition was a zone fault, which is the attempted execution of an instruction address which was fetched in user-mode with (ZPR field) = 00.
- If $ESR[DIZ] = 0$, then the excepting condition was either $EX = 0$ or $G = 1$.

The exception is precise with respect to the attempted execution of the instruction. Program flow will vector to $EVPR[0:15] \parallel 0x0400$.

The following registers will be modified to the specified values:

Table 6-9. Register Settings during Instruction Storage Exceptions

SRR0	Set to the effective address of the instruction for which execute access was not permitted
SRR1	Set to the value of the MSR at the time of the exception
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0400
ESR	DIZ \leftarrow 1 if access failure due to a zone protection fault (ZPR field value of 00 in User State) Note: the absence of the above bit would indicate the exception occurred because the EX bit was clear in an otherwise accessible zone or instruction fetch from a Guarded Region. See Section 6.2.5 on page 6-12 for details of ESR operation.

6.7 External Interrupt Exception

Four groups of events trigger external interrupt exceptions: serial port interrupts, JTAG serial port interrupts, DMA interrupts, and active signals on the external interrupt pins. All interrupting events from these groups are accumulated as a single External Interrupt to the processor. Individual events are configured and enabled by the IOCR and EXIER registers, and reported by the EXISR register. See Section 6.7.1 (External Interrupt Control) on page 6-24 for details on these registers. As a group, all External Interrupts are enabled by the bit MSR[EE].

Note:

the MSR[EE] bit also enables the occurrence of Programmable Interval Timer (PIT) and Fixed Interval Timer (FIT) interrupts. However, after the occurrence of these timer interrupts, control is passed to different exception vectors than for the interrupts discussed in the preceding paragraph. Therefore, these timer exceptions are discussed separately. See Section 6.11 (Programmable Interval Timer Exception) on page 6-34 and Section 6.12 (Fixed Interval Timer Exception) on page 6-35.

6.7.1 External Interrupt Control

6.7.1.1 External Interrupt Enable Register (EXIER)

This 32-bit register contains enable bits for the six external hardware interrupt pins, the DMA channel interrupts, the JTAG serial port interrupts, and the serial port interrupts. All sources of external interrupt are enabled globally by MSR[EE]. Enabling an interrupt source by setting the bit in the EXIER which corresponds to that source will cause an interrupt to occur if the corresponding bit in the EXISR is already set and MSR[EE] is set.

The serial port, JTAG Serial Port and DMA interrupt sources may be enabled by their

respective control registers, in addition to the EXIER. Interrupt sources attached to external interrupt pins also may have enable bits located off-chip in the devices attached to those pins. For an interrupt to occur from any of these sources, all of the associated enable bits (in source-specific registers either on or off the chip, in the EXIER, and the MSR[EE]) must be set.

Figure 6-11 shows the bit definitions for the External Interrupt Enable Register.

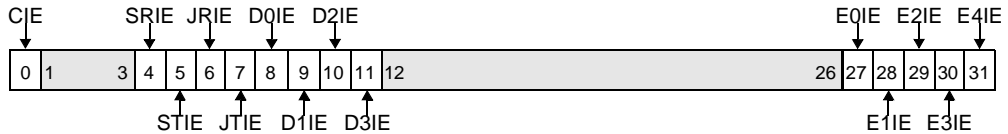


Figure 6-11. External Interrupt Enable Register (EXIER)

0	CIE	Critical Interrupt Enable 0 - Critical Interrupt Pin interrupt disabled 1 - Critical Interrupt Pin interrupt enabled
1:3		reserved
4	SRIE	Serial Port Receiver Interrupt Enable 0 - Serial port receiver interrupt disabled 1 - Serial port receiver interrupt enabled
5	STIE	Serial Port Transmitter Interrupt Enable 0 - Serial port transmitter interrupt disabled 1 - Serial port transmitter interrupt enabled
6	JRIE	JTAG Serial Port Receiver Interrupt Enable 0 - JTAG serial port receiver interrupt disabled 1 - JTAG serial port receiver interrupt enabled
7	JTIE	JTAG Serial Port Transmitter Interrupt Enable 0 - JTAG serial port transmitter interrupt disabled 1 - JTAG serial port transmitter interrupt enabled
8	D0IE	DMA Channel 0 Interrupt Enable 0 - DMA Channel 0 interrupt disabled 1 - DMA Channel 0 Interrupt enabled
9	D1IE	DMA Channel 1 Interrupt Enable 0 - DMA Channel 1 interrupt disabled 1 - DMA Channel 1 interrupt enabled
10	D2IE	DMA Channel 2 Interrupt Enable 0 - DMA Channel 2 interrupt disabled 1 - DMA Channel 2 interrupt enabled
11	D3IE	DMA Channel 3 Interrupt Enable 0 - DMA Channel 3 interrupt disabled 1 - DMA Channel 3 interrupt enabled
12:26		reserved

Figure 6-11. External Interrupt Enable Register (EXIER) (cont.)

27	E0IE	External Interrupt 0 Enable 0 - Interrupt from External Interrupt 0 pin disabled 1 - Interrupt from External Interrupt 0 pin enabled
28	E1IE	External Interrupt 1 Enable 0 - Interrupt from External Interrupt 1 pin disabled 1 - Interrupt from External Interrupt 1 pin enabled
29	E2IE	External Interrupt 2 Enable 0 - Interrupt from External Interrupt 2 pin disabled 1 - Interrupt from External Interrupt 2 pin enabled
30	E3IE	External Interrupt 3 Enable 0 - Interrupt from External Interrupt 3 pin disabled 1 - Interrupt from External Interrupt 3 pin enabled
31	E4IE	External Interrupt 4 Enable 0 - Interrupt from External Interrupt 4 pin disabled 1 - Interrupt from External Interrupt 4 pin enabled

The contents of the EXIER can be written into a general purpose register via the move from device control register (**mfdcr**) instruction. The contents of a general purpose register can be written to the EXIER via the move to device control register (**mtdcr**) instruction.

6.7.1.2 External Interrupt Status Register (EXISR)

This 32-bit register contains the status of the five external hardware interrupts, the DMA channel interrupts, the JTAG serial port interrupts, and the serial port interrupts. When one of these interrupts occurs, the bit corresponding to the interrupt is set in the EXISR.

Figure 6-12 shows the EXISR bit definitions.

Status registers are normally set via hardware, and read and cleared via software. Reading EXISR is done using the **mfdcr** instruction. Clearing is done by writing a word to EXISR using **mtdcr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” causes the existing bit value to be retained.

External hardware interrupts are enabled via the External Interrupt Enable Register (EXIER). The DMA channel interrupts, the JTAG serial port interrupts, and the serial port interrupts may be enabled via the EXIER and must also be enabled by the interrupt enable bits in their respective control registers. Asserting an interrupt input on the PPC403GC causes the corresponding bit in the EXISR to be set, independent of whether the interrupt is enabled in the EXIER.

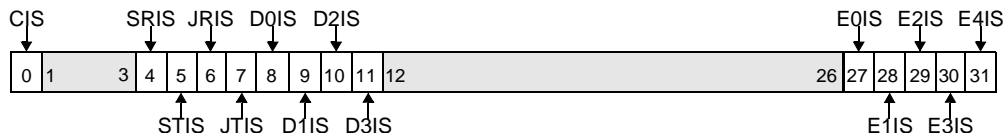


Figure 6-12. External Interrupt Status Register (EXISR)

0	CIS	Critical Interrupt Status 0 - No interrupt pending from the critical interrupt pin 1 - Interrupt pending from the critical interrupt pin
1:3		reserved
4	SRIS	Serial Port Receiver Interrupt Status 0 - No interrupt pending from the serial port receiver 1 - Interrupt pending from the serial port receiver
5	STIS	Serial Port Transmitter Interrupt Status 0 - No interrupt pending from the serial port transmitter 1 - Interrupt pending from the serial port transmitter
6	JRIS	JTAG Serial Port Receiver Interrupt Status 0 - No interrupt pending from the JTAG serial port receiver 1 - Interrupt pending from the JTAG serial port receiver
7	JTIS	JTAG Serial Port Transmitter Interrupt Status 0 - No interrupt pending from the JTAG serial port transmitter 1 - Interrupt pending from the JTAG serial port transmitter
8	D0IS	DMA Channel 0 Interrupt Status 0 - No interrupt pending from DMA Channel 0 1 - Interrupt pending from DMA Channel 0
9	D1IS	DMA Channel 1 Interrupt Status 0 - No interrupt pending from DMA Channel 1 1 - Interrupt pending from DMA Channel 1
10	D2IS	DMA Channel 2 Interrupt Status 0 - No interrupt pending from DMA Channel 2 1 - Interrupt pending from DMA Channel 2
11	D3IS	DMA Channel 3 Interrupt Status 0 - No interrupt pending from DMA Channel 3 1 - Interrupt pending from DMA Channel 3
12:26		reserved
27	E0IS	External Interrupt 0 Status 0 - No interrupt pending from External Interrupt 0 pin 1 - Interrupt pending from External Interrupt 0 pin
28	E1IS	External Interrupt 1 Status 0 - No interrupt pending from External Interrupt 1 pin 1 - Interrupt pending from External Interrupt 1 pin

Figure 6-12. External Interrupt Status Register (EXISR) (cont.)

29	E2IS	External Interrupt 2 Status 0 - No interrupt pending from External Interrupt 2 pin 1 - Interrupt pending from External Interrupt 2 pin
30	E3IS	External Interrupt 3 Status 0 - No interrupt pending from External Interrupt 3 pin 1 - Interrupt pending from External Interrupt 3 pin
31	E4IS	External Interrupt 4 Status 0 - No interrupt pending from External Interrupt 4 pin 1 - Interrupt pending from External Interrupt 4 pin

The external interrupt pins may be programmed via the Input/Output Configuration Register (IOCR) as either edge or level triggered and as positive or negative polarity. To clear external interrupts that have been programmed as edge triggered, the exception handling routine must write a 1 to the corresponding bit in the EXISR using the **mtdcr** instruction. For example, to clear external interrupt 4 which has been programmed as edge triggered, the exception handler must write a 1 to EXISR[E4IS]. (Note that the Critical Interrupt Pin is always edge triggered, therefore its interrupt handler must clear EXISR[CIS] in this same manner.)

For a level sensitive interrupt, the EXISR bit follows the level of the associated interrupt input pin. To clear external interrupts that have been programmed as level sensitive, the exception handling routine must clear the interrupt at the interrupting device, and no clearing of the EXISR is necessary.

All interrupts posted from internal sources are level sensitive. Therefore, to clear interrupts from the DMA channels, the serial port, and the JTAG serial port, the exception handling routine must clear the corresponding bit in the corresponding status register, and no clearing of the EXISR is necessary.

6.7.1.3 Input/Output Configuration Register (IOCR)

The IOCR is a 32-bit register which allows the user to program some external multifunction pins in the PPC403GC. The IOCR contains two bits for each of the non-critical interrupt pins. These bits allow the user to program the polarity of each interrupt pin as positive or negative active and as either edge or level sensitive. Figure 6-13 shows the IOCR bit definitions.

Note that the Critical Interrupt pin is not defined in the IOCR. The Critical Interrupt pin is always negative active, and edge triggered. An external source requests a Critical Interrupt by creating a negative transition on the Critical Interrupt pin (**CINT**). Prior to the transition, **CINT** must be at a high level for at least one SysClk cycle. Then **CINT** must be driven low for at least one SysClk cycle.

The IOCR is a device control register and its contents can be written into a general purpose register via the move from device control register (**mfdcr**) instruction. The contents of a

general purpose register can be written to the IOCR via a move to device control register (**mtdcr**) instruction.

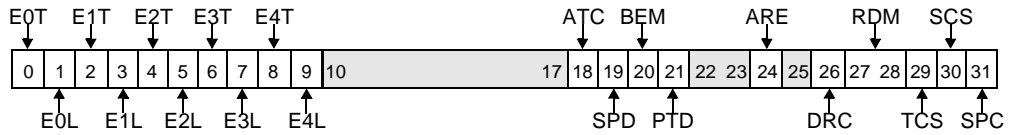


Figure 6-13. Input/Output Configuration Register (IOCR)

0	E0T	External Interrupt 0 Triggering 0 - External Interrupt 0 pin is level sensitive 1 - External Interrupt 0 pin is edge triggered
1	E0L	External Interrupt 0 Active Level 0 - External Interrupt 0 pin is negative level/edge triggered 1 - External Interrupt 0 pin is positive level/edge triggered
2	E1T	External Interrupt 1 Triggering 0 - The External Interrupt 1 pin is level sensitive 1 - The External Interrupt 1 pin is edge triggered
3	E1L	External Interrupt 1 Active Level 0 - External Interrupt 1 pin is negative level/edge triggered 1 - External Interrupt 1 pin is positive level/edge triggered
4	E2T	External Interrupt 2 Triggering 0 - The External Interrupt 2 pin is level sensitive 1 - The External Interrupt 2 pin is edge triggered
5	E2L	External Interrupt 2 Active Level 0 - External Interrupt 2 pin is negative level/edge triggered 1 - External Interrupt 2 pin is positive level/edge triggered
6	E3T	External Interrupt 3 Triggering 0 - The External Interrupt 3 pin is level sensitive 1 - The External Interrupt 3 pin is edge triggered
7	E3L	External Interrupt 3 Active Level 0 - External Interrupt 3 pin is negative level/edge triggered 1 - External Interrupt 3 pin is positive level/edge triggered
8	E4T	External Interrupt 4 Triggering 0 - The External Interrupt 4 pin is level sensitive 1 - The External Interrupt 4 pin is edge triggered
9	E4L	External Interrupt 4 Active Level 0 - External Interrupt 4 pin is negative level/edge triggered 1 - External Interrupt 4 pin is positive level/edge triggered
10:17		reserved
18	ATC	Address Tri-state Control 0 - Tri-state when idle 1 - Drive previous value when idle

Figure 6-13. Input/Output Configuration Register (IOCR) (cont.)

19	SPD	Static Power Disable 0 - Normal operation 1 - Low power operation — Note: Early RAS Mode and TLB array disabled
20	BEM	Byte Enable Mode — SRAM accesses 0 - \overline{WBE} pins are Write Byte Enables 1 - \overline{WBE} pins are Read / Write Byte Enables (with altered timings of Write Byte Enables)
21	PTD	Device-Paced Timeout Disable — SRAM accesses with $BRn[RE] = 1$ 0 - Timeout occurs if Ready does not occur within 128 cycles 1 - No timeout occurs on external accesses
22:23		reserved
24	ARE	Asynchronous Ready Enable — SRAM accesses with $BRn[RE] = 1$ 0 - Data is latched 1 cycle after Ready is sampled high — setup time required 1 - Data is latched 3 cycles after Ready is sampled high — setup requirement removed
25		reserved
26	DRC	DRAM Read on CAS (For DRAM read operations only) 0 - Latch data bus on rising edge of SysClk 1 - Latch data bus on rising edge of \overline{CAS} (on the deactivation of \overline{CAS}); provides more time for data to arrive
27:28	RDM	Real-Time Debug Mode 00 - Trace Status Outputs Disabled 01 - Program Status and Bus Status 10 - Program Status and Trace Output 11 - reserved
29	TCS	Timer Clock Source 0 - Clock source is the SysClk pin 1 - Clock source is the TimerClk pin
30	SCS	Serial Port Clock Source 0 - Clock source is the SysClk pin 1 - Clock source is the SerClk pin
31	SPC	Serial Port Configuration 0 - DSR/DTR 1 - CTS/RTS

6.7.2 External Interrupt Handling

After detecting an External Interrupt event and if the External Interrupt exception is the highest priority exception condition present, the PPC403GC immediately takes the External Interrupt exception and stores the address of the next sequential instruction in SRR0. Simultaneously, the current contents of the MSR are saved in SRR1. The MSR External Interrupt Enable bit (MSR[EE]) is then reset to 0. This disables other External Interrupts from interrupting the exception handler before SRR0 and SRR1 are saved. The MSR is also written with the other values shown in Table 6-10. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the

program counter are written with 0x0500. Exception processing begins at the address in the program counter.

Once inside the exception handling routine, the device requesting the External Interrupt can be determined by examining the External Interrupt Status Register (EXISR). Clearing bits set in the EXISR by the serial port, JTAG, and DMA interrupts requires writing bits in the status registers for each of those devices. Clearing level-triggered interrupts generated via the External Interrupt pins requires resetting the external interrupt source to remove the interrupt.

Note:

To insure that the External Interrupt pin status is properly reflected in the EXISR, devices generating level-triggered interrupts must maintain the active level of the interrupt pin until reset by the exception handler.

Clearing edge-triggered interrupts generated via the external interrupt pins requires clearing the associated bits in the EXISR. Clearing is done by writing a word to EXISR using **mtbcr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1, respectively. The PPC403GC resumes execution at the address in the program counter.

Table 6-10. Register Settings during External Interrupt Exceptions

SRR0	Written with the address of the next instruction to be executed
SRR1	Written with the contents of the MSR
MSR	WE, PR, EE, PE ← 0 CE, ME, DE, PX ← unchanged DR, IR ← 0 ILE ← unchanged LE ← ILE
PC	EVPR[0:15] 0x0500
EXISR	Written to indicate all pending External Interrupts

6.8 Alignment Exception

Alignment Exceptions are caused by misaligned data accesses, by stores (including **dcbz** but not **dcbi** nor **dccci**) to write-thru storage, or by attempting to execute a **dcbz** instruction against a non-cacheable area. Also, if the processor is in Little Endian mode, the execution of any string/multiple instruction will cause an Alignment Exception. In general, the alignment exception handler is expected to emulate the failing operation.

The PPC403GC data cache does not provide write-thru operation. The alignment exception provides the opportunity for system software to emulate the write-thru function.

Execution of the instruction causing the alignment exception is suppressed, and SRR0 is written with the address of that instruction. The Data Exception Address Register (DEAR) is written with the address that caused the alignment exception and the current contents of the MSR are saved into SRR1. The MSR bits are written with the values shown in Table 6-11. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0600. Exception processing begins at the new address in the program counter. Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1, respectively and the PPC403GC resumes execution at the address contained in the program counter.

Programming Note:

There is no means to disable an alignment exception. Therefore, exception handlers should save SRR0 and SRR1 as soon as possible, to avoid inadvertent overwrites of these registers by alignment exceptions that occur within the handler.

Table 6-11. Register Settings during Alignment Exceptions

SRR0	Written with the address of the instruction causing the alignment exception
SRR1	Written with the contents of the MSR
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0600
DEAR	Written with the address that caused the alignment violation

6.9 Program Exceptions

Program Exceptions are caused by attempting to execute an illegal operation, by executing a trap instruction with conditions satisfied, or by attempting to execute a privileged instruction while in the problem state. The ESR bits that differentiate these situations (see Table 6-12) are mutually exclusive: when a Program Exception occurs, the appropriate bit is set and the others are cleared. These exceptions are not maskable. The ESR does not need to be reset by the Program Exception interrupt handler.

Table 6-12. ESR Usage for Program Exceptions

Bit	Mnemonic	Exception Cause
ESR[4]	PIL	Illegal
ESR[5]	PPR	Privileged
ESR[6]	PTR	Trap

When execution of an illegal instruction is attempted, or when execution of a privileged instruction is attempted in problem state, the PPC403GC does not execute the instruction and stores the address of the excepting instruction in SRR0.

Trap instructions can be used as a program exception and/or as a debug event (see Section 10.5 on page 10-4 for definition of debug events). When a trap instruction is detected as a program exception, the PPC403GC stores the address of the trap instruction in SRR0. See **tw** on page 11-174 and **twi** on page 11-177 for a detailed discussion of the behavior of trap instructions with various exceptions enabled.

The current contents of the MSR are written into SRR1. The MSR bits are written with the values shown in Table 6-13. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0700. Exception processing begins at the new address in the program counter. Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter from SRR0 and the MSR from SRR1, and the PPC403GC resumes execution at the address contained in the program counter.

Table 6-13. Register Settings during Program Exceptions

SRR0	Written with the address of the instruction causing the program exception
SRR1	Written with the contents of the MSR
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0700
ESR	Written with the type of the Program Exception. (See Table 6-3 and Table 6-12)

6.10 System Call Exception

System call interrupts occur when a system call (**sc**) instruction is executed. The PPC403GC stores the address of the instruction following the **sc** in SRR0. The current contents of the MSR are written into SRR1. The MSR bits are written with the values shown in Table 6-14. The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x0C00. Exception processing begins at the new address in the program counter. Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1, respectively and the PPC403GC resumes execution at the address contained in the program counter.

Table 6-14. Register Settings during System Call Exceptions

SRR0	Written with the address of the next instruction to be executed
SRR1	Written with the contents of the MSR

Table 6-14. Register Settings during System Call Exceptions (cont.)

MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x0C00

6.11 Programmable Interval Timer Exception

For a discussion of the timer facilities of the PPC403GC, see Section 6.17 (Timer Architecture) on page 6-40. The Programmable Interval Timer is discussed in Section 6.17.3 on page 6-44.

The PPC403GC initiates a Programmable Interval Timer (PIT) interrupt after detecting a time-out from the PIT if the exception is enabled via TCR[PIE] and MSR[EE]. Time-out is considered to be detected when, at the beginning of a cycle, TSR[PIS] = 1 (for the PIT exception, this will be the cycle after the PIT decrements on a PIT count of one). The PPC403GC immediately takes the exception, and the address of the next sequential instruction is saved in SRR0. Simultaneously, the current contents of the MSR are written into SRR1 and the MSR is written with the values shown in Table 6-15.

The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x1000. Exception processing begins with this program counter address. To clear the PIT interrupt, the exception handling routine must clear the PIT interrupt bit TSR[PIS]. Clearing is done by writing a word to TSR using **mtspr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1 respectively and the PPC403GC resumes execution at the address contained in the program counter.

Table 6-15. Register Settings during Programmable Interval Timer Exceptions

SRR0	Written with the address of the next instruction to be executed
SRR1	Written with the contents of the MSR
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x1000
TSR	Set to indicate type of timer event.

6.12 Fixed Interval Timer Exception

For a discussion of the timer facilities of the PPC403GC, see Section 6.17 (Timer Architecture) on page 6-40. The Fixed Interval Timer is discussed in Section 6.17.4 on page 6-46.

The PPC403GC initiates a Fixed Interval Timer (FIT) interrupt after detecting a time-out from the FIT if the exception is enabled via TCR[FIE] and MSR[EE]. Time-out is considered to be detected when, at the beginning of a cycle, TSR[FIS] = 1 (for the FIT exception, this will be the second cycle after the 0→1 transition of the appropriate time-base bit). The PPC403GC immediately takes the exception, and the address of the next sequential instruction is saved in SRR0. Simultaneously, the current contents of the MSR are written into SRR1 and the MSR is written with the values shown in Table 6-16.

The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x1010. Exception processing begins with this program counter address. To clear the FIT interrupt, the exception handling routine must clear the FIT interrupt bit TSR[FIS]. Clearing is done by writing a word to TSR using **mtspr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Executing the return from interrupt instruction (**rfi**) restores the contents of the program counter and the MSR from SRR0 and SRR1, respectively and the PPC403GC resumes execution at the contents of the program counter.

Table 6-16. Register Settings during Fixed Interval Timer Exceptions

SRR0	Written with the address of the next instruction to be executed
SRR1	Written with the contents of the MSR
MSR	WE, PR, EE, PE ← 0 CE, ME, DE, PX ← unchanged DR, IR ← 0 ILE ← unchanged LE ← ILE
PC	EVPR[0:15] 0x1010
TSR	Set to indicate type of timer event.

6.13 Watchdog Timer Exception

For a discussion of the timer facilities of the PPC403GC, see Section 6.17 (Timer Architecture) on page 6-40. The Watchdog Timer (WDT) is discussed in Section 6.17.5 on page 6-47.

The PPC403GC initiates a Watchdog interrupt after detecting the First Timeout from the WDT, if the exception is enabled via TCR[WIE] and MSR[CE]. First Timeout is defined as the occurrence of a 0→1 transition of the appropriate time-base bit while TSR[ENW] = 1 and

TSR[WIS] = 0. The timeout will be detected the second cycle after the 0→1 transition of the appropriate time-base bit. The PPC403GC immediately takes the exception, and the address of the next sequential instruction is saved in SRR2. Simultaneously, the current contents of the MSR are written into SRR3 and the MSR is written with the values shown in Table 6-17.

The high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x1020. Exception processing begins with this program counter address. To clear the WDT interrupt, the exception handling routine must clear the WDT interrupt bit TSR[WIS]. Clearing is done by writing a word to TSR using **mtspr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Executing the return from critical interrupt instruction (**rfci**) restores the contents of the program counter and the MSR from SRR2 and SRR3 respectively and the PPC403GC resumes execution at the contents of the program counter.

Table 6-17. Register Settings during Watchdog Timer Exceptions

SRR2	Written with the address of the next instruction to be executed
SRR3	Written with the contents of the MSR
MSR	WE, PR, CE, EE, DE, PE ← 0 ME, PX ← unchanged DR, IR ← 0 ILE ← unchanged LE ← ILE
PC	EVPR[0:15] 0x1020
TSR	Set to indicate type of timer event.

6.14 Data TLB Miss Exception

The Data TLB Miss Exception is generated if data translation is enabled and a valid TLB entry matching the effective address and PID is not present. The address of the instruction generating the untranslatable effective data address is saved in the SRR0 register. In addition, the hardware will also save the data address which missed in the TLB in the Data Exception Address Register (DEAR).

The Exception Syndrome Register (ESR) will be set to indicate the following:

- Whether the excepting operation was a store (includes **dcbz**, **dcbi**, **dccci**).

The exception is precise. Program flow will vector to EVPR[0:15] || 0x1100.

The following registers will be modified to the specified values:

Table 6-18. Register Settings during Data TLB Miss Exceptions

SRR0	Set to the address of the instruction generating the effective address for which no valid translation exists.
SRR1	Set to the value of the MSR at the time of the exception
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x1100
DEAR	Set to the effective address of the failed access
ESR	DST \leftarrow 1 if excepting operation is a store operation (includes dcbi , dcbz , and dccci). See Section 6.2.5 on page 6-12 for details of ESR operation.

Programming Note:

Data TLB Miss exceptions can happen any time data translation is active. Therefore, insure that SRR0 and SRR1 are saved before enabling translation in an exception handler.

6.15 Instruction TLB Miss Exception

The Instruction TLB Miss Exception is generated if instruction translation is enabled and execution is attempted for an instruction for which a valid TLB entry matching the effective address and PID for the instruction fetch is not present. The SRR0 register will save the address of the instruction whose fetch caused the TLB miss.

The exception is precise with respect to the attempted execution of the instruction. Program flow will vector to EVPR[0:15] || 0x1200.

The following registers will be modified to the specified values:

Table 6-19. Register Settings during Instruction TLB Miss Exceptions

SRR0	Set to the address of the instruction for which no valid translation exists.
SRR1	Set to the value of the MSR at the time of the exception
MSR	WE, PR, EE, PE \leftarrow 0 CE, ME, DE, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x1200

Programming Note:

Instruction TLB Miss exceptions can happen any time instruction translation is active. Therefore, insure that SRR0 and SRR1 are saved before enabling translation in an exception handler.

6.16 Debug Exception Handling

Debug exceptions can be either synchronous or asynchronous. The following debug events generate synchronous exceptions: instruction address compare (IA1, IA2; as a group these are called IAC), data address compare (DR1, DW1, DR2, DW2; as a group these are called DAC), trap with condition satisfied (TIE), branch taken (BT), and instruction completion (IC). These debug events generate asynchronous exceptions: unconditional debug event (UDE), and exceptions (EXC). Each of these conditions is discussed in Section 10.5 (Debug Events) on page 10-4.

For debug events, SRR2 is written with an address, which varies with the type of debug event, as shown in this table:

Table 6-20. SRR2 during Debug Exceptions

Debug Event	Address Saved in SRR2
IAC DAC TIE BT	Address of instruction which caused the event
IC	Address of instruction <u>after</u> the instruction which caused the event
UDE	Address of next instruction to be executed at time of UDE
EXC	Interrupt vector address of the initial exception which caused the EXC debug event

In all cases, SRR3 is written with the contents of the MSR and the MSR is written with the values shown in Table 6-21.

For all debug interrupts, the high-order 16 bits of the program counter are then written with the contents of the EVPR and the low-order 16 bits of the program counter are written with 0x2000. Exception processing begins at the new address in the program counter. Executing the return from critical interrupt instruction (**rfci**) restores the contents of the program counter and the MSR from SRR2 and SRR3, respectively and the PPC403GC resumes execution at the address contained in the program counter.

Table 6-21. Register Settings during Debug Exceptions

SRR2	Written with the address of an instruction. (See Table 6-20 on page 6-38.)
SRR3	Written with the contents of the MSR

Table 6-21. Register Settings during Debug Exceptions (cont.)

MSR	WE, PR, CE, EE, DE, PE \leftarrow 0 ME, PX \leftarrow unchanged DR, IR \leftarrow 0 ILE \leftarrow unchanged LE \leftarrow ILE
PC	EVPR[0:15] 0x2000
DBSR	Set to indicate type of debug event.

6.17 Timer Architecture

The PPC403GC provides four timer facilities: a Time Base, a Programmable Interval Timer, a Fixed Interval Timer, and a Watchdog Timer. These facilities may be used to support time-of-day and data logging functions, to support peripherals which require service on a rigid schedule, to support general system maintenance, and to enable system recovery from faulty software or hardware.

If the PPC403GC is in Wait State ($MSR[WE] = 1$), the timer facilities continue to function. Therefore, the system's timekeeping and error recovery functions remain available. Timer interrupts may be used as a means of exiting Wait State.

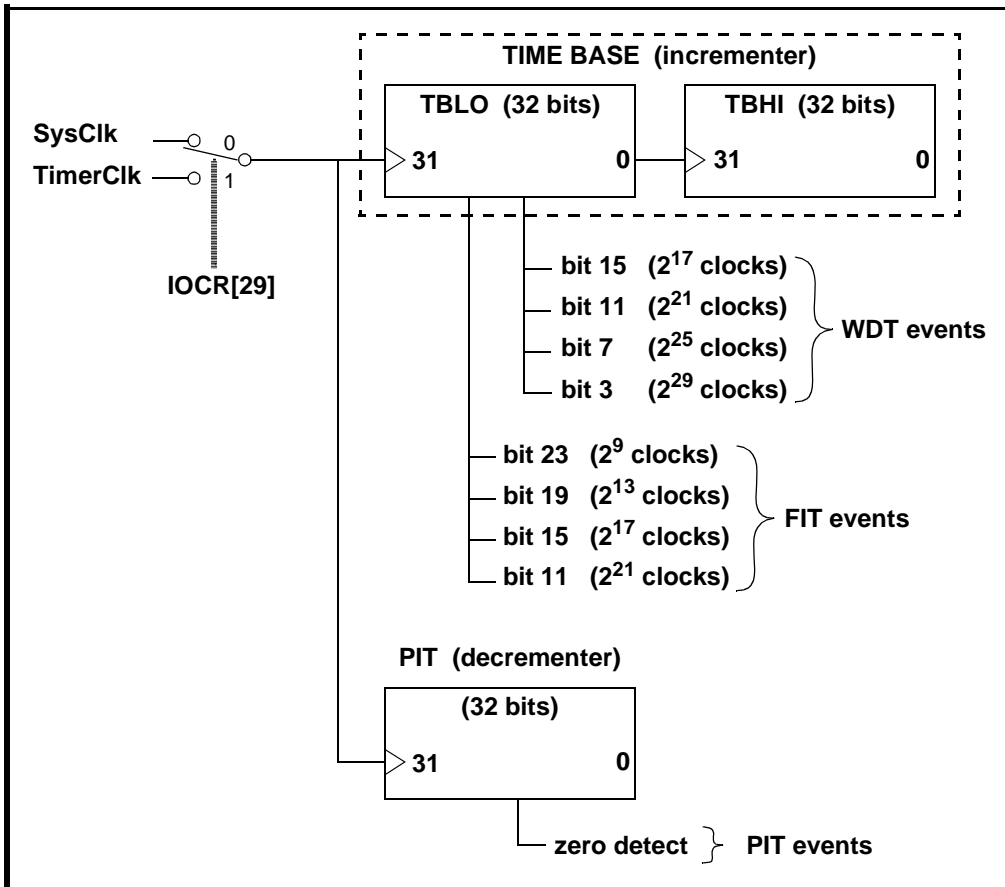


Figure 6-14. Relationship of Timer Facilities to Base Clock

6.17.1 Timer Clocks

The four timer facilities all utilize the same frequency as a base clock. The relationship of these facilities to the base clock is illustrated in Figure 6-14.

The base clock frequency may be selected to be either the system clock or a separate timer clock. Selection is controlled by bit 29 of the IOCR. If the separate timer clock is used, its frequency must be no more than half of the system clock frequency. Further, both the low portion and the high portion of the timer clock must be at least as long as the entire period of the system clock.

IOCR[29]	Selected Time Base Clock
0	SysClk
1	TimerClk

6.17.2 Time Base (TBHI, TBLO, TBHU, TBLU)

The PPC403GC implements a 64-bit time base, accessed via two 32-bit registers TBHI and TBLO. The Time Base increments once for each period of the time base clock, as discussed above. Software access to the Time Base is via **mtspr** and **mfspr** instructions.

All access to the time base registers TBHI and TBLO is privileged.

User-mode read-only access to the Time Base is provided by reading from different SPR numbers. Specifically, read-only access to TBHI is accomplished by reading TBHU, and read-only access to TBLO is accomplished by reading TBLU. Both TBHU and TBLU are read using **mfspr** instructions. An **mtspr** to these registers is boundedly undefined.

The period of the 64-bit Time Base is approximately 23397 years with a 25 MHz time base clock. The Time Base does not generate any interrupts, even when it wraps. It is assumed for most applications that the Time Base will be set once at system reset, and only read thereafter. Note that the Fixed Interval Timer and the Watchdog Timer (discussed below) are driven by 0→1 transitions of selected bits of TBLO. Transitions caused by software alteration of TBLO using **mtspr** will have the same effect as would transitions caused by normal incrementing.

Figure 6-15 illustrates TBHI(TBHU), and Figure 6-16 illustrates TBLO(TBLU).

0	31
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Figure 6-15. Time Base Register (TBHI, TBHU)

0:31		Time High	Current count, high-order. (Note: TBHU is a read-only access vehicle to the time base register TBHI. It is not possible for the contents of TBHU and TBHI to differ.)
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0	31
---	----

Figure 6-16. Time Base Register (TBLO, TBLU)

0:31		Time Low	Current count, low-order. (Note: TBLU is a read-only access vehicle to the time base register TBLO. It is not possible for the contents of TBLU and TBLO to differ.)
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6.17.2.1 Comparison with PowerPC Architecture Time Base

The Time Base of the PPC403GC has essentially the same functionality as the Time Base defined in the PowerPC Architecture, but the two are not the same. This section will highlight the differences, as an aid to porting code.

For the PowerPC Architecture:

- The PowerPC Architecture defines a 64-bit time base, which may be accessed as a pair of 32-bit registers. Different register numbers are used for read access (user or privileged mode) and write access (privileged mode).
- The PowerPC Architecture provides for a **mftb** (move from time base) instruction for user-mode read access to the time base. The register numbers used with this instruction to specify the time base registers (0x10C and 0x10D) are not SPR numbers. However, the **mftb** instruction opcode differs from the **mfspir** opcode by only one bit. The PowerPC Architecture allows an implementation to ignore this bit and handle the **mftb** instruction as **mfspir**. Accordingly, these register numbers may not be used for other SPRs. Further, PowerPC compilers are not free to use the **mftb** opcode with register numbers other than those specified in the PowerPC Architecture as read-access time base registers (0x10C and 0x10D).
- The PowerPC Architecture does not provide for privileged-mode-only read access of the time base (by definition, the user-mode read access mechanism is also available in privileged mode).
- The PowerPC Architecture provides privileged-mode write access to the time base using **mtspir** instructions with SPR numbers 0x11C and 0x11D.

For the PPC403GC:

- The PPC403GC defines a 64-bit time base, which may be accessed as a pair of 32-bit registers. Different register numbers are used for read access (user or privileged mode) and write access (privileged mode). In addition, the PPC403GC allows read access (in privileged mode only) at the same register number as the write access.
- The PPC403GC provides user-mode and privileged-mode read access to the time base via **mfspir** instructions with SPR numbers 0x3CD and 0x3CC. The PPC403GC provides privileged-mode-only read access via **mfspir** instructions with SPR numbers 0x3DD and 0x3DC. The PPC403GC does not implement the **mftb** instruction; an attempt to use it will result in a Program Exception for illegal opcode.
- The PPC403GC provides privileged-mode write access to the time base using **mtspir** instructions with SPR numbers 0x3DD and 0x3DC.

These differences are detailed in the following table:

Table 6-22. Time Base Comparison

PowerPC Architecture				PPC403GC		
	Access Instructions	Reg Number	Access Restrictions	Access Instructions	Reg Number	Access Restrictions
Upper 32 bits	mftbu RT <i>Extended mnemonic for mftb RT,TBU</i>	0x10D	Read-Only	mftbhu RT <i>Extended mnemonic for mfspr RT,TBHU</i>	0x3CC	Read-Only
	mttbu RS <i>Extended mnemonic for mtspr TBU,RS</i>	0x11D	Privileged; Write-Only	mftbhi RT <i>Extended mnemonic for mfspr RT,TBHI</i> mttbhi RS <i>Extended mnemonic for mtspr TBHI,RS</i>	0x3DC	Privileged; Read Privileged; Write
Lower 32 bits	mftb RT <i>Extended mnemonic for mftb RT,TBL</i>	0x10C	Read-Only	mftblu RT <i>Extended mnemonic for mfspr RT,TBLU</i>	0x3CD	Read-Only
	mttbl <i>Extended mnemonic for mtspr TBL,RS</i>	0x11C	Privileged; Write-Only	mftblo RT <i>Extended mnemonic for mfspr RT,TBLO</i> mttblo RS <i>Extended mnemonic for mtspr TBLO,RS</i>	0x3DD	Privileged; Read Privileged; Write

6.17.3 Programmable Interval Timer (PIT)

The PIT is a 32-bit register, that decrements at the same rate as the time base. The PIT is read/written via **mfspr/mtspr**. Writing to the PIT using **mtspr** simultaneously writes to a hidden reload register. Reading the PIT using **mfspr** returns the current PIT contents; there is no mechanism to read the content of the hidden reload register. When written to a non-zero value, the PIT begins decrementing. A PIT event occurs when a decrement occurs on a PIT count of one. When the PIT event occurs, the following things happen:

- 1) If the PIT is in auto-reload mode (TCR[ARE]=1), the PIT reloads with the last value that was written to the PIT using a **mtspr** instruction. The decrement from one immediately causes the reload; an intermediate PIT content of zero does not occur.

If the PIT is not in auto-reload mode (TCR[ARE]=0), decrement from one simply causes a PIT content of zero.

- 2) Timer Status Register bit TSR[PIS] is set.
- 3) If enabled by Timer Control Register bit TCR[PIE] and MSR[EE], a PIT Interrupt is taken. See Section 6.11 for details of register behavior under the PIT interrupt.

The interrupt handler will be expected to reset TSR[PIS] via software. This is done by writing a word to TSR using **mtspr** with a 1 in bit TSR[PIS] (and any other bits that are to be cleared) and 0 in all other bits. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

Forcing the PIT to 0 using the **mtspr** instruction will NOT cause the PIT interrupt; however, decrementing which was in progress at the instant of the **mtspr** instruction may cause the appearance of an interrupt. To eliminate the PIT as a source of interrupts, write a 0 to TCR[PIE] (PIT Interrupt Enable bit).

If it is desired to eliminate all PIT activity, the procedure is:

- 1) Write 0 to TCR[PIE]. This will prevent PIT activity from causing interrupts.
- 2) Write 0 to TCR[ARE] to disable the PIT auto-reload feature.
- 3) Write 0 to PIT. This will halt PIT decrementing. While this action will not cause a PIT interrupt to become pending, a near simultaneous decrement may have done so.
- 4) Write 1 to TSR[PIS] (PIT Interrupt Status bit). This action will clear TSR[PIS] to 0 (see Section 6.17.6). This will clear any PIT interrupt which may be pending. Because the PIT is frozen at zero, no further PIT events are possible.

If the auto-reload feature is disabled (TCR[ARE]=0), then once the PIT decrements to zero, it will stay there until software reloads it using the **mtspr** instruction.

On any reset, TCR[ARE] is cleared to zero. This disables the auto-reload feature.

Figure 6-17 illustrates the PIT.

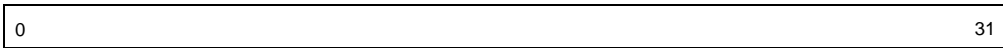


Figure 6-17. Programmable Interval Timer (PIT)

0:31	Programmed Interval Remaining	(the number of clocks remaining until the PIT event)
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6.17.4 Fixed Interval Timer (FIT)

The FIT is a mechanism for providing timer interrupts with a repeatable period, to facilitate system maintenance. It is similar in function to an auto-reload PIT, except that there are fewer selections of interrupt period available. The FIT exception occurs on 0→1 transitions of selected bits from the time base, per the following table:

TCR[FP]	TBLO Bit	Period (Time Base clocks)	Period (33 Mhz clock)
0,0	23	2^9 clocks	15.52 μ SEC
0,1	19	2^{13} clocks	248.2 μ SEC
1,0	15	2^{17} clocks	3.972 msec
1,1	11	2^{21} clocks	63.55 msec

The FIT exception is logged by TSR[FIS] as a pending interrupt. A FIT Interrupt will occur if TCR[FIE] and MSR[EE] are enabled. See Section 6.12 for details of register behavior under the FIT interrupt.

The interrupt handler must reset TSR[FIS] via software. This is done by writing a word to TSR using **mtspr** with a 1 in bit TSR[FIS] (and any other bits that are to be cleared) and 0 in all other bits. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

6.17.5 Watch Dog Timer (WDT)

The Watchdog Timer is a facility intended to aid system recovery from faulty software or hardware. Watchdog timeouts occur on 0→1 transitions of selected bits from the time base, per the following table:

TCR[WP]	TBLO Bit	Period (Time Base clocks)	Period (33 Mhz clock)
0,0	15	2^{17} clocks	3.972 msec
0,1	11	2^{21} clocks	63.55 msec
1,0	7	2^{25} clocks	1.017 sec
1,1	3	2^{29} clocks	16.27 sec

When a WDT timeout occurs while $\text{TSR}[\text{WIS}] = 0$ and $\text{TSR}[\text{ENW}] = 1$, a WDT Interrupt occurs if enabled by $\text{TCR}[\text{WIE}]$ and $\text{MSR}[\text{CE}]$. See Section 6.13 for details of register behavior under the Watchdog interrupt.

The interrupt handler must reset $\text{TSR}[\text{WIS}]$ via software. This is done by writing a word to TSR using **mtspr** with a 1 in bit $\text{TSR}[\text{WIS}]$ (and any other bits that are to be cleared) and 0 in all other bits. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

When a WDT timeout occurs while $\text{TSR}[\text{WIS}] = 1$ and $\text{TSR}[\text{ENW}] = 1$, a hardware reset occurs if enabled by a non-zero value of $\text{TCR}[\text{WRC}]$. The assumption is that $\text{TSR}[\text{WIS}]$ was not cleared because the processor was unable to execute the Watchdog handler, leaving reset as the only available means to restart the system. Note that once $\text{TCR}[\text{WRC}]$ has been set to a non-zero value, it cannot be reset by software; this feature prevents errant software from disabling the WDT reset capability.

A more thorough view of Watchdog behavior is afforded by the following figure and table, which describe the Watchdog state machine. The numbers in parentheses in the figure refer to the discussion of modes of operation which follows the table.

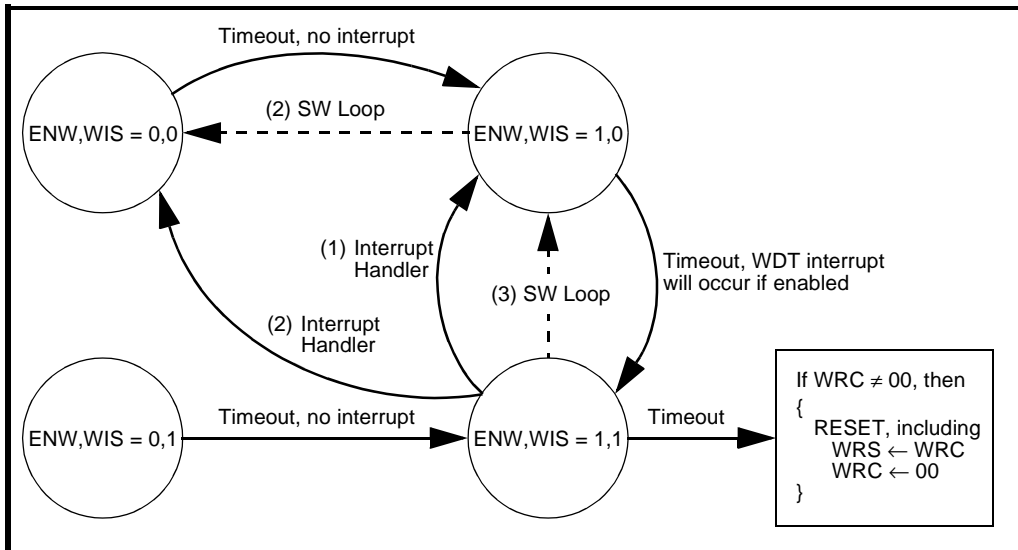


Figure 6-18. Watchdog State Machine

Enable Next WDT TSR[ENW]	WDT Status TSR[WIS]	Action when timer interval expires
0	0	Set Enable Next Watchdog (TSR[ENW]=1).
0	1	Set Enable Next Watchdog (TSR[ENW]=1).
1	0	Set Watchdog interrupt status bit (TSR[WIS]=1). If Watchdog interrupt is enabled (TCR[WIE]=1) and MSR[CE] is enabled, then interrupt.
1	1	Cause Watchdog reset action specified by TCR[WRC]. Reset will copy pre-reset TCR[WRC] into TSR[WRS], and clear TCR[WRC].

The controls described in the above table imply three different modes of operation that a programmer might select for the Watchdog timer. Each of these modes assumes that TCR[WRC] has been set to allow processor reset by the Watchdog facility:

- 1) Always take the Watchdog interrupt when pending, and never attempt to prevent its occurrence. (This is the mode described in the above text.)
 - 1) Clear TSR[WIS] in the watchdog handler.
 - 2) Never use TSR[ENW].

- 2) Always take Watchdog interrupt when pending, but avoid when possible. (Assumes either that a recurring code loop of reliable duration exists outside the interrupt handlers or that a FIT interrupt handler is operational, either of which clears TSR[ENW] more frequently than the watchdog period.)
 - 1) Clear TSR[ENW] to 0 in loop or in FIT handler.

To clear TSR[ENW], use **mtspr** to write a 1 to TSR[ENW] (and to any other bits that are to be cleared), with 0 in all other bit locations.
 - 2) Clear TSR[WIS] in WDT handler (not an expected event).
- 3) Never take the Watchdog interrupt. (Assumes that a recurring code loop of reliable duration exists outside the interrupt handlers or that a FIT interrupt handler is operational. This method only guarantees one Watchdog period before reset occurs.)
 - 1) Clear TSR[WIS] in the loop or in FIT handler.
 - 2) Never use TSR[ENW].

6.17.6 Timer Status Register (TSR)

The TSR may be accessed for read, or for write-to-clear.

Status registers are normally considered to be set via hardware, and read and cleared via software. Reading TSR is done using the **mf spr** instruction. Clearing is done by writing a word to TSR using **mt spr** with a 1 in any bit position that is to be cleared and 0 in all other bit positions. The write-data to the status register is not direct data, but a mask. A “1” causes the bit to be cleared, and a “0” has no effect.

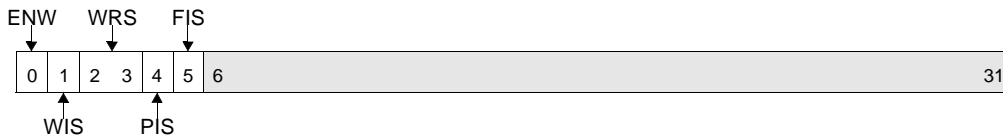


Figure 6-19. Timer Status Register (TSR)

0	ENW	Enable Next Watchdog 0 - Action on next Watchdog event is to set TSR[0]. 1 - Action on next Watchdog event is governed by TSR[1]. (See Section 6.17.5 on page 6-47)
1	WIS	Watchdog Interrupt Status 0 - No Watchdog interrupt is pending. 1 - Watchdog interrupt is pending.
2:3	WRS	Watchdog Reset Status 00 - No Watchdog reset has occurred. 01 - Core reset has been forced by the Watchdog. 10 - Chip reset has been forced by the Watchdog. 11 - System reset has been forced by the Watchdog.
4	PIS	PIT Interrupt Status 0 - No PIT interrupt is pending. 1 - PIT interrupt is pending.
5	FIS	FIT Interrupt Status 0 - No FIT interrupt is pending. 1 - FIT interrupt is pending.
6:31		reserved

6.17.7 Timer Control Register (TCR)

The TCR controls PIT, FIT, and WDT options.

TCR[WRC] are cleared to zero by all forms of processor reset (see Chapter 5, Reset and Initialization, on page 5-1 for discussion of types of processor reset). These bits are set only by software; however, hardware does not allow software to clear these bits once they have been set. Once software has written a 1 to one of these bits, that bit remains a 1 until a reset (of any type) occurs. This is to prevent errant code from disabling the Watchdog reset function.

TCR[ARE] is cleared to zero by all forms of processor reset. This disables the auto-reload feature of the PIT.

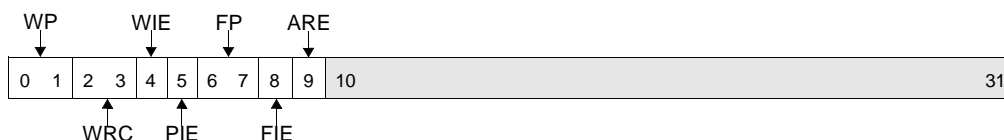


Figure 6-20. Timer Control Register (TCR)

0:1	WP	Watchdog Period 00 - 2^{17} clocks 01 - 2^{21} clocks 10 - 2^{25} clocks 11 - 2^{29} clocks	
2:3	WRC	Watchdog Reset Control 00 - No Watchdog reset will occur. 01 - Core reset will be forced by the Watchdog. 10 - Chip reset will be forced by the Watchdog. 11 - System reset will be forced by the Watchdog.	TCR[WRC] resets to 00. This field may be set by software, but cannot be cleared by software (except by a software-induced reset).
4	WIE	Watchdog Interrupt Enable 0 - DisableWDT interrupt. 1 - Enable WDT interrupt.	
5	PIE	PIT Interrupt Enable 0 - Disable PIT interrupt. 1 - Enable PIT interrupt.	
6:7	FP	FIT Period 00 - 2^9 clocks 01 - 2^{13} clocks 10 - 2^{17} clocks 11 - 2^{21} clocks	
8	FIE	FIT Interrupt Enable 0 - Disable FIT interrupt. 1 - Enable FIT interrupt.	

Figure 6-20. Timer Control Register (TCR) (cont.)

9	ARE	Auto Reload Enable 0 - Disable auto reload. 1 - Enable auto reload. (disables on reset)
10:31		reserved

Serial Port Operation

This chapter describes the asynchronous serial port on the on-chip peripheral bus (OPB) of the PPC403GC. The following sections discuss the serial port hardware elements, operations and operating modes, and details of registers and buffers.

7.1 Overview

The serial port unit (SPU) runs at speeds up to one-sixteenth of the processor (SysClk) clock rate and provides features typically found on advanced serial communications controllers, including DMA peripheral support, internal loopback mode, automatic echo mode, and automatic handshaking capability on both receive and transmit operations.

The SPU comprises three main elements: receiver, transmitter, and baud rate generator, as shown in Figure 7-1:

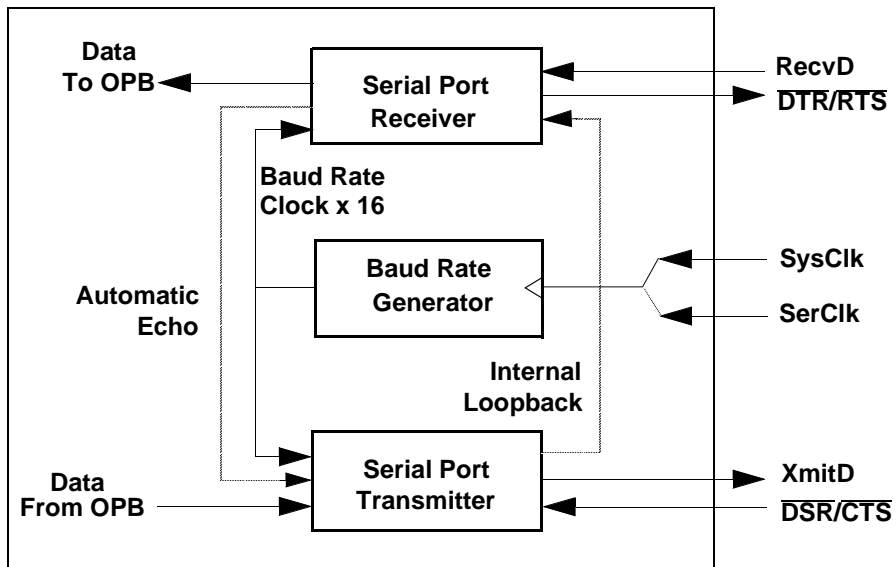


Figure 7-1. Serial Port Functional Block Diagram

7.1.1 SPU Operating Mode Selection

The SPU can be configured to operate in normal, loopback, or automatic echo mode by setting the Loopback Mode (LM) bits in the Serial Port Control (SPCTL) register, as indicated in Table 7-1:

Table 7-1. SPU Operating Mode Selection

Mode	SPCTL Register Bit Settings
Normal	LM = 00
Internal Loopback	LM = 01
Automatic Echo	LM = 10

7.1.1.1 Normal Mode

In Normal Mode, the SPU performs like a standard UART. Bytes of data are received and transmitted via the RecvD and XmitD lines respectively. Handshaking interaction between the SPU and external devices occurs directly via the $\overline{\text{DTR}}/\text{RTS}$ and $\overline{\text{DSR}}/\text{CTS}$ I/Os.

7.1.1.2 Internal Loopback Mode

In internal loopback mode, data being transmitted is internally routed to the receiver. The $\overline{\text{DTR}}/\text{RTS}$ outputs from the receiver are also internally routed to the $\overline{\text{DSR}}/\text{CTS}$ inputs of the transmitter. Externally, the XmitD and $\overline{\text{DTR}}/\text{RTS}$ outputs are held in their inactive states, and any transitions on the RecvD and $\overline{\text{DSR}}/\text{CTS}$ inputs are ignored. Note that in this mode of operation, both the transmitter and the receiver must be enabled.

7.1.1.3 Automatic Echo Mode

In automatic echo mode, as each bit of data is received on the RecvD input, it is retransmitted on the XmitD output with a delay of one baud rate clock cycle. Thus the transmitter is acting in a 'pass-through' mode, implying that any errors in the data stream are also transmitted as they are seen. Note that in this mode the receiver must be enabled and the transmitter disabled. All handshaking signals will operate as they do in normal mode.

7.1.2 SPU Handshaking I/O Pair Selection

As shown in Figure 7-1, the $\overline{\text{DTR}}/\text{RTS}$ handshaking outputs and $\overline{\text{DSR}}/\text{CTS}$ handshaking inputs are multiplexed. The Serial Port Configuration (SPC) bit in the IOCR determines the function of the pin. To select the $\overline{\text{DTR}}/\overline{\text{DSR}}$ I/O pair, a 0 must be written to the SPC bit, and to select the RTS/CTS I/O pair, a 1 must be written to the SPC bit.

7.1.3 SPU Registers

Serial Port registers are memory mapped and thus are accessed via load/store instructions at the address of the register. Since the SPU is a byte device, its registers are eight bits and are usually accessed using load byte and store byte instructions. Load/store half-word and word instructions can also access the serial port registers. When these instructions are used, the bus interface unit (BIU) breaks register accesses into discrete byte operations.

Table 7-2 shows the memory-mapped addresses for the user-accessible registers in the serial port. Note that although logically the SPRB and SPTB are separate registers, they are mapped to the same physical address.

Table 7-2. Serial Port Register Addresses, Names, and Access Modes

Memory Mapped I/O Address	Name	Mnemonic	Access Modes
0x4000 0000	Serial Port Line Status Register	SPLS	Read/Write
0x4000 0001	Reserved		
0x4000 0002	Serial Port Handshake Status Register	SPHS	Read/Write
0x4000 0003	Reserved		
0x4000 0004	Baud Rate Divisor High Register	BRDH	Read/Write
0x4000 0005	Baud Rate Divisor Low Register	BRDL	Read/Write
0x4000 0006	Serial Port Control Register	SPCTL	Read/Write
0x4000 0007	Serial Port Receiver Command Register	SPRC	Read/Write
0x4000 0008	Serial Port Transmitter Command Register	SPTC	Read/Write
0x4000 0009	Serial Port Receive/Transmit Buffer	SPRB/ SPTB	SPRB is read only SPTB is write only

Figure 7-2 represents the serial port registers as they relate to the individual components within the SPU.

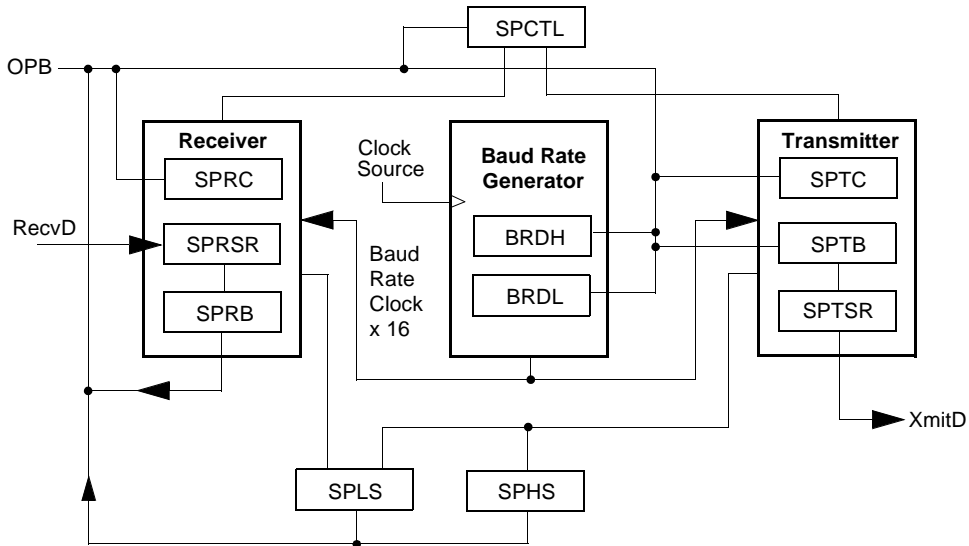


Figure 7-2. SPU Registers and Buffers

The Serial Port Control Register (SPCTL) controls the overall operation of the serial port. It provides the data frame format to the transmitter and receiver (number of data/stop bits and parity generation/detection), controls the state of the $\overline{\text{DTR}}$ and $\overline{\text{RTS}}$ signals (Active/Inactive), and specifies the SPU mode of operation (Normal, Internal Loopback, Auto Echo).

The Line Status Register (SPLS) and Handshake Status Register (SPHS) gather status information for the serial port. The SPLS contains status information for the receiver (RxReady, Parity, Framing and Overrun Errors, and Line Break Detection) and the transmitter (TxReady and TxEmpty). The SPHS contains the status of the input handshake signals ($\overline{\text{CTS}}$ /DSR Inactive).

The Baud Rate Generator contains the two baud rate divisor registers, BRDH and BRDL. Although both baud rate registers are 8-bit registers, only the least significant four bits of the BRDH are implemented. The contents of these registers are concatenated to form a 12-bit divisor which is used to derive the frequency at which to transmit and receive data through the SPU.

The serial port transmitter consists of an eight-bit transmit buffer (SPTB), a parallel-to-serial shift register (SPTSR), and a command register (SPTC). The SPTC contains control information specific to the transmitter such as the transmitter enable, DMA mode and interrupt enables, line break generation enable, pattern generation mode enable, and auto-handshaking enable (Stop/Pause on $\overline{\text{CTS}}$ input). Data to be transmitted is loaded into the SPTB until the data is transferred into the SPTSR when transmission begins. The

transmitter reports SPTSR and SPTB full/empty status, reflected as TxEmpty and TxReady respectively in the SPLS register. The transmitter also provides the status of the handshaking inputs for the SPS register.

The serial port receiver consists of an eight-bit receive buffer (SPRB), a serial-to-parallel shift register (SPRSR), and a command register (SPRC). The SPRC contains control information specific to the receiver such as the receiver enable, DMA mode and interrupt enables, and auto-handshaking enable (hw/sw control of the RTS output). When a data byte has been received by the SPRSR, provided that no errors were detected, it is transferred to the SPRB and SPRB full status (reflected in RxReady) is reported to the SPLS register. Data characters that contain errors are discarded and the error condition (framing, parity, overrun or line breaks) is posted in the SPLS register.

For a complete bit description of these registers, refer to Section 7.3, “SPU Register Descriptions”.

7.2 SPU Operations

7.2.1 SPU Baud Rate Generator

The frequency used to transmit and receive data through the SPU is derived from the Baud Rate Generator Clock input and the contents of the baud rate divisor registers. The Baud Rate Generator Clock input can come from either the processor clock (SysClk) or an external clock source from the SerClk input pin. To select SysClk as the Baud Rate Generator Clock input, the serial port clock source (SCS) bit in the Input/Output Configuration Register (IOCR) is set to 0. Setting the SCS bit to 1 forces the external clock source on the SerClk input pin to be selected as the Baud Rate Generator Clock. Note that in this case, the SerClk external clock source frequency must be less than one-half of the SysClk frequency.

The baud rate generator divides the rate of the Baud Rate Generator Clock by the value obtained by the concatenated value of the two baud rate divisor registers, BRDH and BRDL, resulting in a clock frequency 16 times faster than the desired baud rate. As shown in Figure 7-1, the output from the baud rate generator drives the transmitter and receiver baud rate inputs. Those inputs are then divided by 16 internally to the receiver and the transmitter to generate the required Baud Rate Clock frequency.

The baud rate for the serial port can be calculated via the following equation:

$$\text{Baud Rate} = \frac{1}{16} \times \frac{\text{Clock Source}}{(\text{BRDH} \parallel \text{BRDL}) + 1}$$

where Clock Source is the frequency of either SysClk or SerClk (based on the setting of the SCS bit of the IOCR register).

Table 7-3 shows selected contents of the baud rate divisor registers and the resulting baud rates when a 3.6864 MHz clock input is applied to the SerClk input and the external clock

input is selected in the SCS bit of the IOCR.

Table 7-3. Baud Rate Divisor Selection

BRDH Contents	BRDL Contents	Baud Rate
0x02	0xFF	300
0x00	0xBF	1200
0x00	0x5F	2400
0x00	0x2F	4800
0x00	0x17	9600
0x00	0x0B	19200
0x00	0x05	38400

7

7.2.2 SPU Transmitter

As mentioned previously, the main components of the serial port transmitter are an eight-bit transmit buffer (SPTB), a parallel-to-serial shift register (SPTSR), and a command register (SPTC). To enable the transmitter, the ET bit of the SPTC must be set to 1. If ET is set to 0, the transmitter is disabled, no data is transmitted, and no interrupts ($\overline{\text{DSR}}$ inactive, $\overline{\text{CTS}}$ inactive, Transmit Buffer Ready, or Transmitter Shift Register Empty) are requested. If ET is reset to 0 during transmission, the transmission immediately terminates and the XmitD output is driven to 1.

Transmit Buffer Ready (TxReady) and Transmit Shift Register Empty (TxEmpty) are the only two bits in the SPLS register that reflect transmitter status (represented by bits TBR and TSR respectively). The following table describes what the possible combinations of these status bits represent:

Table 7-4. TxReady / TxEmpty Status Representation

TxReady	TxEmpty	Meaning
1	1	Transmitter is idle; no data in transmit buffer Note that this is the transmitter status out of reset
0	1	Transmitter is idle; data was either just loaded into transmit buffer, or is being held there due to handshaking line loss.
1	0	Transmitter is transmitting a character; no new data loaded into transmit buffer
0	0	Transmitter is transmitting a character; next character waiting in transmit buffer

Data to be transmitted is first loaded into the SPTB; TxReady will update from a logic 1 to a logic 0. If the transmitter is enabled, $\overline{\text{DSR/CTS}}$ is active, and the SPTSR is empty (TxEmpty = 1), the data is immediately transferred to the SPTSR, causing TxEmpty to update from a logic 1 to a logic 0, and TxReady to return to a value of logic 1, indicating that the SPTB is ready to be loaded with another piece of data. When a piece of data is transferred to the SPTSR, the appropriate, start, stop and parity bits are added, and the transmission of the character begins immediately. Note that for 7-data bit frame formats, the least significant 7 bits of the SPTB are transmitted, least-significant-bit first.

While the transmitter is shifting out the current piece of data, the SPTB may be loaded with the next piece of data. When transmission of the current piece of data completes, and assuming the $\overline{\text{DSR/CTS}}$ input has not gone inactive during that character's transmission, the next piece of data will be transferred to the SPTSR and the process repeats. Note that TxEmpty stays at a value of logic 0 until either a handshaking error is flagged, or no more characters are loaded into the SPTB.

7.2.2.1 Pattern Generation Mode

Pattern Generation Mode (PGM) is enabled by the PGM bit in the SPTC, $\text{SPTC}[\text{PGM}] = 1$. When PGM is enabled, the serial port transmitter will operate basically the same as when PGM is disabled, except that the generation of start and stop bits during character transmissions are suppressed. Thus the SPU will essentially become a pattern generator, where only the 7 or 8 data bits and parity bit (if enabled) will be transmitted. This allows the serial port transmitter to be used for pulse width modulation with duty cycle variation controlled by frame size, baud rate, and data pattern.

7.2.2.2 Transmitter Stop/Pause Mode

How the SPU responds to the $\overline{\text{DSR/CTS}}$ handshaking input depends on which input it functionally represents and the value of the Stop/Pause Enable (SPE) bit of the SPTC register. Recall that the function of the $\overline{\text{DSR/CTS}}$ input is selected via the SPC bit of the IOCR. Assume that the SPC bit of the IOCR is a logic 1, indicating that $\overline{\text{DSR/CTS}}$ represents a $\overline{\text{CTS}}$ handshaking input.

The SPE bit in the SPTC determines whether the transmitter enters either pause mode or stop mode based on the status of the $\overline{\text{CTS}}$ handshaking input. When SPE is set to 0, the transmitter enters pause mode. If the $\overline{\text{CTS}}$ handshaking input goes inactive during the transmission of a character, the transmitter will finish the transmission of the character and then wait for the $\overline{\text{CTS}}$ input line to return to its active state before continuing operations. Note that the $\overline{\text{CTS}}$ inactive status bit in the SPHS register will be set, but in this mode the transmitter does not wait for the bit to be cleared before continuing.

When SPE is set to 1, the transmitter enters stop mode. In this case, if the $\overline{\text{CTS}}$ handshaking input goes inactive the transmitter will also finish the transmission of the current character and flag the error in the SPHS register, but this time it will suspend its operation until both the $\overline{\text{CTS}}$ handshaking input returns to its active state and the $\overline{\text{CTS}}$ inactive status bit has been cleared in the SPHS register.

If the serial port uses $\overline{\text{DSR}}/\overline{\text{CTS}}$ as a $\overline{\text{DSR}}$ signal (SPC of IOCR = logic 0), losing the $\overline{\text{DSR}}$ signal always forces the serial port transmitter into a stop mode of operation until the $\overline{\text{DSR}}$ Inactive bit in the SPHS is reset to 0 and the $\overline{\text{DSR}}$ input is active.

7.2.2.3 Transmitter Line Break Generation

Setting the Transmit Break (TB) bit of the SPTC to a logic 1 forces a continuous stream of zeros on the XmitD output, assuming that the transmitter is enabled. The SPU transmitter will continue to transmit break characters until the TB bit is reset to a logic 0.

Setting the TB bit to 1 should only be done when the serial port transmitter is idle. Forcing the transmission of break characters when the serial port transmitter is active has undefined results.

7.2.2.4 Transmitter DMA Mode

The DMA Mode/Interrupt Enable (DME) field of the SPTC controls the use of the serial port transmitter as a DMA destination, as well as the enable/masking of the TxReady (TBR) interrupt. The following table describes what the bit settings represent:

Table 7-5. DMA Mode / Interrupt Enable Field Representation

DME	Meaning
00	SPU transmitter disabled as a DMA destination device TxReady (TBR) interrupt generation disabled
01	SPU transmitter disabled as a DMA destination device TxReady (TBR) interrupt generation enabled
10	SPU transmitter used as a destination for DMA Channel 2
11	SPU transmitter used as a destination for DMA Channel 3

When the transmitter is used as a destination for DMA transfers, requests are made to the appropriate DMA channel whenever TxReady in the SPLS register is a logic 1. The DMA responds to the request by providing another character to transfer to the SPTB. To operate in this mode, the appropriate DMA Channel Control Register (DMACRn) must be configured to accept DMA requests from an internal source. Setting the Peripheral Location (PL) bit of the DMACRn to a logic 1 configures DMA channel to accept DMA requests from the serial port.

7.2.2.5 Transmitter Interrupts

The serial port transmitter interrupts can be generated based on three conditions: TxReady (TBR) or TxEmpty (TSR) being active in the SPLS register, or a handshaking error (DIS or CIS) is flagged in the SPHS register. Each of these conditions have separate interrupt enables in the SPTC.

As mentioned in Table 7-5 above, setting the DME field of the SPTC to a value of 0b01 enables TxReady interrupt generation. Thus an interrupt will be generated whenever the SPTB is ready to be loaded with new data. The TIE bit of the SPTC is the enable for generating interrupts based on TxEmpty. When TxEmpty and TIE are both ones, the SPU will raise the transmitter interrupt request to the asynchronous interrupt controller unit to indicate that character transmission has completed. Similarly, the Error Interrupt Enable (EIE) bit of the SPTC enables interrupt requests when either a $\overline{\text{DSR}}$ or $\overline{\text{CTS}}$ inactive error is flagged, indicating that the $\overline{\text{DSR/CTS}}$ handshaking signal became inactive during the transmission of a character.

When a transmitter interrupt request to the asynchronous interrupt controller occurs, the Serial Port Transmitter Interrupt Status (STIS) bit of the External Interrupt Status Register (EXISR) is set. Note however that the exception will only be processed if the Serial Port Transmitter Interrupt Enable (STIE) bit of the External Interrupt Enable Register (EXIER) and the External Interrupt Enable (EE) bit of the Machine State Register (MSR) are also set.

7.2.3 SPU Receiver

The main components of the SPU receiver are an eight-bit receive buffer (SPRB), a serial-to-parallel shift register (SPRSR), and a command register (SPRC). To enable the receiver, the ER bit of the SPRC must be set to one. When the serial port receiver is enabled, data received from the RecvD pin is input to the SPRSR. If a character is received without errors, the character is transferred from the SPRSR to the SPRB and the RxReady (RBR) bit in the SPLS is set. Note that if the data frame is configured for seven bits, the most significant bit of the byte loaded from the SPRB is set to 0 and the received data occupies the rest of the byte. The RBR bit of the SPLS register is reset to 0 when the data byte in the SPRB is read by the processor.

If errors are detected during the reception of a character, then the error condition (Parity Error, Framing Error, Overrun Error or Line Break Detect) is posted in the SPLS register and the data byte discarded. Parity Errors are detected when the received parity of a data frame does not match the expected parity of the data frame. This causes the Parity Error (PE) bit of the SPLS register to be set. Framing errors imply that one or both of the stop bits of the received data frame were a zero. When this error is detected, the Framing Error (FE) bit of the SPLS register is set. Note that framing errors are also flagged when a line break is detected.

A line break is detected when a character is received and all of the bits of the frame, including data, parity and stop bits are zeros. This condition will cause the Line Break (LB) bit of the SPLS is set to 1. Note that line breaks are only detected on character boundaries. If a line break begins within a character, a framing error is detected. If the line break condition persists for the time equivalent to receiving another character, the line break error is detected. After a line break is detected, the serial port receiver begins searching for the end of the line break, defined as a period of logic one equivalent to the time required to receive one data bit of a frame. When the end of the line break is detected, receiver operation continues normally.

There are two cases where the SPRSR receives a character without errors but that character is not transferred to the SPRB and is instead held in the SPRSR. The first is when the SPRB is full and the second is if there are any receiver errors (noted earlier) posted in the SPLS register. The character being held in the SPRSR will not be moved into the SPRB until application software either removes the character currently in the SPRB by performing a read operation, or clears the error condition(s) in the SPLS register. Errors are cleared from the SPLS register by writing a logic 1 to the appropriate bit. Note that an Overrun Error occurs when the SPRSR is holding a valid character (it cannot move into the SPRB due to the conditions mentioned) and another character starts to be received. In this event, the character in the SPRSR is overwritten with the new character and the Overrun Error (OE) bit in the SPLS register is set.

7.2.3.1 Receiver Control of RTS

Recall that the function of the $\overline{\text{DTR}}/\overline{\text{RTS}}$ handshaking output is selected via the SPC bit of the IOCR. Assume that the SPC bit of the IOCR is a logic 1, indicating that $\overline{\text{DTR}}/\overline{\text{RTS}}$ represents a $\overline{\text{RTS}}$ handshaking output.

The Pause Mode Enable (PME) bit of the SPRC register determines if the spu receiver will be given control of the state of the $\overline{\text{RTS}}$ handshaking output. If the PME bit is set to 0, software controls the $\overline{\text{RTS}}$ output via the RTS bit in the SPCTL register. If the PME bit is set to 1, the receiver hardware controls the $\overline{\text{RTS}}$ output, provided that the RTS bit in the SPCTL register is set active. In this mode, the serial port receiver attempts to pause the sending device (prevent it from sending characters in order to give the processor a chance to catch up) by driving the $\overline{\text{RTS}}$ output inactive if one of two conditions exist:

- 1) The SPRB is full (RBR of SPLS register = 1) and there are only six more bits of the incoming character left to be received.
- 2) Any of the receiver error bits are set in the SPLS register (Parity, Framing, Overrun errors, or Line Break Detection).

The $\overline{\text{RTS}}$ output is driven active again once the condition that drove the $\overline{\text{RTS}}$ output inactive is removed. Note that when receiver pause mode is enabled, hardware control can be blocked by setting the RTS bit in the SPCTL register to a logic 0, thus forcing the value of the $\overline{\text{RTS}}$ handshaking output to be inactive.

If the serial port uses $\overline{\text{DTR}}/\overline{\text{RTS}}$ as a $\overline{\text{DTR}}$ signal (SPC of IOCR = logic 0), software will always have control over the output based on the value specified for the DTR bit in the SPCTL register.

7.2.3.2 Receiver DMA Mode

The DMA Mode / Interrupt Enable (DME) field of the SPRC register controls the use of the serial port receiver as a DMA source, as well as the enable/masking of the RxReady (RBR) interrupt. The following table describes what the bit settings represent:

Table 7-6. DMA Mode / Interrupt Enable Field Representation

DME	Meaning
00	SPU receiver disabled as a DMA source RxReady (RBR) interrupt generation disabled
01	SPU receiver disabled as a DMA source RxReady (RBR) interrupt generation enabled
10	SPU receiver used as a source for DMA Channel 2
11	SPU receiver used as a source for DMA Channel 3

When the receiver is used as a source for DMA transfers, requests are made to the appropriate DMA channel whenever RxReady in the SPLS register is a logic 1. The DMA responds to the request by reading the data from the SPRB. To operate in this mode, the appropriate DMA Channel Control Register (DMACRn) must be configured to accept DMA requests from an internal source. Setting the Peripheral Location (PL) bit of the DMACRn to 1 configures the DMA channel to accept DMA requests from the serial port.

7.2.3.3 Receiver Interrupts

The serial port receiver interrupts are generated based on two conditions: RxReady (RBR) or any of the receiver errors (PE, FE, OE, LB) being active in the SPLS register. Both of these conditions have separate interrupt enables in the SPRC register.

As mentioned in Table 7-5 above, setting the DME field in the SPRC register to a value of 0b01 enables RxReady interrupt generation. Thus an interrupt request will be sent to the asynchronous interrupt control unit whenever the SPRB has received a new character. Similarly, the Error Interrupt Enable (EIE) bit of the SPRC register enables an interrupt request whenever a framing, parity, overrun error, or line break is detected.

When a receiver interrupt request to the asynchronous interrupt controller occurs, the Serial Port Receiver Interrupt Status (SRIS) bit of the External Interrupt Status Register (EXISR) is set. Note however that the exception will only be processed if the Serial Port Receiver Interrupt Enable (SRIE) bit of the External Interrupt Enable Register (EXIER) and the External Interrupt Enable (EE) bit of the Machine State Register (MSR) are also set.

7.3 SPU Register Descriptions

The following sections provide a complete bit description of the 9 addressable SPU registers.

7.3.1 Baud Rate Divisor Registers

The BRDH and BRDL registers store a divisor for reducing the rate of the input clock source to a convenient baud rate. The contents of the BRDH are concatenated with the contents of the BRDL to form a 12-bit divisor. The baud rate calculation using the 12-bit divisor is described in Section 7.2.1., “SPU Baud Rate Generator”. Figure 7-3 shows the BRDH fields.

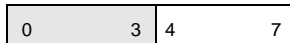


Figure 7-3. Baud Rate Divisor High Register (BRDH)

0:3		reserved	
4:7		Divisor High Bits	The four most significant bits of the baud rate divisor; concatenated with the contents of the BRDL.

Figure 7-4 shows the BRDL field.

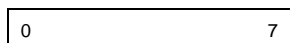


Figure 7-4. Baud Rate Divisor Low Register (BRDL)

0:7		Divisor Low Bits	The eight least significant bits of the baud rate divisor; concatenated with the contents of the BRDH.
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7.3.2 Serial Port Control Register (SPCTL)

The SPCTL configures the serial port for normal mode, internal loopback mode, and automatic echo mode. This register also controls the activity of the $\overline{\text{DTR}}/\text{RTS}$ signal and the frame format of the serial transfers. Figure 7-5 shows the SPCTL fields.

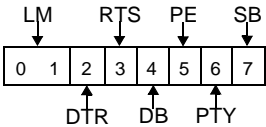


Figure 7-5. Serial Port Control Register (SPCTL)

0:1	LM	Loopback Modes 00 - Normal Operation 01 - Internal Loopback Mode 10 - Automatic Echo Mode 11 - Reserved	
2	DTR	Data Terminal Ready 0 - DTR signal is inactive 1 - DTR signal is active	
3	RTS	Request To Send 0 - RTS signal is inactive 1 - RTS is active	
4	DB	Data Bits 0 - 7 Data bits 1 - 8 Data bits	When DB = 0, a data frame contains the least significant seven bits (bits 1:7) in the SPTB or the SPRB.
5	PE	Parity Enable 0 - No parity 1 - Parity enabled	When PE = 0, parity detection and generation are disabled for the serial port receiver and transmitter.
6	PTY	Parity 0 - Even parity 1 - Odd parity	When PTY = 0, even parity is used in parity detection and generation. When PTY = 1, odd parity is used.
7	SB	Stop Bits 0 - One stop bit 1 - Two stop bits	When SB = 0, one stop bit is used to detect the end of a received frame, and one stop bit is transmitted at the end of each data frame. When SB = 1, two stop bits are used.

7.3.3 Serial Port Handshake Status Register (SPHS)

The SPHS reports the status of the $\overline{\text{DSR}}$ or $\overline{\text{CTS}}$ signal while the serial port transmitter is enabled. Figure 7-6 shows the SPHS bits.

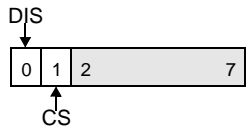


Figure 7-6. Serial Port Handshake Register (SPHS)

0	DIS	$\overline{\text{DSR}}$ Input Inactive Error: 0 - $\overline{\text{DSR}}$ input is active 1 - $\overline{\text{DSR}}$ input has gone inactive	To reset the DIS bit, the application software must store a 1 in this bit location at the address of the SPHS.
1	CS	$\overline{\text{CTS}}$ Input Inactive Error: 0 - $\overline{\text{CTS}}$ input is active 1 - $\overline{\text{CTS}}$ input has gone inactive	To reset the CS bit, the application software must store a 1 in this bit location at the address of the SPHS.
2:7		reserved	

7.3.4 Serial Port Line Status Register (SPLS)

The SPLS reflects the status of the serial port receiver and transmitter, and it reports errors detected in a received character. The bits in the SPLS are reset to 0 by writing a 1 to the bit positions using a store instruction. Writing a 0 to a bit position does not affect the bit value. Figure 7-7 shows the SPLS bits.

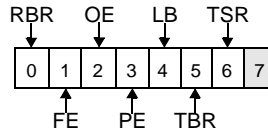


Figure 7-7. Serial Port Line Status Register (SPLS)

0	RBR	Receive Buffer Ready 0 - Receive buffer is not full 1 - Receive buffer is full	Reset by hardware when received data is read from the SPRB into a GPR using a load instruction or during chip reset; can be reset by software
1	FE	Framing Error 0 - No framing error detected 1 - Framing error detected	Must be reset by software
2	OE	Overrun Error 0 - No overrun error detected 1 - Overrun error detected	Must be reset by software
3	PE	Parity Error 0 - No parity error detected 1 - Parity error detected	Must be reset by software
4	LB	Line Break 0 - No line break detected 1 - Line break detected	Must be reset by software
5	TBR	Transmit Buffer Ready 0 - Transmit buffer is full (not ready) 1 - Transmit buffer is empty and ready	TBR is set to 1 whenever the SPTSR is loaded with a character from the SPTB. TBR is reset to 0 when a new character is stored in the SPTB.
6	TSR	Transmitter Shift Register Ready 0 - Transmitter Shift Register is full 1 - Transmitter Shift Register is empty	TSR is set to 1 whenever the SPTSR is empty. TSR is reset to 0 when a new character is transferred from the SPTB into the SPTSR and remains reset as characters are transmitted.
7		reserved	

7.3.5 Serial Port Receive Buffer (SPRB)

Figure 7-8 shows the SPRB field.

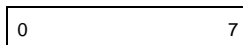


Figure 7-8. Serial Port Receive Buffer (SPRB)

0:7	Received Data
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7.3.6 Serial Port Receiver Command Register (SPRC)

The SPRC controls the serial port receiver. Figure 7-9 shows the fields in the SPRC.

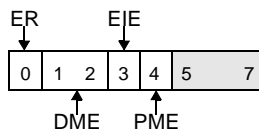


Figure 7-9. Serial Port Receiver Command Register (SPRC)

0	ER	Enable Receiver 0 - Disable receiver 1 - Enable receiver	For the serial port receiver to operate, ER must be set to 1. If ER is reset to 0, the serial port receiver is disabled, no data is shifted into the SPRSR, and no serial port receiver interrupts are active.
1:2	DME	DMA Mode, Interrupt Enable 00 - DMA is disabled; RBR interrupt is disabled 01 - DMA is disabled; RBR interrupt is enabled 10 - DMA is enabled; Receiver is source for DMA channel 2 11 - DMA is enabled; Receiver is source for DMA channel 3	
3	EIE	Error Interrupt Enable 0 - Receiver error interrupt disabled 1 - Receiver error interrupts enabled	
4	PME	Pause Mode Enable 0 - RTS is controlled by software 1 - RTS is controlled by hardware	
5:7		reserved	

7.3.7 Serial Port Transmit Buffer (SPTB)

The SPTB holds characters to be transmitted using the SPTSR. If the serial port transmitter is enabled and the SPTSR is empty, data loaded into the SPTB is loaded into the SPTSR and transmitted.

When data is loaded from the SPTB into the SPTSR, then SPLS[TBR] is set to 1 and SPLS[TSR] is reset to 0.

Figure 7-10 shows the SPTB field.

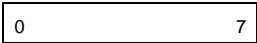


Figure 7-10. Serial Port Transmit Buffer (SPTB)

0:7		Transmit Data	Data to be transmitted by the SPTSR
-----	--	---------------	-------------------------------------

7.3.8 Serial Port Transmit Command Register (SPTC)

Figure 7-11 shows the SPTC fields.

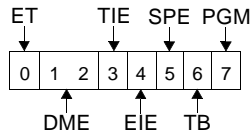


Figure 7-11. Serial Port Transmitter Command Register (SPTC)

0	ET	Enable Transmitter: 0 - Disable transmitter 1 - Enable transmitter (Chip Reset or System Reset clears to 0.)
1:2	DME	DMA Mode, Interrupt Enable 00 - DMA disabled; TBR interrupt disabled 01 - DMA disabled; TBR interrupt enabled 10 - DMA enabled; serial port transmitter is DMA channel 2 destination 11 - DMA enabled; serial port transmitter is DMA channel 3 destination
3	TIE	Transmitter Empty Interrupt Enable 0 - Transmitter shift register empty interrupt disabled 1 - Transmitter shift register empty interrupt enabled
4	EIE	Transmitter Error Interrupt Enable: 0 - Transmitter shift register error interrupt disabled 1 - Transmitter shift register error interrupt enabled
5	SPE	Stop/Pause on $\overline{\text{CTS}}$ Inactive 0 - Pause mode when $\overline{\text{CTS}}$ is inactive 1 - Stop mode when $\overline{\text{CTS}}$ is inactive
6	TB	Transmit Break 0 - Disable break character generation 1 - Enable break character generation
7	PGM	Pattern Generation Mode 0 - Disable pattern generation 1 - Enable pattern generation (Chip Reset or System Reset clears to 0.)

Instruction and Data Caches

The PPC403GC incorporates two internal caches, a 2KB instruction cache and a 1KB data cache. The Instruction Cache Unit (ICU) stores instructions to be passed as needed to the instruction queue in the Execution Unit (EXU). The Instruction Cache is used to minimize the access time of frequently executed instructions.

The Data Cache Unit (DCU) stores data blocks to be passed as needed between the EXU and external memory banks. The Data Cache is used to minimize the access time of frequently used data items in memory. The cache features byte-writeability to improve the performance of byte and halfword operations.

8.1 Instruction Cache Unit

The ICU contains a two-way set-associative 2KB cache memory. Each of the two ways is organized as 64 lines of 16 bytes (4 instructions) each. As shown in Figure 8-1, tag ways A and B store address bits $A_{0:21}$ for each instruction line in cache ways A and B.

The next six bits of each instruction address ($A_{22:27}$) serve as the index to the cache array. Two cache lines that correspond to the same line index (one in each way) are referred to as a congruence class.

Tags (2-way Set)		Instructions (2-way Set)	
Way A	Way B	Way A (4 words/line)	Way B (4 words/line)
$A_{0:21}$ Line 0A	$A_{0:21}$ Line 0B	Line 0A	Line 0B
$A_{0:21}$ Line 1A	$A_{0:21}$ Line 1B	Line 1A	Line 1B
2	2	2	2
2	2	2	2
2	2	2	2
$A_{0:21}$ Line 62A	$A_{0:21}$ Line 62B	Line 62A	Line 62B
$A_{0:21}$ Line 63A	$A_{0:21}$ Line 63B	Line 63A	Line 63B

Figure 8-1. Instruction Cache Organization

When a cache line is to be allocated, the side of the cache to receive the line is determined by using a Least Recently Used (LRU) policy. The index, determined by the instruction address, selects a congruence class. Within a congruence class, the line which is marked as Least-Recently-Used (LRU), via an LRU bit in the tag array, is replaced. The LRU bit is then set to identify as Least-Recently-Used the line opposite the line just filled.

As illustrated in Figure 8-2, the processor is capable, under some circumstances, of executing more than one instruction at a time. The ICU can send two instructions per cycle to the execution unit. This enables the incoming flow of instructions to keep pace with the execution rate.

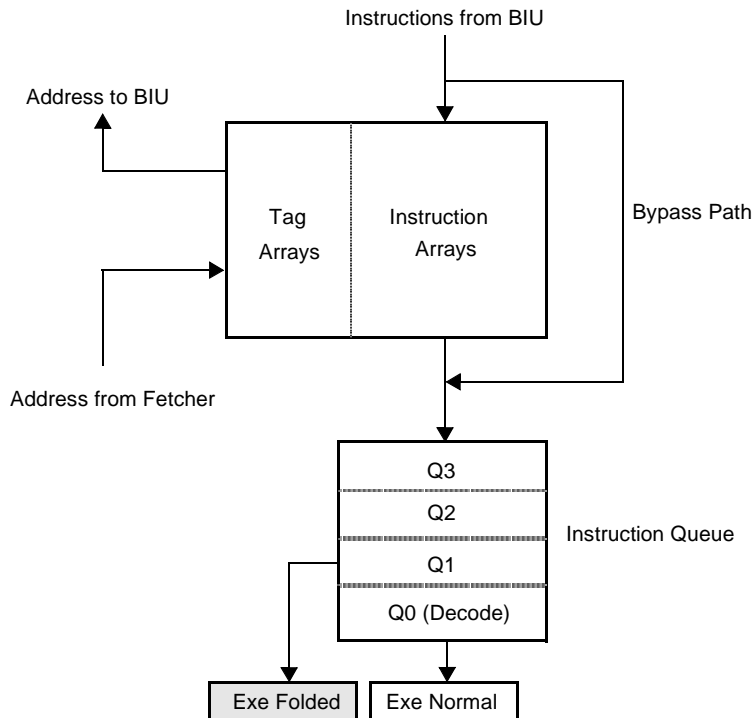


Figure 8-2. Instruction Flow

A separate bypass path is available to handle cache-inhibited instructions and to improve performance during line fill operations. If a request from the fetcher causes an entire line to be obtained from memory, the queue does not have to wait for the entire line to reach the cache. As soon as the target word (the word requested by the fetcher) is available, it is sent via the bypass path to the queue, while the line fill continues.

8.1.1 Instruction Cache Operations

The instruction cache is used to minimize access latency for frequently executed instructions. Instruction lines from cacheable memory regions are copied into the instruction cache, from which they can be accessed by the fetcher far more quickly than they can be obtained from memory. Cache lines are loaded either target-word-first or sequentially, controlled by bank register bit BRn[SLF] (see discussion on page 3-41). Target-word-first fills start at the requested fullword, continue to the end of the line, and then wrap around to fill the remaining fullwords at the beginning of the line. Sequential fills start at the first word of the cache line and proceed sequentially to the last word of the line.

Cache line fills will always run to completion, even if the instruction stream branches away from the rest of the line. The ICU buffers a full four-word line from the BIU, prior to placing the line into the cache during each fill. The initially requested instruction will be forwarded directly to the Instruction Dispatcher immediately upon receipt from the BIU. While the line buffer is filling, the ICU may service requests for additional instructions that hit in the cache. As the requested instructions are received from the BIU, they will be forwarded to the execution unit before the line is filled in the cache, if they are currently being requested by the fetcher. The filled line will always be placed in the Instruction Cache unless an external memory subsystem error (an Instruction Machine Check) occurs during the fill. The movement of the entire cache line from the buffer into the cache takes place in one clock cycle.

During one clock cycle, the cache can send either a single instruction or an aligned doubleword containing two instructions to the execution unit. Cache hits are sent as doublewords, while instructions arriving by the bypass path are sent as single words. The maximum execution rate is two instructions per cycle, so the bandwidth from the ICU of two instructions per cycle is ordinarily sufficient to keep the queue full.

8.1.2 Instruction Cacheability Control

When instruction address translation is disabled, cacheability for fetching is controlled by the Instruction Cache Cacheability Register (ICCR). A “1” in the ICCR means that caching is enabled (opposite of the meaning of the “I” bit in the TLB). Each bit in the ICCR controls cacheability on a 128MB region (see Section 9.5.1.3 on page 9-26).

When data translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

When instruction address translation is enabled ($MSR[IR] = 1$), cacheability for fetching is controlled by the “I” bit in the TLB entry for the memory page. If $I = 1$, then caching is inhibited. Cacheability is controlled separately for each page, which can range in size from 1KB to 16MB. Note that $MSR[IR]$ controls fetching behavior only; instruction cache ops use $MSR[DR]$, not $MSR[IR]$, to determine translation of their operands.

The sources of cacheability control are summarized in Table 8-1 below.

Table 8-1. Sources of Cacheability Control

Translation State		Cacheability Control Source		
$MSR[IR]$	$MSR[DR]$	For Instruction Fetching	For I-cache Operands	For D-cache Operands
0	0	ICCR	ICCR	DCCR
0	1	ICCR	TLB	TLB
1	0	TLB	ICCR	DCCR
1	1	TLB	TLB	TLB

The performance of the PPC403GC will be significantly lower while executing in cache disabled regions.

Programming Note:

If a data block corresponding to the effective address exists in the cache, but the effective address is non-cacheable, fetches to that address are considered programming errors (the cache block should previously have been invalidated). The only instructions that may legitimately access this effective address in the instruction cache are the cache management instructions **icbi**, **icbt**, **iccci**, and **icread**.

Following system reset, address translation is disabled and all ICCR bits are reset to zero so that no memory regions are cacheable. Before regions can be designated as cacheable in the ICCR, it is necessary to execute the **iccci** instruction 64 times, once for each congruence class in the cache array. This invalidates all 64 congruence classes prior to enabling the cache. The ICCR can then be reconfigured and the ICU can begin normal operation.

8.1.3 Instruction Cache Coherency

The Instruction Cache does not perform any “snooping” of external memory or the Data Cache; therefore, it will be necessary for the programmer to follow a set of special procedures for Instruction Cache synchronization if either self-modifying code is used or if storage containing instructions gets updated by a peripheral device. A code example illustrates the necessary steps for self-modifying code. This example assumes that `addr1` is both data and instruction cacheable.

```
stw      regN, addr1    # the data in regN is to become an instruction at addr1
dcbst    addr1          # forces data from the data cache to memory
sync                                           # wait until the data actually reaches the memory
icbi     addr1          # the previous value at addr1 might already be in
                        # the instruction cache; invalidate in the cache
isync                                           # the previous value at addr1 might already have been
                        # pre-fetched into the queue; invalidate the queue
                        # so that the instruction must be re-fetched
```

8.2 Data Cache Unit

The DCU manages data transfers between external cacheable memory and the general-purpose registers in the execution unit.

The DCU contains a two-way set-associative 1KB copy-back cache memory. Each of the two ways is organized as 32 lines of 16 bytes each. As shown in Figure 8-3, tag ways A and B store address bits $A_{0:22}$ for each data line in cache ways A and B.

The next five bits of each instruction address ($A_{23:27}$) serve as the index to the cache array. Two cache lines that correspond to the same line index (one in each way) are referred to as a congruence class.

Tags (2-way Set)		Data (2-way Set)	
Way A	Way B	Way A (16 bytes/line)	Way B (16 bytes/line)
$A_{0:22}$ Line 0A	$A_{0:22}$ Line 0B	Line 0A	Line 0B
$A_{0:22}$ Line 1A	$A_{0:22}$ Line 1B	Line 1A	Line 1B
2	2	2	2
2	2	2	2
2	2	2	2
$A_{0:22}$ Line 30A	$A_{0:22}$ Line 30B	Line 30A	Line 30B
$A_{0:22}$ Line 31A	$A_{0:22}$ Line 31B	Line 31A	Line 31B

Figure 8-3. Data Cache Organization

When a cache line is to be allocated, the side of the cache to receive the line is determined by using a Least Recently Used (LRU) policy. The index, determined by the data address, selects a congruence class. Within a congruence class, the line which is marked as Least-Recently-Used (LRU), via an LRU bit in the tag array, is replaced. The LRU bit is then set to identify as Least-Recently-Used the line opposite the line just filled.

Since the DCU is a copy-back cache, allocation of cache lines occurs on cache misses during either store or load operations.

A separate bypass path is available to handle cache-inhibited data operations and to improve performance during line fill operations.

8.2.1 Data Cache Operations

The data cache unit is used to minimize access latency for frequently used data in external memory. The DCU supports byte-writeability to improve the performance of byte and halfword store operations.

Cache flushing (copying data in the cache that has been updated by the processor to main storage) and filling (loading requested data from main storage into the cache) are triggered by Load, Store and Cache Control Instructions executed by the processor. Cache flushes are always sequential, starting at the first word of the cache block and proceeding sequentially to the end of the block.

Cache lines are loaded either target-word-first or sequentially, controlled by bank register bit BRn[SLF] (see discussion on page 3-41). Target-word-first fills start at the requested fullword, continue to the end of the line, and then wrap around to fill the remaining fullwords at the beginning of the line. Sequential fills start at the first word of the cache line and proceed sequentially to the last word of the line. The words are placed into the cache as received, and the line is marked valid when the fourth word is filled. The GPRs receive the requested byte, halfword, or fullword of data immediately upon being received from main storage via a cache bypass mechanism, so that the program does not have to wait for the completion of the entire line fill. Subsequent requests to the cache line being filled are also forwarded. Subsequent load or store instructions that hit in the cache (to any line except the one being filled) can be serviced during the line fill, in cycles in which a word is not being received from the BIU.

Cache lines are always flushed or filled in their entirety, even if the program does not request the rest of the bytes in the line, and even if an external memory subsystem error (Data Machine Check) occurs during the flush or fill operation.

8.2.2 Data Cache Write Strategy

8.2.2.1 Copy-back Strategy

PPC403GC DCU operations employ a copy-back (store-in) strategy to update cached data and maintain coherency with external memory. A copy-back cache updates only the data cache, not external memory, during store operations. Only data lines that have been modified are flushed to external memory, and then only when it is necessary to free up locations for incoming lines, or when the lines are explicitly written using **dcbf** or **dcbst** instructions. Cache flushes are always sequential, starting at the first word of the cache block and proceeding sequentially to the end of the block.

A copy-back strategy is contrasted with a write-thru strategy, in which stores are written simultaneously to the cache and to the memory. The copy-back strategy used by the PPC403GC minimizes the amount of external bus activity, and avoids unnecessary contention for the external bus between the Instruction Cache and the Data Cache.

8.2.2.2 Write-thru Strategy

A write-thru strategy may make it easier to maintain coherency between cache and memory, at the expense of slower execution of cacheable stores. While the PPC403GC does not provide write-thru caching in hardware, it does provide a storage attribute that selects write-thru. If write-thru is selected, alignment exceptions occur on any store-type accesses (except **dcbi** and **dccci**) to allow software to emulate the write-thru function. In real mode, data cache write-thru may be controlled on 128MB regions via the Data Cache Write-thru Register (DCWR); see Section 9.5.1.1 on page 9-22. In virtual mode, data cache write-thru policy is controlled on memory page size regions by the “W” bit in the TLB entry.

Programming Note:

The PowerPC Architecture does not support memory models in which write-thru is enabled and caching is inhibited.

Note that PPC403GC hardware does not initialize DCWR on power-up or reset. Software must initialize (DCWR) $\leftarrow 0$ prior to the first store operation if alignment exceptions are to be avoided.

8.2.3 Data Cacheability Control

8

When data address translation is disabled, cacheability is controlled by the Data Cache Cacheability Register (DCCR). A “1” in the DCCR means that caching is enabled (opposite of the meaning of the “I” bit in the TLB). Each bit in the DCCR controls cacheability on a 128MB region (see Section 9.5.1.2 on page 9-24).

When data address translation is enabled, cacheability is controlled by the “I” bit in the TLB entry for the memory page. If I = 1, then caching is inhibited. Cacheability is controlled separately for each page, which can range in size from 1KB to 16MB.

The sources of cacheability control are summarized in Table 8-1 on page 8-4.

Programming Note:

If a data block corresponding to the effective address exists in the cache, but the effective address is non-cacheable, loads and stores (including **dcbz**) to that address are considered programming errors (the cache block should previously have been flushed). The only instructions that may legitimately access this effective address in the data cache are the cache management instructions **dcbf**, **dcbi**, **dcbst**, **dcbt**, **dcbstst**, **dccci**, and **dcread**.

Following system reset, address translation is disabled and all DCCR bits are reset to zero so that no memory regions are cacheable. Before regions can be designated as cacheable in the DCCR, it is necessary to execute the **dccci** instruction 32 times, once for each congruence class in the cache array. This invalidates all 32 congruence classes prior to enabling the cache. The DCCR can then be reconfigured and the DCU can begin normal operation.

8.2.4 Data Cache Coherency

The Data Cache does not provide any snooping facilities; therefore, the application program must make careful use of disabled regions and cache control instructions in order to ensure proper operation of the cache in systems where external devices are capable of updating memory.

8.3 Cache Instructions

8.3.1 ICU Instructions

The following instructions are used to control instruction cache operations. For details on these instructions, see chapter 10, “Instruction Set”. In the PPC403GC, a block is implemented as one cache line of 16 bytes. A cache line is the unit of storage affected by all cache block instructions.

- **icbi** Instruction cache block invalidate.

This instruction is issued to invalidate an individual line.

- **icbt** Instruction cache block touch.

A block fill is initiated by issuing this instruction. This instruction may be used to pre-load execution-time-sensitive code into the cache, prior to the first attempt to execute the code. This is a privileged-mode instruction.

- **iccci** Instruction cache congruence class invalidate.

A congruence class of two lines is invalidated by issuing this instruction. This is a privileged-mode instruction.

Because **iccci** can cause TLB-miss exceptions, it is not recommended to use **iccci** when MSR[DR] = 1; if it is used, care should be taken that the specific operand address will not cause an exception.

- **icread** instruction cache read.

This is a debugging instruction which reads either an instruction cache tag entry, or an instruction word from an instruction cache line. The behavior of the instruction is controlled by bits in the CDBCR (see Section 8.4 on page 8-12). This is a privileged-mode instruction.

8.3.2 DCU Instructions

Data cache flushes and fills are triggered by load, store and cache control instructions executed by the processor. Cache control instructions are provided to fill, flush, or invalidate cache lines. The following instructions are used to control data cache operations. For details on these instructions, see chapter 10, “Instruction Set”.

- **dcbf** data cache block flush.

This instruction causes a line, if found in the cache and marked as modified, to be flushed to external memory; the line is then marked invalid. This operation is performed regardless of whether the address is marked as cacheable.

- **dcbi** data cache block invalidate.

This instruction causes a line, if found in the cache, to be invalidated without regard to cacheability status. The invalidation is performed without flushing any modified data to memory. This is a privileged-mode instruction.

- **dcbst** data cache block store.

This instruction causes a line, if found in the cache and marked as modified, to be stored to external memory. If the line is not marked as modified, no action is performed. Lines in the cache are not invalidated by this instruction. This operation is performed regardless of whether the address is marked as cacheable.

- **dcbt** data cache block touch.

This instruction causes a cacheable line to be filled into the cache, if not already there. If the address is noncacheable, this instruction is a no-op.

- **dcbtst** data cache block touch for store.

This instruction functions identically to the **dcbt** instruction on the PPC403GC, and is provided for compatibility with compilers and other tools.

- **dcbz** data cache block set to zero.

This instruction causes a line in the cache to be filled with zeros and marked as modified. If the line is not currently in the cache (and the address is marked as cacheable and non-write-thru), the line is established, filled with zeros, and marked as modified without actually filling the line from external memory. If the line is marked as either non-cacheable or write-thru, an alignment exception results.

- **dccci** data cache congruence class invalidate.

A congruence class of two lines is invalidated by issuing this instruction. This is a privileged-mode instruction.

Because **dccci** can cause data storage and TLB-miss exceptions, it is not recommended to use **dccci** when $\text{MSR}[\text{DR}] = 1$; if it is used, care should be taken that the specific operand address will not cause an exception.

- **dcread** data cache read.

This is a debugging instruction which reads either a data cache tag entry, or a data word from a data cache line. The behavior of the instruction is controlled by bits in the CDBCR. This is a privileged-mode instruction.

8.4 Cache Debugging Features

To aid in the debug of cache problems, special resources are provided. For ICU debug, the **icread** instruction and the ICDBDR special purpose register are provided (see Section 8.4.1 on page 8-13). For DCU debug, the **dcread** instruction is provided (see Section 8.4.2 on page 8-14). Both the **icread** and the **dcread** instructions are controlled by the CDBCR special purpose register.

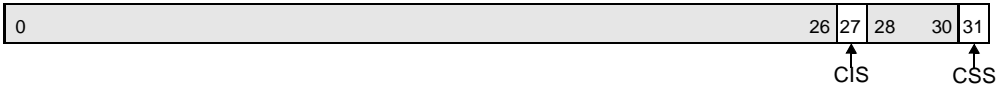


Figure 8-4. Cache Debug Control Register (CDBCR)

0:26		reserved
27	CIS	Cache Information Select 0 - Information is cache Data 1 - Information is cache Tag
28:30		reserved
31	CSS	Cache Side Select 0 - Cache side is A 1 - Cache side is B

8.4.1 ICU Debugging

The **icread** instruction (detailed description on page 11-74) is a debugging tool for reading the instruction cache entries for the congruence class specified by EA_{22:27}. The cache information will be read into the Instruction Cache Debug Data Register (ICDBDR), from where it can subsequently be moved into a GPR via a **mfspr** instruction.

0	31
---	----

Figure 8-5. Instruction Cache Debug Data Register (ICDBDR)

0:31	Instruction Cache Information	see icread , page 11-74
------	-------------------------------	--------------------------------

If (CDBCR[CIS] = 0), the information will be one word of instruction cache data from the addressed line. The word is specified by EA_{28:29}. If (CDBCR[CSS] = 0), the data will be from the A-side, otherwise from the B-side.

If (CDBCR[CIS] = 1), the information will be the cache tag. If (CDBCR[CSS] = 0), the tag will be from the A-side, otherwise from the B-side. Instruction cache tag information is placed into the ICDBDR as follows:

0:21	TAG	Cache Tag
22:26		reserved
27	V	Cache Line Valid 0 - Not valid 1 - Valid
28:30		reserved
31	LRU	Least Recently Used 0 - A side least-recently-used 1 - B side least-recently-used

8.4.2 DCU Debugging

The **dcread** instruction (detailed description on page 11-60) is a debugging tool for reading the data cache entries for the congruence class specified by $EA_{23:27}$. The cache information will be read into a General Purpose Register.

If $(CDBCR[CIS] = 0)$, the information will be one word of data-cache data from the addressed line. The word is specified by $EA_{28:29}$ (an alignment exception will result if $EA_{30:31} \neq 00$). If $(CDBCR[CSS] = 0)$, the data will be from the A-side, otherwise from the B-side.

If $(CDBCR[CIS] = 1)$, the information will be the cache tag. If $(CDBCR[CSS] = 0)$, the tag will be from the A-side, otherwise from the B-side. Data cache tag information is placed into the GPR as follows:

0:22	TAG	Cache Tag
23:25		reserved
26	D	Cache Line Dirty 0 - Not dirty 1 - Dirty
27	V	Cache Line Valid 0 - Not valid 1 - Valid
28:30		reserved
31	LRU	Least Recently Used 0 - A side least-recently-used 1 - B side least-recently-used

Note:

“Dirty” means that the cache line has been accessed via a store instruction since it was established, and could possibly be inconsistent with external memory.

Memory Management

The PPC403GC Memory Management Unit (MMU) provides address translation and protection functions for embedded applications. Together with appropriate system level software, the MMU provides the following functions:

- Translation of 4GB logical address space into physical addresses
- Independent enable of Instruction and Data translation / protection
- Page level access control via the translation mechanism
- Software control of page replacement strategy
- Additional virtual-mode control over protection via zones
- Real-mode write protection mechanism

9.1 Translation

The instruction unit generates all instruction addresses; these addresses are both for sequential instruction fetches and addresses that correspond to a change in program flow (branches and interrupts). The integer unit generates addresses for data accesses. Both instruction and data effective addresses are translated by the MMU, yielding real addresses which are sent to the storage subsystem. In particular, both the instruction and data cache are accessed with real addresses.

The PPC403GC MMU supports demand paged virtual memory as well as a variety of other management schemes that depend on precise control of logical to physical address mapping and flexible memory protection. Translation misses and protection faults cause precise exceptions. Sufficient information is available to correct the fault and restart the faulting instruction.

The MMU divides logical storage into pages. The page represents the granularity of logical address translation and protection control. Eight page sizes (1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M) are simultaneously supported. In order for a logical to physical translation to exist, a valid entry for the page containing the logical address must be in the TLB (Translation Lookaside Buffer). Addresses for which no TLB entry exists cause TLB-Miss exceptions.

Translation is activated via bits in the MSR (Machine State Register). The IR (Instruction Relocate) bit activates the translation mechanism for instruction accesses, and the DR

(Data Relocate) bit activates the translation mechanism for data accesses. These bits may be specified independently and changed at any time by a program in supervisor state. Note that IR and DR are cleared and the processor is placed in the supervisor state by any exception. Any subsequent discussion about translation or protection will assume that the appropriate IR or DR bit in the MSR is set.

9.1.1 Virtual to Real Address Translation

A program references memory using the effective address computed by the processor when it executes a load, store, branch, or cache instruction, and when it fetches the next instruction. The effective address is translated to a real address according to the procedures described in this section. The memory subsystem uses the real address for the access.

In the translation process, the effective address and an 8-bit process ID are used to create a 40-bit virtual address. This address is used to locate the associated entry in the Translation Lookaside Buffer (TLB). The TLB contains pointers to the location in physical memory where the data referred to by the virtual address is contained. See Figure 9-1.

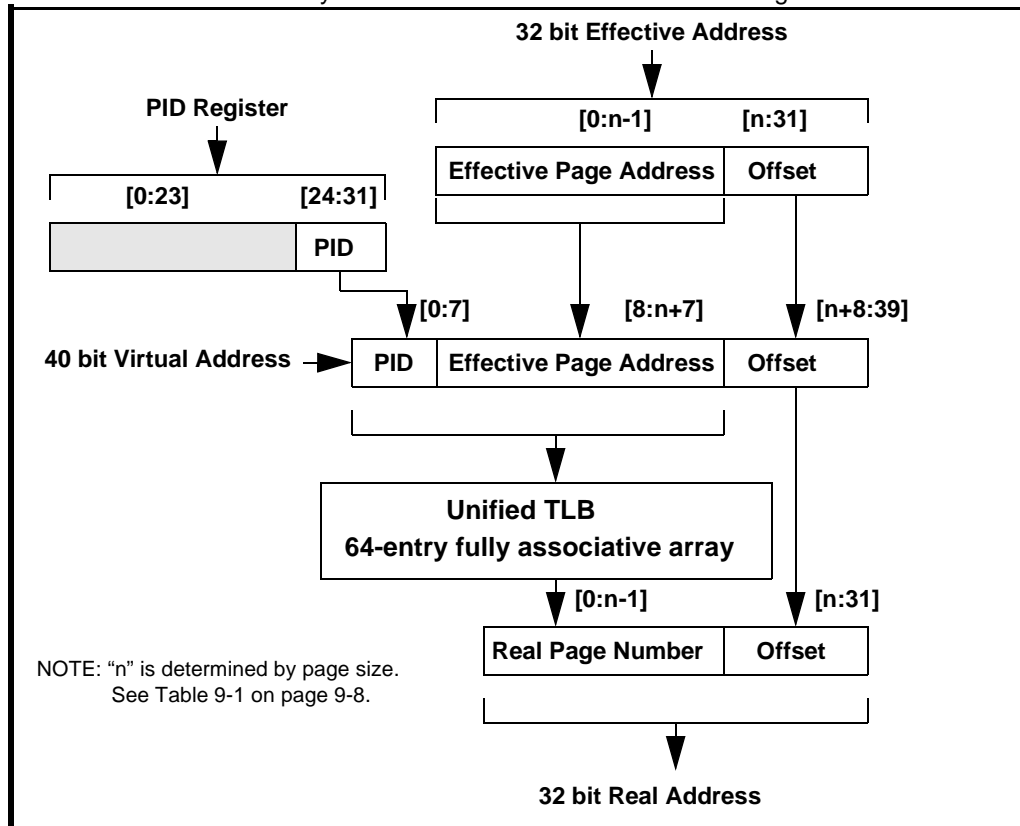


Figure 9-1. Effective to Real Address Translation Flow

9.2 Translation Lookaside Buffer (TLB)

The TLB is the hardware resource that controls translation, protection, and storage attributes. The instruction and data units share one unified 64-entry, fully-associative TLB. Fully associative means that a given page entry can be placed anywhere in the TLB. Maintenance of TLB entries is under software control. System level software completely determines TLB entry replacement strategy and the format and use of any page state information. The TLB entry contains all the information required to identify the page, to specify the translation and protection controls, and to specify the storage attributes. Subsequent sections will describe the fields in detail.

Caution for TLB users:

- No access to the TLB may occur within 700 nsec from any of the following:
 - the deactivation of Reset;
 - any change of SysClk frequency, including the restart of SysClk from a stopped state (change of SysClk duty cycle does not require access restrictions);
 - enabling normal-power operation by clearing IOCR[SPD] to 0.
- No access to the TLB may occur while the chip is in the power-reduced mode set by IOCR[SPD] = 1. This power-reduced mode is intended for achieving minimum chip power dissipation in a clock-stopped state; it is not intended for use during normal chip operation.

9.2.1 Unified TLB

The main Unified TLB (UTLB) contains a HI (Tag) portion and a LO (Data) portion with 64 entries each. The Tag portion contains 34 bits per entry, and the Data portion contains 32 bits per entry. In normal operation with translation enabled, the UTLB Tag portion compares some or all of the Effective Address bits $EA_{0:21}$ with some or all of the Effective Page Number bits $EPN_{0:21}$ based on the Size bits $SIZE_{0:2}$. 64 entries are simultaneously checked for a match. If an entry matches, the corresponding Data portion of the UTLB provides the Real Page Number (RPN), access control bits (ZSEL, EX, WR), and storage attributes (W, I, M, G). It is considered a programming violation if multiple entries match during a TLB look-up, and the results of such a look-up are undefined.

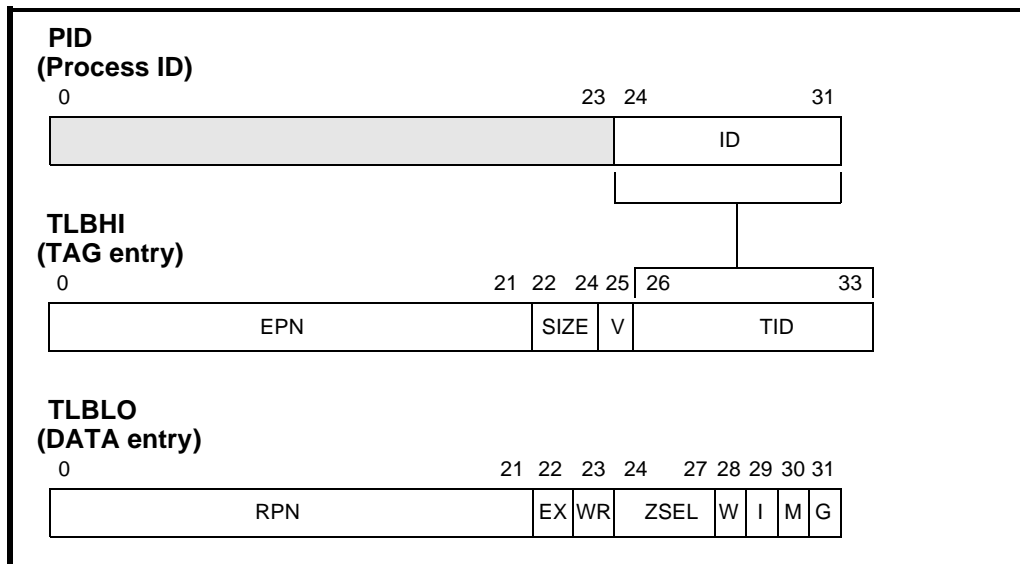


Figure 9-2. TLB Entries

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The virtual address space has also been extended by adding an 8-bit Process ID (PID) register and an associated Translation ID (TID) field in the TLB which is also compared during the TLB look-up. See Section 9.4.1.1 (TID Protection) on page 9-15 for a discussion of the PID.

The Tag and Data entries are written by copying information from the GPRs and the PID, using the **tlbwe** instruction (see page 11-172). The Tag and Data entries are read by copying information to GPRs and the PID, using the **tlbre** instruction (see page 11-168). Software can also search for specific entries using the **tlbsx** instruction (see page 11-170).

9.2.2 Shadow Instruction TLB (ITLB)

As a performance enhancement, there are 4 instruction-side TLB entries kept in a shadow array managed by hardware. This array, called the Instruction TLB (ITLB), is intended to avoid TLB contention between instruction accesses to the TLB and load/store operations. Replacement and invalidation of these entries is managed by hardware during routine execution (see Section 9.2.2.1, ITLB Consistency, on page 9-7 for details).

The ITLB is a four-entry fully-associative array which can be thought of as a level-1 instruction-side TLB, with the main TLB serving as a level-2 instruction-side and a level-1 data-side TLB. The ITLB is used only by instruction fetch accesses for storing instruction address translations. Each ITLB entry contains the translation information for a page. The processor uses the ITLB for address translation of instruction accesses when $MSR[IR] = 1$.

The instruction unit accesses the ITLB independently of the rest of the MMU. Accesses to the ITLB are transparent to the executing program, except that hits in the ITLB contribute to a higher overall instruction throughput by allowing data translations to occur in parallel. Therefore, when instruction accesses hit in the ITLB, the address translation mechanisms in the UTLB are available for use by data accesses simultaneously.

The Shadow ITLB automatically requests a new entry from the UTLB when an ITLB miss is encountered. A 2-cycle penalty occurs at each ITLB miss that is also a UTLB hit; the penalty is larger if it is also a UTLB miss. A round robin replacement algorithm is used to replace existing entries with new entries.

Figure 9-3 illustrates the relation of ITLB and UTLB in address translation:

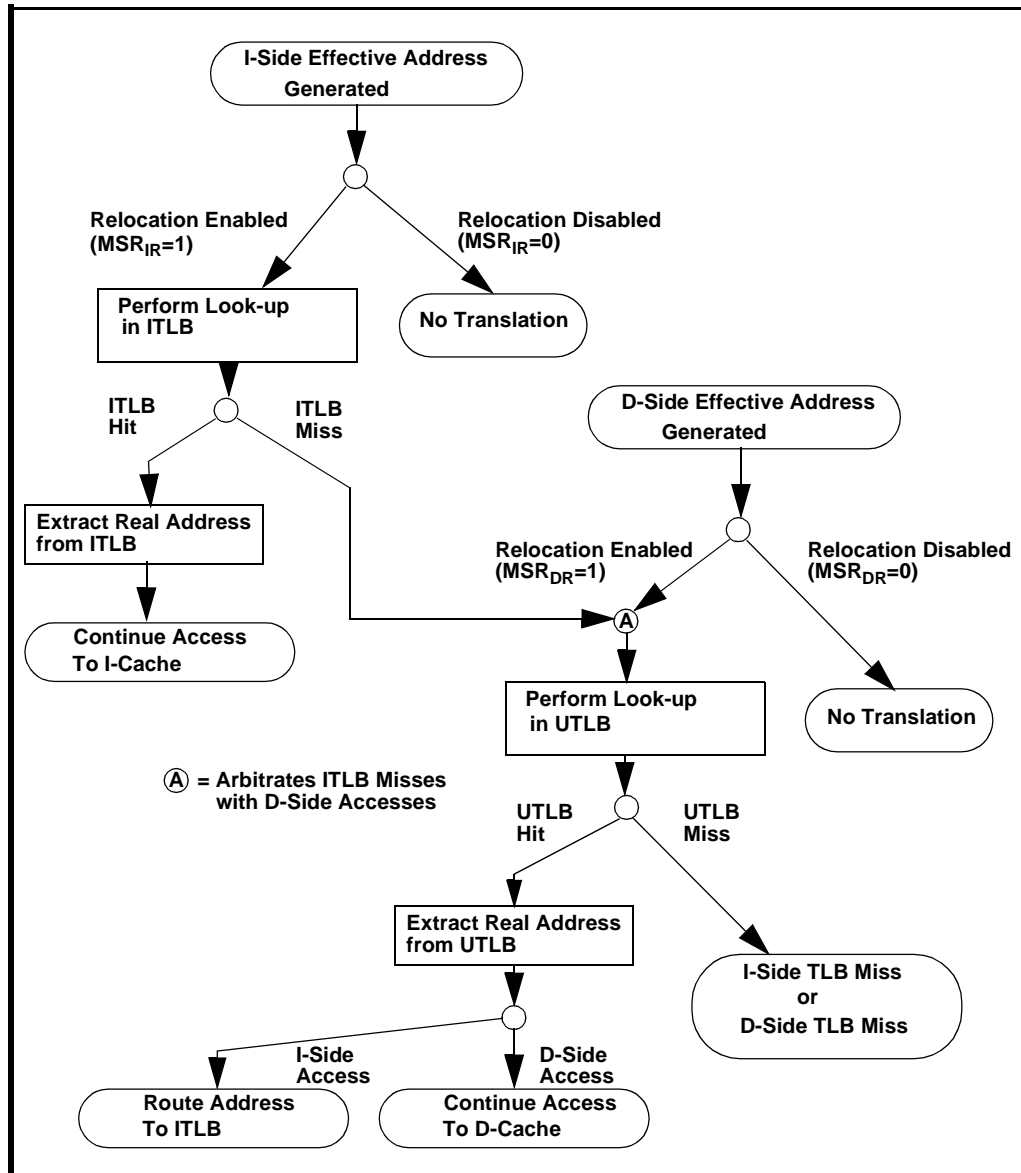


Figure 9-3. ITLB/UTLB Address Resolution

9.2.2.1 ITLB Consistency

The processor assists in maintaining the integrity of the entries in the ITLB by invalidating the entire contents under certain conditions. The conditions under which this will happen are:

- **isync** instruction
- processor context switch (all interrupts, **rfi**, **rfci**)

Essentially, the ITLB is only invalidated when a context synchronizing event occurs. These include all interrupts (including **sc** instruction execution) and the instructions **rfi**, **rfci**, and **isync**. If software performs updates to the translation/protection mechanism (main TLB, PID, ZPR, or MSR) and wishes to synchronize these updates with the ITLB, then software must perform the necessary context synch.

A typical example would be the manipulation of the TLB by an operating system within an interrupt handler for a TLB-miss. On entry to the interrupt handler, the ITLB was invalidated and translation was disabled. If the operating system simply made the TLB-updates and returned from the handler (**rfi**), then no additional explicit software action would be required to synchronize the ITLB.

If, instead, the operating system re-enabled translation within the handler, and then performed TLB-updates within the handler, those updates would not be effective in the ITLB until the **rfi** to return from the handler. For those TLB-updates to be reflected in the ITLB within the handler, an **isync** must be issued after the TLB-updates are done. Failure to properly synchronize the ITLB can cause unexpected behavior.

Programming Note:

A good rule-of-thumb is to follow any software manipulation of the translation mechanism while translation is active by a context synchronizing operation, usually **isync**.

9.2.3 TLB Fields

Each TLB entry describes a page that is eligible for translation and access controls. Fields in the TLB entry fall into four categories: information required to identify the page to the hardware translation mechanism; control information specifying the translation; access control information; and storage attribute control information.

9.2.3.1 Page Identification Fields

When an effective address is presented to the MMU for processing, the MMU applies several selection criteria to each TLB entry to select the appropriate entry. Although it is possible to place multiple entries into the TLB that match a specific effective address and PID, this is considered a programming error and the results are undefined. The following fields in the TLB entry identify the page. Except as noted, all comparisons must succeed to validate this entry for subsequent processing.

EPN — Effective Page Number (22 bits)

This field is compared to some number of bits 0:21 of the Effective Address (EA) presented to the MMU. The exact comparison depends on the page size and is specified in Table 9-1 below:

Table 9-1. TLB Fields Related to Page Size

Page Size	SIZE Field	“n” Bits Compared	EPN to EA Comparison	RPN Bits Required = 0
1KB	000	22	$EPN_{0:21} \leftrightarrow EA_{0:21}$	none
4KB	001	20	$EPN_{0:19} \leftrightarrow EA_{0:19}$	$RPN_{20:21} = 0$
16KB	010	18	$EPN_{0:17} \leftrightarrow EA_{0:17}$	$RPN_{18:21} = 0$
64KB	011	16	$EPN_{0:15} \leftrightarrow EA_{0:15}$	$RPN_{16:21} = 0$
256KB	100	14	$EPN_{0:13} \leftrightarrow EA_{0:13}$	$RPN_{14:21} = 0$
1MB	101	12	$EPN_{0:11} \leftrightarrow EA_{0:11}$	$RPN_{12:21} = 0$
4MB	110	10	$EPN_{0:9} \leftrightarrow EA_{0:9}$	$RPN_{10:21} = 0$
16MB	111	8	$EPN_{0:7} \leftrightarrow EA_{0:7}$	$RPN_{8:21} = 0$

SIZE — Page Size (3 bits)

Selects 1 of 8 page sizes, 1KB through 16MB; see Table 9-1 above.

V — Valid (1 bit)

This bit indicates that this TLB entry is valid and may be used for translation. The presence of a valid TLB entry implies read access unless overridden by zone

protection. The valid bit can be written with a TLB write instruction (**tlbwe**) or can be flash invalidated by a TLB Invalidate All instruction (**tlbia**).

TID — Translation ID (8 bits)

This field is loaded from the PID register during a TLB write (**tlbwe**) operation. The value of the TID field is compared with the value of the Process ID (PID) register (see Figure 9-4 on page 9-15) during TLB accesses, as an extension to the effective address. This mechanism provides a convenient way to associate a translation with one of 255 unique software entities, typically a process or thread maintained by system level software. A TID value of 0x00 disables the TID/PID comparison and can be used to identify a TLB entry as valid for all processes, i.e. the current value of the PID is irrelevant for a TLB entry with a TID value of 0x00.

9.2.3.2 Translation Fields

After a TLB entry has been identified as matching the effective address and (possibly) the PID, the following field defines how the effective address will be translated:

RPN — Real Page Number (22 bits)

The RPN bits are used to replace some (or all) of EA_{0:21}, according to page size. For example, a 16K page uses EA_{0:17} for comparison. The translation mechanism replaces EA_{0:17} with RPN_{0:17} to form the physical address, and EA_{18:31} carries forward to become the real page offset. See Figure 9-1 on page 9-2.

NOTE: Software is required to set all unused bits of RPN (as determined by page size) to 0. See Table 9-1 on page 9-8.

9.2.3.3 Access Control Fields

ZSEL — Zone Select (4 bits)

This field selects one of 16 zone fields (Z0-Z15) from the Zone Protection Register (ZPR). The ZPR field bits are used to modify the access protection specified by the V, EX, and WR bits of the TLB entry and is described in detail in Section 9.4.1.4 (Zone Protection) on page 9-16.

EX — Execute Enable (1 bit)

When set, instruction execution is allowed at addresses within this page. ZPR settings may override the EX bit; see Section 9.4.1.4 (Zone Protection) on page 9-16.

WR — Write Enable (1 bit)

When set, store operations are permitted to addresses within this page. ZPR settings may override the WR bit; see Section 9.4.1.4 (Zone Protection) on page 9-16.

9.2.3.4 Storage Attribute Fields

W — Write Through (1 bit)

When an access is designated as write-through (W=1), if the data is in cache, a store

operation updates the cached copy of the data and the external memory location. Contrast this with a copy-back policy, which updates the memory location only when the cache line is cast out. In PPC403GC the data cache does not support write-through operation; therefore, when the W bit is active, a store operation will cause an alignment exception, allowing software to emulate this function.

In real mode, the function of the “W” bit is handled by the Data Cache Write-thru Register (DCWR).

Note that the write-through attribute only applies to the data cache.

Note that the PowerPC Architecture does not support memory models in which write-through is enabled and caching is inhibited. It is considered a programming error to use these memory models. The results of this programming error are boundedly undefined.

I — Inhibited (1 bit)

If I=1, the memory access is completed by referencing the location in main memory, bypassing the chip cache. During the access, the accessed location is not put into the cache.

In real mode, the function of the “I” bit is handled by the Instruction Cache Cacheability Register (ICCR) and the Data Cache Cacheability Register (DCCR). In these real-mode registers, the polarity of the bit is reversed (“1” is cacheable, rather than inhibited).

Note that the PowerPC Architecture does not support memory models in which write-through is enabled and caching is inhibited. It is considered a programming error to use these memory models. The results of this programming error are boundedly undefined.

It is considered a programming error if the target location of a load, store, **dcbz**, or fetch access to caching inhibited storage is in the cache. The results of this programming error are boundedly undefined. It is not considered a programming error for the target locations of other cache management instructions to caching inhibited storage to be in the cache.

M — Memory Coherent (1 bit)

Architecturally, for implementations that support multiprocessing, this storage attribute bit is provided to allow improved performance in systems where hardware-enforced coherency is relatively slow, and software is able to enforce the required coherency. When M=0, the processor does not enforce data coherency. When M=1, the processor enforces data coherency and the corresponding access is considered to be a global access. PPC403GC does not provide multi-processor support nor hardware support for cache coherency; the M bit is implemented, but has no effect.

G — Guarded (1 bit)

When set, indicates that the hardware may not speculatively access the location for prefetch or out-of-order load access. This facility is typically used to protect Memory-Mapped I/O from inadvertent access. Attempted execution of an instruction from an address for which G = 1 while instruction translation is enabled will produce an Instruction Storage exception.

In real mode, the function of the “G” bit is handled by the Storage Guarded Register (SGR).

9.3 TLB Operations

9.3.1 Exceptions

The processor relies on the exception processing mechanism for the implementation of the paged virtual memory environment and for enforcing protection of designated memory areas.

Whenever an enabled exception (an interrupt) occurs, the processor clears both the MSR[IR] and MSR[DR] bits. Therefore, at least at the beginning of all exception handlers, the processor operates in real mode for instruction accesses and data accesses. Note that when address translation is disabled (MSR[IR] = 0 and MSR[DR] = 0) for a particular access (fetch, load, or store), the effective address is treated as the real address and is passed directly to the memory subsystem (including caches) as a direct address. Such direct addresses bypass all memory protection checks of the MMU except for Protection Bounds checking (see Section 9.4.2 on page 9-18).

The MMU generates the following exceptions:

9.3.1.1 Data Storage Exception

A Data Storage exception is generated when data translation is active and the desired access to the effective address is not permitted for any of the following reasons:

- In Problem State
 - Data load, store, **icbi**, **dcbz**, **dcbst**, or **dcbf** with an effective address with (ZPR field) = 00. (**dcbt** and **dcbtst** will no-op in this situation, rather than cause an exception. Privileged instructions cannot cause (ZPR field) = 00 Data Storage exceptions.)
 - Data store or **dcbz** to an effective address with the WR bit clear and (ZPR field) ≠ 11. (The privileged instructions **dcbi** and **dccci** are treated as “stores”, but will cause Program exceptions, rather than Data Storage exceptions.)
- In Supervisor State
 - Data store, **dcbi**, **dcbz**, or **dccci** to an effective address with the WR bit clear and (ZPR field) other than 11 or 10.

See Section 9.4.1.4 on page 9-16 for a detailed discussion of the Zone Protection mechanism. See Section 6.5 on page 6-21 for a detailed discussion of the Data Storage exception.

9.3.1.2 Instruction Storage Exception

An Instruction Access Exception is generated when instruction translation is active and execution is attempted for an instruction whose fetch access to the effective address is not permitted for any of the following reasons:

- In Problem State
 - Instruction fetch from an effective address with (ZPR field) = 00.
 - Instruction fetch from an effective address with the EX bit clear and (ZPR field) \neq 11.
 - Instruction fetch from an effective address contained within a Guarded region (G=1).
- In Supervisor State
 - Instruction fetch from an effective address with the EX bit clear and (ZPR field) other than 11 or 10.
 - Instruction fetch from an effective address contained within a Guarded region (G=1).

See Section 9.4.1.4 on page 9-16 for a detailed discussion of the Zone Protection mechanism. See Section 6.6 on page 6-23 for a detailed discussion of the Instruction Storage exception.

9.3.1.3 Data TLB Miss Exception

The Data TLB Miss Exception is generated if data translation is enabled and a valid TLB entry matching the effective address and PID is not present. The exception applies to data access instructions and cache ops (excluding cache touch instructions).

See Section 6.14 on page 6-36 for a detailed discussion.

9.3.1.4 Instruction TLB Miss Exception

The Instruction TLB Miss Exception is generated if instruction translation is enabled and execution is attempted for an instruction for which a valid TLB entry matching the effective address and PID for the instruction fetch is not present.

See Section 6.15 on page 6-37 for a detailed discussion.

9.3.2 Page Reference and Change Recording

When performing physical page management, it is useful to know whether a given physical page has been referenced or altered. Note that this may be more involved than whether a given TLB entry has been used to reference or alter memory, since multiple TLB entries may translate to the same physical page. If it is necessary to replace the contents of some physical page with other contents, a page which has been “referenced” (accessed for any purpose) is more likely to be maintained than a page which has never been referenced. If the contents of a given physical page are to be replaced, then the contents of that page must be written to the backing store before replacement, if anything in that page has been changed. Software must maintain records to control this process.

Similarly, when performing TLB management, it is useful to know whether a given TLB entry has been referenced. When making a decision about which entry to cast-out of the TLB, an entry which has been referenced is more likely to be maintained in the TLB than an entry which has never been referenced.

The PPC403GC does not maintain hardware reference bits, but TLB-miss exceptions may be used to allow software to maintain reference information for a TLB entry and for its associated physical page. The entry is built, with its Valid bit and its WR bit off, and the index and effective page number of the entry are retained by software. The first attempt of application code to use the page will cause a miss exception (because the entry is marked invalid). The miss handler records the reference to the TLB entry and to the associated physical page in a software table, and then turns on the Valid bit (note that the Valid bit itself may be regarded as a reference bit for the TLB entry). Subsequent read accesses to the page via this TLB entry will proceed normally.

In a demand-paged environment, when the contents of a physical page are to be replaced, if any storage in that physical page has been altered, then the backing storage must be updated. The information that a physical page is dirty is typically recorded in a “change” bit for that page.

The PPC403GC does not maintain hardware change bits, but Data Storage exceptions may be used to allow software to maintain change information for a physical page. For the example just given for reference recording, the first write access to the page via the TLB entry, after the entry has been made valid, will create a $WR = 0$ Data Storage exception. The miss handler records the change to the physical page in a software table, and then turns on the WR bit. All subsequent accesses to the page via this TLB entry will proceed normally.

9.3.3 TLB Reload

The processor does not imply any format for the page tables or the page table entries. Software has significant flexibility in implementing a custom replacement strategy. For example, it is possible for software is to “lock” TLB entries that correspond to frequently used storage, so that those entries are never cast out of the TLB, and TLB-miss exceptions to those pages never occur.

The TLB reload (tablewalk) function is performed in software with some hardware assist. This hardware assist consists of:

- Automatic storage of the missed effective address in the SRR0 register for I-side miss or in DEAR for D-side miss.
- Instructions for reading, writing, searching, and invalidating the TLB, as described briefly in the following sections:

9.3.3.1 TLB Search Instruction (**tlbsx** / **tlbsx.**)

The TLB search instruction (**tlbsx** RT,RA,RB) is used for locating entries in the TLB (to find the TLB entry associated with an exception, or to locate candidate entries to cast out). This instruction searches through the UTLB array looking for a matching entry. The value to be matched is the effective address, $EA = (RA|0) + (RB)$.

If found, an index of the entry is placed in bits 26:31 of RT. Register RT can then be used as the source register for a **tlbre** or **tlbwe** instruction, to read or write the entry itself. If the match was not found, the contents of RT are undefined.

In the case of the TLB search (**tlbsx.** RT,RA,RB) instruction, the condition register CR0[EQ] bit is set based on whether the entry is found (1 = found, 0 = not found).

See the instruction description on page 11-170 for details.

9.3.3.2 TLB Read/Write Instructions (**tlbre** / **tlbwe**)

The TLB entries can be accessed using the (**tlbre** RT,RA,WS) and the (**tlbwe** RS,RA,WS) instructions for reading and writing respectively. Separate extended mnemonics are available for each high/low half of the TLB entry. The high portion corresponds to the TAG and is associated with WS=0, and the low portion corresponds to the DATA and is associated with WS=1. See the instruction descriptions on page 11-168 (**tlbre**) and on page 11-172 (**tlbwe**) for details.

9.3.3.3 TLB Invalidate Instruction (**tlbia**)

The TLB Invalidate All (**tlbia**) instruction is used to invalidate all entries of the TLB by resetting the valid bit while leaving all other bits unchanged. See the instruction description on page 11-167 for details.

A single TLB entry may be invalidated by writing a “0” into the entry’s Valid bit using the **tlbwe** instruction.

9.3.3.4 TLB Sync Instruction (**tlbsync**)

The TLB sync (**tlbsync**) instruction, is used to guarantee that all TLB operations have completed for all processors in a multi-processor system. PPC403GC provides no multiprocessor support, so this instruction performs no function. The instruction is included to facilitate code portability.

See the instruction description on page 11-171 for details.

9.4 Access Protection

9.4.1 Virtual-mode Access Protection

For MMU access protection to be in effect, at least one of MSR[IR] or MSR[DR] must be active. MSR[IR] enables protection on instruction fetches (which are inherently read-only). MSR[DR] enables protection on data accesses (loads and stores).

9.4.1.1 TID Protection

The first level of access protection afforded by the MMU is the Translation ID (TID) field of the TLB entry. This 8 bit field, if non-zero, is compared to the contents of the Process ID (PID) register (see Figure 9-4 below). These must match (in addition to successful comparison of effective address) in a valid TLB entry if any access is to be allowed. In typical use, it is assumed that a Supervisor State program (such as a real-time operating system) set the PID register prior to enabling the Problem State program which is subject to access control.

If the TID is zero, then the associated memory page is accessible to all programs, regardless of their Process ID. This feature allows for common code or data to be shared by multiple processes. This common area is still subject to all of the other access protection mechanisms described below.



Figure 9-4. Process ID (PID)

0:23		reserved
24:31		Process ID

9.4.1.2 EX Protection

If $MSR[IR] = 1$, then instruction fetches are subject to MMU translation, and are afforded MMU access protection. The fetch activity is inherently read-only, so write protection is not needed. Instead, using the EX bit of the TLB, a memory page is marked as executable (contains instructions) or not executable (contains data or memory-mapped control hardware).

If an instruction is pre-fetched from a memory page for which $EX = 0$, the instruction will be tagged as an error. If the processor subsequently attempts to execute this instruction, an Instruction Storage Exception will result. This exception is precise with respect to the attempted execution. If the fetcher discards the instruction without attempting to execute it, no exception will result.

The Zone Protection (see Section 9.4.1.4 below) can alter the execution protection.

9.4.1.3 WR Protection

If $MSR[DR] = 1$, then data loads and stores are subject to MMU translation, and are afforded MMU access protection. The existence of a TLB entry describing a memory page implies read access; write access is controlled by the WR bit of the TLB entry.

If a store (including **dcbz**, **dcbi**, or **dccci**) is made to an effective address that has $WR = 0$, a Data Storage Exception will result. This exception is precise.

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The Zone Protection (see Section 9.4.1.4 below) can alter the write protection. In addition, Zone Protection is the only mechanism to prevent read access of a page defined by a TLB entry.

9.4.1.4 Zone Protection

Each TLB entry contains a 4-bit Zone Select (ZSEL) field. A zone is an arbitrary identifier for grouping TLB entries (memory pages) for purposes of protection. Up to 16 different groups (zones) may be defined. Any one group may have any number of member pages.

Each zone is associated with a 2-bit field in the Zone Protection Register (ZPR). The values of the field define how protection will be applied to every page which is a member of that zone. The protection attributes of every page in the zone may be altered by changing the value in the ZPR. Without the ZPR mechanism, the change would require finding, reading, altering, and rewriting the TLB entry for each page in the zone, individually. The ZPR provides a much faster means of altering the protection for groups of memory pages.

The ZSEL values 0 – 15 select ZPR fields Z0 – Z15, respectively. The fields are defined within the ZPR as follows:

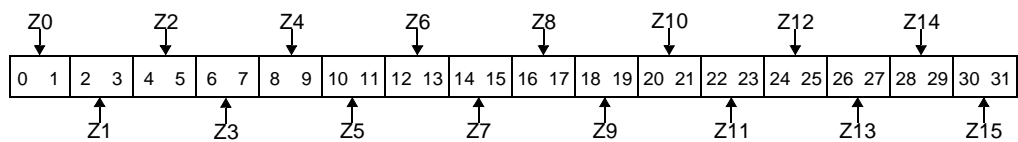


Figure 9-5. Zone Protection Register (ZPR)

0:1	Z0	TLB Page Access Control for all pages in this Zone. EX (Execute Enable) and WR (Write Enable) are bits from the TLB entry which translates the effective address and PID.	
		In Problem State (MSR[PR] = 1) 00 - no access 01 - access governed by EX and WR 10 - access governed by EX and WR 11 - access as if EX and WR both set	In Supervisor State (MSR[PR] = 0) 00 - access governed by EX and WR 01 - access governed by EX and WR 10 - access as if EX and WR both set 11 - access as if EX and WR both set
2:3	Z1	see description of Z0	
4:5	Z2	see description of Z0	
6:7	Z3	see description of Z0	
8:9	Z4	see description of Z0	
10:11	Z5	see description of Z0	
12:13	Z6	see description of Z0	
14:15	Z7	see description of Z0	
16:17	Z8	see description of Z0	
18:19	Z9	see description of Z0	
20:21	Z10	see description of Z0	
22:23	Z11	see description of Z0	
24:25	Z12	see description of Z0	
26:27	Z13	see description of Z0	
28:29	Z14	see description of Z0	
30:31	Z15	see description of Z0	

While it may be quite normal for EX and WR values to be identical for all member pages of a group, this is not required. The ZPR field alters the protection defined by the EX and WR bits, on a page-by-page basis, as shown in Figure 9-5. An application program (presumed to

be running in the Problem State) may have access as defined by EX and WR of the individual pages, or no access (denies loads as well as stores and execution), or complete access.

A '00' value of a ZPR field is the only available mechanism to deny read access to a page defined by an otherwise valid TLB entry. The EX and WR bit definitions do not allow for read protection. Note that the **icbi** instruction is considered a load with respect to access protection; executed in user-mode, it will cause a Data Storage Exception if MSR[DR] = 1 and a ZPR field of '00' is associated with the effective address.

For a given ZPR field value, a program in Supervisor State always has equal or greater access than a program in Problem State. The Supervisor can never be denied read (load) access for a valid TLB entry.

9.4.2 Real-mode Access Protection

The PPC403GC contains a real-mode write-protection mechanism based on Protection Bounds registers. This mechanism can be used to define regions of memory where writes are not permitted.

The Protection Bounds mechanism only applies to real-mode operation (MSR[DR] = 0). If MSR[DR] = 1, the Protection Bounds mechanism is disabled, regardless of the state of MSR[PE].

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- Two pairs of Bounds Registers are provided to protect against inadvertent write access: PBL1 / PBU1 and PBL2 / PBU2.

These register pairs indicate a memory range for which access protection is provided. The PX bit in the Machine State Register (MSR) specifies whether the range registers are “inclusive” (write access is allowed only INSIDE the two ranges) or “exclusive” (write access is allowed only OUTSIDE the two ranges). PX=1 means “exclusive”.

Situations may be set up where the regions overlap, but the following rules hold: In “exclusive” mode, write access WITHIN EITHER region gives a Protection Exception. In “inclusive” mode, write access OUTSIDE BOTH regions gives a Protection Exception.

The comparison is as follows: $PBL \leq EA < PBU$, where EA is the Effective Address of the write access. Notice that this includes the PBL but excludes the PBU in the region.

The Bound Registers are 20-bit registers, which get compared to the upper 20 bits of the EA. This means that the protected region is a multiple of 4K bytes.

- All of memory is open to Read access. Only Write access is protected by Bounds Registers.

In addition, the BIU Bank Registers offer read and write protection to critical devices, via an asynchronous, imprecise Machine Check. See the discussion of the BU field on page 3-26 or page 3-41.

- The MSR Protection Enable bit (MSR[PE]) enables the bounds protection mechanism. When MSR[PE] = 0, protection is disabled and R/W access is enabled for ALL of memory.

The MSR[PE] bit is automatically reset upon any interrupt, giving the interrupt handler access to all of memory.

- At processor reset, the values of the MSR[PX] and the MSR[PE] bit are 0, as are the rest of the exception enable bits in the MSR.
- Protection Bounds Exceptions are a form of Data Storage Exception. Protection Bounds Exceptions are precise; the bounds violation is recognized before the instruction is executed, and the execution is suppressed. See Section 6.5 (Data Storage Exception) on page 6-21 for details of the exception handling.

9.4.2.1 Protection Bounds Registers



Figure 9-6. Bounds Registers (PBL1, PBL2, PBU1, PBU2)

0-19		Bound Address (address bits 0:19)
20-31		reserved

9.4.3 Access Protection for Cache Instructions

- Architecturally the instructions **dcbi** and **dcbz** are treated as “stores” since they can change data (or cause loss of data by invalidating a dirty line). Both instructions can cause protection bounds Data Storage Exceptions, if data translation is disabled.

If data translation is enabled, both **dcbi** and **dcbz** can cause WR = 0 data storage exceptions. **dcbz** can cause the (ZPR-field) = 0 data storage exception when executed in user mode; **dcbi** cannot, since it is a privileged instruction.

- The **dccci** instruction may also be considered a “store” since it can change data by invalidating a dirty line; however, **dccci** is not address-specific (it affects an entire congruence class regardless of the operand address of the instruction). Because it is not address-specific, it will not cause bounds exceptions. To restrict possible damage from an instruction which can change data and yet avoids the protection mechanism, the **dccci** instruction is privileged.

If data translation is enabled, **dccci** can cause WR = 0 data storage exceptions (the operand is treated as if it were address-specific). **dccci** cannot cause (ZPR-field) = 0 data storage exceptions, since it is a privileged instruction.

Because **dccci** can cause data storage and TLB-miss exceptions, it is not recommended to use **dccci** when MSR[DR] = 1; if it is used, care should be taken that the specific operand address will not cause an exception.

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- Architecturally **dcbt** and **dcbtst** are treated as “loads” since they do not change data; therefore there is no bounds protection on these instructions and they cannot cause WR = 0 data storage exceptions.

Touch instructions are considered “speculative” loads; therefore, if a (ZPR-field) = 0 data storage exception would otherwise result from the execution of **dcbt** or **dcbtst**, the instruction becomes a no-op and the exception does not occur. Similarly, TLB-miss exceptions do not occur for these instructions.

- Architecturally **dcbf** and **dcbst** are treated as “loads”. Flushing or storing a line from the cache is not architecturally considered a “store” since the store has already been done to update the cache and the **dcbf** or **dcbst** is only updating the main memory’s copy. Therefore, neither **dcbf** nor **dcbst** can cause protection bounds or WR = 0 Data Storage Exceptions. Since neither of these instructions is privileged, they can both cause (ZPR-field) = 0 data storage exceptions, if data translation is enabled.
- dcread** is a “load” from a non-specific address, and is privileged. Therefore, it does not receive bounds protection, and cannot cause (ZPR-field) = 0 or WR = 0 data storage exceptions.
- icbi** and **icbt** are considered “loads”, and so do not receive bounds protection and cannot cause WR = 0 data storage exceptions. **icbi** can cause (ZPR-field) = 0 data storage exceptions, if data translation is enabled. Since **icbt** is privileged, it cannot cause (ZPR-field) = 0 data storage exceptions.

- The **iccci** instruction cannot change data, because an instruction cache line cannot be a dirty line. The **iccci** instruction is not address-specific, hence it is not eligible for bounds protection. The **iccci** instruction is privileged. It will not cause either (ZPR-field) = 0 or WR = 0 data storage exceptions.

Because **iccci** can cause TLB-miss exceptions, it is not recommended to use **iccci** when MSR[DR] = 1; if it is used, care should be taken that the specific operand address will not cause an exception.

- **icread** is a “load” from a non-specific address, and is privileged. Therefore, it does not receive bounds protection, and cannot cause (ZPR-field) = 0 or WR = 0 data storage exceptions.

Table 9-2. Protection Applied to Cache Instructions

Instruction	Possible Protection Exception		
	Bounds Exception	Zone Exception	WR = 0 Exception
dcbf	No	Yes	No
dcbi	Yes	No	Yes
dcbst	No	Yes	No
dcbt	No	No (instruction no-ops)	No
dcbtst	No	No (instruction no-ops)	No
dcbz	Yes	Yes	Yes
dccci	No	No	Yes
dcread	No	No	No
icbi	No	Yes	No
icbt	No	No	No
iccci	No	No	No
icread	No	No	No

9.4.4 Access Protection for String Instructions

The **stswx** instruction with the string length equal to zero (XER[TBC] = 0) is a no-op. The **stswx** will not cause a Bounds Protection error when the the XER[TBC] = 0.

When data translation is enabled and XER[TBC] = 0, neither **lswx** nor **stswx** can cause either (ZPR-field) = 0 or WR = 0 data storage exceptions or TLB-miss exceptions.

9.5 Real Mode Control of WIMG Storage Attributes

The WIMG bits appear in the TLB entry and provide storage attributes for translated memory accesses. The PPC403GC implementation provides additional SPR registers to allow for specification of these storage attributes on a 128MB granularity of real memory addresses when translation is disabled. These registers divide the 4GB real memory address space into thirty-two 128MB sections such that storage attribute control register bit 0 controls the lowest 128MB region, bit 1 the next 128MB region, etc.

Note that the PPC403GC does not present bit 0 of the real address externally for use in the physical address. This allows two real addresses, possibly programmed with different storage attributes, to reference the same external physical memory. See Section 2.2.1 (Double-Mapping) on page 2-2 and Section 2.2.4 (Physical Address Map) on page 2-4 for further discussion.

9.5.1 Storage Attribute Control Registers

The following four 32-bit registers are defined to control storage attributes in real mode. When the translation is enabled, these registers are ignored, and the WIMG bits in the TLB are used.

9.5.1.1 Data Cache Write-thru Register (DCWR)

The DCWR controls the Write-thru (W) storage attribute in real mode (data translation disabled), for the D-cache. Write-thru is not applicable to the I-cache. Each bit of this 32-bit register controls the W attribute for a 128MB region of real storage, as selected by address bits 0:4.

Note that the data cache on PPC403GC does not support write-thru mode, and an alignment exception will occur on any store-type access (including **dcbz** but not **dcbi** nor **dccci**) to W=1 storage. The alignment exception provides system software the opportunity to emulate the write-thru function. See Section 6.8 on page 6-31 for details of the alignment exception. Note that PPC403GC hardware does not initialize DCWR on power-up or reset. Software must initialize (DCWR) $\leftarrow 0$ prior to the first store operation if alignment exceptions are to be avoided.

Note that the PowerPC Architecture does not support memory models in which write-thru is enabled and caching is inhibited.

This SPR is valid for read and write, and is privileged.

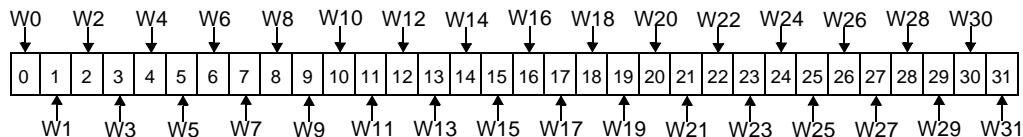


Figure 9-7. Data Cache Write-thru Register (DCWR)

0	W0	0 = copy-back; 1 = write-thru	0x0000 0000 --- 0x07FF FFFF
1	W1	0 = copy-back; 1 = write-thru	0x0800 0000 --- 0x0FFF FFFF
2	W2	0 = copy-back; 1 = write-thru	0x1000 0000 --- 0x17FF FFFF
3	W3	0 = copy-back; 1 = write-thru	0x1800 0000 --- 0x1FFF FFFF
4	W4	0 = copy-back; 1 = write-thru	0x2000 0000 --- 0x27FF FFFF
5	W5	0 = copy-back; 1 = write-thru	0x2800 0000 --- 0x2FFF FFFF
6	W6	0 = copy-back; 1 = write-thru	0x3000 0000 --- 0x37FF FFFF
7	W7	0 = copy-back; 1 = write-thru	0x3800 0000 --- 0x3FFF FFFF
8	W8	0 = copy-back; 1 = write-thru	0x4000 0000 --- 0x47FF FFFF
9	W9	0 = copy-back; 1 = write-thru	0x4800 0000 --- 0x4FFF FFFF
10	W10	0 = copy-back; 1 = write-thru	0x5000 0000 --- 0x57FF FFFF
11	W11	0 = copy-back; 1 = write-thru	0x5800 0000 --- 0x5FFF FFFF
12	W12	0 = copy-back; 1 = write-thru	0x6000 0000 --- 0x67FF FFFF
13	W13	0 = copy-back; 1 = write-thru	0x6800 0000 --- 0x6FFF FFFF
14	W14	0 = copy-back; 1 = write-thru	0x7000 0000 --- 0x77FF FFFF
15	W15	0 = copy-back; 1 = write-thru	0x7800 0000 --- 0x7FFF FFFF
16	W16	0 = copy-back; 1 = write-thru	0x8000 0000 --- 0x87FF FFFF
17	W17	0 = copy-back; 1 = write-thru	0x8800 0000 --- 0x8FFF FFFF
18	W18	0 = copy-back; 1 = write-thru	0x9000 0000 --- 0x97FF FFFF
19	W19	0 = copy-back; 1 = write-thru	0x9800 0000 --- 0x9FFF FFFF
20	W20	0 = copy-back; 1 = write-thru	0xA000 0000 --- 0xA7FF FFFF
21	W21	0 = copy-back; 1 = write-thru	0xA800 0000 --- 0xAFFF FFFF
22	W22	0 = copy-back; 1 = write-thru	0xB000 0000 --- 0xB7FF FFFF
23	W23	0 = copy-back; 1 = write-thru	0xB800 0000 --- 0xBFFF FFFF
24	W24	0 = copy-back; 1 = write-thru	0xC000 0000 --- 0xC7FF FFFF
25	W25	0 = copy-back; 1 = write-thru	0xC800 0000 --- 0xCFFF FFFF

Figure 9-7. Data Cache Write-thru Register (DCWR) (cont.)

26	W26	0 = copy-back; 1 = write-thru	0xD000 0000 --- 0xD7FF FFFF
27	W27	0 = copy-back; 1 = write-thru	0xD800 0000 --- 0xDFFF FFFF
28	W28	0 = copy-back; 1 = write-thru	0xE000 0000 --- 0xE7FF FFFF
29	W29	0 = copy-back; 1 = write-thru	0xE800 0000 --- 0xEFFF FFFF
30	W30	0 = copy-back; 1 = write-thru	0xF000 0000 --- 0xF7FF FFFF
31	W31	0 = copy-back; 1 = write-thru	0xF800 0000 --- 0xFFFF FFFF

9.5.1.2 Data Cache Cacheability Register (DCCR)

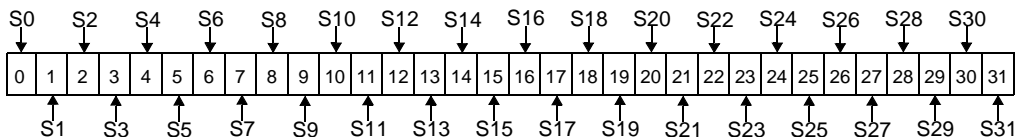
Each bit controls the Inhibited (I) attribute for a 128MB region of real memory, for data accesses. A '1' means cacheable. Note that the polarity of this bit is opposite that of the 'I' bit from the TLB entry.

When data address translation is disabled, cacheability for the effective address of the operand of instructions (other than instruction cache ops) is determined by the DCCR. For the operands of instruction cache ops, the ICCR is used.

Note that the PowerPC Architecture does not support memory models in which write-thru is enabled and caching is inhibited.

Following system reset, all DCCR bits are reset to zero so that no memory regions are cacheable. Before memory regions can be designated as cacheable in the DCCR, it is necessary to execute the **dccci** instruction 32 times, once for each congruence class in the cache array. This invalidates all 32 congruence classes prior to enabling the cache. The DCCR can then be reconfigured and the DCU can begin normal operation.

Each bit of the DCCR represents the cacheability state of a 128MB region of the effective address space. When a DCCR bit is set to one, the memory region corresponding to that bit is allowed to be cached. Data blocks in cacheable regions can be placed in the data cache and reused by the execution unit without causing external memory accesses.

**Figure 9-8. Data Cache Cacheability Register (DCCR)**

0	S0	0 = noncacheable; 1 = cacheable	0x0000 0000 --- 0x07FF FFFF
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Figure 9-8. Data Cache Cacheability Register (DCCR) (cont.)

1	S1	0 = noncacheable; 1 = cacheable	0x0800 0000 --- 0x0FFF FFFF
2	S2	0 = noncacheable; 1 = cacheable	0x1000 0000 --- 0x17FF FFFF
3	S3	0 = noncacheable; 1 = cacheable	0x1800 0000 --- 0x1FFF FFFF
4	S4	0 = noncacheable; 1 = cacheable	0x2000 0000 --- 0x27FF FFFF
5	S5	0 = noncacheable; 1 = cacheable	0x2800 0000 --- 0x2FFF FFFF
6	S6	0 = noncacheable; 1 = cacheable	0x3000 0000 --- 0x37FF FFFF
7	S7	0 = noncacheable; 1 = cacheable	0x3800 0000 --- 0x3FFF FFFF
8	S8	0 = noncacheable; 1 = cacheable	0x4000 0000 --- 0x47FF FFFF
9	S9	0 = noncacheable; 1 = cacheable	0x4800 0000 --- 0x4FFF FFFF
10	S10	0 = noncacheable; 1 = cacheable	0x5000 0000 --- 0x57FF FFFF
11	S11	0 = noncacheable; 1 = cacheable	0x5800 0000 --- 0x5FFF FFFF
12	S12	0 = noncacheable; 1 = cacheable	0x6000 0000 --- 0x67FF FFFF
13	S13	0 = noncacheable; 1 = cacheable	0x6800 0000 --- 0x6FFF FFFF
14	S14	0 = noncacheable; 1 = cacheable	0x7000 0000 --- 0x77FF FFFF
15	S15	0 = noncacheable; 1 = cacheable	0x7800 0000 --- 0x7FFF FFFF
16	S16	0 = noncacheable; 1 = cacheable	0x8000 0000 --- 0x87FF FFFF
17	S17	0 = noncacheable; 1 = cacheable	0x8800 0000 --- 0x8FFF FFFF
18	S18	0 = noncacheable; 1 = cacheable	0x9000 0000 --- 0x97FF FFFF
19	S19	0 = noncacheable; 1 = cacheable	0x9800 0000 --- 0x9FFF FFFF
20	S20	0 = noncacheable; 1 = cacheable	0xA000 0000 --- 0xA7FF FFFF
21	S21	0 = noncacheable; 1 = cacheable	0xA800 0000 --- 0xAFFF FFFF
22	S22	0 = noncacheable; 1 = cacheable	0xB000 0000 --- 0xB7FF FFFF
23	S23	0 = noncacheable; 1 = cacheable	0xB800 0000 --- 0xBFFF FFFF
24	S24	0 = noncacheable; 1 = cacheable	0xC000 0000 --- 0xC7FF FFFF
25	S25	0 = noncacheable; 1 = cacheable	0xC800 0000 --- 0xCFFF FFFF
26	S26	0 = noncacheable; 1 = cacheable	0xD000 0000 --- 0xD7FF FFFF
27	S27	0 = noncacheable; 1 = cacheable	0xD800 0000 --- 0xDFFF FFFF
28	S28	0 = noncacheable; 1 = cacheable	0xE000 0000 --- 0xE7FF FFFF
29	S29	0 = noncacheable; 1 = cacheable	0xE800 0000 --- 0xEFFF FFFF
30	S30	0 = noncacheable; 1 = cacheable	0xF000 0000 --- 0xF7FF FFFF
31	S31	0 = noncacheable; 1 = cacheable	0xF800 0000 --- 0xFFFF FFFF

9.5.1.3 Instruction Cache Cacheability Register (ICCR)

Each bit controls the Inhibited (I) attribute for a 128MB region of real memory, for instruction fetches. A '1' means cacheable. Note that the polarity of this bit is opposite that of the 'I' bit from the TLB entry.

When instruction address translation is disabled, the ICCR determines cacheability for instruction fetching.

When data address translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

Following system reset, all ICCR bits are reset to zero so that no memory regions are cacheable. Before regions can be designated as cacheable in the ICCR, it is necessary to execute the **iccci** instruction 64 times, once for each congruence class in the cache array. This invalidates all 64 congruence classes prior to enabling the cache. The ICCR can then be reconfigured and the ICU can begin normal operation.

Each bit of the ICCR, shown in Figure 9-9, represents the cacheability state of a 128MB region of the effective address space. When an ICCR bit is set to one, the memory region corresponding to that bit is allowed to be cached. Instructions fetched from that region are placed in the instruction cache, where they can be accessed as needed by the execution unit.

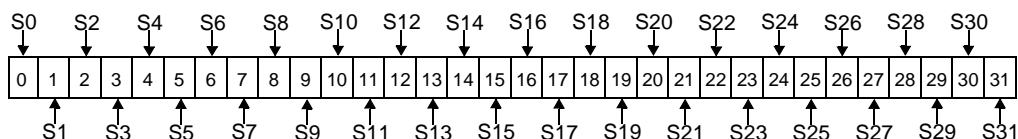


Figure 9-9. Instruction Cache Cacheability Register (ICCR)

0	S0	0 = noncacheable; 1 = cacheable	0x0000 0000 --- 0x07FF FFFF
1	S1	0 = noncacheable; 1 = cacheable	0x0800 0000 --- 0x0FFF FFFF
2	S2	0 = noncacheable; 1 = cacheable	0x1000 0000 --- 0x17FF FFFF
3	S3	0 = noncacheable; 1 = cacheable	0x1800 0000 --- 0x1FFF FFFF
4	S4	0 = noncacheable; 1 = cacheable	0x2000 0000 --- 0x27FF FFFF
5	S5	0 = noncacheable; 1 = cacheable	0x2800 0000 --- 0x2FFF FFFF
6	S6	0 = noncacheable; 1 = cacheable	0x3000 0000 --- 0x37FF FFFF
7	S7	0 = noncacheable; 1 = cacheable	0x3800 0000 --- 0x3FFF FFFF
8	S8	0 = noncacheable; 1 = cacheable	0x4000 0000 --- 0x47FF FFFF
9	S9	0 = noncacheable; 1 = cacheable	0x4800 0000 --- 0x4FFF FFFF
10	S10	0 = noncacheable; 1 = cacheable	0x5000 0000 --- 0x57FF FFFF

Figure 9-9. Instruction Cache Cacheability Register (ICCR) (cont.)

11	S11	0 = noncacheable; 1 = cacheable	0x5800 0000 --- 0x5FFF FFFF
12	S12	0 = noncacheable; 1 = cacheable	0x6000 0000 --- 0x67FF FFFF
13	S13	0 = noncacheable; 1 = cacheable	0x6800 0000 --- 0x6FFF FFFF
14	S14	0 = noncacheable; 1 = cacheable	0x7000 0000 --- 0x77FF FFFF
15	S15	0 = noncacheable; 1 = cacheable	0x7800 0000 --- 0x7FFF FFFF
16	S16	0 = noncacheable; 1 = cacheable	0x8000 0000 --- 0x87FF FFFF
17	S17	0 = noncacheable; 1 = cacheable	0x8800 0000 --- 0x8FFF FFFF
18	S18	0 = noncacheable; 1 = cacheable	0x9000 0000 --- 0x97FF FFFF
19	S19	0 = noncacheable; 1 = cacheable	0x9800 0000 --- 0x9FFF FFFF
20	S20	0 = noncacheable; 1 = cacheable	0xA000 0000 --- 0xA7FF FFFF
21	S21	0 = noncacheable; 1 = cacheable	0xA800 0000 --- 0xAFFF FFFF
22	S22	0 = noncacheable; 1 = cacheable	0xB000 0000 --- 0xB7FF FFFF
23	S23	0 = noncacheable; 1 = cacheable	0xB800 0000 --- 0xBFFF FFFF
24	S24	0 = noncacheable; 1 = cacheable	0xC000 0000 --- 0xC7FF FFFF
25	S25	0 = noncacheable; 1 = cacheable	0xC800 0000 --- 0xCFFF FFFF
26	S26	0 = noncacheable; 1 = cacheable	0xD000 0000 --- 0xD7FF FFFF
27	S27	0 = noncacheable; 1 = cacheable	0xD800 0000 --- 0xDFFF FFFF
28	S28	0 = noncacheable; 1 = cacheable	0xE000 0000 --- 0xE7FF FFFF
29	S29	0 = noncacheable; 1 = cacheable	0xE800 0000 --- 0xEFFF FFFF
30	S30	0 = noncacheable; 1 = cacheable	0xF000 0000 --- 0xF7FF FFFF
31	S31	0 = noncacheable; 1 = cacheable	0xF800 0000 --- 0xFFFF FFFF

9.5.1.4 Storage Guarded Register (SGR)

The SGR controls the Guarded (G) storage attribute in real mode, for both instruction and data storage. Each bit of this 32-bit register controls the G attribute for a 128MB region of real storage, as selected by address bits 0:4. This attribute is used to prevent speculative accesses to non-well-behaved regions of storage, such as memory-mapped I/O devices. This attribute has no effect on data accesses in PPC403GC, since PPC403GC does not perform speculative loads or stores. For instruction fetches, the memory access to a guarded region will be held off until the execution pipeline is empty, guaranteeing that the access is necessary and therefore not speculative. For this reason, performance is degraded when executing out of guarded regions, and software should avoid marking regions of instruction storage as guarded unnecessarily.

This SPR is valid for read and write. Out of reset, this register is set to 0xFFFF FFFF, marking all of storage as guarded. For maximum performance, system software should clear the guarded attribute of appropriate regions as soon as possible.

In instruction translate mode (MSR[IR] = 1), the G attribute comes from the TLB entry, and attempting to execute from a guarded region in translate mode will cause an Instruction Storage exception. See Section 6.6 (Instruction Storage Exception) on page 6-23 for more information.

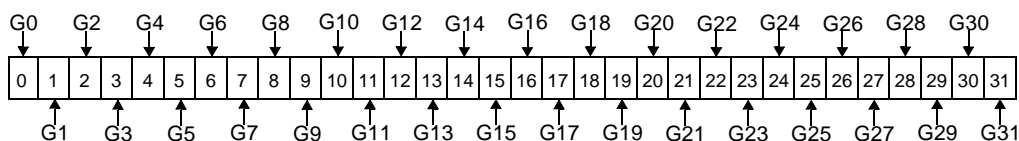


Figure 9-10. Storage Guarded Register (SGR)

0	G0	0 = normal; 1 = guarded	0x0000 0000 --- 0x07FF FFFF
1	G1	0 = normal; 1 = guarded	0x0800 0000 --- 0x0FFF FFFF
2	G2	0 = normal; 1 = guarded	0x1000 0000 --- 0x17FF FFFF
3	G3	0 = normal; 1 = guarded	0x1800 0000 --- 0x1FFF FFFF
4	G4	0 = normal; 1 = guarded	0x2000 0000 --- 0x27FF FFFF
5	G5	0 = normal; 1 = guarded	0x2800 0000 --- 0x2FFF FFFF
6	G6	0 = normal; 1 = guarded	0x3000 0000 --- 0x37FF FFFF
7	G7	0 = normal; 1 = guarded	0x3800 0000 --- 0x3FFF FFFF
8	G8	0 = normal; 1 = guarded	0x4000 0000 --- 0x47FF FFFF
9	G9	0 = normal; 1 = guarded	0x4800 0000 --- 0x4FFF FFFF
10	G10	0 = normal; 1 = guarded	0x5000 0000 --- 0x57FF FFFF

Figure 9-10. Storage Guarded Register (SGR) (cont.)

11	G11	0 = normal; 1 = guarded	0x5800 0000 --- 0x5FFF FFFF
12	G12	0 = normal; 1 = guarded	0x6000 0000 --- 0x67FF FFFF
13	G13	0 = normal; 1 = guarded	0x6800 0000 --- 0x6FFF FFFF
14	G14	0 = normal; 1 = guarded	0x7000 0000 --- 0x77FF FFFF
15	G15	0 = normal; 1 = guarded	0x7800 0000 --- 0x7FFF FFFF
16	G16	0 = normal; 1 = guarded	0x8000 0000 --- 0x87FF FFFF
17	G17	0 = normal; 1 = guarded	0x8800 0000 --- 0x8FFF FFFF
18	G18	0 = normal; 1 = guarded	0x9000 0000 --- 0x97FF FFFF
19	G19	0 = normal; 1 = guarded	0x9800 0000 --- 0x9FFF FFFF
20	G20	0 = normal; 1 = guarded	0xA000 0000 --- 0xA7FF FFFF
21	G21	0 = normal; 1 = guarded	0xA800 0000 --- 0xAFFF FFFF
22	G22	0 = normal; 1 = guarded	0xB000 0000 --- 0xB7FF FFFF
23	G23	0 = normal; 1 = guarded	0xB800 0000 --- 0xBFFF FFFF
24	G24	0 = normal; 1 = guarded	0xC000 0000 --- 0xC7FF FFFF
25	G25	0 = normal; 1 = guarded	0xC800 0000 --- 0xCFFF FFFF
26	G26	0 = normal; 1 = guarded	0xD000 0000 --- 0xD7FF FFFF
27	G27	0 = normal; 1 = guarded	0xD800 0000 --- 0xDFFF FFFF
28	G28	0 = normal; 1 = guarded	0xE000 0000 --- 0xE7FF FFFF
29	G29	0 = normal; 1 = guarded	0xE800 0000 --- 0xEFFF FFFF
30	G30	0 = normal; 1 = guarded	0xF000 0000 --- 0xF7FF FFFF
31	G31	0 = normal; 1 = guarded	0xF800 0000 --- 0xFFFF FFFF

This chapter provides an overview of the debug facilities of the PPC403GC processor. The PPC403GC debug facilities include debug modes for the various types of debugging encountered during hardware and software development. Also included are debug events which allow the developer to control the debug process. The debug modes and debug events are controlled using debug registers in the chip. The debug registers can be accessed either through software running on the processor or through the JTAG port. The debug interfaces include the JTAG port as well as a Trace Status port. The JTAG port can also be used for board test.

The debug modes, events, controls, and interfaces provide a powerful combination of debug facilities for a wide range of hardware and software development tools.

10.1 Development Tool Support

The OS Open Real-time Operating System Debugger product from IBM is an example of an operating system-aware debugger, implemented using software traps.

The RISCWatch 400 product from IBM is an example of a development tool that uses the External Debug Mode, Debug Events, and the JTAG port to implement a hardware and software development tool. The RISCTrace[™] feature of RISCWatch 400, combined with a logic analyzer, is an example of a development tool that uses the Real-time Trace Debug Mode of the processor to perform real-time instruction tracing.

Logic analyzers from Hewlett Packard and Tektronix provide PPC403GC disassembler support and support for the RISCTrace feature of RISCWatch 400.

10.2 Debug Modes

There are four debug modes in the PPC403GC. Each mode supports different types of debug tools commonly used in embedded systems development. Internal Debug Mode supports ROM monitors, External Debug Mode supports emulators, Real-time Trace Debug Mode supports cache reconstruction tools, and Bus Status Debug Mode supports logic analyzers (external bus activity debug). Multiple modes can be enabled simultaneously, except for Real-time Trace Debug Mode and Bus Status Mode. The events which initiate Internal and External Debug Modes and Real-time Trace Mode are defined in the Debug

Control Register (DBCR). Real-time Trace and Bus Status Debug Modes are enabled by the Input/Output Configuration Register (IOCR).

10.2.1 Internal Debug Mode

Internal Debug Mode supports accessing all architected processor resources, setting hardware and software breakpoints, and monitoring processor status. While in this mode, debug events can generate debug exceptions, which can interrupt normal program flow so that monitor software can collect processor status and alter processor resources.

Internal Debug Mode relies on exception handling software at a dedicated interrupt vector, running in the processor, and an external communications path to debug software. It is used while the processor is executing instructions and enables debugging of application or operating system related problems.

Access to debugger software executing in the processor, while in internal debug mode, is through a communications port on the processor board, such as a serial port.

10.2.2 External Debug Mode

External Debug Mode supports stopping, starting, and stepping the processor, accessing all architected processor resources, setting hardware and software breakpoints, and monitoring processor status. Access to the processor, while in External Debug Mode, is through the JTAG port. While in this mode, debug events can be used to cause the processor to become architecturally frozen. While the processor is frozen, normal instruction execution stops and all architected resources of the processor can be accessed and altered. External bus activity (DMA, DRAM refresh, serial port, etc.), if active, will continue while in External Debug Mode.

10

An external debugger is considered to be a privileged user. It is given access to all resources (registers and opcodes) in order to facilitate program debug. Therefore, the occurrence of a privileged exception is prevented when a privileged instruction is executed by the JTAG mechanism while the processor is in Problem State. Storage access is still governed by MSR[PR] (storage access is not forced to privileged mode) while in External Debug Mode; therefore, it may be necessary for the debugger to modify either MSR or TLB values to access protected memory.

External Debug Mode only relies on internal processor resources and therefore can be used to debug both system hardware and software problems. It can also be used for software development on systems without a control program or to debug control program problems.

10.2.3 Real-time Trace Debug Mode

Real-time Trace Debug Mode supports tracing the instruction stream being executed out of the instruction cache in real-time. While in this mode, debug events can be used to start the broadcast of trace information. This mode does not alter the performance of the processor.

Real Time Trace Mode must be enabled in the Input / Output Configuration Register (IOCR). When not needed, Real Time Trace Mode should be left disabled to reduce chip I/O power.

The Trace Status signals provide trace information while in Real-time Trace Debug Mode.

10.2.4 Bus Status Debug Mode

Bus Status Debug Mode supports analysis of external bus activity via a logic analyzer attached to the processor. While in this mode, bus activity qualifiers are provided using the Trace Status signals. This mode does not alter the performance of the processor.

To enable Bus Status Mode, the Real-Time Debug Mode bits (IOCR[RDM]) must be set to b'01' (see Section 6.7.1.3 on page 6-28). To debug bus activity of boot code using a logic analyzer, the very first lines of the boot code must enable Bus Status Mode. When not needed, Bus Status Mode should be left disabled to reduce chip I/O power.

10.3 Processor Control

This section describes the debug facilities available for controlling the processor. Not all of these facilities are available in all debug modes.

Block Folding	The folding (dual dispatch) of instructions in the instruction queue can be blocked using the JTAG debug port.
Instruction Step	The processor can be stepped one instruction at a time while it is stopped using the JTAG debug port.
Instruction Stuff	While the processor is stopped, instructions can be stuffed into the processor and executed using the JTAG debug port.
Halt	The processor can be stopped by activating the external HALT signal. This signal can be used to stop the processor on an external event, such as a logic analyzer trigger. Activating this signal causes the processor to become architecturally frozen. While frozen, normal instruction execution stops and all architected resources of the processor can be accessed and altered via the JTAG port. Normal execution continues after this signal is deactivated.
Stop	The processor can be stopped using the JTAG debug port. Activating a stop causes the processor to become architecturally frozen. While frozen, normal instruction execution stops and all architected resources of the processor can be accessed and altered via the JTAG port. Normal execution continues after this bit is reset.

Reset	The processor can be reset either using the external reset pin, using the JTAG debug port, or using the DBCR. There are three different resets that can be activated using the JTAG debug port: core, chip, and system reset (see Chapter 5 on page 5-1).
Freeze Timers	The timer resources can be controlled using the JTAG debug port or the DBCR. The timers can either be allowed to run, frozen always, or frozen when a debug event occurs.
Debug Events	Debug events are used to trigger a debug operation to take place. The operation depends on the debug mode. Debug events are only applicable to External, Internal, and Trace debug modes. For more information and a list of debug events see Section 10.5.
Trap Instructions	There are two trap instructions, <code>tw</code> and <code>twi</code> , included in the instruction set. These instructions, along with debug events, can be used to implement software breakpoints.

10.4 Processor Status

The processor execution status, exception status, and most recent reset can be monitored.

Execution Status	The execution status of the processor can be monitored by using the Trace Status signals when the processor is in Bus Status Mode or Trace Status Mode, or by using the JTAG debug port. Either of these resources can be used to determine if the processor is stopped, waiting, or running.
Exception Status	The status of pending synchronous exceptions can be monitored using the JTAG debug port.
Most Recent Reset	The type of the most recent reset can be determined by reading the DBSR, either via the JTAG port or by using an mfsprr instruction in software.

10.5 Debug Events

Debug events are used to trigger a debug operation to take place. While in Internal Debug Mode, the processor generates a debug exception when a debug event occurs. In External Debug Mode, the processor stops when a debug event occurs. In Real-Time Trace Debug Mode, the processor begins broadcasting trace information on the Trace Status signals

when a debug event occurs. Debug events have no effect on Bus Status Debug Mode. Debug events are controlled by the Debug Control Register (DBCR).

Branch Taken	The Branch Taken debug event will occur prior to the execution of a branch instruction where the branch direction is determined to be taken. Branch Taken will not cause a debug event if $MSR[DE] = 0$ in Internal Debug Mode.
Data Address Compare	The Data Address Compare debug event will occur prior to the execution of an instruction that accesses a data address that matches the contents of one of the two Data Address Compare Registers. Via the DBCR, the data address compare can be set up to occur on reads and/or writes, from byte addresses, or from any byte within halfword, word, or quad-word addresses.
Exception	The Exception debug event occurs after an exception is taken. Exception debug events include the critical class of exceptions unless in Internal Debug Mode. Critical Exceptions will not cause a debug event if $MSR[DE] = 0$ in Internal Debug Mode.
Instruction Address Compare	The Instruction Address Compare debug event occurs prior to the execution of an instruction at an address that matches the contents of one of the two Instruction Address Compare Registers.
Instruction Completion	The Instruction Completion debug event occurs after the completion of any instruction. Instruction Completion will not cause a debug event if $MSR[DE] = 0$ in Internal Debug Mode.
Trap	The Trap debug event occurs prior to the execution of a trap instruction where the conditions are such that the trap will occur.
Unconditional	The Unconditional debug event occurs immediately upon being set using the JTAG debug port.

A simple debug event is the detection of a single item from the list above (for example, perform the debug operation when a read is detected from a certain address).

In addition to these simple debug events, the PPC403GC can be set to detect compound debug events. A compound debug event is a specified sequence of simple debug events (for example, perform the debug operation on the first branch taken after a read is detected from a certain address three times).

DBCR[FER] records the number of enabled “first” debug events which must occur before a debug operation is performed. If $DBCR[FER] \neq 0$ when a debug event occurs, then it is decremented, and execution resumes without a debug operation being performed. If

DBCR[FER] = 0 when a debug event occurs, this event is recorded in the DBSR. A debug operation will then occur if no “second” debug event has been enabled in the DBCR, or if this event is a “second” debug event that has been enabled in the DBCR. If there is an enabled second debug event, and this event is not of its type, then execution resumes without a debug operation.

To clarify the operation of compound debug events, the following outline describes the logic that is followed when executing code with debug events enabled:

- 1) Execute code, waiting for a debug event to be detected by hardware. When a debug event is detected, go to 2.
- 2) Is count of First Events Remaining zero (DBCR[FER] = 0) ?
 - No: decrement DBCR[FER] and go to 1.
 - Yes: go to 3
- 3) Set DBSR bit corresponding to this debug event.
- 4) Is any “Second” debug event enabled in DBCR[SBT,SED,STD,SIA,SDA] ?
 - No: perform a debug operation, as specified in Section 10.5, then go to 1.
 - Yes: go to 5.
- 5) Is this debug event an enabled “Second” debug event in DBCR[SBT,SED,STD,SIA,SDA] ?
 - No: go to 1.
 - Yes: perform a debug operation, as specified in Section 10.5, then go to 1.

10.6 Debug Registers

This section describes debug related registers that are accessible to code running on the processor. These registers are intended for use by debug tools, not by application code. Use of these registers by application code may cause unexpected results.

Debug events are controlled by debug tools such as RISCWatch 400, OS Open, and OpenBIOS from IBM. Such debug tools are designed assuming that they have complete ownership of the PPC403GC debug resources. Application code which also uses the debug resources may render the debug tools non-functional.

10.6.1 Debug Control Register (DBCR)

This register is designed to be used by development tools such as debuggers, not by application software. This register is privileged, hence unavailable in user mode. Using this register can cause unexpected results such as program hangs and processor resets.

The Debug Control Register (DBCR) is used to enable debug events, reset the processor, control timer operation during debug events, enable JTAG serial interrupts, and set the debug mode of the processor.

10.6.1.1 Note on DAC Size Fields

The Data Address Compare (DAC) debug event can be set to react to any byte in a larger block of memory, in addition to reacting to a precise address match. The Data Address Compare Size fields (D1S and D2S) allow DAC debug events to react to any byte in a halfword (field = 01 — Ignore 1 least significant bit), any byte in a word (field = 10 — Ignore 2 least significant bits), or any byte in a cache line of four words (field = 11 — Ignore 4 least significant bits). These capabilities are in addition to exact address compare (field = 00 — Compare All Bits).

The addresses for DAC are the operand addresses (effective addresses) of storage operations. As an example, suppose that it is desired to react to all accesses to byte 3 of a word-aligned target. DAC set for precise compare would fail to recognize access to that byte via either word or halfword operations, since that byte address is not the effective address of the operation. In such a case, the DAC Size field must be set for a wider capture range (for example, ignore 2 least significant bits if word operations to the non-word-aligned byte are to be detected). This wider capture range can result in excess debug events (events that are within the specified capture range, but reflect operations to bytes other than the desired byte). These excess debug events must be handled by software.

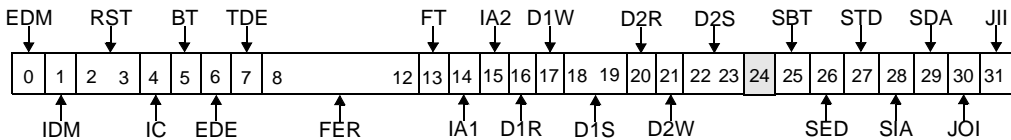


Figure 10-1. Debug Control Register (DBCR)

0	EDM	External Debug Mode 0 = Disable 1 = Enable
1	IDM	Internal Debug Mode 0 - Disable 1 - Enable

Figure 10-1. Debug Control Register (DBCR) (cont.)

2 : 3	RST	Reset 00 - No Action 01 - Core Reset 10 - Chip Reset 11 - System Reset	
		WARNING : Writing 01, 10, or 11 to these bits will cause a processor reset to occur.	
4	IC	Instruction Completion Debug Event 0 - Disable 1 - Enable	(Instruction Completion will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
5	BT	Branch Taken Debug Event 0 - Disable 1 - Enable	(Branch Taken will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
6	EDE	Exception Debug Event 0 - Disable 1 - Enable	(Critical Exceptions will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
7	TDE	TRAP Debug Event 0 - Disable 1 - Enable	
8:12	FER	First Events Remaining	Action on Debug Events is enabled when FER = 0. If FER ≠ 0, a Debug Event causes FER to decrement.
13	FT	Freeze Timers On Debug Event 0 - Free-run Timers 1 - Freeze Timers	
14	IA1	Instruction Address Compare 1 Enable 0 - Disable 1 - Enable	
15	IA2	Instruction Address Compare 2 Enable 0 - Disable 1 - Enable	
16	D1R	Data Address Compare 1 Read Enable 0 - Disable 1 - Enable	
17	D1W	Data Address Compare 1 Write Enable 0 - Disable 1 - Enable	
18 : 19	D1S	Data Address Compare 1 Size 00 - Compare All Bits 01 - Ignore 1 least significant bit 10 - Ignore 2 least significant bits 11 - Ignore 4 least significant bits	(halfword) (word) (quadword, or cache line)
20	D2R	Data Address Compare 2 Read Enable 0 - Disable 1 - Enable	

Figure 10-1. Debug Control Register (DBCR) (cont.)

21	D2W	Data Address Compare 2 Write Enable 0 - Disable 1 - Enable
22 : 23	D2S	Data Address Compare 2 Size 00 - Compare All Bits 01 - Ignore 1 least significant bit (halfword) 10 - Ignore 2 least significant bits (word) 11 - Ignore 4 least significant bits (quadword, or cache line)
24		reserved
25	SBT	Second Branch Taken Debug Event 0 - Disable 1 - Enable
26	SED	Second Exception Debug Event 0 - Disable 1 - Enable
27	STD	Second TRAP Debug Event 0 - Disable 1 - Enable
28	SIA	Second Instruction Address Compare Enable (Uses address register IAC2.) 0 - Disable 1 - Enable
29	SDA	Second Data Address Compare Enable (Uses DBCR fields D2R, D2W, and D2S, and address register DAC2.) 0 - Disable 1 - Enable
30	JOI	JTAG Serial Outbound Interrupt Enable (not a debug event) 0 - Disable 1 - Enable
31	JII	JTAG Serial Inbound Interrupt Enable (not a debug event) 0 - Disable 1 - Enable

10.6.2 Debug Status Register (DBSR)

This register is designed to be used by development tools such as debuggers, not by application software. This register is privileged, hence unavailable in user mode. Using this register can cause unexpected results.

The Debug Status Register (DBSR) contains status on Debug Events, the JTAG Serial Buffers, and the most recent reset . The status is obtained by reading the register. The status bits are normally set by debug events, by any of three types of reset, and by writing and reading the JTAG Serial Buffers.

Individual bits of the DBSR can be cleared to 0 by a write to this register with a 1 in the bit positions to be cleared and a 0 in the bit positions that are to remain unaltered.

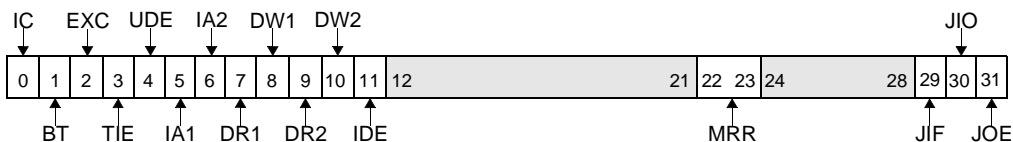


Figure 10-2. Debug Status Register (DBSR)

0	IC	Instruction Completion Debug Event 0 = Event Didn't Occur 1 = Event Occurred
1	BT	Branch Taken Debug Event 0 = Event Didn't Occur 1 = Event Occurred
2	EXC	Exception Debug Event 0 = Event Didn't Occur 1 = Event Occurred
3	TIE	TRAP Instruction Debug Event 0 = Event Didn't Occur 1 = Event Occurred
4	UDE	Unconditional Debug Event 0 = Event Didn't Occur 1 = Event Occurred
5	IA1	Instruction Address Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
6	IA2	Instruction Address Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
7	DR1	Data Address Read Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
8	DW1	Data Address Write Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
9	DR2	Data Address Read Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
10	DW2	Data Address Write Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred

Figure 10-2. Debug Status Register (DBSR) (cont.)

11	IDE	Imprecise Debug Event 0 = Event Didn't Occur 1 = Debug Event Occurred while MSR[DE] = 0	
12:21		reserved	
22:23	MRR	Most Recent Reset 00 = No Reset Occurred since these bits last cleared by software. 01 = Core Reset 10 = Chip Reset 11 = System Reset	These two bits are set to one of three values when a reset occurs. These two bits are undefined at power-up.
24:28		reserved	
29	JIF	JTAG Serial Inbound Buffer Full 0 = Empty 1 = Full	This bit is set to 1 when the JSIB is written. This bit is cleared to 0 when the JSIB is read.
30	JIO	JTAG Serial Inbound Buffer Overrun 0 = No Overrun 1 = Overrun Occurred	This bit is set to 1 when a second write to the JSIB via the JTAG port is done without an inter- vening read via software.
31	JOE	JTAG Serial Outbound Buffer Empty 0 = Full 1 = Empty	This bit is set to 1 when the JSOB is read via the JTAG port. This bit is cleared to 0 by writing to the JSOB via software.

10.6.3 Data Address Compare Registers (DAC1-DAC2)

The PPC403GC has the capability to take a debug event upon loads, stores, or cache operations to either of two addresses. The addresses are defined in the DAC1 and DAC2 registers. The fields D1R and D1W of the DBCR control the Data Address 1 debug event, and D2R and D2W control the Data Address 2 debug event.

The address in DAC1 specifies an exact byte address for the Data Address 1 event; however, it may be desired to take a debug event on any byte within a half-word (that is, ignore one least significant bit of DAC1), or to take a debug event on any byte within a word (that is, ignore two least significant bits of DAC1), or to take a debug event on any byte within a quad-word (that is, ignore four least significant bits of DAC1). These options are controlled by the D1S field in the DBCR. Similarly, the D2S field of the DBCR controls these options for DAC2.

The addresses for DAC are the operand addresses (effective addresses) of storage operations. As an example, suppose that it is desired to react to all accesses to byte 3 of a word-aligned target. DAC set for precise compare would fail to recognize access to that byte via either word or halfword operations, since that byte address is not the effective address of the operation. In such a case, the DAC Size field must be set for a wider capture range (for example, ignore 2 least significant bits if word operations to the non-word-aligned byte are to be detected). This wider capture range can result in excess debug events (events that are

within the specified capture range, but reflect operations to bytes other than the desired byte). These excess debug events must be handled by software.

0	31
---	----

Figure 10-3. Data Address Compare Registers (DAC1-DAC2)

0:31		Data Address Compare, Byte Address	Data Address Compare Size fields of DBCR determine byte, halfword, or word usage.
------	--	------------------------------------	---

10.6.3.1 DAC Applied to Cache Instructions

This section describes the Data Address Compare (DAC) debug events as they apply to cache instructions.

Architecturally the instructions **dcbi** and **dcbz** are treated as “stores” since they can change data (or cause loss of data by invalidating a dirty line); therefore they can cause DAC-Write debug events.

The **dccci** instruction may also be considered a “store” since it can change data by invalidating a dirty line; however, **dccci** is not address-specific (it affects an entire congruence class regardless of the operand address of the instruction). Because it is not address-specific, it will not cause DAC debug events.

10 Architecturally **dcbt**, **dcbtst**, **dcbf**, **dcbst** are treated as “loads” since they do not change data. Flushing or storing a line from the cache is not architecturally considered a “store” since the store has already been done to update the cache and the **dcbf** or **dcbst** is only updating the main memory’s copy.

dcbt and **dcbst** can cause DAC-Read debug events, if the effective address is cacheable. If the address is non-cacheable, these instructions are no-ops and will not cause DAC debug events.

If data translation is enabled and the effective address of either **dcbt** or **dcbst** encounters a Data Storage Exception due to a TLB miss or a zone fault, the instruction becomes a no-op. Under this condition, these instructions still can cause DAC-Read debug events.

Although **dcbf** and **dcbst** are architecturally treated as “loads”, they can create DAC-Write debug events (not DAC-Read). In a debug environment, the fact that main memory (external memory) is being written is considered to be the event of interest.

Even though **dcread** is not address-specific (it affects an entire congruence class regardless of the operand address of the instruction), it will cause DAC-Read debug events.

All instruction-cache operations (**icbi**, **icbt**, **iccci**, and **icread**) are architecturally treated as “loads”. These instructions will not cause DAC debug events on PPC403GC.

Table 10-1. DAC Applied to Cache Instructions

Instruction	Possible Data Address Compare (DAC) Debug Event	
	DAC-Read	DAC-Write
dcbf	No	Yes
dcbi	No	Yes
dcbst	No	Yes
dcbt	Yes (if cacheable)	No
dcbtst	Yes (if cacheable)	No
dcbz	No	Yes
dccci	No	No
dcread	Yes	No
icbi	No	No
icbt	No	No
iccci	No	No
icread	No	No

10.6.3.2 DAC Applied to String Instructions

The **stswx** instruction with the string length equal to zero (XER[TBC] field) is a no-op. The **lswx** instruction with the string length equal to zero will alter the RT contents with undefined data, as allowed by the architecture. Neither **stswx** nor **lswx** with zero length will cause a DAC debug event since storage is not accessed by these instructions.

10.6.4 Instruction Address Compare (IAC1-IAC2)

The PPC403GC has the capability to take a debug event upon an attempt to execute an instruction from either of two addresses. The addresses, which must be word aligned, are defined in the IAC1 and IAC2 registers. The IA1 field of the DBCR controls the Instruction Address 1 debug event, and IA2 controls the Instruction Address 2 debug event.

0	29	30	31
---	----	----	----

Figure 10-4. Instruction Address Compare (IAC1-IAC2)

0:29		Instruction Address Compare, Word Address (omit 2 lo-order bits of complete address)
30:31		reserved

10.7 Debug Interfaces

The PPC403GC processor has three debug interfaces that can be used to support both hardware and software development.

Trace Status Port	The Trace Status port provides real-time trace information and bus status information. This port is designed to support logic analyzers and development tools.
Serial Port	The serial port can be used for applications and it can also be used to support ROM monitor debuggers. For more information on the serial port see Chapter 7.
JTAG Debug Port	The JTAG debug port complies with the IEEE 1149.1 Test Access Port standard. It also includes enhancements to support debug. The enhancements comply with the IEEE 1149.1 specification for vendor-specific extensions, and are therefore compatible with standard JTAG hardware for boundary-scan system testing.

10.7.1 Trace Status Port

The PPC403GC implements a Trace Status interface to support the tracing of code running in real-time. This interface is designed to be connected to a high speed data collection device such as a logic analyzer. A software tool, such as RISCWatch, with trace capability, such as RISCTrace, can use the data collected from this port to trace code running on the processor. The result is a trace of the code executed, including code that was executed out of the instruction cache if it was enabled.

10

10.7.1.1 Trace Status Signals

There are 7 Trace Status signals, TS0 - TS6, which are active high outputs from the PPC403GC. They are designed to be sampled on the rising edge of the processor clock.

10.7.1.2 Trace Status Connector

A 20-pin male 2x10 header connector is suggested for connecting to the Trace Status port. This connector definition matches the requirements of the RISCTrace feature of RISCWatch, used with logic analyzers from Hewlett-Packard and Tektronix. The connector is shown in Figure 10-5. The connector should be placed as close as possible to the PPC403GC to ensure signal integrity.

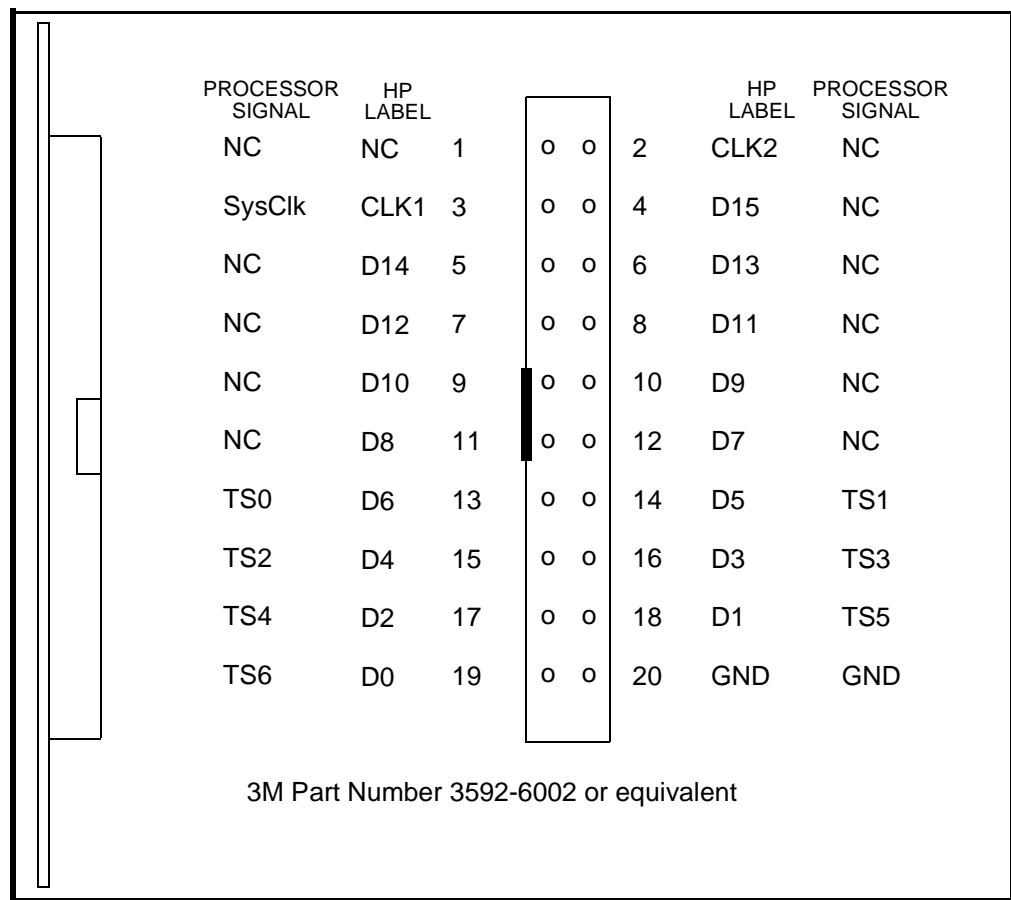


Figure 10-5. Trace Status Connector

10.7.2 IEEE 1149.1 Test Access Port (JTAG)

The IEEE 1149.1 Test Access Port, commonly called JTAG (Joint Test Action Group), is an architectural standard which is described in IEEE standards document 1149.1. The standard provides a method for accessing internal facilities on a chip using a four or five signal interface. The JTAG port was originally designed to support scan-based board testing. The JTAG port has been enhanced to allow for the attachment of a debug tool such as the RISCWatch 400 product from IBM. Please refer to the IEEE 1149.1 Test Access Port standards document for more information on the JTAG port.

Table 10-2. JTAG Port Summary

JTAG Signals	The JTAG port implements the four required JTAG signals: TCLK, TMS, TDI, and TDO. It does not implement the optional $\overline{\text{TRST}}$ signal.
JTAG Clock Requirements	The frequency of the TCLK signal can range from DC up to 1/2 the frequency of the processor clock.
JTAG Reset Requirements	The JTAG debug port logic is reset at the same time as a system reset. When a system reset is performed the JTAG TAP Controller returns to the Test-Logic Reset state.

10.7.2.1 JTAG Connector

A 16-pin male 2x8 header connector is suggested for connecting to the JTAG port. This connector definition matches the requirements of the RISCWatch 400 debugger from IBM. The connector is shown in Figure 10-6 and the signals are shown in Table 10-3 on page 10-17. The connector should be placed as close as possible to the PPC403GC to ensure signal integrity. Note that position 14 does not contain a pin.

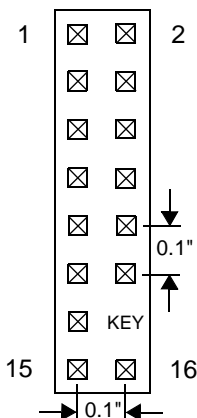


Figure 10-6. JTAG Connector (top view) Physical Layout

Table 10-3. JTAG Connector Signals

Connector Pin	PPC403GC I/O	Signal	Description
1	Out	TDO	JTAG Test Data Out
2		nc	reserved
3	In	TDI ¹	JTAG Test Data In
4		nc	reserved
5		nc	reserved
6		+POWER ²	Processor Power OK
7	In	TCK ³	JTAG Test Clock
8		nc	reserved
9	In	TMS ¹	JTAG Test Mode Select
10		nc	reserved
11	In	HALT ³	Processor Halt
12		nc	reserved
13		nc	reserved
14		key	The pin at this position should be removed.
15		nc	reserved
16		GND	Ground

- 1) It is suggested that a 10K Ohm pullup resistor be connected to this signal. The pullup resistor will reduce chip power consumption. It is not required.
- 2) The +POWER signal is sourced from the target development board and is used as a status signal to indicate that the processor is operational. This signal does not supply power, either to the RISCWatch 400 hardware or to the processor. The active level on this signal may be either +5V or +3.3V (note that the PPC403GC may have either +5V or +3.3V I/O, but the processor itself may be powered only by +3.3V). A series resistor (1K ohm or less) should be used to provide short circuit current limiting protection.
- 3) It is required that a 10K Ohm pullup resistor be connected to this signal. The pullup resistor will ensure proper chip operation when these inputs are not used.

10.7.2.2 JTAG Instructions

The JTAG port implements the **extest**, **sample/preload**, and **bypass** instructions as specified by the IEEE 1149.1 standard. Invalid instructions behave as the **bypass** instruction and there are four private instructions.

Table 10-4. JTAG Instructions

Instruction	Code	Comments
Extest	0000	Per IEEE 1149.1 standard.
Sample/Preload	0001	Per IEEE 1149.1 standard.
JTAG 3	0011	Private
JTAG 5	0101	Private
JTAG 7	0111	Private
JTAG B	1011	Private
Bypass	1111	Per IEEE 1149.1 standard.

10.7.2.3 JTAG Boundary Scan Chain

Boundary Scan Description Language (BSDL), IEEE 1149.1b-1994, is a supplement to IEEE 1149.1-1990 and IEEE 1149.1a-1993 Standard Test Access Port and Boundary-Scan Architecture. It is a subset of the IEEE 1076-1993 Standard VHSIC Hardware Description Language (VHDL). BSDL allows a rigorous description of testability features in components which comply with the standard. It is used by Automated Test Pattern Generation tools for package interconnect tests and by Electronic Design Automation tools for Synthesized Test Logic and Verification. The language provides for robust extensions which can be used for internal Test Generation and to write software for Hardware Debug and Diagnostics.

The primary sections of BSDL include the Logical Port Description, the Physical Pin Map, the Instruction Set and the Boundary Register Description.

The Logical Port Description is used to assign meaningful symbolic names to the pins of the chip. Each pin has a logical type of in, out, inout, buffer or linkage which defines the logical direction of signal flow.

The Physical Pin Map correlates the logical ports of the chip to the physical pins of a specific package. It is possible to have several Physical Pin Maps within a single BSDL description where each map is given a unique name.

The Instruction Set statements describe the bit patterns which must be shifted into the Instruction Register of the chip in order to place the chip into the various test modes defined

by the standard. It also allows for the description of instructions which are unique to the chip.

The Boundary Register Description is a list of each cell or shift stage of the Boundary Register. Each cell has a unique number where the cell numbered '0' is the closest to the Test Data Out (TDO) pin and the cell with the highest number is closest to the Test Data In (TDI) pin. Each cell has additional information associated with it. This information includes a cell type, the logical port associated with the cell, the logical function of the cell, the safe value, the control cell number, the disable value and the result value.

The BSDL for the PPC403GC included in this chapter may be used by PCB design and test engineers for the purposes described in the IEEE 1149.1 standard. Both the BSDL and the conformance of the chip to the standard were verified by TestBench, an IBM EDA tool.

```
-- TestBench generated BSDL May 15 11:15 1996
-- TestBench verified chip compliance May 15 11:45 1996
-- TestBench is a registered trademark of IBM
-- Boundary Scan Description Language (BSDL) for
-- PowerPC 403 GC Embedded Controller
--
```

```
entity PPC403GC is
  generic (PHYSICAL_PIN_MAP : string := "PQFP_160");
```

```
port (
  A6:          inout  bit;
  A7:          inout  bit;
  A8:          inout  bit;
  A9:          inout  bit;
  A10:         inout  bit;
  A11:         inout  bit;
  A12:         out    bit;
  A13:         out    bit;
  A14:         out    bit;
  A15:         out    bit;
  A16:         out    bit;
  A17:         out    bit;
  A18:         out    bit;
  A19:         out    bit;
  A20:         out    bit;
  A21:         out    bit;
  A22:         inout  bit;
  A23:         inout  bit;
  A24:         inout  bit;
  A25:         inout  bit;
```

```

A26:          inout  bit;
A27:          inout  bit;
A28:          inout  bit;
A29:          inout  bit;
AMuxCAS:      out    bit;
BootW:        in     bit;
BusError:     in     bit;
BusReq_DMADXFER: out  bit;
CAS0:         out    bit;
CAS1:         out    bit;
CAS2:         out    bit;
CAS3:         out    bit;
CINT:         in     bit;
CS0:          out    bit;
CS1:          out    bit;
CS2:          out    bit;
CS3:          out    bit;
CS4_RAS3:     out    bit;
CS5_RAS2:     out    bit;
CS6_RAS1:     out    bit;
CS7_RAS0:     out    bit;
D0:           inout  bit;
D1:           inout  bit;
D2:           inout  bit;
D3:           inout  bit;
D4:           inout  bit;
D5:           inout  bit;
D6:           inout  bit;
D7:           inout  bit;
D8:           inout  bit;
D9:           inout  bit;
D10:          inout  bit;
D11:          inout  bit;
D12:          inout  bit;
D13:          inout  bit;
D14:          inout  bit;
D15:          inout  bit;
D16:          inout  bit;
D17:          inout  bit;
D18:          inout  bit;
D19:          inout  bit;
D20:          inout  bit;
D21:          inout  bit;
D22:          inout  bit;
D23:          inout  bit;

```



```

D24:          inout  bit;
D25:          inout  bit;
D26:          inout  bit;
D27:          inout  bit;
D28:          inout  bit;
D29:          inout  bit;
D30:          inout  bit;
D31:          inout  bit;
DMAA0:        out    bit;
DMAA1:        out    bit;
DMAA2:        out    bit;
DMAA3_XACK:   out    bit;
DMAR0:        in     bit;
DMAR1:        in     bit;
DMAR2:        in     bit;
DMAR3_XREQ:   in     bit;
DRAMOE:       out    bit;
DRAMWE:       out    bit;
DSR_CTS:      in     bit;
DTR_RTS:      out    bit;
EOT_TC0:      inout  bit;
EOT_TC1:      inout  bit;
EOT_TC2:      inout  bit;
EOT_TC3_XSize0: inout  bit;
Error:        out    bit;
GND1:         linkage bit;
GND2:         linkage bit;
GND3:         linkage bit;
GND4:         linkage bit;
GND5:         linkage bit;
GND6:         linkage bit;
GND7:         linkage bit;
GND8:         linkage bit;
GND9:         linkage bit;
GND10:        linkage bit;
GND11:        linkage bit;
GND12:        linkage bit;
GND13:        linkage bit;
GND14:        linkage bit;
GND15:        linkage bit;
GND16:        linkage bit;
GND17:        linkage bit;
GND18:        linkage bit;
GND19:        linkage bit;
Halt:         in     bit;

```

```

HoldAck:          out      bit;
HoldReq:          in       bit;
INT0:             in       bit;
INT1:             in       bit;
INT2:             in       bit;
INT3:             in       bit;
INT4:             in       bit;
IVR:              linkage bit;
OE_XSize1:        inout    bit;
R_W:              inout    bit;
Ready:           in       bit;
RecvD:           in       bit;
Reset:           in       bit; --inout
SerClk:          in       bit;
SysClk:          in       bit;
TCK:             in       bit;
TDI:             in       bit;
TDO:             out      bit;
TMS:             in       bit;
TS0:             out      bit;
TS1:             out      bit;
TS2:             out      bit;
TS3:             out      bit;
TS4:             out      bit;
TS5:             out      bit;
TS6:             out      bit;
TestA:           in       bit;
TestB:           in       bit;
TestC_HoldPri:   in       bit;
TestD:           in       bit;
TimerClk:        in       bit;
VDD1:            linkage bit;
VDD2:            linkage bit;
VDD3:            linkage bit;
VDD4:            linkage bit;
VDD5:            linkage bit;
VDD6:            linkage bit;
VDD7:            linkage bit;
VDD8:            linkage bit;
VDD9:            linkage bit;
VDD10:           linkage bit;
VDD11:           linkage bit;
VDD12:           linkage bit;
VDD13:           linkage bit;
VDD14:           linkage bit;

```

```

WBE0_A4:          inout  bit;
WBE1_A5:          inout  bit;
WBE2_A30:         inout  bit;
WBE3_A31:         inout  bit;
XmitD:           out    bit
);

use STD_1149_1_1994.all;

attribute COMPONENT_CONFORMANCE of PPC403GC : entity is
    "STD_1149_1_1993";

attribute PIN_MAP of PPC403GC : entity is PHYSICAL_PIN_MAP;

constant PQFP_160: PIN_MAP_STRING :=
    " GND1          :    1, " &
    " DMAR0         :    2, " &
    " DMAR1         :    3, " &
    " DMAR2         :    4, " &
    " DMAR3_XREQ    :    5, " &
    " TCK           :    6, " &
    " TMS           :    7, " &
    " TDI           :    8, " &
    " Halt          :    9, " &
    " GND2          :   10, " &
    " BootW         :   11, " &
    " BusError      :   12, " &
    " Ready         :   13, " &
    " HoldReq       :   14, " &
    " GND3          :   15, " &
    " TDO           :   16, " &
    " TS0           :   17, " &
    " TS1           :   18, " &
    " TS2           :   19, " &
    " VDD1          :   20, " &
    " VDD2          :   21, " &
    " SysClk        :   22, " &
    " TestA         :   23, " &
    " TestB         :   24, " &
    " TimerClk      :   25, " &
    " SerClk        :   26, " &
    " RecvD         :   27, " &
    " DSR_CTS       :   28, " &
    " GND4          :   29, " &
    " GND5          :   30, " &

```

```

" INT0           : 31," &
" INT1           : 32," &
" INT2           : 33," &
" INT3           : 34," &
" INT4           : 35," &
" CINT           : 36," &
" TestC_HoldPri  : 37," &
" TestD          : 38," &
" IVR            : 39," &
" VDD3           : 40," &
" GND6           : 41," &
" D0             : 42," &
" D1             : 43," &
" D2             : 44," &
" D3             : 45," &
" D4             : 46," &
" D5             : 47," &
" D6             : 48," &
" VDD4           : 49," &
" GND7           : 50," &
" D7             : 51," &
" D8             : 52," &
" D9             : 53," &
" D10            : 54," &
" D11            : 55," &
" D12            : 56," &
" D13            : 57," &
" D14            : 58," &
" GND8           : 59," &
" GND9           : 60," &
" VDD5           : 61," &
" D15            : 62," &
" D16            : 63," &
" D17            : 64," &
" D18            : 65," &
" D19            : 66," &
" D20            : 67," &
" D21            : 68," &
" VDD6           : 69," &
" GND10          : 70," &
" D22            : 71," &
" D23            : 72," &
" D24            : 73," &
" D25            : 74," &
" D26            : 75," &

```

```

" D27           : 76," &
" D28           : 77," &
" D29           : 78," &
" D30           : 79," &
" VDD7          : 80," &
" GND11         : 81," &
" D31           : 82," &
" TS6           : 83," &
" TS5           : 84," &
" TS4           : 85," &
" TS3           : 86," &
" XmitD         : 87," &
" DTR_RTS       : 88," &
" VDD8          : 89," &
" GND12         : 90," &
" Reset         : 91," &
" A6            : 92," &
" A7            : 93," &
" A8            : 94," &
" A9            : 95," &
" A10           : 96," &
" A11           : 97," &
" A12           : 98," &
" A13           : 99," &
" VDD9          : 100," &
" GND13         : 101," &
" GND14         : 102," &
" A14           : 103," &
" A15           : 104," &
" A16           : 105," &
" A17           : 106," &
" A18           : 107," &
" A19           : 108," &
" A20           : 109," &
" A21           : 110," &
" GND15         : 111," &
" A22           : 112," &
" A23           : 113," &
" A24           : 114," &
" A25           : 115," &
" A26           : 116," &
" A27           : 117," &
" A28           : 118," &
" A29           : 119," &
" VDD10         : 120," &

```

```

" GND16           : 121, " &
" WBE0_A4         : 122, " &
" WBE1_A5         : 123, " &
" WBE2_A30        : 124, " &
" WBE3_A31        : 125, " &
" OE_XSize1       : 126, " &
" R_W             : 127, " &
" EOT_TC0         : 128, " &
" VDD11           : 129, " &
" GND17           : 130, " &
" EOT_TC1         : 131, " &
" EOT_TC2         : 132, " &
" EOT_TC3_XSize0  : 133, " &
" HoldAck         : 134, " &
" BusReq_DMADXFER : 135, " &
" Error           : 136, " &
" DRAMOE          : 137, " &
" DRAMWE          : 138, " &
" AMuxCAS         : 139, " &
" VDD12           : 140, " &
" GND18           : 141, " &
" CAS0            : 142, " &
" CAS1            : 143, " &
" CAS2            : 144, " &
" CAS3            : 145, " &
" CS7_RAS0        : 146, " &
" CS6_RAS1        : 147, " &
" CS5_RAS2        : 148, " &
" VDD13           : 149, " &
" GND19           : 150, " &
" CS4_RAS3        : 151, " &
" CS3             : 152, " &
" CS2             : 153, " &
" CS1             : 154, " &
" CS0             : 155, " &
" DMAA0           : 156, " &
" DMAA1           : 157, " &
" DMAA2           : 158, " &
" DMAA3_XACK      : 159, " &
" VDD14           : 160 " ;

```

```

attribute TAP_SCAN_CLOCK of TCK: signal is (10.0e6,BOTH);
attribute TAP_SCAN_IN   of TDI: signal is true;
attribute TAP_SCAN_MODE of TMS: signal is true;
attribute TAP_SCAN_OUT  of TDO: signal is true;

```

```

-- TAP_SCAN_RESET not present

attribute COMPLIANCE_PATTERNS of PPC403GC: entity is
  "(SysClk,TestA,TestB,Reset) (0011)";

attribute INSTRUCTION_LENGTH of PPC403GC: entity is 4;

attribute INSTRUCTION_OPCODE of PPC403GC: entity is
  "EXTTEST(0000),SAMPLE(0001),"&
  "JTAG3(0011),JTAG5(0101),JTAG7(0111),JTAGB(1011),"&
  "BYPASS(1111)";

attribute INSTRUCTION_CAPTURE of PPC403GC: entity is "0001";

attribute INSTRUCTION_PRIVATE of PPC403GC: entity is
  "JTAG3,JTAG5,JTAG7,JTAGB";

attribute BOUNDARY_LENGTH of PPC403GC: entity is 132;

-- cell type portname      function safe cntl dis res
attribute BOUNDARY_REGISTER of PPC403GC: entity is
  " 0 (BC_1, DSR_CTS,      input,  X          )," &
  " 1 (BC_1, RecvD,       input,  X          )," &
  " 2 (BC_1, SerClk,      input,  X          )," &
  " 3 (BC_1, DTR_RTS,     output3, 0, 12, 0, Z)," &
  " 4 (BC_1, XmitD,       output3, 0, 12, 0, Z)," &
  " 5 (BC_1, *,           control, 0          )," &
  " 6 (BC_1, *,           control, 0          )," &
  " 7 (BC_1, *,           control, 0          )," &
  " 8 (BC_1, *,           control, 0          )," &
  " 9 (BC_1, *,           control, 0          )," &
  "10 (BC_1, *,           control, 0          )," &
  "11 (BC_1, *,           control, 0          )," &
  "12 (BC_1, *,           control, 0          )," &
  "13 (BC_1, *,           control, 0          )," &
  "14 (BC_1, *,           control, 0          )," &
  "15 (BC_1, DMAA3_XACK,   output3, 0, 12, 0, Z)," &
  "16 (BC_1, DMAA2,       output3, 0, 12, 0, Z)," &
  "17 (BC_1, DMAA1,       output3, 0, 12, 0, Z)," &
  "18 (BC_1, DMAA0,       output3, 0, 12, 0, Z)," &
  "19 (BC_1, CS0,         output3, 0, 13, 0, Z)," &
  "20 (BC_1, CS1,         output3, 0, 13, 0, Z)," &
  "21 (BC_1, CS2,         output3, 0, 13, 0, Z)," &
  "22 (BC_1, CS3,         output3, 0, 13, 0, Z)," &
  "23 (BC_1, CS4_RAS3,    output3, 0, 12, 0, Z)," &

```

```

" 24 (BC_1, CS5_RAS2,          output3, 0, 11, 0, Z)," &
" 25 (BC_1, CS6_RAS1,          output3, 0, 10, 0, Z)," &
" 26 (BC_1, CS7_RAS0,          output3, 0, 9, 0, Z)," &
" 27 (BC_1, CAS3,              output3, 0, 12, 0, Z)," &
" 28 (BC_1, CAS2,              output3, 0, 12, 0, Z)," &
" 29 (BC_1, CAS1,              output3, 0, 12, 0, Z)," &
" 30 (BC_1, CAS0,              output3, 0, 12, 0, Z)," &
" 31 (BC_1, AMuxCAS,           output3, 0, 12, 0, Z)," &
" 32 (BC_1, DRAMWE,            output3, 0, 12, 0, Z)," &
" 33 (BC_1, DRAMOE,            output3, 0, 12, 0, Z)," &
" 34 (BC_1, Error,             output3, 0, 12, 0, Z)," &
" 35 (BC_1, BusReq_DMADXFER,   output3, 0, 12, 0, Z)," &
" 36 (BC_1, HoldAck,           output3, 0, 12, 0, Z)," &
" 37 (BC_7, EOT_TC3_XSize0,    bidir, 0, 5, 0, Z)," &
" 38 (BC_7, EOT_TC2,           bidir, 0, 6, 0, Z)," &
" 39 (BC_7, EOT_TC1,           bidir, 0, 7, 0, Z)," &
" 40 (BC_7, EOT_TC0,           bidir, 0, 8, 0, Z)," &
" 41 (BC_7, R_W,               bidir, 0, 13, 0, Z)," &
" 42 (BC_7, OE_XSize1,         bidir, 0, 13, 0, Z)," &
" 43 (BC_7, WBE3_A31,          bidir, 0, 13, 0, Z)," &
" 44 (BC_7, WBE2_A30,          bidir, 0, 13, 0, Z)," &
" 45 (BC_7, WBE1_A5,           bidir, 0, 13, 0, Z)," &
" 46 (BC_7, WBE0_A4,           bidir, 0, 13, 0, Z)," &
" 47 (BC_7, A29,               bidir, 0, 14, 0, Z)," &
" 48 (BC_7, A28,               bidir, 0, 14, 0, Z)," &
" 49 (BC_7, A27,               bidir, 0, 14, 0, Z)," &
" 50 (BC_7, A26,               bidir, 0, 14, 0, Z)," &
" 51 (BC_7, A25,               bidir, 0, 14, 0, Z)," &
" 52 (BC_7, A24,               bidir, 0, 14, 0, Z)," &
" 53 (BC_7, A23,               bidir, 0, 14, 0, Z)," &
" 54 (BC_7, A22,               bidir, 0, 14, 0, Z)," &
" 55 (BC_1, A21,               output3, 0, 14, 0, Z)," &
" 56 (BC_1, A20,               output3, 0, 14, 0, Z)," &
" 57 (BC_1, A19,               output3, 0, 14, 0, Z)," &
" 58 (BC_1, A18,               output3, 0, 14, 0, Z)," &
" 59 (BC_1, A17,               output3, 0, 14, 0, Z)," &
" 60 (BC_1, A16,               output3, 0, 14, 0, Z)," &
" 61 (BC_1, A15,               output3, 0, 14, 0, Z)," &
" 62 (BC_1, A14,               output3, 0, 14, 0, Z)," &
" 63 (BC_1, A13,               output3, 0, 14, 0, Z)," &
" 64 (BC_1, A12,               output3, 0, 14, 0, Z)," &
" 65 (BC_7, A11,               bidir, 0, 14, 0, Z)," &
" 66 (BC_7, A10,               bidir, 0, 14, 0, Z)," &
" 67 (BC_7, A9,                bidir, 0, 14, 0, Z)," &
" 68 (BC_7, A8,                bidir, 0, 14, 0, Z)," &

```



```

" 69 (BC_7, A7,          bidir, 0, 14, 0, Z)," &
" 70 (BC_7, A6,          bidir, 0, 14, 0, Z)," &
" 71 (BC_1, TS3,         output3, 0, 12, 0, Z)," &
" 72 (BC_1, TS4,         output3, 0, 12, 0, Z)," &
" 73 (BC_1, TS5,         output3, 0, 12, 0, Z)," &
" 74 (BC_1, TS6,         output3, 0, 12, 0, Z)," &
" 75 (BC_7, D31,         bidir, 0, 85, 0, Z)," &
" 76 (BC_7, D30,         bidir, 0, 85, 0, Z)," &
" 77 (BC_7, D29,         bidir, 0, 85, 0, Z)," &
" 78 (BC_7, D28,         bidir, 0, 85, 0, Z)," &
" 79 (BC_7, D27,         bidir, 0, 85, 0, Z)," &
" 80 (BC_7, D26,         bidir, 0, 85, 0, Z)," &
" 81 (BC_7, D25,         bidir, 0, 85, 0, Z)," &
" 82 (BC_7, D24,         bidir, 0, 85, 0, Z)," &
" 83 (BC_7, D23,         bidir, 0, 86, 0, Z)," &
" 84 (BC_7, D22,         bidir, 0, 86, 0, Z)," &
" 85 (BC_1, *,           control, 0          )," &
" 86 (BC_1, *,           control, 0          )," &
" 87 (BC_7, D21,         bidir, 0, 86, 0, Z)," &
" 88 (BC_7, D20,         bidir, 0, 86, 0, Z)," &
" 89 (BC_7, D19,         bidir, 0, 86, 0, Z)," &
" 90 (BC_7, D18,         bidir, 0, 86, 0, Z)," &
" 91 (BC_7, D17,         bidir, 0, 86, 0, Z)," &
" 92 (BC_7, D16,         bidir, 0, 86, 0, Z)," &
" 93 (BC_7, D15,         bidir, 0, 102, 0, Z)," &
" 94 (BC_7, D14,         bidir, 0, 102, 0, Z)," &
" 95 (BC_7, D13,         bidir, 0, 102, 0, Z)," &
" 96 (BC_7, D12,         bidir, 0, 102, 0, Z)," &
" 97 (BC_7, D11,         bidir, 0, 102, 0, Z)," &
" 98 (BC_7, D10,         bidir, 0, 102, 0, Z)," &
" 99 (BC_7, D9,          bidir, 0, 102, 0, Z)," &
"100 (BC_7, D8,          bidir, 0, 102, 0, Z)," &
"101 (BC_7, D7,          bidir, 0, 103, 0, Z)," &
"102 (BC_1, *,           control, 0          )," &
"103 (BC_1, *,           control, 0          )," &
"104 (BC_7, D6,          bidir, 0, 103, 0, Z)," &
"105 (BC_7, D5,          bidir, 0, 103, 0, Z)," &
"106 (BC_7, D4,          bidir, 0, 103, 0, Z)," &
"107 (BC_7, D3,          bidir, 0, 103, 0, Z)," &
"108 (BC_7, D2,          bidir, 0, 103, 0, Z)," &
"109 (BC_7, D1,          bidir, 0, 103, 0, Z)," &
"110 (BC_7, D0,          bidir, 0, 103, 0, Z)," &
"111 (BC_1, TestD,       input, X            )," &
"112 (BC_1, TestC_HoldPri, input, X            )," &
"113 (BC_1, CINT,        input, X            )," &

```

```

"114 (BC_1, INT4,          input,  X          ), " &
"115 (BC_1, INT3,          input,  X          ), " &
"116 (BC_1, INT2,          input,  X          ), " &
"117 (BC_1, INT1,          input,  X          ), " &
"118 (BC_1, INT0,          input,  X          ), " &
"119 (BC_1, TimerClk,      input,  X          ), " &
"120 (BC_1, TS2,           output3, 0, 12, 0, Z), " &
"121 (BC_1, TS1,           output3, 0, 12, 0, Z), " &
"122 (BC_1, TS0,           output3, 0, 12, 0, Z), " &
"123 (BC_1, HoldReq,       input,  X          ), " &
"124 (BC_1, Ready,         input,  X          ), " &
"125 (BC_1, BusError,      input,  X          ), " &
"126 (BC_1, BootW,         input,  X          ), " &
"127 (BC_1, Halt,          input,  X          ), " &
"128 (BC_1, DMAR3_XREQ     input,  X          ), " &
"129 (BC_1, DMAR2,         input,  X          ), " &
"130 (BC_1, DMAR1,         input,  X          ), " &
"131 (BC_1, DMAR0,         input,  X          ) ";

```

```
end PPC403GC;
```

Descriptions of the PPC403GC instructions follow. Each description contains these elements:

- Instruction names (mnemonic and full)
- Instruction syntax
- Instruction format diagram specific to the individual instruction
- Pseudocode description of the instruction operation
- Prose description of the instruction operation
- Registers altered
- Architecture notes identifying the associated PowerPC Architecture component

Where appropriate, instruction descriptions list invalid instruction forms and provide programming notes.

11.1 Instruction Formats

For a more complete discussion of instruction formats, including a summary of instruction field usage and a compilation of general instruction format diagrams appropriate to the PPC403GC, see Section A.3 on page A-50.

Instructions are four bytes long. Instruction addresses are always word-aligned.

Instruction bits 0 through 5 always contain the primary opcode. Many instructions have an extended opcode in another field. The remaining instruction bits contain additional fields. All instruction fields belong to one of the following categories:

- Defined

These instructions contain values, such as opcodes, that cannot be altered. The instruction format diagrams specify the values of defined fields.

- Variable

These fields contain operands, such as general purpose register selectors and immediate values, that may vary from execution to execution. The instruction format diagrams specify the operands in variable fields.

- Reserved

Bits in a reserved field should be set to 0. In the instruction format diagrams, reserved fields are shaded.

If any bit in a defined field does not contain the expected value, the instruction is illegal and an illegal instruction exception occurs. If any bit in a reserved field does not contain 0, the instruction form is invalid and its result is architecturally undefined. The PPC403GC executes all invalid instruction forms without causing an illegal instruction exception.

11.2 Pseudocode

The pseudocode that appears in the instruction descriptions provides a semi-formal language for describing instruction operations.

The pseudocode uses the following notation:

←	Assignment
∧	AND logical operator
¬	NOT logical operator
∨	OR logical operator
⊕	Exclusive-OR (XOR) logical operator
+	Twos complement addition
−	Twos complement subtraction, unary minus
×	Multiplication
÷	Division yielding a quotient
%	Remainder of an integer division; $(33 \% 32) = 1$.
	Concatenation
=, ≠	Equal, not equal relations
<, >	Signed comparison relations
$\overset{u}{<}$, $\overset{u}{>}$	Unsigned comparison relations
if...then...else...	Conditional execution; if <i>condition</i> then <i>a</i> else <i>b</i> , where <i>a</i> and <i>b</i> represent one or more pseudocode statements. Indenting indicates the ranges of <i>a</i> and <i>b</i> . If <i>b</i> is null, the else does not appear.
do	Do loop. “to” and “by” clauses specify incrementing an iteration variable; “while” and “until” clauses specify terminating conditions. Indenting indicates the range of the loop.

leave	Leave innermost do loop or do loop specified in a leave statement.
n	A decimal number
x'n'	A hexadecimal number
b'n'	A binary number
FLD	An instruction field
FLD _b	A bit in an instruction field
FLD _{b:b}	A range of bits in an instruction field
FLD _{b,b,...}	A list of bits, by number or name, in a named field
REG _b	A bit in a named register
REG _{b:b}	A range of bits in a named register
REG _{b,b,...}	A list of bits, by number or name, in a named register
REG[FLD]	A field in a named register
REG[FLD, FLD ...]	A list of fields in a named register
GPR(r)	General Purpose Register r, where $0 \leq r \leq 31$.
(GPR(r))	The contents of General Purpose Register r, where $0 \leq r \leq 31$.
DCR(DCRN)	A DCR specified by the DCRF field in a mfdcr or mtdcr instruction
SPR(SPRN)	An SPR specified by the SPRF field in a mfspr or mtspr instruction
RA, RB, ...	GPRs
(Rx)	The contents of a GPR, where x is A, B, S, or T
(RA 0)	The contents of the register RA or 0, if the RA field is 0.
c _{0:3}	A four-bit object used to store condition results in compare instructions.
ⁿ b	The bit or bit value <i>b</i> is replicated <i>n</i> times.
xx	Bit positions which are don't-cares.
CEIL(x)	Least integer $\geq x$.
EXTS(x)	The result of extending x on the left with sign bits.
PC	Program counter.
RESERVE	Reserve bit; indicates whether a process has reserved a block of storage.

CIA	Current instruction address; the 32-bit address of the instruction being described by a sequence of pseudocode. This address is used to set the next instruction address (NIA). Does not correspond to any architected register.
NIA	Next instruction address; the 32-bit address of the next instruction to be executed. In pseudocode, a successful branch is indicated by assigning a value to NIA. For instructions that do not branch, the NIA is CIA +4.
MS(addr, n)	The number of bytes represented by <i>n</i> at the location in main storage represented by <i>addr</i> .
EA	Effective address; the 32-bit address, derived by applying indexing or indirect addressing rules to the specified operand, that specifies an location in main storage.
ROTL((RS),n)	Rotate left; the contents of RS are shifted left the number of bits specified by <i>n</i> .
MASK(MB,ME)	Mask having 1's in positions MB through ME (wrapping if MB > ME) and 0's elsewhere.
instruction(EA)	An instruction operating on a data or instruction cache block associated with an effective address.

The following table lists the pseudocode operators and their associativity in descending order of precedence:

Table 11-1. Operator Precedence

Operators	Associativity
REG _b , REG[FLD], function evaluation	Left to right
ⁿ b	Right to left
¬, − (unary minus)	Right to left
×, ÷	Left to right
+, −	Left to right
	Left to right
=, ≠, <, >, < ^u , > ^u	Left to right
∧, ⊕	Left to right
∨	Left to right
←	None

11.3 Register Usage

Each instruction description lists the registers altered by the instruction. Some register changes are explicitly detailed in the instruction description (for example, the target register of a load instruction). Other registers are changed, with the details of the change not included in the instruction description. This category frequently includes the Condition Register (CR) and the Fixed-point Exception Register (XER). For discussion of CR, see Section 2.3.3 on page 2-13. For discussion of XER, see Section 2.3.2.5 on page 2-10.

add

Add

add	RT,RA,RB	(OE=0, Rc=0)
add.	RT,RA,RB	(OE=0, Rc=1)
addo	RT,RA,RB	(OE=1, Rc=0)
addo.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	266	Rc
0	6	11	16	21 22		31

$(RT) \leftarrow (RA) + (RB)$

The sum of the contents of register RA and the contents of register RB is placed into register RT.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

addc	RT,RA,RB	(OE=0, Rc=0)
addc.	RT,RA,RB	(OE=0, Rc=1)
addco	RT,RA,RB	(OE=1, Rc=0)
addco.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	10	Rc
0	6	11	16	21 22		31

$(RT) \leftarrow (RA) + (RB)$
if $(RA) + (RB) \geq 2^{32} - 1$ then
 $XER[CA] \leftarrow 1$
else
 $XER[CA] \leftarrow 0$

The sum of the contents of register RA and register RB is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

adde

Add Extended

adde RT,RA,RB (OE=0, Rc=0)
adde. RT,RA,RB (OE=0, Rc=1)
addeo RT,RA,RB (OE=1, Rc=0)
addeo. RT,RA,RB (OE=1, Rc=1)

31	RT	RA	RB	OE	138	Rc
0	6	11	16	21 22		31

```
(RT) ← (RA) + (RB) + XER[CA]
if (RA) + (RB) + XER[CA]  $\overset{u}{>} 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0
```

The sum of the contents of register RA, register RB, and XER[CA] is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

addi RT,RA,IM

14	RT	RA	IM
0	6	11	16
0			31

$$(RT) \leftarrow (RA|0) + \text{EXTS}(IM)$$

If the RA field is 0, the IM field, sign-extended to 32 bits, is placed into register RT.

If the RA field is nonzero, the sum of the contents of register RA and the contents of the IM field, sign-extended to 32 bits, is placed into register RT.

Registers Altered

- RT

Programming Note

To place an immediate, sign-extended value into the GPR specified by the RT field, set the RA field to 0.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-2. Extended Mnemonics for addi

Mnemonic	Operands	Function	Other Registers Changed
la	RT, D(RA)	Load address. (RA ≠ 0) D is an offset from a base address that is assumed to be (RA). $(RT) \leftarrow (RA) + \text{EXTS}(D)$ <i>Extended mnemonic for</i> addi RT,RA,D	
li	RT, IM	Load immediate. $(RT) \leftarrow \text{EXTS}(IM)$ <i>Extended mnemonic for</i> addi RT,0,IM	
subi	RT, RA, IM	Subtract EXTS(IM) from (RA 0). Place result in RT. <i>Extended mnemonic for</i> addi RT,RA,-IM	

addic

Add Immediate Carrying

addic RT,RA,IM

12	RT	RA	IM
0	6	11	16
			31

```
(RT) ← (RA) + EXTS(IM)
if (RA) + EXTS(IM)  $\geq 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0
```

The sum of the contents of register RA and the contents of the IM field, sign-extended to 32 bits, is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-3. Extended Mnemonics for addic

Mnemonic	Operands	Function	Other Registers Changed
subic	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for addic RT,RA,-IM</i>	

addic. RT,RA,IM

13	RT	RA	IM
0	6	11	16
			31

```

(RT) ← (RA) + EXTS(IM)
if (RA) + EXTS(IM)  $\geq 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the contents of register RA and the contents of the IM field, sign-extended to 32 bits, is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO}

Programming Note

addic. is one of three instructions that implicitly update CR[CR0] without having an RC field. The other instructions are **andi.** and **andis..**

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-4. Extended Mnemonics for addic.

Mnemonic	Operands	Function	Other Registers Changed
subic.	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for addic. RT,RA,-IM</i>	CR[CR0]

addis

Add Immediate Shifted

addis RT,RA,IM

15	RT	RA	IM
0	6	11	16
			31

$$(RT) \leftarrow (RA|0) + (IM \parallel ^{16}0)$$

If the RA field is 0, the IM field is concatenated on its right with sixteen 0-bits and placed into register RT.

If the RA field is nonzero, the contents of register RA are added to the contents of the extended IM field. The sum is stored into register RT.

Registers Altered

- RT

Programming Note

An **addi** instruction stores a sign-extended 16-bit value in a GPR. An **addis** instruction followed by an **ori** instruction stores an arbitrary 32-bit value in a GPR, as shown in the following example:

addis RT, 0, high 16 bits of value
ori RT, RT, low 16 bits of value

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-5. Extended Mnemonics for addis

Mnemonic	Operands	Function	Other Registers Changed
lis	RT, IM	Load immediate shifted. $(RT) \leftarrow (IM \parallel ^{16}0)$ <i>Extended mnemonic for addis RT,0,IM</i>	
subis	RT, RA, IM	Subtract $(IM \parallel ^{16}0)$ from $(RA 0)$. Place result in RT. <i>Extended mnemonic for addis RT,RA,-IM</i>	

addme

Add to Minus One Extended

addme	RT,RA	(OE=0, Rc=0)
addme.	RT,RA	(OE=0, Rc=1)
addmeo	RT,RA	(OE=1, Rc=0)
addmeo.	RT,RA	(OE=1, Rc=1)

31	RT	RA		OE	234	Rc
0	6	11	16	21 22		31

```

(RT) ← (RA) + XER[CA] + (−1)
if (RA) + XER[CA] + 0xFFFF FFFF  $\overset{u}{>} 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the contents of register RA, XER[CA], and −1 is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Invalid Instruction Forms

- Reserved fields

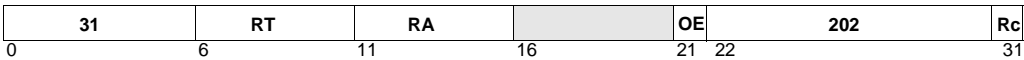
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

addze

Add to Zero Extended

addze	RT,RA	(OE=0, Rc=0)
addze.	RT,RA	(OE=0, Rc=1)
addzeo	RT,RA	(OE=1, Rc=0)
addzeo.	RT,RA	(OE=1, Rc=1)



```
(RT) ← (RA) + XER[CA]
if (RA) + XER[CA]  $\overset{u}{>} 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0
```

The sum of the contents of register RA and XER[CA] is placed into register RT.
XER[CA] is set to a value determined by the unsigned magnitude of the result of the add operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

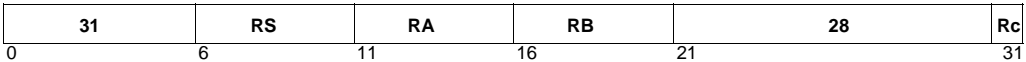
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

and RA,RS,RB (Rc=0)
and. RA,RS,RB (Rc=1)



$(RA) \leftarrow (RS) \wedge (RB)$

The contents of register RS is ANDed with the contents of register RB and the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

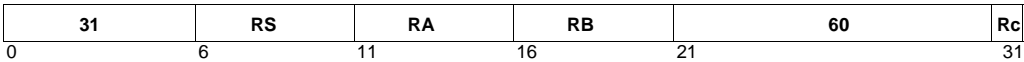
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

andc

AND with Complement

andc RA,RS,RB (Rc=0)
andc. RA,RS,RB (Rc=1)



$(RA) \leftarrow (RS) \wedge \neg(RB)$

The contents of register RS is ANDed with the ones complement of the contents of register RB; the result is placed into register RA.

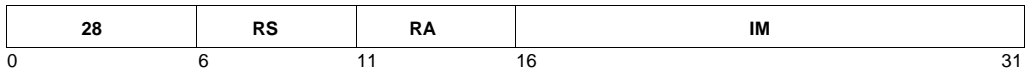
Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

andi. RA,RS,IM



$$(RA) \leftarrow (RS) \wedge (^{16}0 \parallel IM)$$

The IM field is extended to 32 bits by concatenating 16 0-bits on its left. The contents of register RS is ANDed with the extended IM field; the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO}

Programming Note

The **andi.** instruction can test whether any of the 16 least-significant bits in a GPR are 1-bits.

andi. is one of three instructions that implicitly update CR[CR0] without having an Rc field. The other instructions are **addic.** and **andis.**

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

andis.

AND Immediate Shifted

andis. RA,RS,IM

29	RS	RA	IM
0	6	11	16
			31

$$(RA) \leftarrow (RS) \wedge (IM \parallel 160)$$

The IM field is extended to 32 bits by concatenating 16 0-bits on its right. The contents of register RS are ANDed with the extended IM field; the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO}

Programming Note

The **andis.** instruction can test whether any of the 16 most-significant bits in a GPR are 1-bits.

andis. is one of three instructions that implicitly update CR[CR0] without having an Rc field. The other instructions are **addic.** and **andi.**.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

b	target	(AA=0, LK=0)
ba	target	(AA=1, LK=0)
bl	target	(AA=0, LK=1)
bla	target	(AA=1, LK=1)

18	LI	AA	LK
0	6	30	31

```
If AA = 1 then
    LI ← target6:29
    NIA ← EXTS(LI || 20)
else
    LI ← (target – CIA)6:29
    NIA ← CIA + EXTS(LI || 20)
if LK = 1 then
    (LR) ← CIA + 4
PC ← NIA
```

The next instruction address (NIA) is the effective address of the branch. The NIA is formed by adding a displacement to a base address. The displacement is obtained by concatenating two 0-bits to the right of the LI field and sign-extending the result to 32 bits.

If the AA field contains 0, the base address is the address of the branch instruction, which is also the current instruction address (CIA). If the AA field contains 1, the base address is 0.

Program flow is transferred to the NIA.

If the LK field contains 1, then (CIA + 4) is placed into the LR.

Registers Altered

- LR if LK contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

bc

Branch Conditional

bc	BO, BI, target	(AA=0, LK=0)
bca	BO, BI, target	(AA=1, LK=0)
bcl	BO, BI, target	(AA=0, LK=1)
bcla	BO, BI, target	(AA=1, LK=1)

16	BO	BI	BD	AA	LK
0	6	11	16	30	31

```

if  $BO_2 = 0$  then
     $CTR \leftarrow CTR - 1$ 
if  $(BO_2 = 1 \vee ((CTR = 0) = BO_3)) \wedge (BO_0 = 1 \vee (CR_{BI} = BO_1))$  then
    if  $AA = 1$  then
         $BD \leftarrow target_{16:29}$ 
         $NIA \leftarrow EXTS(BD \parallel ^20)$ 
    else
         $BD \leftarrow (target - CIA)_{16:29}$ 
         $NIA \leftarrow CIA + EXTS(BD \parallel ^20)$ 
    else
         $NIA \leftarrow CIA + 4$ 
if  $LK = 1$  then
     $(LR) \leftarrow CIA + 4$ 
 $PC \leftarrow NIA$ 

```

If bit 2 of the BO field contains 0, the CTR is decremented.

The BI field specifies a bit in the CR to be used as the condition of the branch.

The next instruction address (NIA) is the effective address of the branch. The NIA is formed by adding a displacement to a base address. The displacement is obtained by concatenating two 0-bits to the right of the BD field and sign-extending the result to 32 bits.

If the AA field contains 0, the base address is the address of the branch instruction, which is also the current instruction address (CIA). If the AA field contains 1, the base address is 0.

The BO field controls options that determine when program flow is transferred to the NIA. The BO field also controls Branch Prediction, a performance-improvement feature. See Section 2.7.4 and Section 2.7.5 for a complete discussion.

If the LK field contains 1, then $(CIA + 4)$ is placed into the LR.

Registers Altered

- CTR if BO_2 contains 0
- LR if LK contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla

Mnemonic	Operands	Function	Other Registers Changed
bdnz	target	Decrement CTR. Branch if CTR \neq 0. <i>Extended mnemonic for</i> bc 16,0,target	
bdnza		<i>Extended mnemonic for</i> bca 16,0,target	
bdnzl		<i>Extended mnemonic for</i> bcl 16,0,target	(LR) \leftarrow CIA + 4.
bdnzla		<i>Extended mnemonic for</i> bcla 16,0,target	(LR) \leftarrow CIA + 4.
bdnzf	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 0,cr_bit,target	
bdnzfa		<i>Extended mnemonic for</i> bca 0,cr_bit,target	
bdnzfl		<i>Extended mnemonic for</i> bcl 0,cr_bit,target	(LR) \leftarrow CIA + 4.
bdnzfla		<i>Extended mnemonic for</i> bcla 0,cr_bit,target	(LR) \leftarrow CIA + 4.
bdnzt	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 8,cr_bit,target	
bdnzta		<i>Extended mnemonic for</i> bca 8,cr_bit,target	
bdnztl		<i>Extended mnemonic for</i> bcl 8,cr_bit,target	(LR) \leftarrow CIA + 4.
bdnztla		<i>Extended mnemonic for</i> bcla 8,cr_bit,target	(LR) \leftarrow CIA + 4.

bc

Branch Conditional

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bdz	target	Decrement CTR. Branch if CTR = 0. <i>Extended mnemonic for</i> bc 18,0,target	
bdza		<i>Extended mnemonic for</i> bca 18,0,target	
bdzl		<i>Extended mnemonic for</i> bcl 18,0,target	(LR) ← CIA + 4.
bdzla		<i>Extended mnemonic for</i> bcla 18,0,target	(LR) ← CIA + 4.
bdzf	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 2,cr_bit,target	
bdzfa		<i>Extended mnemonic for</i> bca 2,cr_bit,target	
bdzfl		<i>Extended mnemonic for</i> bcl 2,cr_bit,target	(LR) ← CIA + 4.
bdzfla		<i>Extended mnemonic for</i> bcla 2,cr_bit,target	(LR) ← CIA + 4.
bdzt	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 10,cr_bit,target	
bdzta		<i>Extended mnemonic for</i> bca 10,cr_bit,target	
bdztl		<i>Extended mnemonic for</i> bcl 10,cr_bit,target	(LR) ← CIA + 4.
bdztla		<i>Extended mnemonic for</i> bcla 10,cr_bit,target	(LR) ← CIA + 4.
beq	[cr_field,] target	Branch if equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+2,target	
beqa		<i>Extended mnemonic for</i> bca 12,4*cr_field+2,target	
beql		<i>Extended mnemonic for</i> bcl 12,4*cr_field+2,target	(LR) ← CIA + 4.
beqla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+2,target	(LR) ← CIA + 4.

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bf	cr_bit, target	Branch if CR _{cr_bit} = 0. <i>Extended mnemonic for bc 4,cr_bit,target</i>	
bfa		<i>Extended mnemonic for bca 4,cr_bit,target</i>	
bfl		<i>Extended mnemonic for bcl 4,cr_bit,target</i>	LR
bfla		<i>Extended mnemonic for bcla 4,cr_bit,target</i>	LR
bge	[cr_field,] target	Branch if greater than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bc 4,4*cr_field+0,target</i>	
bgea		<i>Extended mnemonic for bca 4,4*cr_field+0,target</i>	
bgei		<i>Extended mnemonic for bcl 4,4*cr_field+0,target</i>	LR
bgeia		<i>Extended mnemonic for bcla 4,4*cr_field+0,target</i>	LR
bgt	[cr_field,] target	Branch if greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bc 12,4*cr_field+1,target</i>	
bgt a		<i>Extended mnemonic for bca 12,4*cr_field+1,target</i>	
bgt i		<i>Extended mnemonic for bcl 12,4*cr_field+1,target</i>	LR
bgt i a		<i>Extended mnemonic for bcla 12,4*cr_field+1,target</i>	LR
ble	[cr_field,] target	Branch if less than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bc 4,4*cr_field+1,target</i>	
ble a		<i>Extended mnemonic for bca 4,4*cr_field+1,target</i>	
ble i		<i>Extended mnemonic for bcl 4,4*cr_field+1,target</i>	LR
ble i a		<i>Extended mnemonic for bcla 4,4*cr_field+1,target</i>	LR

bc

Branch Conditional

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla (cont.)

Mnemonic	Operands	Function	Other Registers Changed
blt	[cr_field,] target	Branch if less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+0,target	
blta		<i>Extended mnemonic for</i> bca 12,4*cr_field+0,target	
bltl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+0,target	(LR) ← CIA + 4.
bltla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+0,target	(LR) ← CIA + 4.
bne	[cr_field,] target	Branch if not equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+2,target	
bnea		<i>Extended mnemonic for</i> bca 4,4*cr_field+2,target	
bnel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+2,target	(LR) ← CIA + 4.
bnela		<i>Extended mnemonic for</i> bcla 4,4*cr_field+2,target	(LR) ← CIA + 4.
bng	[cr_field,] target	Branch if not greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+1,target	
bnga		<i>Extended mnemonic for</i> bca 4,4*cr_field+1,target	
bngl		<i>Extended mnemonic for</i> bcl 4,4*cr_field+1,target	(LR) ← CIA + 4.
bngla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+1,target	(LR) ← CIA + 4.
bnl	[cr_field,] target	Branch if not less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+0,target	
bnla		<i>Extended mnemonic for</i> bca 4,4*cr_field+0,target	
bnll		<i>Extended mnemonic for</i> bcl 4,4*cr_field+0,target	(LR) ← CIA + 4.
bnlla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+0,target	(LR) ← CIA + 4.

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bns	[cr_field,] target	Branch if not summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target	
bnsa		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target	
bnsi		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.
bnsia		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.
bnu	[cr_field,] target	Branch if not unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target	
bnu a		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target	
bnu l		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.
bnu la		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.
bs o	[cr_field,] target	Branch if summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target	
bs o a		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target	
bs o l		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.
bs o la		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.
bt	cr_bit, target	Branch if CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 12,cr_bit,target	
bt a		<i>Extended mnemonic for</i> bca 12,cr_bit,target	
bt l		<i>Extended mnemonic for</i> bcl 12,cr_bit,target	(LR) ← CIA + 4.
bt la		<i>Extended mnemonic for</i> bcla 12,cr_bit,target	(LR) ← CIA + 4.

bc

Branch Conditional

Table 11-6. Extended Mnemonics for bc, bca, bcl, bcla (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bun	[cr_field,] target	Branch if unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target	
buna		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target	
bunl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.
bunla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.

bcctr BO, BI (LK=0)
bcctrl BO, BI (LK=1)

19	BO	BI		528	LK
0	6	11	16	21	31

```

if BO2 = 0 then
    CTR ← CTR - 1
if (BO2 = 1 ∨ ((CTR = 0) = BO3)) ∧ (BO0 = 1 ∨ (CRBI = BO1)) then
    NIA ← CTR0:29 || 200
else
    NIA ← CIA + 4
if LK = 1 then
    (LR) ← CIA + 4
PC ← NIA

```

The BI field specifies a bit in the CR to be used as the condition of the branch.

The next instruction address (NIA) is the target address of the branch. The NIA is formed by concatenating the 30 most significant bits of the CTR with two 0-bits on the right.

The BO field controls options that determine when program flow is transferred to the NIA. The BO field also controls Branch Prediction, a performance-improvement feature. See Section 2.7.4 and Section 2.7.5 for a complete discussion.

If the LK field contains 1, then (CIA + 4) is placed into the LR.

Registers Altered

- CTR if BO₂ contains 0
- LR if LK contains 1

Invalid Instruction Forms

- Reserved fields
- If bit 2 of the BO field contains 0, the instruction form is invalid, but the pseudocode applies. If the branch condition is true, the branch is taken; the NIA is the contents of the CTR after it is decremented.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

bcctr

Branch Conditional to Count Register

Table 11-7. Extended Mnemonics for bcctr, bcctrl

Mnemonic	Operands	Function	Other Registers Changed
bctr		Branch unconditionally, to address in CTR. <i>Extended mnemonic for bcctr 20,0</i>	
bctrl		<i>Extended mnemonic for bcctrl 20,0</i>	(LR) ← CIA + 4.
beqctr	[cr_field]	Branch if equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 12,4*cr_field+2</i>	
beqctrl		<i>Extended mnemonic for bcctrl 12,4*cr_field+2</i>	(LR) ← CIA + 4.
bfctr	cr_bit	Branch if CR _{cr_bit} = 0, to address in CTR. <i>Extended mnemonic for bcctr 4,cr_bit</i>	
bfctrl		<i>Extended mnemonic for bcctrl 4,cr_bit</i>	(LR) ← CIA + 4.
bgectr	[cr_field]	Branch if greater than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+0</i>	
bgectrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+0</i>	(LR) ← CIA + 4.
bgtctr	[cr_field]	Branch if greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 12,4*cr_field+1</i>	
bgtctrl		<i>Extended mnemonic for bcctrl 12,4*cr_field+1</i>	(LR) ← CIA + 4.
blectr	[cr_field]	Branch if less than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+1</i>	
blectrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+1</i>	(LR) ← CIA + 4.

Table 11-7. Extended Mnemonics for bcctr, bcctrl (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bltctr	[cr_field]	Branch if less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 12,4*cr_field+0</i>	
bltctrl		<i>Extended mnemonic for bcctrl 12,4*cr_field+0</i>	(LR) ← CIA + 4.
bnctr	[cr_field]	Branch if not equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+2</i>	
bnctrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+2</i>	(LR) ← CIA + 4.
bngctr	[cr_field]	Branch if not greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+1</i>	
bngctrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+1</i>	(LR) ← CIA + 4.
bnlctr	[cr_field]	Branch if not less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+0</i>	
bnlctrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+0</i>	(LR) ← CIA + 4.
bnsctr	[cr_field]	Branch if not summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+3</i>	
bnsctrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+3</i>	(LR) ← CIA + 4.
bnuctr	[cr_field]	Branch if not unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 4,4*cr_field+3</i>	
bnuctrl		<i>Extended mnemonic for bcctrl 4,4*cr_field+3</i>	(LR) ← CIA + 4.

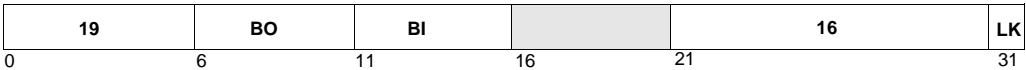
bcctr

Branch Conditional to Count Register

Table 11-7. Extended Mnemonics for bcctr, bcctrl (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bsoctr	[cr_field]	Branch if summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 12,4*cr_field+3</i>	
bsoctrl		<i>Extended mnemonic for bcctrl 12,4*cr_field+3</i>	(LR) ← CIA + 4.
btctr	cr_bit	Branch if CR _{cr_bit} = 1, to address in CTR. <i>Extended mnemonic for bcctr 12,cr_bit</i>	
btctrl		<i>Extended mnemonic for bcctrl 12,cr_bit</i>	(LR) ← CIA + 4.
bunctr	[cr_field]	Branch if unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bcctr 12,4*cr_field+3</i>	
bunctrl		<i>Extended mnemonic for bcctrl 12,4*cr_field+3</i>	(LR) ← CIA + 4.

bclr	BO, BI	(LK=0)
bclrl	BO, BI	(LK=1)



```
if BO2 = 0 then
    CTR ← CTR - 1
if (BO2 = 1 ∨ ((CTR = 0) = BO3)) ∧ (BO0 = 1 ∨ (CRBI = BO1)) then
    NIA ← LR0:29 || 200
else
    NIA ← CIA + 4
if LK = 1 then
    (LR) ← CIA + 4
PC ← NIA
```

If bit 2 of the BO field contains 0, the CTR is decremented.

The BI field specifies a bit in the CR to be used as the condition of the branch.

The next instruction address (NIA) is the target address of the branch. The NIA is formed by concatenating the 30 most significant bits of the LR with two 0-bits on the right.

The BO field controls options that determine when program flow is transferred to the NIA. The BO field also controls Branch Prediction, a performance-improvement feature. See Section 2.7.4 and Section 2.7.5 for a complete discussion.

If the LK field contains 1, then (CIA + 4) is placed into the LR.

Registers Altered

- CTR if BO₂ contains 0
- LR if LK contains 1

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

bclr

Branch Conditional to Link Register

Table 11-8. Extended Mnemonics for bclr, bclrl

Mnemonic	Operands	Function	Other Registers Changed
blr		Branch unconditionally, to address in LR. <i>Extended mnemonic for bclr 20,0</i>	
blrl		<i>Extended mnemonic for bclrl 20,0</i>	(LR) ← CIA + 4.
bdnzlr		Decrement CTR. Branch if CTR ≠ 0, to address in LR. <i>Extended mnemonic for bclr 16,0</i>	
bdnzlrl		<i>Extended mnemonic for bclrl 16,0</i>	(LR) ← CIA + 4.
bdnzflr	cr_bit	Decrement CTR. Branch if CTR ≠ 0 AND CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for bclr 0,cr_bit</i>	
bdnzflrl		<i>Extended mnemonic for bclrl 0,cr_bit</i>	(LR) ← CIA + 4.
bdnztlr	cr_bit	Decrement CTR. Branch if CTR ≠ 0 AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for bclr 8,cr_bit</i>	
bdnztlrl		<i>Extended mnemonic for bclrl 8,cr_bit</i>	(LR) ← CIA + 4.
bdzlr		Decrement CTR. Branch if CTR = 0, to address in LR. <i>Extended mnemonic for bclr 18,0</i>	
bdzlrl		<i>Extended mnemonic for bclrl 18,0</i>	(LR) ← CIA + 4.

Table 11-8. Extended Mnemonics for bclr, bclrl (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bdzflr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0 to address in LR. <i>Extended mnemonic for bclr 2,cr_bit</i>	
bdzflrl		<i>Extended mnemonic for bclrl 2,cr_bit</i>	(LR) ← CIA + 4.
bdztlr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for bclr 10,cr_bit</i>	
bdztlrl		<i>Extended mnemonic for bclrl 10,cr_bit</i>	(LR) ← CIA + 4.
beqlr	[cr_field]	Branch if equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 12,4*cr_field+2</i>	
beqlrl		<i>Extended mnemonic for bclrl 12,4*cr_field+2</i>	(LR) ← CIA + 4.
bflr	cr_bit	Branch if CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for bclr 4,cr_bit</i>	
bflrl		<i>Extended mnemonic for bclrl 4,cr_bit</i>	(LR) ← CIA + 4.
bgehr	[cr_field]	Branch if greater than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+0</i>	
bgehlrl		<i>Extended mnemonic for bclrl 4,4*cr_field+0</i>	(LR) ← CIA + 4.
bgtlr	[cr_field]	Branch if greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 12,4*cr_field+1</i>	
bgtlrl		<i>Extended mnemonic for bclrl 12,4*cr_field+1</i>	(LR) ← CIA + 4.

bclr

Branch Conditional to Link Register

Table 11-8. Extended Mnemonics for bclr, bclrl (cont.)

Mnemonic	Operands	Function	Other Registers Changed
blelr	[cr_field]	Branch if less than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+1</i>	
blelrl		<i>Extended mnemonic for bclrl 4,4*cr_field+1</i>	(LR) ← CIA + 4.
bltlr	[cr_field]	Branch if less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 12,4*cr_field+0</i>	
bltlrl		<i>Extended mnemonic for bclrl 12,4*cr_field+0</i>	(LR) ← CIA + 4.
bnelr	[cr_field]	Branch if not equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+2</i>	
bnelrl		<i>Extended mnemonic for bclrl 4,4*cr_field+2</i>	(LR) ← CIA + 4.
bnglr	[cr_field]	Branch if not greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+1</i>	
bnglrl		<i>Extended mnemonic for bclrl 4,4*cr_field+1</i>	(LR) ← CIA + 4.
bnllr	[cr_field]	Branch if not less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+0</i>	
bnllrl		<i>Extended mnemonic for bclrl 4,4*cr_field+0</i>	(LR) ← CIA + 4.
bnslr	[cr_field]	Branch if not summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+3</i>	
bnsrlrl		<i>Extended mnemonic for bclrl 4,4*cr_field+3</i>	(LR) ← CIA + 4.

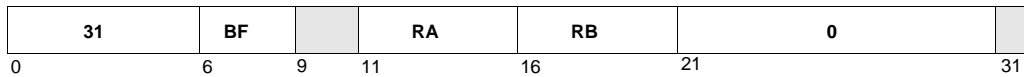
Table 11-8. Extended Mnemonics for bclr, bclrl (cont.)

Mnemonic	Operands	Function	Other Registers Changed
bnulr	[cr_field]	Branch if not unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 4,4*cr_field+3</i>	
bnulrl		<i>Extended mnemonic for bclrl 4,4*cr_field+3</i>	(LR) ← CIA + 4.
bsolr	[cr_field]	Branch if summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 12,4*cr_field+3</i>	
bsolrl		<i>Extended mnemonic for bclrl 12,4*cr_field+3</i>	(LR) ← CIA + 4.
btlr	cr_bit	Branch if CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for bclr 12,cr_bit</i>	
btlrl		<i>Extended mnemonic for bclrl 12,cr_bit</i>	(LR) ← CIA + 4.
bunlr	[cr_field]	Branch if unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for bclr 12,4*cr_field+3</i>	
bunlrl		<i>Extended mnemonic for bclrl 12,4*cr_field+3</i>	(LR) ← CIA + 4.

cmp

Compare

cmp BF,0,RA,RB



```
c0:3 ← 40
if (RA) < (RB) then c0 ← 1
if (RA) > (RB) then c1 ← 1
if (RA) = (RB) then c2 ← 1
c3 ← XER[SO]
n ← BF
CR[CRn] ← c0:3
```

The contents of register RA are compared with the contents of register RB using a 32-bit signed compare.

The CR field specified by the BF field is updated to reflect the results of the compare and the value of XER[SO] is placed into the same CR field.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- CR[CRn] where *n* is specified by the BF field

Invalid Instruction Forms

- Reserved fields

Programming Note

11

The PowerPC Architecture defines this instruction as **cmp BF,L,RA,RB**, where L selects operand size for 64-bit PowerPC implementations. For all 32-bit PowerPC implementations, L = 0 is required (L = 1 is an invalid form); hence for PPC403GC, use of the extended mnemonic **cmpw BF,RA,RB** is recommended.

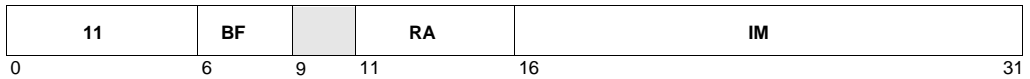
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-9. Extended Mnemonics for cmp

Mnemonic	Operands	Function	Other Registers Changed
cmpw	[BF,] RA, RB	Compare Word. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmp BF,0,RA,RB	

cmpi BF,0,RA,IM



```

c0:3 ← 40
if (RA) < EXTS(IM) then c0 ← 1
if (RA) > EXTS(IM) then c1 ← 1
if (RA) = EXTS(IM) then c2 ← 1
c3 ← XER[SO]
n ← BF
CR[CRn] ← c0:3

```

The IM field is sign-extended to 32 bits. The contents of register RA are compared with the extended IM field, using a 32-bit signed compare.

The CR field specified by the BF field is updated to reflect the results of the compare and the value of XER[SO] is placed into the same CR field.

Registers Altered

- CR[CRn] where n is specified by the BF field

Invalid Instruction Forms

- Reserved fields

Programming Note

The PowerPC Architecture defines this instruction as **cmpi BF,L,RA,IM**, where L selects operand size for 64-bit PowerPC implementations. For all 32-bit PowerPC implementations, L = 0 is required (L = 1 is an invalid form); hence for PPC403GC, use of the extended mnemonic **cmpwi BF,RA,IM** is recommended.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

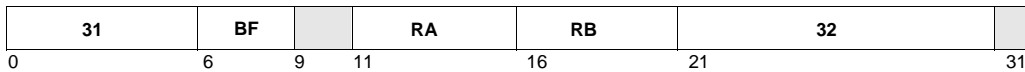
Table 11-10. Extended Mnemonics for cmpi

Mnemonic	Operands	Function	Other Registers Changed
cmpwi	[BF,] RA, IM	Compare Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for cmpi BF,0,RA,IM</i>	

cmpl

Compare Logical

cmpl BF,0,RA,RB



```
c0:3 ← 40
if (RA) <u (RB) then c0 ← 1
if (RA) > (RB) then c1 ← 1
if (RA) = (RB) then c2 ← 1
c3 ← XER[SO]
n ← BF
CR[CRn] ← c0:3
```

The contents of register RA are compared with the contents of register RB, using a 32-bit unsigned compare.

The CR field specified by the BF field is updated to reflect the results of the compare and the value of XER[SO] is placed into the same CR field.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- CR[CR_n] where *n* is specified by the BF field

Invalid Instruction Forms

- Reserved fields

Programming Notes

11

The PowerPC Architecture defines this instruction as **cmpl BF,L,RA,RB**, where L selects operand size for 64-bit PowerPC implementations. For all 32-bit PowerPC implementations, L = 0 is required (L = 1 is an invalid form); hence for PPC403GC, use of the extended mnemonic **cmplw BF,RA,RB** is recommended.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-11. Extended Mnemonics for cmpl

Mnemonic	Operands	Function	Other Registers Changed
cmplw	[BF,] RA, RB	Compare Logical Word. Use CR0 if BF is omitted. <i>Extended mnemonic for cmpl BF,0,RA,RB</i>	

cmpli BF,0,RA,IM

10	BF		RA	IM
0	6	9	11	16
				31

```

c0:3 ← 40
if (RA) < (u160 || IM) then c0 ← 1
if (RA) > (u160 || IM) then c1 ← 1
if (RA) = (u160 || IM) then c2 ← 1
c3 ← XER[SO]
n ← BF
CR[CRn] ← c0:3

```

The IM field is extended to 32 bits by concatenating 16 0-bits to its left. The contents of register RA are compared with IM using a 32-bit unsigned compare.

The CR field specified by the BF field is updated to reflect the results of the compare and the value of XER[SO] is placed into the same CR field.

Registers Altered

- CR[CRn] where *n* is specified by the BF field

Invalid Instruction Forms

- Reserved fields

Programming Note

The PowerPC Architecture defines this instruction as **cmpli BF,L,RA,IM**, where L selects operand size for 64-bit PowerPC implementations. For all 32-bit PowerPC implementations, L = 0 is required (L = 1 is an invalid form); hence for PPC403GC, use of the extended mnemonic **cmplwi BF,RA,IM** is recommended.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-12. Extended Mnemonics for cmpli

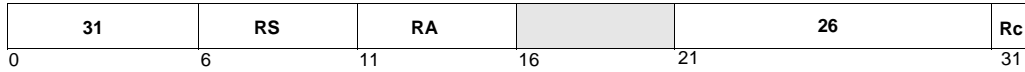
Mnemonic	Operands	Function	Other Registers Changed
cmplwi	[BF,] RA, IM	Compare Logical Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for cmpli BF,0,RA,IM</i>	

cntlzw

Count Leading Zeros Word

cntlzw RA,RS (Rc=0)

cntlzw.	RA,RS	(Rc=1)
---------	-------	--------



```

n ← 0
do while n < 32
    if (RS)n = 1 then leave
    n ← n + 1
(RA) ← n

```

The consecutive leading 0 bits in register RS are counted; the count is placed into register RA.

The count ranges from 0 through 32, inclusive.

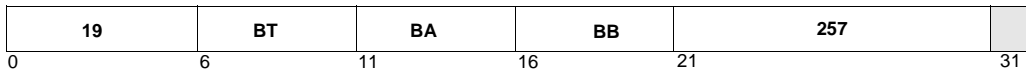
Registers Altered

- RA
- $CR[CR0]_{LT, GT, EQ, SO}$ if Rc contains 1

Invalid Instruction Forms

- Reserved fields

crand BT,BA,BB



$$CR_{BT} \leftarrow CR_{BA} \wedge CR_{BB}$$

The CR bit specified by the BA field is ANDed with the CR bit specified by the BB field; the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

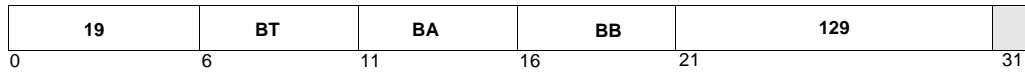
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

crandc

Condition Register AND with Complement

crandc BT,BA,BB



$$CR_{BT} \leftarrow CR_{BA} \wedge \neg CR_{BB}$$

The CR bit specified by the BA field is ANDed with the ones complement of the CR bit specified by the BB field; the result is placed into the CR bit specified by the BT field.

Registers Altered

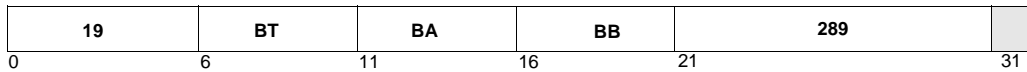
- CR

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

creqv BT,BA,BB

$$CR_{BT} \leftarrow \neg(CR_{BA} \oplus CR_{BB})$$

The CR bit specified by the BA field is XORed with the CR bit specified by the BB field; the ones complement of the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

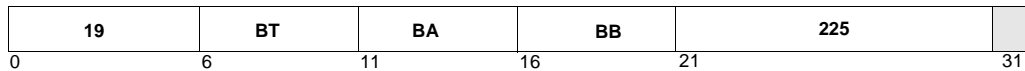
Table 11-13. Extended Mnemonics for creqv

Mnemonic	Operands	Function	Other Registers Changed
crset	bx	Condition register set. <i>Extended mnemonic for</i> creqv bx,bx,bx	

crnand

Condition Register NAND

crnand BT,BA,BB



$$CR_{BT} \leftarrow \neg(CR_{BA} \wedge CR_{BB})$$

The CR bit specified by the BA field is ANDed with the CR bit specified by the BB field; the ones complement of the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

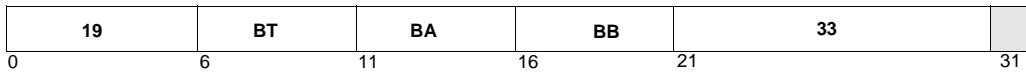
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

crnor BT,BA,BB



$$CR_{BT} \leftarrow \neg(CR_{BA} \vee CR_{BB})$$

The CR bit specified by the BA field is ORed with the CR bit specified by the BB field; the ones complement of the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

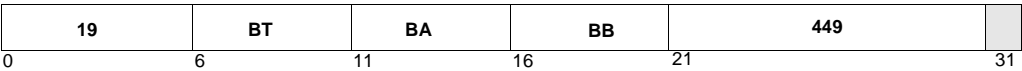
Table 11-14. Extended Mnemonics for crnor

Mnemonic	Operands	Function	Other Registers Changed
crnot	bx, by	Condition register not. <i>Extended mnemonic for crnor bx,by,by</i>	

cror

Condition Register OR

cror BT,BA,BB



$CR_{BT} \leftarrow CR_{BA} \vee CR_{BB}$

The CR bit specified by the BA field is ORed with the CR bit specified by the BB field; the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

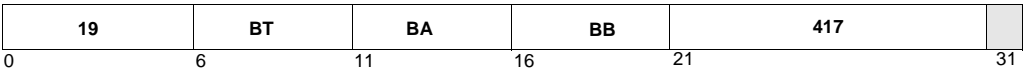
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-15. Extended Mnemonics for cror

Mnemonic	Operands	Function	Other Registers Changed
crmove	bx, by	Condition register move. <i>Extended mnemonic for cror bx,by,by</i>	

crorc BT,BA,BB



$CR_{BT} \leftarrow CR_{BA} \vee \neg CR_{BB}$

The condition register (CR) bit specified by the BA field is ORed with the ones complement of the CR bit specified by the BB field; the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

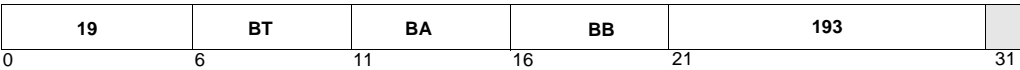
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

crxor

Condition Register XOR

crxor BT,BA,BB



$$CR_{BT} \leftarrow CR_{BA} \oplus CR_{BB}$$

The CR bit specified by the BA field is XORed with the CR bit specified by the BB field; the result is placed into the CR bit specified by the BT field.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

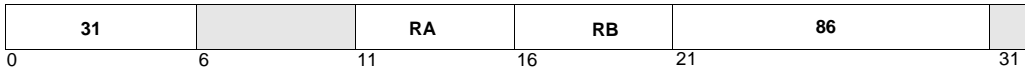
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-16. Extended Mnemonics for crxor

Mnemonic	Operands	Function	Other Registers Changed
crclr	bx	Condition register clear. <i>Extended mnemonic for crxor bx,bx,bx</i>	

dcbf RA,RB



$$EA \leftarrow (RA|0) + (RB)$$

$$DCBF(EA)$$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the data block corresponding to the effective address is in the data cache and marked as modified (stored into), the data block is copied back to main storage and then marked invalid in the data cache. If the data block is not marked as modified, it is simply marked invalid in the data cache. The operation is performed whether or not the effective address is marked as cacheable.

If the data block at the effective address is not in the data cache, no operation is performed.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Exceptions

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “store” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

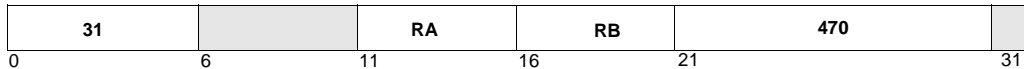
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

dcbi

Data Cache Block Invalidate

dcbi RA, RB



$EA \leftarrow (RA|0) + (RB)$
DCBI(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the data block at the effective address is in the data cache, the data block is marked invalid, regardless of whether or not the effective address is marked as cacheable. If modified data existed in the data block prior to the operation of this instruction, that data is lost.

If the data block at the effective address is not in the data cache, no operation is performed.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

Execution of this instruction is privileged.

Exceptions

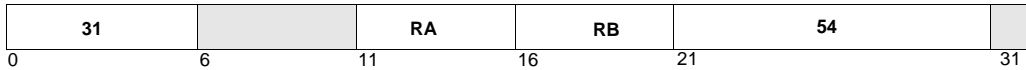
This instruction is considered a “store” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “store” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

dcbst RA,RB



$$EA \leftarrow (RA|0) + (RB)$$

$$DCBST(EA)$$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0, and is the contents of register RA otherwise.

If the data block at the effective address is in the data cache and marked as modified, the data block is copied back to main storage and marked as unmodified in the data cache.

If the data block at the effective address is in the data cache, and is not marked as modified, or if the data block at the effective address is not in the data cache, no operation is performed.

The operation specified by this instruction is performed whether or not the effective address is marked as cacheable.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Exceptions

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “store” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

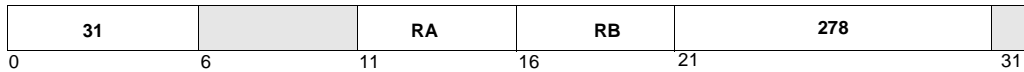
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

dcbt

Data Cache Block Touch

dcbt RA,RB



$EA \leftarrow (RA|0) + (RB)$
DCBT(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

If the data block at the effective address is not in the data cache and the effective address is marked as cacheable, the block is read from main storage into the data cache.

If the data block at the effective address is in the data cache, or if the effective address is marked as non-cacheable, no operation is performed.

This instruction is not allowed to cause Data Storage Exceptions or Data TLB Miss Exceptions. If execution of the instruction would otherwise cause such an exception, then no operation is performed, and no exception occurs.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

The **dcbt** instruction allows a program to begin a cache block fetch from main storage before the program needs the data. The program can later load data from the cache into registers without incurring the latency of a cache miss.

Exceptions

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

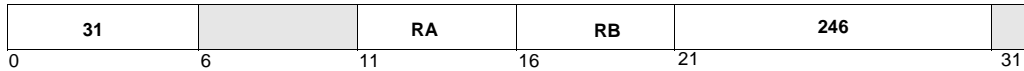
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

dcbtst

Data Cache Block Touch for Store

dcbtst RA, RB



$EA \leftarrow (RA|0) + (RB)$
DCBTST(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the data block at the effective address is not in the data cache and the effective address is marked as cacheable, the data block is loaded into the data cache.

If the effective address is marked as non-cacheable, or if the data block at the effective address is in the data cache, no operation is performed.

This instruction is not allowed to cause Data Storage Exceptions or Data TLB Miss Exceptions. If execution of the instruction would otherwise cause such an exception, then no operation is performed, and no exception occurs.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

The **dcbtst** instruction allows a program to begin a cache block fetch from main storage before the program needs the data. The program can later store data from GPRs into the cache block, without incurring the latency of a cache miss.

Architecturally, **dcbtst** brings data into the cache in “Exclusive” mode, which allows the program to alter the cached data. “Exclusive” mode is part of the MESI protocol for multi-processor systems, and is not implemented on the PPC403GC. The implementation of the **dcbtst** instruction on the PPC403GC is identical to the implementation of the **dcbt** instruction.

Exceptions

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

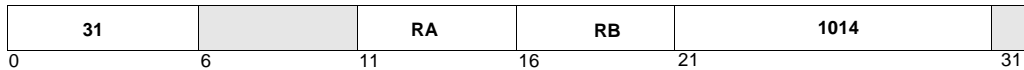
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

dcbz

Data Cache Block Set to Zero

dcbz RA, RB



$EA \leftarrow (RA|0) + (RB)$
DCBZ(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the data block at the effective address is in the data cache and the effective address is marked as cacheable and non-write-through, the data in the cache block is set to 0.

If the data block at the effective address is not in the data cache and the effective address is marked as cacheable and non-write-through, a cache block is established and set to 0. Note that nothing is read from main storage, as described in the programming note below.

If the effective address is marked as non-cacheable or as write-through, an alignment exception occurs.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

Because the **dcbz** instruction can establish an address in the data cache without copying the contents of that address from main storage, the address established may be invalid with respect to the storage subsystem. A subsequent operation may cause the address to be copied back to main storage to make room for a new data block. A machine check exception could result.

If **dcbz** is attempted to an effective address which is marked as non-cacheable, the software alignment exception handler should emulate the instruction by storing zeros to the block in main storage. Note: if a data block corresponding to the effective address exists in the cache, but the effective address is non-cacheable, **dcbz** to that address is considered a programming error (see Section 8.2.3 on page 8-8).

If **dcbz** is attempted to an effective address which is marked as write-through, the software alignment exception handler should emulate the instruction by storing zeros to the block in main storage. An effective address which is marked as write-through should also be marked as cacheable; when **dcbz** is attempted to such an address, the alignment exception handler should maintain coherency of cache and memory.

Exceptions

If **dcbz** is attempted to an effective address which is marked as non-cacheable or as write-through, an alignment exception occurs.

This instruction is considered a “store” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “store” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

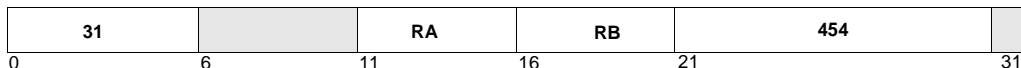
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

dccci

Data Cache Congruence Class Invalidate

dccci RA, RB



$EA \leftarrow (RA|0) + (RB)$
DCCCI(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

Both cache lines in the congruence class specified by $EA_{23:27}$ are invalidated, whether or not they match the effective address. If modified data existed in the cache congruence class prior to the operation of this instruction, that data is lost.

The operation specified by this instruction is performed whether or not the effective address is marked as cacheable.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Note

Execution of this instruction is privileged.

This instruction is intended for use in the power-on reset routine to invalidate the entire data cache tag array before enabling the data cache. A series of **dccci** instruction should be executed, one for each congruence class. Cacheability can then be enabled.

Exceptions

The execution of a **dccci** instruction can cause a Data TLB Miss Exception, at the specified effective address, in spite of the non-specific intent of that effective address.

This instruction is considered a “store” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction will not cause data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

dcread

Data Cache Read

dcread RT,RA,RB

31	RT	RA	RB	486	31
0	6	11	16	21	31

$EA \leftarrow (RA[0] + (RB))$

if ((CDBCR[CIS] = 0) \wedge (CDBCR[CSS] = 0)) then (RT \leftarrow (d-cache data, side A)

if ((CDBCR[CIS] = 0) \wedge (CDBCR[CSS] = 1)) then (RT \leftarrow (d-cache data, side B)

if ((CDBCR[CIS] = 1) \wedge (CDBCR[CSS] = 0)) then (RT \leftarrow (d-cache tag, side A)

if ((CDBCR[CIS] = 1) \wedge (CDBCR[CSS] = 1)) then (RT \leftarrow (d-cache tag, side B)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

This instruction is a debugging tool for reading the data cache entries for the congruence class specified by $EA_{23:27}$. The cache information will be read into the General Purpose Register RT.

If (CDBCR[CIS] = 0), the information will be one word of data-cache data from the addressed congruence class. The word is specified by $EA_{28:29}$ ($EA_{0:22}$ are ignored; an alignment exception will result if $EA_{30:31} \neq 00$). If (CDBCR[CSS] = 0), the data will be from the A-side, otherwise from the B-side.

If (CDBCR[CIS] = 1), the information will be a cache tag from the addressed congruence class ($EA_{0:22}$ and $EA_{28:29}$ are ignored; an alignment exception will result if $EA_{30:31} \neq 00$). If (CDBCR[CSS] = 0), the tag will be from the A-side, otherwise from the B-side. Data cache tag information is placed into register RT as follows:

0:22	TAG	Cache Tag
23:25		reserved
26	D	Cache Line Dirty 0 - Not dirty 1 - Dirty
27	V	Cache Line Valid 0 - Not valid 1 - Valid
28:30		reserved
31	LRU	Least Recently Used 0 - A side least-recently-used 1 - B side least-recently-used

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

Programming Note

Execution of this instruction is privileged.

Exceptions

An alignment exception will result if $EA_{30:31} \neq 00$.

The execution of a **dcread** instruction can cause a Data TLB Miss Exception, at the specified effective address, in spite of the non-specific intent of that effective address.

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

divw

Divide Word

divw	RT,RA,RB	(OE=0, Rc=0)
divw.	RT,RA,RB	(OE=0, Rc=1)
divwo	RT,RA,RB	(OE=1, Rc=0)
divwo.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	491	Rc
0	6	11	16	21 22		31

$$(RT) \leftarrow (RA) \div (RB)$$

The contents of register RA are divided by the contents of register RB. The quotient is placed into register RT.

Both the dividend and the divisor are interpreted as signed integers. The quotient is the unique signed integer that satisfies:

$$\text{dividend} = (\text{quotient} \times \text{divisor}) + \text{remainder}$$

where the remainder has the same sign as the dividend and its magnitude is less than that of the divisor.

If an attempt is made to perform $(x'8000\ 0000' \div -1)$ or $(n \div 0)$, the contents of register RT are undefined; if the Rc also contains 1, the contents of CR[CR0] are undefined. Either invalid division operation sets XER[OV, SO] to 1 if the OE field contains 1.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[OV, SO] if OE contains 1

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Programming Note

The 32-bit remainder can be calculated using the following sequence of instructions:

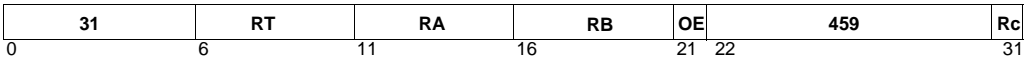
divw	RT,RA,RB	# RT = quotient
mullw	RT,RT,RB	# RT = quotient \times divisor
subf	RT,RT,RA	# RT = remainder

The sequence does not calculate correct results for the invalid divide operations.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

divwu	RT,RA,RB	(OE=0, Rc=0)
divwu.	RT,RA,RB	(OE=0, Rc=1)
divwuo	RT,RA,RB	(OE=1, Rc=0)
divwuo.	RT,RA,RB	(OE=1, Rc=1)



$(RT) \leftarrow (RA) \div (RB)$

The contents of register RA are divided by the contents of register RB. The quotient is placed into register RT.

The dividend and the divisor are interpreted as unsigned integers. The quotient is the unique unsigned integer that satisfies

$dividend = (quotient \times divisor) + remainder$

If an attempt is made to perform $(n \div 0)$, the contents of register RT are undefined; if the Rc also contains 1, the contents of CR[CR0] are also undefined. The invalid division operation also sets XER[OV, SO] to 1 if the OE field contains 1.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[OV, SO] if OE contains 1

Programming Note

The 32-bit remainder can be calculated using the following sequence of instructions

divwu	RT,RA,RB	# RT = quotient
mullwu	RT,RT,RB	# RT = quotient × divisor
subf	RT,RT,RA	# RT = remainder

This sequence does not calculate the correct result if the divisor is zero.

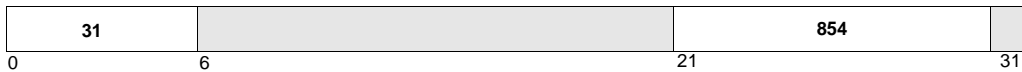
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

eieio

Enforce In Order Execution of I/O

eieio



The **eieio** instruction ensures that all loads and stores preceding an **eieio** instruction complete with respect to main storage before any loads and stores following the **eieio** instruction access main storage.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Note

Architecturally, **eieio** orders storage access, not instruction completion. Therefore, non-storage operations after **eieio** could complete before storage operations that were before **eieio**. The **sync** instruction guarantees ordering of both instruction completion and storage access. For the PPC403GC, the **eieio** instruction is implemented to behave as a **sync** instruction. To write code which is portable between various PowerPC implementations, programmers should use the mnemonic which corresponds to the desired behavior.

Architecture Note

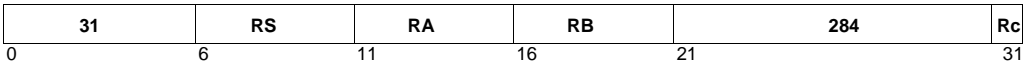
This instruction is part of the PowerPC Virtual Environment Architecture.

eqv

eqv.

RA,RS,RB
RA,RS,RB

(Rc=0)
(Rc=1)



$(RA) \leftarrow \neg((RS) \oplus (RB))$

The contents of register RS are XORed with the contents of register RB; the ones complement of the result is placed into register RA.

Registers Altered

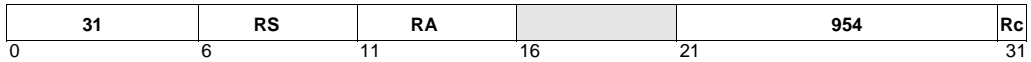
- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Extend Sign Byte

extsb	RA,RS	(Rc=0)
extsb.	RA,RS	(Rc=1)



$$(RA) \leftarrow \text{EXTS}(RS)_{24:31}$$

The least significant byte of register RS is sign-extended to 32 bits by replicating bit 24 of the register into bits 0 through 23 of the result. The result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

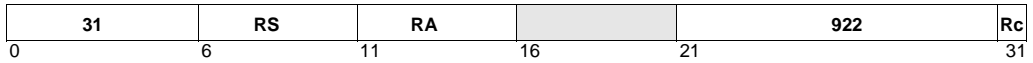
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

extsh RA,RS (Rc=0)
extsh. RA,RS (Rc=1)



$(RA) \leftarrow \text{EXTS}(RS)_{16:31}$

The least significant halfword of register RS is sign-extended to 32 bits by replicating bit 16 of the register into bits 0 through 15 of the result. The result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Invalid Instruction Forms

- Reserved fields

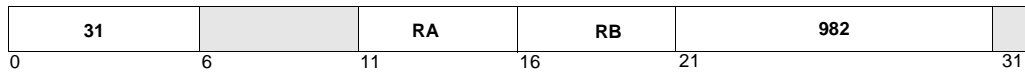
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

icbi

Instruction Cache Block Invalidate

icbi RA,RB



$EA \leftarrow (RA|0) + (RB)$
ICBI(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the instruction block at the effective address is in the instruction cache, the cache block is marked invalid.

If the instruction block at the effective address is not in the instruction cache, no operation is performed.

The operation specified by this instruction is performed whether or not the effective address is marked as cacheable.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

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Programming Note

Instruction cache ops use MSR[DR], not MSR[IR], to determine translation of their operands.

When data translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

Exceptions

Instruction Storage Exceptions and Instruction-side TLB Miss Exceptions are associated with the fetching of instructions, not with the execution of instructions. Exceptions that occur during the execution of instruction cache ops cause data-side exceptions (Data Storage Exceptions and Data TLB Miss Exceptions).

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

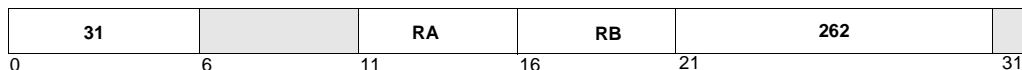
Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

icbt

Instruction Cache Block Touch

icbt RA, RB



$EA \leftarrow (RA|0) + (RB)$
ICBT(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

If the instruction block at the effective address is not in the instruction cache, and is marked as cacheable, the instruction block is loaded into the instruction cache.

If the instruction block at the effective address is already in the instruction cache, or if the effective address is marked as non-cacheable, no operation is performed.

This instruction is not allowed to cause Data Storage Exceptions or Data TLB Miss Exceptions. If execution of the instruction would otherwise cause such an exception, then no operation is performed, and no exception occurs.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

Execution of this instruction is privileged.

This instruction allows a program to begin a cache block fetch from main storage before the program needs the instruction. The program can later branch to the instruction address and fetch the instruction from the cache without incurring the latency of a cache miss.

Instruction cache ops use MSR[DR], not MSR[IR], to determine translation of their operands.

When data translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

Exceptions

Instruction Storage Exceptions and Instruction-side TLB Miss Exceptions are associated with the fetching of instructions, not with the execution of instructions. Exceptions that occur during the execution of instruction cache ops cause data-side exceptions (Data Storage Exceptions and Data TLB Miss Exceptions).

This instruction is not allowed to cause Data TLB Miss Exceptions. If execution of the instruction would otherwise cause such an exception, then no operation is performed, and no exception occurs.

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

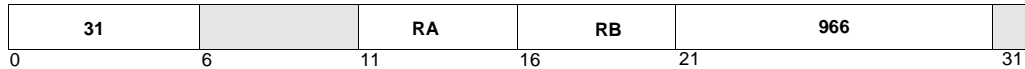
Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

iccci

Instruction Cache Congruence Class Invalidate

iccci RA,RB



$EA \leftarrow (RA|0) + (RB)$
ICCCI(EA)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

Both cache lines in the congruence class specified by $EA_{22:27}$ are invalidated, whether or not they match the effective address.

The operation specified by this instruction is performed whether or not the effective address is marked cacheable.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Notes

Execution of this instruction is privileged.

This instruction is intended for use in the power-on reset routine to invalidate the entire instruction cache tag array before enabling the instruction cache. A series of **iccci** instructions should be executed, one for each congruence class. Cacheability can then be enabled.

Instruction cache ops use MSR[DR], not MSR[IR], to determine translation of their operands.

When data translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

Exceptions

Instruction Storage Exceptions and Instruction-side TLB Miss Exceptions are associated with the fetching of instructions, not with the execution of instructions. Exceptions that occur during the execution of instruction cache ops cause data-side exceptions (Data Storage Exceptions and Data TLB Miss Exceptions).

The execution of an **iccci** instruction can cause a Data TLB Miss Exception, at the specified effective address, in spite of the non-specific intent of that effective address.

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

icread

Instruction Cache Read

icread RA, RB

31		RA	RB	998	
0	6	11	16	21	31

$EA \leftarrow (RA|0) + (RB)$
 if ((CDBCR[CIS] = 0) \wedge (CDBCR[CSS] = 0)) then (ICDBDR) \leftarrow (i-cache data, side A)
 if ((CDBCR[CIS] = 0) \wedge (CDBCR[CSS] = 1)) then (ICDBDR) \leftarrow (i-cache data, side B)
 if ((CDBCR[CIS] = 1) \wedge (CDBCR[CSS] = 0)) then (ICDBDR) \leftarrow (i-cache tag, side A)
 if ((CDBCR[CIS] = 1) \wedge (CDBCR[CSS] = 1)) then (ICDBDR) \leftarrow (i-cache tag, side B)

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

This instruction is a debugging tool for reading the instruction cache entries for the congruence class specified by $EA_{22:27}$. The cache information will be read into the Instruction Cache Debug Data Register (ICDBDR), from where it can be read into a GPR via **mficbdr**.

If (CDBCR[CIS] = 0), the information will be one word of instruction cache data from the addressed congruence class. The word is specified by $EA_{28:29}$ ($EA_{0:21}$ and $EA_{30:31}$ are ignored). If (CDBCR[CSS] = 0), the data will be from the A-side, otherwise from the B-side.

If (CDBCR[CIS] = 1), the information will be a cache tag from the addressed congruence class ($EA_{0:21}$ and $EA_{28:31}$ are ignored). If (CDBCR[CSS] = 0), the tag will be from the A-side, otherwise from the B-side. Instruction cache tag information is placed in the ICDBDR as follows:

0:21	TAG	Cache Tag
22:26		reserved
27	V	Cache Line Valid 0 - Not valid 1 - Valid
28:30		reserved
31	LRU	Least Recently Used 0 - A side least-recently-used 1 - B side least-recently-used

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- ICDBDR

Invalid Instruction Forms

- Reserved fields

Programming Note

Execution of this instruction is privileged.

The instruction pipeline will not automatically wait for data from **icread** to arrive at ICDBDR before attempting to use the contents of that register. Therefore, insert at least one instruction between **icread** and **mficdbdr**:

icread r5,r6	# read cache information
nop	# minimum separation
mficdbdr r7	# move information to GPR

Instruction cache ops use MSR[DR], not MSR[IR], to determine translation of their operands.

When data translation is disabled, cacheability for the effective address of the operand of instruction cache ops is determined by the ICCR, not the DCCR.

Exceptions

Instruction Storage Exceptions and Instruction-side TLB Miss Exceptions are associated with the fetching of instructions, not with the execution of instructions. Exceptions that occur during the execution of instruction cache ops cause data-side exceptions (Data Storage Exceptions and Data TLB Miss Exceptions).

The execution of an **iccci** instruction can cause a Data TLB Miss Exception, at the specified effective address, in spite of the non-specific intent of that effective address.

This instruction is considered a “load” with respect to Data Storage exceptions. See Section 9.4.3 (Access Protection for Cache Instructions) on page 9-20 for further discussion.

This instruction is considered a “load” with respect to data address compare (DAC) debug exceptions. See Section 10.6.3.1 (DAC Applied to Cache Instructions) on page 10-12 for further discussion.

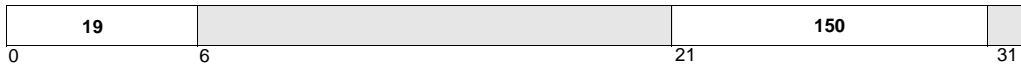
Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

isync

Instruction Synchronize

isync



The **isync** instruction is a context synchronizing instruction.

The **isync** instruction provides an ordering function for the effects of all instructions executed by the processor. Executing **isync** insures that all instructions preceding the **isync** instruction have completed before the **isync** instruction completes, except that storage accesses caused by those instructions need not have completed. No subsequent instructions are initiated by the processor until after the **isync** instruction completes. Finally, execution of **isync** causes the processor to discard any prefetched instructions, with the effect that subsequent instructions will be fetched and executed in the context established by the instructions preceding the **isync** instruction.

The **isync** instruction has no effect on caches.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Note

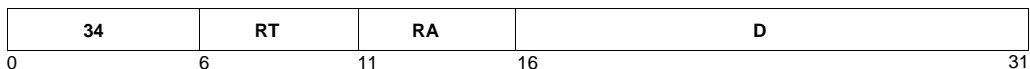
See the discussion of context synchronizing instructions in Section 2.10.1 on page 2-37.

The following code example illustrates the necessary steps for self-modifying code. This example assumes that `addr1` is both data and instruction cacheable.

```
stw      regN, addr1    # the data in regN is to become an instruction at addr1
dcbst    addr1          # forces data from the data cache to memory
sync                                           # wait until the data actually reaches the memory
icbi     addr1          # the previous value at addr1 might already be in
                        # the instruction cache; invalidate in the cache
isync                                           # the previous value at addr1 might already have been
                        # pre-fetched into the queue; invalidate the queue
                        # so that the instruction will be re-fetched
```

Architecture Note

This instruction is part of the PowerPC Virtual Environment Architecture.

lbz RT,D(RA)

$$EA \leftarrow (RA|0) + \text{EXTS}(D)$$

$$(RT) \leftarrow {}^{24}0 \parallel \text{MS}(EA,1)$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

The byte at the effective address is extended to 32 bits by concatenating 24 0-bits to its left. The result is placed into register RT.

Registers Altered

- RT

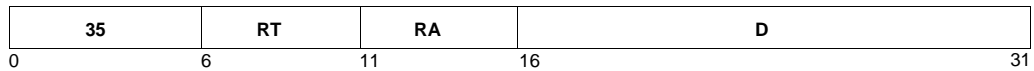
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lbzu

Load Byte and Zero with Update

lbzu RT,D(RA)



$EA \leftarrow (RA|0) + EXTS(D)$
 $(RA) \leftarrow EA$
 $(RT) \leftarrow {}^{24}0 \parallel MS(EA,1)$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The effective address is placed into register RA.

The byte at the effective address is extended to 32 bits by concatenating 24 0-bits to its left. The result is placed into register RT.

Registers Altered

- RA
- RT

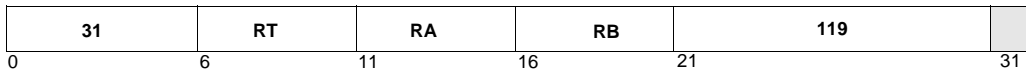
Invalid Instruction Forms

- RA=RT
- RA=0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lbzux RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RA) \leftarrow EA$
 $(RT) \leftarrow {}^{24}0 \parallel MS(EA,1)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The effective address is placed into register RA.

The byte at the effective address is extended to 32 bits by concatenating 24 0-bits to its left. The result is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA
- RT

Invalid Instruction Forms

- Reserved fields
- RA=RT
- RA=0

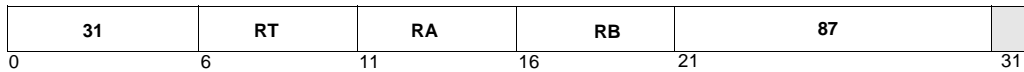
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lbzx

Load Byte and Zero Indexed

lbzx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RT) \leftarrow {}^{24}0 \parallel MS(EA,1)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

The byte at the effective address is extended to 32 bits by concatenating 24 0-bits to its left. The result is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

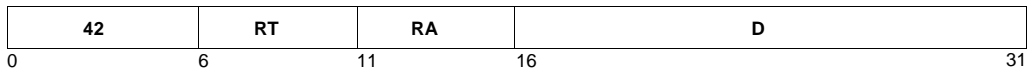
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lha RT,D(RA)



$$EA \leftarrow (RA \neq 0) + \text{EXTS}(D)$$

$$(RT) \leftarrow \text{EXTS}(\text{MS}(EA, 2))$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The halfword at the effective address is sign-extended to 32 bits and placed into register RT.

Registers Altered

- RT

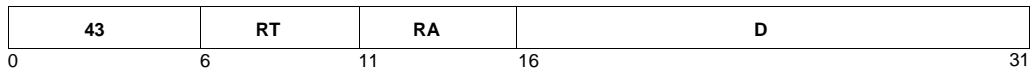
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhau

Load Halfword Algebraic with Update

lhau RT,D(RA)



$EA \leftarrow (RA \& 0) + \text{EXTS}(D)$

$(RA) \leftarrow EA$

$(RT) \leftarrow \text{EXTS}(\text{MS}(EA, 2))$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The halfword at the effective address is sign-extended to 32 bits and placed into register RT.

Registers Altered

- RA
- RT

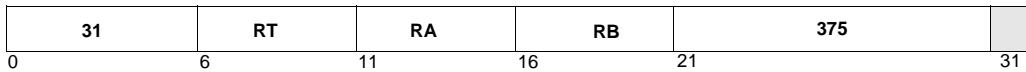
Invalid Instruction Forms

- RA=RT
- RA=0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhaux RT,RA,RB



$$EA \leftarrow (RA \ll 0) + (RB)$$

$$(RA) \leftarrow EA$$

$$(RT) \leftarrow \text{EXTS}(\text{MS}(EA, 2))$$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The halfword at the effective address is sign-extended to 32 bits and placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA
- RT

Invalid Instruction Forms

- Reserved fields
- RA=RT
- RA=0

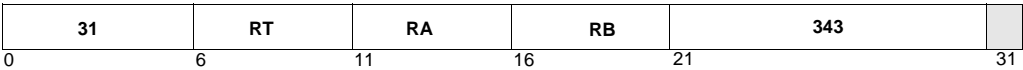
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhax

Load Halfword Algebraic Indexed

lhax RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RT) \leftarrow EXTS(MS(EA,2))$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The halfword at the effective address is sign-extended to 32 bits and placed into register RT. If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

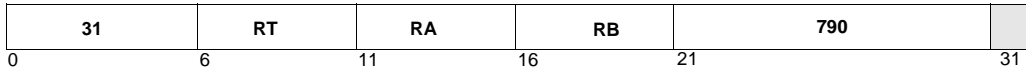
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhbrx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RT) \leftarrow {}^{16}0 \parallel MS(EA+1,1) \parallel MS(EA,1)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The halfword at the effective address is byte-reversed. The resulting halfword is extended to 32 bits by concatenating 16 0-bits to its left. The result is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

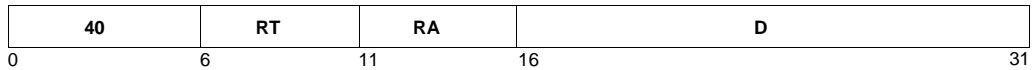
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhz

Load Halfword and Zero

lhz RT,D(RA)



$EA \leftarrow (RA|0) + \text{EXTS}(D)$
 $(RT) \leftarrow {}^{16}0 \parallel \text{MS}(EA,2)$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The halfword at the effective address is extended to 32 bits by concatenating 16 0-bits to its left. The result is placed into register RT.

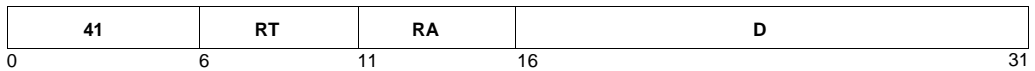
Registers Altered

- RT

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhzu RT,D(RA)



$$EA \leftarrow (RA \ll 0) + \text{EXTS}(D)$$

$$(RA) \leftarrow EA$$

$$(RT) \leftarrow {}^{16}0 \parallel \text{MS}(EA, 2)$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The halfword at the effective address is extended to 32 bits by concatenating 16 0-bits to its left. The result is placed into register RT.

Registers Altered

- RA
- RT

Invalid Instruction Forms

- RA=RT
- RA=0

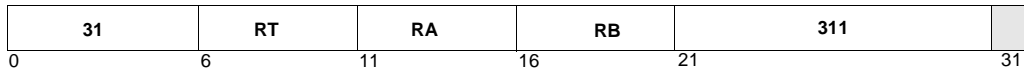
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhzux

Load Halfword and Zero with Update Indexed

lhzux RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RA) \leftarrow EA$
 $(RT) \leftarrow {}^{16}0 \parallel MS(EA,2)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The halfword at the effective address is extended to 32 bits by concatenating 16 0-bits to its left. The result is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA
- RT

Invalid Instruction Forms

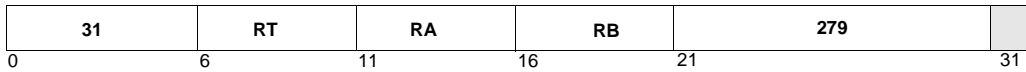
- Reserved fields
- RA=RT
- RA=0

11

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lhzx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RT) \leftarrow {}^{16}0 \parallel MS(EA,2)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The halfword at the effective address is extended to 32 bits by concatenating 16 0-bits to its left. The result is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

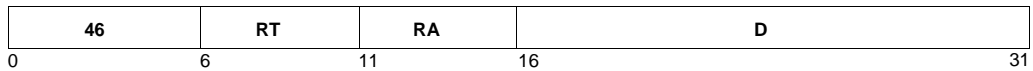
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lmw

Load Multiple Word

lmw RT,D(RA)



```
EA ← (RA|0) + EXTS(D)
r ← RT
do while r ≤ 31
    if ((r ≠ RA) ∨ (r = 31)) then
        (GPR(r)) ← MS(EA,4)
    r ← r + 1
    EA ← EA + 4
```

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field in the instruction to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

A series of consecutive words starting at the effective address are loaded into a set of consecutive GPRs, starting with register RT and continuing to and including GPR(31). Register RA is not altered by this instruction (unless RA is GPR(31), which is an invalid form of this instruction). The word which would have been placed into register RA is discarded.

Registers Altered

- RT through GPR(31).

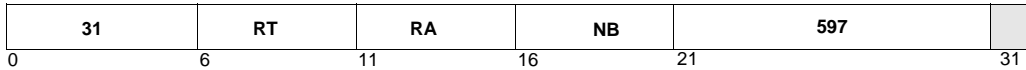
Invalid Instruction Forms

- RA is in the range of registers to be loaded, including the case where RA = RT = 0.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lswi RT,RA,NB



```

EA ← (RA)0
if NB = 0 then
    CNT ← 32
else
    CNT ← NB
n ← CNT
R_FINAL ← ((RT + CEIL(CNT/4) - 1) % 32)
r ← RT - 1
i ← 0
do while n > 0
    if i = 0 then
        r ← r + 1
        if r = 32 then
            r ← 0
        if ((r ≠ RA) ∨ (r = R_FINAL)) then
            (GPR(r)) ← 0
        if ((r ≠ RA) ∨ (r = R_FINAL)) then
            (GPR(r)_{i:i+7}) ← MS(EA,1)
        i ← i + 8
    if i = 32 then
        i ← 0
    EA ← EA + 1
    n ← n - 1

```

An effective address is determined by the RA field. If the RA field contains 0, the effective address is 0. Otherwise, the effective address is the contents of register RA.

A byte count CNT is determined by examining the NB field. If the NB field is 0, the byte count is CNT = 32. Otherwise, the byte count is CNT = NB.

A series of CNT consecutive bytes in main storage, starting with the byte at the effective address, are loaded into CEIL(CNT/4) consecutive GPRs, four bytes per GPR, until the byte count is exhausted. Bytes are placed into GPRs with the byte having the lowest address loaded into the most significant byte. Bit positions to the right of the last byte loaded in the last GPR used are set to 0.

The set of consecutive registers loaded starts at register RT, continues through GPR(31) and wraps to register 0, loading until the byte count is exhausted, which occurs in register R_FINAL. Register RA is not altered (unless RA = R_FINAL, which is an invalid form of this instruction). Bytes which would have been loaded into register RA are discarded.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

lswi

Load String Word Immediate

Registers Altered

- RT and subsequent GPRs as described above.

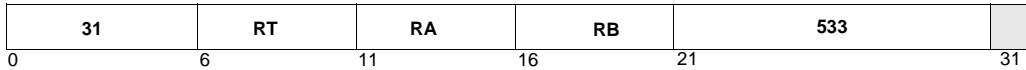
Invalid Instruction Forms

- Reserved fields
- RA is in the range of registers to be loaded
- $RA = RT = 0$

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

ISWX RT,RA,RB



```

EA ← (RA[0] + (RB)
CNT ← XER[TBC]
n ← CNT
R_FINAL ← ((RT + CEIL(CNT/4) - 1) % 32)
r ← RT - 1
i ← 0
do while n > 0
  if i = 0 then
    r ← r + 1
    if r = 32 then
      r ← 0
    if (((r ≠ RA) ∧ (r ≠ RB)) ∨ (r = R_FINAL)) then
      (GPR(r)) ← 0
    if (((r ≠ RA) ∧ (r ≠ RB)) ∨ (r = R_FINAL)) then
      (GPR(r)[i:i+7]) ← MS(EA,1)
    i ← i + 8
    if i = 32 then
      i ← 0
    EA ← EA + 1
    n ← n - 1

```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

A byte count CNT is obtained from XER[TBC].

A series of CNT consecutive bytes in main storage, starting with the byte at the effective address, are loaded into CEIL(CNT/4) consecutive GPRs, four bytes per GPR, until the byte count is exhausted. Bytes are placed into GPRs with the byte having the lowest address loaded into the most significant byte. Bit positions to the right of the last byte loaded in the last register used are set to 0.

The set of consecutive GPRs loaded starts at register RT, continues through GPR(31), and wraps to register 0, loading until the byte count is exhausted, which occurs in register R_FINAL. Register RA is not altered (unless RA = R_FINAL, which is an invalid form of this instruction). Register RB is not altered (unless RB = R_FINAL, which is an invalid form of this instruction). Bytes which would have been loaded into registers RA or RB are discarded.

If XER[TBC] is 0, the byte count is 0 and the contents of register RT are undefined.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

lswx

Load String Word Indexed
Registers Altered

- RT and subsequent GPRs as described above.

Invalid Instruction Forms

- Reserved fields
- RA or RB is in the range of registers to be loaded.
- RA = RT = 0

Programming Note

If XER[TBC] is 0 the contents of register RT are undefined.

The PowerPC Architecture states that, if XER[TBC] = 0 and if accessing the EA would otherwise cause a precise data exception (if not for the zero length), then **lswx** will be treated as a no-op and the exception will not occur. Data Storage Exceptions and Data TLB Miss Exceptions are examples of precise data exceptions.

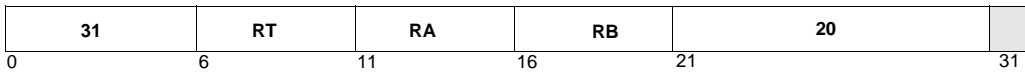
However, the architecture makes no statement regarding imprecise exceptions related to **lswx** with XER[TBC] = 0. The PPC403GC will generate an imprecise exception (Machine Check) on this instruction under these circumstances:

- The instruction passes all protection checking; and
- the address is cacheable; and
- the address misses in the D-cache (resulting in a line fill request to the BIU); and
- the address encounters some form of memory subsystem error (non-configured, etc).

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwarx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $RESERVE \leftarrow 1$
 $(RT) \leftarrow MS(EA,4)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The word at the effective address is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Execution of the **lwarx** instruction sets the reservation bit.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

Programming Note

The reservation bit can be set to 1 only by the execution of the **lwarx** instruction. When execution of the **stwcx.** instruction completes, the reservation bit will be 0, independent of whether or not the **stwcx.** instruction sent (RS) to memory. CR[CR0]_{EQ} must be examined to determine if (RS) was sent to memory. It is intended that **lwarx** and **stwcx.** be used in pairs in a loop, to create the effect of an atomic operation to a memory area which is a semaphore between asynchronous processes.

```

loop:  lwarx           # read the semaphore from memory; set reservation
      "alter"         # change the semaphore bits in register as required
      stwcx.          # attempt to store semaphore; reset reservation
      bne loop        # an asynchronous process has intervened; try again

```

All usage of **lwarx** and **stwcx.** (including usage within asynchronous processes) should be paired as shown in this example. If the asynchronous process in this example had paired **lwarx** with any store other than **stwcx.** then the reservation bit would not have been cleared in the asynchronous process, and the code above would have overwritten the semaphore.

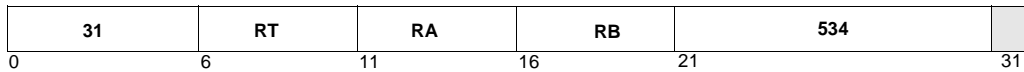
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwbrx

Load Word Byte-Reverse Indexed

lwbrx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $(RT) \leftarrow MS(EA+3,1) \parallel MS(EA+2,1) \parallel MS(EA+1,1) \parallel MS(EA,1)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The word at the effective address is byte-reversed: the least significant byte becomes the most significant byte, the next least significant byte becomes the next most significant byte, and so on. The resulting word is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

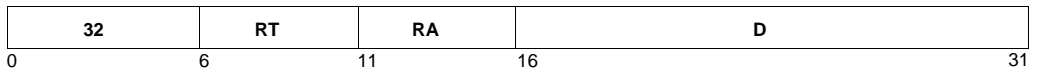
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwz RT,D(RA)



$$EA \leftarrow (RA \neq 0) + \text{EXTS}(D)$$

$$(RT) \leftarrow \text{MS}(EA, 4)$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The word at the effective address is placed into register RT.

Registers Altered

- RT

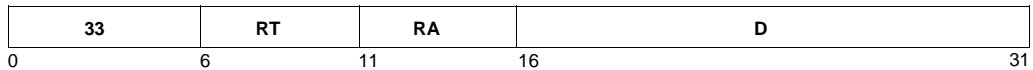
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwzu

Load Word and Zero with Update

lwzu RT,D(RA)



$EA \leftarrow (RA|0) + EXTS(D)$
 $(RA) \leftarrow EA$
 $(RT) \leftarrow MS(EA,4)$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The word at the effective address is placed into register RT.

Registers Altered

- RA
- RT

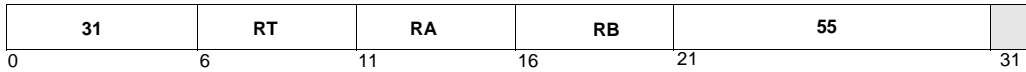
Invalid Instruction Forms

- RA=RT
- RA=0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwzux RT,RA,RB



$EA \leftarrow (RA[0] + (RB))$
 $(RA) \leftarrow EA$
 $(RT) \leftarrow MS(EA,4)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception. The effective address is placed into register RA.

The word at the effective address is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA
- RT

Invalid Instruction Forms

- Reserved fields
- RA=RT
- RA=0

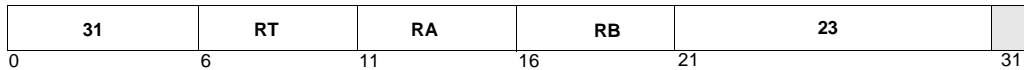
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

lwzx

Load Word and Zero Indexed

lwzx RT,RA,RB



$EA \leftarrow (RA|0) + (RB)$

$(RT) \leftarrow MS(EA,4)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The word at the effective address is placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

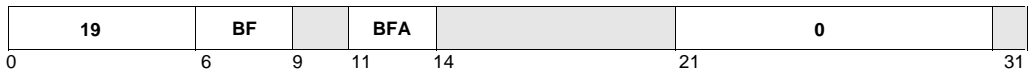
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mcrf BF,BFA



$$m \leftarrow \text{BFA}$$

$$n \leftarrow \text{BF}$$

$$(\text{CR}[\text{CR}_n]) \leftarrow (\text{CR}[\text{CR}_m])$$

The contents of the CR field specified by the BFA field are placed into the CR field specified by the BF field.

Registers Altered

- $\text{CR}[\text{CR}_n]$ where n is specified by the BF field.

Invalid Instruction Forms

- Reserved fields

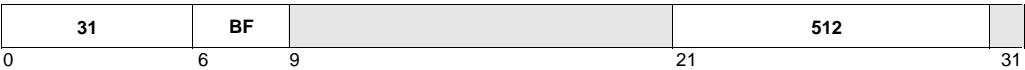
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mcrxr

Move to Condition Register from XER

mcrxr **BF**



```
n ← BF
(CR[CRn]) ← XER0:3
XER0:3 ← 40
```

The contents of XER_{0:3} are placed into the CR field specified by the BF field. XER_{0:3} are then set to 0.

This transfer is positional, by bit number, so the mnemonics associated with each bit are changed. See the following table for clarification.

Bit	XER Usage	CR Usage
0	SO	LT
1	OV	GT
2	CA	EQ
3	reserved	SO

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- CR[CR*n*] where *n* is specified by the BF field.
- XER[SO, OV, CA]

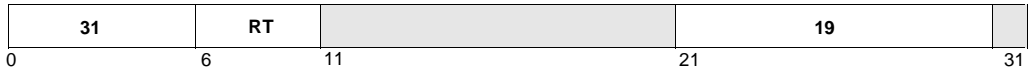
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mfcrr RT



$(RT) \leftarrow (CR)$

The contents of the CR are placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

Architecture Note

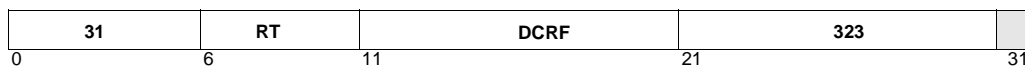
This instruction is part of the PowerPC User Instruction Set Architecture.

This instruction is specific to the PowerPC Embedded Controller family

mfdcr

Move from Device Control Register

mfdcr RT,DCRN



$DCRN \leftarrow DCRF_{5:9} \parallel DCRF_{0:4}$
 $(RT) \leftarrow (DCR(DCRN))$

The contents of the DCR specified by the DCRF field are placed into register RT. See Table 12-3 (PPC403GC Device Control Registers) on page 12-4 for a listing of DCR mnemonics and corresponding DCRN and DCRF values.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields
- Invalid DCRF values

Programming Note

Execution of this instruction is privileged.

The DCR number (DCRN) specified in the assembler language coding of the **mfdcr** instruction refers to an actual DCR number (see Table 12-3 on page 12-4). The assembler handles the unusual DCR number encoding to generate the DCRF field.

11

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

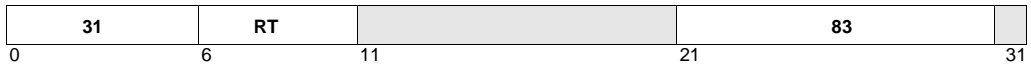
Table 11-17. Extended Mnemonics for mfdcr

Mnemonic	Operands	Function	Other Registers Changed
mfbear mfbesr mibr0 mibr1 mibr2 mibr3 mibr4 mibr5 mibr6 mibr7 mfdmacc0 mfdmacc1 mfdmacc2 mfdmacc3 mfdmacr0 mfdmacr1 mfdmacr2 mfdmacr3 mfdmact0 mfdmact1 mfdmact2 mfdmact3 mfdmada0 mfdmada1 mfdmada2 mfdmada3 mfdmasa0 mfdmasa1 mfdmasa2 mfdmasa3 mfdmasr mfexisr mfexier mfiochr	RT	Move from device control register DCRN. <i>Extended mnemonic for</i> mfdcr RT,DCRN See Table 12-3 on page 12-4 for listing of valid DCRN values.	

mfmsr

Move From Machine State Register

mfmsr RT



$(RT) \leftarrow (MSR)$

The contents of the MSR are placed into register RT.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields

Programming Note

Execution of this instruction is privileged.

Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

mf spr RT,SPRN



$SPRN \leftarrow SPRF_{5:9} \parallel SPRF_{0:4}$
 $(RT) \leftarrow (SPR(SPRN))$

The contents of the SPR specified by the SPRF field are placed into register RT. See Table 12-2 (PPC403GC Special Purpose Registers) on page 12-2 for a listing of SPR mnemonics and corresponding SPRN and SPRF values.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT

Invalid Instruction Forms

- Reserved fields
- Invalid SPRF values

Programming Note

Execution of this instruction is privileged if instruction bit 11 is '1'. See Section 2.9.4 (Privileged SPRs) on page 2-36 for further discussion.

The SPR number (SPRN) specified in the assembler language coding of the **mf spr** instruction refers to an actual SPR number (see Table 12-2 on page 12-2). The assembler handles the unusual SPR number encoding to generate the SPRF field. Also, see Section 2.9.4 for a discussion of the encoding of Privileged SPRs.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

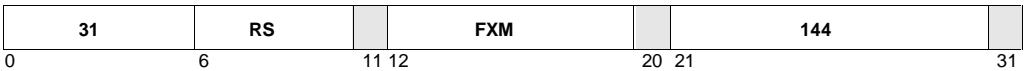
mfspr

Move From Special Purpose Register

Table 11-18. Extended Mnemonics for mfspr

Mnemonic	Operands	Function	Other Registers Changed
mfcdbcr mfctr mfdac1 mfdac2 mfdbsr mfdccr mfdcwr mfdear mfesr mfevpr mfiac1 mfiac2 mficcr mficdbdr mflr mfpbl1 mfpbl2 mfpbu1 mfpbu2 mfpid mfpit mfpvr mfsgr mfsprg0 mfsprg1 mfsprg2 mfsprg3 mfsrr0 mfsrr1 mfsrr2 mfsrr3 mftbhi mftbhu mftblo mftblu mftcr mftsr mfxer mfzpr	RT	Move from special purpose register SPRN. <i>Extended mnemonic for</i> mfspr RT,SPRN See Table 12-2 on page 12-2 for listing of valid SPRN values.	

mtcrf FXM,RS



$$\text{mask} \leftarrow {}^4(\text{FXM}_0) \parallel {}^4(\text{FXM}_1) \parallel \dots \parallel {}^4(\text{FXM}_6) \parallel {}^4(\text{FXM}_7)$$
$$(\text{CR}) \leftarrow ((\text{RS}) \wedge \text{mask}) \vee ((\text{CR}) \wedge \neg \text{mask})$$

Some or all of the contents of register RS are placed into the CR as specified by the FXM field.

Each bit in the FXM field controls the copying of 4 bits in register RS into the corresponding bits in the CR. The correspondence between the bits in the FXM field and the bit copying operation is shown in the following table:

FXM Bit Number	Bits Controlled
0	0:3
1	4:7
2	8:11
3	12:15
4	16:19
5	20:23
6	24:27
7	28:31

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- CR

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

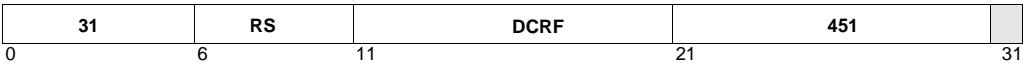
mtcrf

Move to Condition Register Fields

Table 11-19. Extended Mnemonics for mtcrrf

Mnemonic	Operands	Function	Other Registers Changed
mtcr	RS	Move to Condition Register. <i>Extended mnemonic for mtcrrf 0xFF,RS</i>	

mtdcr DCRN,RS



$$\text{DCRN} \leftarrow \text{DCRF}_{5:9} \parallel \text{DCRF}_{0:4}$$
$$(\text{DCR}(\text{DCRN})) \leftarrow (\text{RS})$$

The contents of register RS are placed into the DCR specified by the DCRF field. See Table 12-3 (PPC403GC Device Control Registers) on page 12-4 for a listing of DCR mnemonics and corresponding DCRN and DCRF values.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- DCR(DCRN)

Invalid Instruction Forms

- Reserved fields
- Invalid DCRF values

Programming Note

Execution of this instruction is privileged.

The DCR number (DCRN) specified in the assembler language coding of the **mtdcr** instruction refers to an actual DCR number (see Table 12-3 on page 12-4). The assembler handles the unusual DCR number encoding to generate the DCRF field.

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

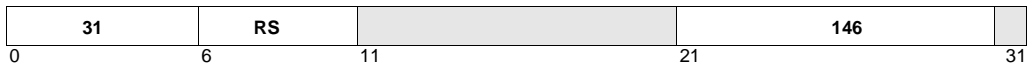
mtdcr

Move To Device Control Register

Table 11-20. Extended Mnemonics for mtdcr

Mnemonic	Operands	Function	Other Registers Changed
mtbear mtbesr mtbr0 mtbr1 mtbr2 mtbr3 mtbr4 mtbr5 mtbr6 mtbr7 mtdmacc0 mtdmacc1 mtdmacc2 mtdmacc3 mtdmacr0 mtdmacr1 mtdmacr2 mtdmacr3 mtdmact0 mtdmact1 mtdmact2 mtdmact3 mtdmada0 mtdmada1 mtdmada2 mtdmada3 mtdmasa0 mtdmasa1 mtdmasa2 mtdmasa3 mtdmasr mtexisr mtexier mtiocr	RS	Move to device control register DCRN. <i>Extended mnemonic for mtdcr DCRN,RS</i> See Table 12-3 on page 12-4 for listing of valid DCRN values.	

mtmsr RS



$$(\text{MSR}) \leftarrow (\text{RS})$$

The contents of register RS are placed into the MSR.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- MSR

Invalid Instruction Forms

- Reserved fields

Programming Note

The **mtmsr** instruction is privileged and execution synchronizing.

Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

mtspr

Move To Special Purpose Register

mtspr SPRN,RS



$SPRN \leftarrow SPRF_{5:9} \parallel SPRF_{0:4}$
 $(SPR(SPRN)) \leftarrow (RS)$

The contents of register RS are placed into the SPR specified by the SPRF field. See Table 12-2 (PPC403GC Special Purpose Registers) on page 12-2 for a listing of SPR mnemonics and corresponding SPRN and SPRF values.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- SPR(SPRN)

Invalid Instruction Forms

- Reserved fields
- Invalid SPRF values

Programming Note

Execution of this instruction is privileged if instruction bit 11 is '1'. See Section 2.9.4 (Privileged SPRs) on page 2-36 for further discussion.

The SPR number (SPRN) specified in the assembler language coding of the **mtspr** instruction refers to an actual SPR number (see Table 12-2 on page 12-2). The assembler handles the unusual SPR number encoding to generate the SPRF field. Also, see Section 2.9.4 for a discussion of the encoding of Privileged SPRs.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

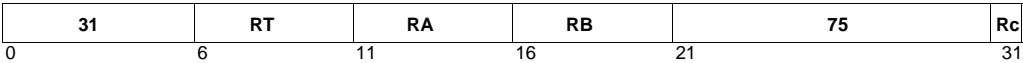
Table 11-21. Extended Mnemonics for mtspr

Mnemonic	Operands	Function	Other Registers Changed
mtcdbcr mtctr mtdac1 mtdac2 mtdbsr mtdccr mtdcwr mtesr mtevpr mtiac1 mtiac2 mticcr mticdbdr mtlr mtpbl1 mtpbl2 mtpbu1 mtpbu2 mtpid mtpit mtsgr mtsprg0 mtsprg1 mtsprg2 mtsprg3 mtsrr0 mtsrr1 mtsrr2 mtsrr3 mttbhi mttblo mttcr mttsr mtxer mtzpr	RS	Move to special purpose register SPRN. <i>Extended mnemonic for</i> mtspr SPRN,RS See Table 12-2 on page 12-2 for listing of valid SPRN values.	

mulhw

Multiply High Word

mulhw RT,RA,RB (Rc=0)
mulhw. RT,RA,RB (Rc=1)



$$\text{prod}_{0:63} \leftarrow (\text{RA}) \times (\text{RB}) \text{ (signed)}$$
$$(\text{RT}) \leftarrow \text{prod}_{0:31}$$

The 64-bit signed product of registers RA and RB is formed. The most significant 32 bits of the result is placed into register RT.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Programming Note

The most significant 32 bits of the product, unlike the least significant 32 bits, may differ depending on whether the registers RA and RB are interpreted as signed or unsigned quantities. The **mulhw** instruction generates the correct result when these operands are interpreted as signed quantities. The **mulhwu** instruction generates the correct result when these operands are interpreted as unsigned quantities.

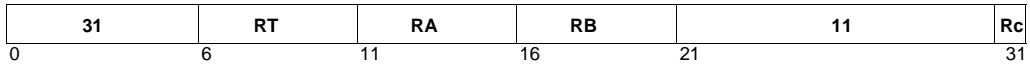
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mulhwu

Multiply High Word Unsigned

mulhwu	RT,RA,RB	(Rc=0)
mulhwu.	RT,RA,RB	(Rc=1)


$$\begin{aligned} \text{prod}_{0:63} &\leftarrow (\text{RA}) \times (\text{RB}) \text{ (unsigned)} \\ (\text{RT}) &\leftarrow \text{prod}_{0:31} \end{aligned}$$

The 64-bit unsigned product of registers RA and RB is formed. The most significant 32 bits of the result are placed into register RT.

Registers Altered

- RT
- $CR[CR0]_{LT, GT, EQ, SO}$ if Rc contains 1

Programming Note

The most significant 32 bits of the product, unlike the least significant 32 bits, may differ depending on whether the registers RA and RB are interpreted as signed or unsigned quantities. The **mulhw** instruction generates the correct result when these operands are interpreted as signed quantities. The **mulhbw** instruction generates the correct result when these operands are interpreted as unsigned quantities.

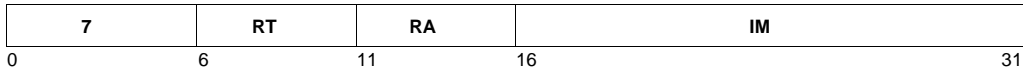
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mulli

Multiply Low Immediate

mulli RT,RA,IM



$\text{prod}_{0:47} \leftarrow (\text{RA}) \times \text{IM}$
 $(\text{RT}) \leftarrow \text{prod}_{16:47}$

The 48-bit product of register RA and the IM field is formed. Both register RA and the IM field are interpreted as signed quantities. The least significant 32 bits of the product are placed into register RT.

Registers Altered

- RT

Programming Note

The least significant 16 bits of the product are correct, regardless of whether register RA and field IM are interpreted as signed or unsigned numbers.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

mullw	RT,RA,RB	(OE=0, Rc=0)
mullw.	RT,RA,RB	(OE=0, Rc=1)
mullwo	RT,RA,RB	(OE=1, Rc=0)
mullwo.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	235	Rc
0	6	11	16	21	22	31

$\text{prod}_{0:63} \leftarrow (\text{RA}) \times (\text{RB}) \text{ (signed)}$
 $(\text{RT}) \leftarrow \text{prod}_{32:63}$

The 64-bit signed product of register RA and register RB is formed. The least significant 32 bits of the result is placed into register RT.

If all bits in positions 0 through 31 of the 64 bit product do not equal bit 0 of the result in register RT and OE=1, XER[SO, OV] are set to 1.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE=1

Programming Note

The least significant 32 bits of the product are correct, regardless of whether register RA and register RB are interpreted as signed or unsigned numbers.

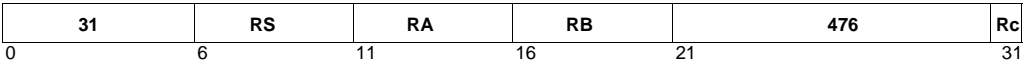
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

nand

NAND

nand RA,RS,RB (Rc=0)
nand. RA,RS,RB (Rc=1)



$$(RA) \leftarrow \neg((RS) \wedge (RB))$$

The contents of register RS is ANDed with the contents of register RB; the ones complement of the result is placed into register RA.

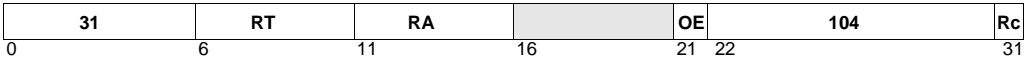
Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

neg	RT,RA	(OE=0, Rc=0)
neg.	RT,RA	(OE=0, Rc=1)
nego	RT,RA	(OE=1, Rc=0)
nego.	RT,RA	(OE=1, Rc=1)



$(RT) \leftarrow \neg(RA) + 1$

The twos complement of the contents of register RA are placed into register RT.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[CA, SO, OV] if OE=1

Invalid Instruction Forms

- Reserved fields

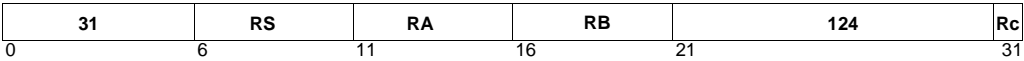
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

nor

NOR

nor RA,RS,RB (Rc=0)
nor. RA,RS,RB (Rc=1)



$$(RA) \leftarrow \neg((RS) \vee (RB))$$

The contents of register RS is ORed with the contents of register RB; the ones complement of the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

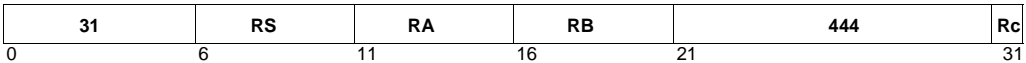
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-22. Extended Mnemonics for nor, nor.

Mnemonic	Operands	Function	Other Registers Changed
not	RA, RS	Complement register. (RA) ← ¬(RS) <i>Extended mnemonic for nor RA,RS,RS</i>	
not.		<i>Extended mnemonic for nor. RA,RS,RS</i>	CR[CR0]

or RA,RS,RB (Rc=0)
or. RA,RS,RB (Rc=1)



$(RA) \leftarrow (RS) \vee (RB)$

The contents of register RS is ORed with the contents of register RB; the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

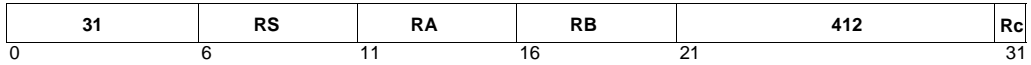
Table 11-23. Extended Mnemonics for or, or.

Mnemonic	Operands	Function	Other Registers Changed
mr	RT, RS	Move register. (RT) ← (RS) <i>Extended mnemonic for or RT,RS,RS</i>	
mr.		<i>Extended mnemonic for or. RT,RS,RS</i>	CR[CR0]

orc

OR with Complement

orc RA,RS,RB (Rc=0)
orc. RA,RS,RB (Rc=1)



$$(RA) \leftarrow (RS) \vee \neg(RB)$$

The contents of register RS is ORed with the ones complement of the contents of register RB; the result is placed into register RA.

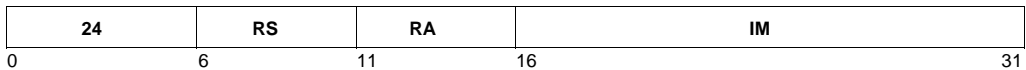
Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

ori RA,RS,IM



$(RA) \leftarrow (RS) \vee (^{16}0 \parallel IM)$

The IM field is extended to 32 bits by concatenating 16 0-bits on the left. Register RS is ORed with the extended IM field; the result is placed into register RA.

Registers Altered

- RA

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

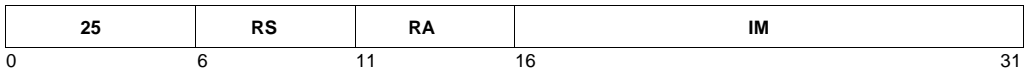
Table 11-24. Extended Mnemonics for ori

Mnemonic	Operands	Function	Other Registers Changed
nop		Preferred no-op, triggers optimizations based on no-ops. <i>Extended mnemonic for ori 0,0,0</i>	

oris

OR Immediate Shifted

oris RA,RS,IM



$$(RA) \leftarrow (RS) \vee (IM \parallel ^{16}0)$$

The IM Field is extended to 32 bits by concatenating 16 0-bits on the right. Register RS is ORed with the extended IM field and the result is placed into register RA.

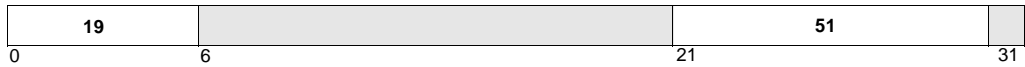
Registers Altered

- RA

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

rfci



(PC) ← (SRR2)
(MSR) ← (SRR3)

The program counter (PC) is restored with the contents of SRR2 and the MSR is restored with the contents of SRR3.

Instruction execution returns to the address contained in the PC.

Registers Altered

- MSR

Programming Note

Execution of this instruction is privileged.

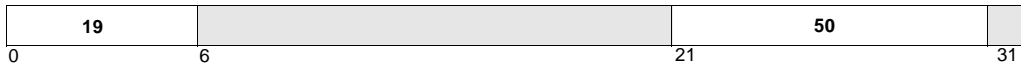
Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

rfi

Return From Interrupt

rfi



$(PC) \leftarrow (SRR0)$
 $(MSR) \leftarrow (SRR1)$

The program counter (PC) is restored with the contents of SRR0 and the MSR is restored with the contents of SRR1.

Instruction execution returns to the address contained in the PC.

Registers Altered

- MSR

Invalid Instruction Forms

- Reserved fields

Programming Note

Execution of this instruction is privileged.

Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

rlwimi RA,RS,SH,MB,ME (Rc=0)
rlwimi. RA,RS,SH,MB,ME (Rc=1)

20	RS	RA	SH	MB	ME	Rc
0	6	11	16	21	26	31

$r \leftarrow \text{ROTL}((RS), SH)$
 $m \leftarrow \text{MASK}(MB, ME)$
 $(RA) \leftarrow (r \wedge m) \vee ((RA) \wedge \neg m)$

The contents of register RS are rotated left by the number of bit positions specified in the SH field. A mask is generated, having 1-bits starting at the bit position specified in the MB field and ending in the bit position specified by the ME field, with 0-bits elsewhere.

If the starting point of the mask is at a higher bit position than the ending point, the 1-bits portion of the mask wraps from the highest bit position back around to the lowest. The rotated data is inserted into register RA, in positions corresponding to the bit positions in the mask that contain a 1-bit.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-25. Extended Mnemonics for rlwimi, rlwimi.

Mnemonic	Operands	Function	Other Registers Changed
inslwi	RA, RS, n, b	Insert from left immediate. ($n > 0$) $(RA)_{b:b+n-1} \leftarrow (RS)_{0:n-1}$ <i>Extended mnemonic for</i> rlwimi RA,RS,32-b,b,b+n-1	
inslwi.		<i>Extended mnemonic for</i> rlwimi. RA,RS,32-b,b,b+n-1	CR[CR0]
insrwi	RA, RS, n, b	Insert from right immediate. ($n > 0$) $(RA)_{b:b+n-1} \leftarrow (RS)_{32-n:31}$ <i>Extended mnemonic for</i> rlwimi RA,RS,32-b-n,b,b+n-1	
insrwi.		<i>Extended mnemonic for</i> rlwimi. RA,RS,32-b-n,b,b+n-1	CR[CR0]

rlwinm

Rotate Left Word Immediate then AND with Mask

rlwinm RA,RS,SH,MB,ME (Rc=0)
rlwinm. RA,RS,SH,MB,ME (Rc=1)

21	RS	RA	SH	MB	ME	Rc
0	6	11	16	21	26	31

$r \leftarrow \text{ROTL}((RS), SH)$
 $m \leftarrow \text{MASK}(MB, ME)$
 $(RA) \leftarrow r \wedge m$

The contents of register RS is rotated left by the number of bit positions specified in the SH field. A mask is generated, having 1-bits starting at the bit position specified in the MB field and ending in the bit position specified by the ME field with 0-bits elsewhere.

If the starting point of the mask is at a higher bit position than the ending point, the 1-bits portion of the mask wraps from the highest bit position back around to the lowest. The rotated data is ANDed with the generated mask; the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-26. Extended Mnemonics for rlwinm, rlwinm.

Mnemonic	Operands	Function	Other Registers Changed
crlwi	RA, RS, n	Clear left immediate. ($n < 32$) $(RA)_{0:n-1} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,0,n,31	
crlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,n,31	CR[CR0]

Table 11-26. Extended Mnemonics for rlwinm, rlwinm. (cont.)

Mnemonic	Operands	Function	Other Registers Changed
clrlslwi	RA, RS, b, n	Clear left and shift left immediate. ($n \leq b < 32$) $(RA)_{b-n:31-n} \leftarrow (RS)_{b:31}$ $(RA)_{32-n:31} \leftarrow {}^n0$ $(RA)_{0:b-n-1} \leftarrow {}^{b-n}0$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,b-n,31-n	
clrlslwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,b-n,31-n	CR[CR0]
clrrwi	RA, RS, n	Clear right immediate. ($n < 32$) $(RA)_{32-n:31} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,0,0,31-n	
clrrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,0,31-n	CR[CR0]
extlwi	RA, RS, n, b	Extract and left justify immediate. ($n > 0$) $(RA)_{0:n-1} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{n:31} \leftarrow {}^{32-n}0$ <i>Extended mnemonic for</i> rlwinm RA,RS,b,0,n-1	
extlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,b,0,n-1	CR[CR0]
extrwi	RA, RS, n, b	Extract and right justify immediate. ($n > 0$) $(RA)_{32-n:31} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{0:31-n} \leftarrow {}^{32-n}0$ <i>Extended mnemonic for</i> rlwinm RA,RS,b+n,32-n,31	
extrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,b+n,32-n,31	CR[CR0]
rotlwi	RA, RS, n	Rotate left immediate. $(RA) \leftarrow \text{ROTL}((RS), n)$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,0,31	
rotlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,0,31	CR[CR0]
rotrwi	RA, RS, n	Rotate right immediate. $(RA) \leftarrow \text{ROTL}((RS), 32-n)$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,0,31	
rotrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,0,31	CR[CR0]

rlwinm

Rotate Left Word Immediate then AND with Mask

Table 11-26. Extended Mnemonics for rlwinm, rlwinm. (cont.)

Mnemonic	Operands	Function	Other Registers Changed
slwi	RA, RS, n	Shift left immediate. ($n < 32$) $(RA)_{0:31-n} \leftarrow (RS)_{n:31}$ $(RA)_{32-n:31} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,0,31-n	
slwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,0,31-n	CR[CR0]
srwi	RA, RS, n	Shift right immediate. ($n < 32$) $(RA)_{n:31} \leftarrow (RS)_{0:31-n}$ $(RA)_{0:n-1} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,n,31	
srwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,n,31	CR[CR0]

rlwnm RA,RS,RB,MB,ME (Rc=0)
rlwnm. RA,RS,RB,MB,ME (Rc=1)

23	RS	RA	RB	MB	ME	Rc
0	6	11	16	21	26	31

$r \leftarrow \text{ROTL}((RS), (RB)_{27:31})$
 $m \leftarrow \text{MASK}(MB, ME)$
 $(RA) \leftarrow r \wedge m$

The contents of register RS is rotated left by the number of bit positions specified by the contents of register RB bits 27 through 31. A mask is generated having 1-bits starting at the bit position specified in the MB field and ending in the bit position specified by the ME field with 0-bits elsewhere.

If the starting point of the mask is at a higher bit position than the ending point, the ones portion of the mask wraps from the highest bit position back around to the lowest. The rotated data is ANDed with the generated mask and the result is placed into register RA.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

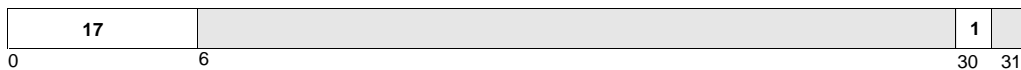
Table 11-27. Extended Mnemonics for rlwnm, rlwnm.

Mnemonic	Operands	Function	Other Registers Changed
rotlw	RA, RS, RB	Rotate left. $(RA) \leftarrow \text{ROTL}((RS), (RB)_{27:31})$ <i>Extended mnemonic for</i> rlwnm RA,RS,RB,0,31	
rotlw.		<i>Extended mnemonic for</i> rlwnm. RA,RS,RB,0,31	CR[CR0]

SC

System Call

SC



```
(SRR1) ← (MSR)
(SRR0) ← (PC)
PC ← EVPR0:15 || x'0C00'
(MSR[WE, EE, PR, PE, DR, IR]) ← 0
(MSR[LE]) ← (MSR[ILE])
```

A system call exception is generated. The contents of the MSR are copied into SRR1 and (4 + address of **sc** instruction) is placed into SRR0.

The PC is then loaded with the exception vector address. The exception vector address is calculated by concatenating the high halfword of the Exception Vector Prefix Register (EVPR) to the left of 0x0C00.

The MSR[WE, PR, EE, PE, DR, IR] bits are set to 0, and MSR[ILE] is copied to MSR[LE].

Program execution continues at the new address in the PC.

The **sc** instruction is context synchronizing.

Registers Altered

- SRR0
- SRR1
- MSR[WE, EE, PR, PE, DR, IR, LE]

11

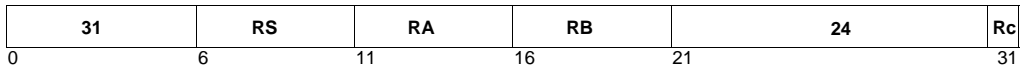
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

slw RA,RS,RB (Rc=0)
slw. RA,RS,RB (Rc=1)



```

n ← (RB)27:31
r ← ROTL((RS), n)
if (RB)26 = 0 then
    m ← MASK(0, 31 – n)
else
    m ← 320
(RA) ← r ∧ m

```

The contents of register RS are shifted left by the number of bits specified by bits 27 through 31 of register RB. Bits shifted left out of the most significant bit are lost, and 0-bits are supplied to fill vacated bit positions on the right. The result is placed into register RA.

If bit 26 of register RB contains a one, register RA is set to zero.

Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sraw

Shift Right Algebraic Word

sraw RA,RS,RB (Rc=0)
sraw. RA,RS,RB (Rc=1)

31	RS	RA	RB	792	Rc
0	6	11	16	21	31

```

n ← (RB)27:31
r ← ROTL((RS), 32 - n)
if (RB)26 = 0 then
    m ← MASK(n, 31)
else
    m ← 320
s ← (RS)0
(RA) ← (r ∧ m) ∨ (32s ∧ ¬m)
XER[CA] ← s ∧ ((r ∧ ¬m) ≠ 0)

```

The contents of register RS are shifted right by the number of bits specified by bits 27 through 31 of register RB. Bits shifted out of the least significant bit are lost. Bit 0 of register RS is replicated to fill the vacated positions on the left. The result is placed into register RA.

If register RS contains a negative number and any 1-bits were shifted out of the least significant bit position, XER[CA] is set to 1; otherwise, it is set to 0.

If bit 26 of register RB contains 1, register RA and XER[CA] are set to bit 0 of register RS.

Registers Altered

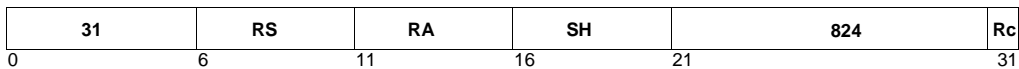
- RA
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

11

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

srawi	RA,RS,SH	(Rc=0)
srawi.	RA,RS,SH	(Rc=1)



```
n ← SH
r ← ROTL((RS), 32 – n)
m ← MASK(n, 31)
s ← (RS)0
(RA) ← (r ∧ m) ∨ (32s ∧ ¬m)
XER[CA] ← s ∧ ((r ∧ ¬m)≠0)
```

The contents of register RS are shifted right by the number of bits specified in the SH field. Bits shifted out of the least significant bit are lost. Bit 0 of register RS is replicated to fill the vacated positions on the left. The result is placed into register RA.

If register RS contains a negative number and any 1-bits were shifted out of the least significant bit position, XER[CA] is set to 1; otherwise, it is set to 0.

Registers Altered

- RA
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

srw

Shift Right Word

srw RA,RS,RB (Rc=0)
srw. RA,RS,RB (Rc=1)

31	RS	RA	RB	536	Rc
0	6	11	16	21	31

```

n ← (RB)27:31
r ← ROTL((RS), 32 – n)
if (RB)26 = 0 then
    m ← MASK(n, 31)
else
    m ← 320
(RA) ← r ∧ m

```

The contents of register RS are shifted right by the number of bits specified by bits 27 through 31 of register RB. Bits shifted right out of the least significant bit are lost, and 0-bits are supplied to fill the vacated bit positions on the left. The result is placed into register RA.

If bit 26 of register RB contains a one, register RA is set to 0.

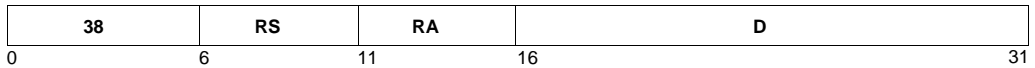
Registers Altered

- RA
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stb RS,D(RA)



$EA \leftarrow (RA|0) + EXTS(D)$

$MS(EA, 1) \leftarrow (RS)_{24:31}$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

The least significant byte of register RS is stored into the byte at the effective address in main storage.

Registers Altered

- None

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stbu

Store Byte with Update

stbu RS,D(RA)

39	RS	RA	D
0	6	11	16
			31

$EA \leftarrow (RA|0) + EXTS(D)$
 $MS(EA, 1) \leftarrow (RS)_{24:31}$
 $(RA) \leftarrow EA$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

The least significant byte of register RS is stored into the byte at the effective address in main storage.

The effective address is placed into register RA.

Registers Altered

- RA

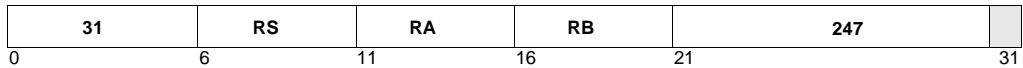
Invalid Instruction Forms

RA = 0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stbux RS,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $MS(EA, 1) \leftarrow (RS)_{24:31}$
 $(RA) \leftarrow EA$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

The least significant byte of register RS is stored into the byte at the effective address in main storage.

The effective address is placed into register RA.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA

Invalid Instruction Forms

- Reserved fields
- $RA = 0$

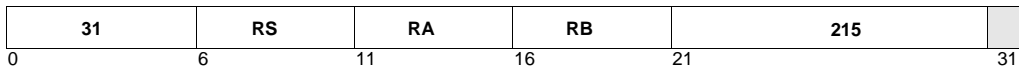
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stbx

Store Byte Indexed

stbx RS,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $MS(EA, 1) \leftarrow (RS)_{24:31}$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

The least significant byte of register RS is stored into the byte at the effective address in main storage.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

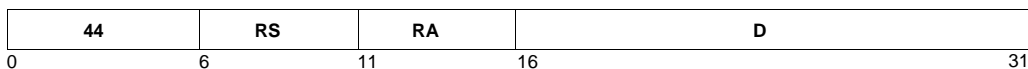
Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sth RS,D(RA)



$$EA \leftarrow (RA|0) + \text{EXTS}(D)$$

$$MS(EA, 2) \leftarrow (RS)_{16:31}$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0 and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The least significant halfword of register RS is stored into the halfword at the effective address in main storage.

Registers Altered

- None

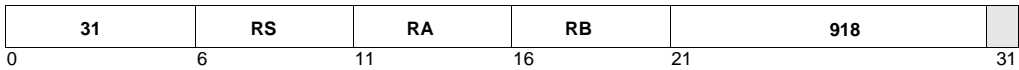
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sthbrx

Store Halfword Byte-Reverse Indexed

sthbrx RS,RA,RB



$EA \leftarrow (RA|0) + (RB)$
 $MS(EA, 2) \leftarrow (RS)_{24:31} \parallel (RS)_{16:23}$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The least significant halfword of register RS is byte-reversed. The result is stored into the halfword at the effective address in main storage.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

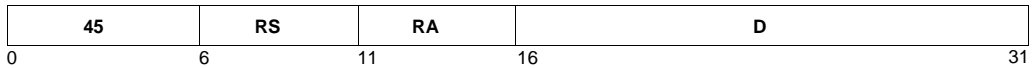
- None

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sthu RS,D(RA)

$$EA \leftarrow (RA|0) + \text{EXTS}(D)$$

$$MS(EA, 2) \leftarrow (RS)_{16:31}$$

$$(RA) \leftarrow EA$$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The least significant halfword of register RS is stored into the halfword at the effective address in main storage.

The effective address is placed into register RA.

Registers Altered

- RA

Invalid Instruction Forms

- RA = 0

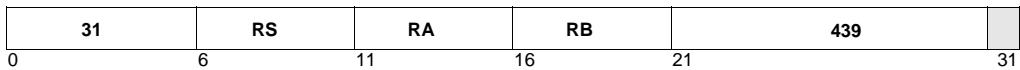
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sthux

Store Halfword with Update Indexed

sthux RS,RA,RB



```
EA ← (RA|0) + (RB)
MS(EA, 2) ← (RS)16:31
(RA) ← EA
```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The least significant halfword of register RS is stored into the halfword at the effective address in main storage.

The effective address is placed into register RA.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

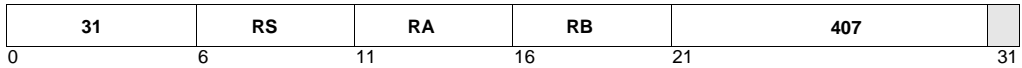
- RA

Invalid Instruction Forms

- Reserved fields
- RA=0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sthx RS,RA,RB

$$EA \leftarrow (RA[0] + (RB))$$

$$MS(EA, 2) \leftarrow (RS)_{16:31}$$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be halfword-aligned (a multiple of 2). If it is not, it will cause an alignment exception.

The least significant halfword of register RS is stored into the halfword at the effective address in main storage.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stmw

Store Multiple Word

stmw RS,D(RA)

47	RS	RA	D
0	6	11	16
			31

```
EA ← (RA|0) + EXTS(D)
r ← RS
do while r ≤ 31
    MS(EA, 4) ← (GPR(r))
    r ← r + 1
    EA ← EA + 4
```

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of a series of consecutive registers, starting with register RS and continuing through GPR(31), are stored into consecutive words in main storage starting at the effective address.

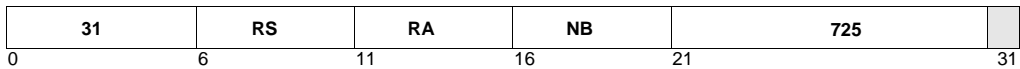
Registers Altered

- None

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stswi RS,RA,NB



```
EA ← (RA|0)
if NB = 0 then
  n ← 32
else
  n ← NB
r ← RS - 1
i ← 0
do while n > 0
  if i = 0 then
    r ← r + 1
  if r = 32 then
    r ← 0
  MS(EA,1) ← (GPR(r)i:i+7)
  i ← i + 8
  if i = 32 then
    i ← 0
  EA ← EA + 1
  n ← n - 1
```

An effective address is determined by the RA field. If the RA field contains 0, the effective address is 0; otherwise, the effective address is the contents of register RA.

A byte count is determined by the NB field. If the NB field contains 0, the byte count is 32; otherwise, the byte count is the NB field.

The contents of a series of consecutive GPRs (starting with register RS, continuing through GPR(31), wrapping to GPR(0), and continuing to the final byte count) are stored into main storage starting at the effective address. The bytes in each GPR are accessed starting with the most significant byte. The byte count determines the number of transferred bytes.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

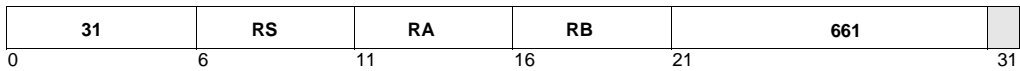
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stswx

Store String Word Indexed

stswx RS,RA,RB



```
EA ← (RA|0) + (RB)
n ← XER[TBC]
r ← RS - 1
i ← 0
do while n > 0
  if i = 0 then
    r ← r + 1
  if r = 32 then
    r ← 0
  MS(EA, 1) ← (GPR(r)ii+7)
  i ← i + 8
  if i = 32 then
    i ← 0
  EA ← EA + 1
  n ← n - 1
```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise.

A byte count is contained in XER[TBC].

The contents of a series of consecutive GPRs (starting with register RS, continuing through GPR(31), wrapping to GPR(0), and continuing to the final byte count) are stored starting at the effective address. The bytes in each GPR are accessed starting with the most significant byte. The byte count determines the number of transferred bytes.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Note

If XER[TBC] contains 0, the **stswx** instruction transfers no bytes; the instruction will be treated as a no-op.

The PowerPC Architecture states that, if XER[TBC] = 0 and if accessing the EA would otherwise cause a precise data exception (if not for the zero length), then **stswx** will be treated as a no-op and the exception will not occur. Data Storage Exceptions and Data TLB Miss Exceptions are examples of precise data exceptions.

However, the architecture makes no statement regarding imprecise exceptions related to **stswx** with XER[TBC] = 0. The PPC403GC will generate an imprecise exception (Machine Check) on this instruction under these circumstances:

- The instruction passes all protection checking; and
- the address is cacheable; and
- the address misses in the D-cache (resulting in a line fill request to the BIU); and
- the address encounters some form of memory subsystem error (non-configured, etc).

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stw

Store Word

stw RS,D(RA)

36	RS	RA	D
0	6	11	16
			31

$EA \leftarrow (RA|0) + \text{EXTS}(D)$
 $MS(EA, 4) \leftarrow (RS)$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of register RS are stored at the effective address.

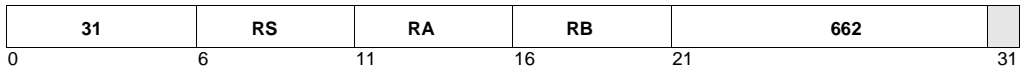
Registers Altered

- None

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stwbrx RS,RA,RB



$$EA \leftarrow (RA[0] + (RB)$$

$$MS(EA, 4) \leftarrow (RS)_{24:31} \parallel (RS)_{16:23} \parallel (RS)_{8:15} \parallel (RS)_{0:7}$$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of register RS are byte-reversed: the least significant byte becomes the most significant byte, the next least significant byte becomes the next most significant byte, and so on. The result is stored into word at the effective address.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stwcx.

Store Word Conditional Indexed

stwcx. RS,RA,RB

31	RS	RA	RB	150	1
0	6	11	16	21	31

```

EA ← (RA|0) + (RB)
if RESERVE = 1 then
    MS(EA, 4) ← (RS)
    RESERVE ← 0
    (CR[CR0]) ← 200 || 1 || XERso
else
    (CR[CR0]) ← 200 || 0 || XERso

```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

If the reservation bit contains 1 when the instruction is executed, the contents of register RS are stored into the word at the effective address and the reservation bit is cleared. If the reservation bit contains 0 when the instruction is executed, no store operation is performed.

CR[CR0] is set as follows:

- CR[CR0]_{LT, GT} are cleared
- CR[CR0]_{EQ} is set to the state of the reservation bit at the start of the instruction
- CR[CR0]_{SO} is set to the contents of the XER[SO] bit.

Programming Note

11

The reservation bit can be set to 1 only by the execution of the **lwarx** instruction. When execution of the **stwcx.** instruction completes, the reservation bit will be 0, independent of whether or not the **stwcx.** instruction sent (RS) to memory. CR[CR0]_{EQ} must be examined to determine if (RS) was sent to memory. It is intended that **lwarx** and **stwcx.** be used in pairs in a loop, to create the effect of an atomic operation to a memory area which is a semaphore between asynchronous processes.

```

loop:  lwarx                # read the semaphore from memory; set reservation
      "alter"             # change the semaphore bits in register as required
      stwcx.              # attempt to store semaphore; reset reservation
      bne loop            # an asynchronous process has intervened; try again

```

All usage of **lwarx** and **stwcx.** (including usage within asynchronous processes) should be paired as shown in this example. If the asynchronous process in this example had paired **lwarx** with any store other than **stwcx.** then the reservation bit would not have been cleared in the asynchronous process, and the code above would have overwritten the semaphore.

stwcx.

Store Word Conditional Indexed

Registers Altered

- CR[CR0]_{LT, GT, EQ, SO}

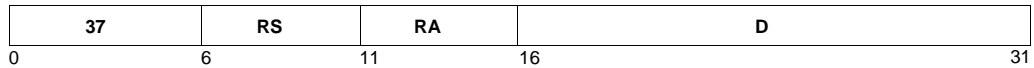
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stwu

Store Word with Update

stwu RS,D(RA)



$EA \leftarrow (RA|0) + EXTS(D)$
 $MS(EA, 4) \leftarrow (RS)$
 $(RA) \leftarrow EA$

An effective address is formed by adding a displacement to a base address. The displacement is obtained by sign-extending the 16-bit D field to 32 bits. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of register RS are stored into the word at the effective address.

The effective address is placed into register RA.

Registers Altered

- RA

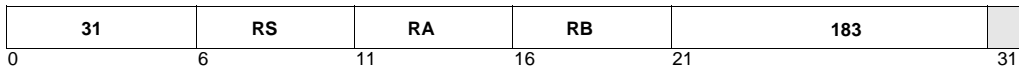
Invalid Instruction Forms

- RA = 0

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stwux RS,RA,RB



```
EA ← (RA|0) + (RB)
MS(EA, 4) ← (RS)
(RA) ← EA
```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of register RS are stored into the word at the effective address.

The effective address is placed into register RA.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RA

Invalid Instruction Forms

- Reserved fields
- RA = 0

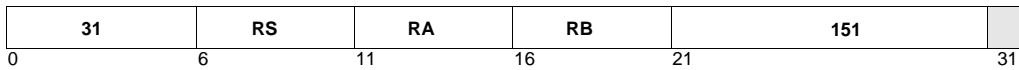
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

stwx

Store Word Indexed

stwx RS,RA,RB



$EA \leftarrow (RA|0) + (RB)$

$MS(EA,4) \leftarrow (RS)$

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 when the RA field is 0, and is the contents of register RA otherwise. The EA must be word-aligned (a multiple of 4). If it is not, it will cause an alignment exception.

The contents of register RS are stored into the word at the effective address.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

subf	RT,RA,RB	(OE=0, Rc=0)
subf.	RT,RA,RB	(OE=0, Rc=1)
subfo	RT,RA,RB	(OE=1, Rc=0)
subfo.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	40	Rc
0	6	11	16	21	22	31

$$(RT) \leftarrow \neg(RA) + (RB) + 1$$

The sum of the ones complement of register RA, register RB, and 1 is stored into register RT.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-28. Extended Mnemonics for subf, subf., subfo, subfo.

Mnemonic	Operands	Function	Other Registers Changed
sub	RT, RA, RB	Subtract (RB) from (RA). (RT) $\leftarrow \neg(RB) + (RA) + 1$. <i>Extended mnemonic for</i> subf RT,RB,RA	
sub.		<i>Extended mnemonic for</i> subf. RT,RB,RA	CR[CR0]
subo		<i>Extended mnemonic for</i> subfo RT,RB,RA	XER[SO, OV]
subo.		<i>Extended mnemonic for</i> subfo. RT,RB,RA	CR[CR0] XER[SO, OV]

subfc

Subtract From Carrying

subfc	RT,RA,RB	(OE=0, Rc=0)
subfc.	RT,RA,RB	(OE=0, Rc=1)
subfco	RT,RA,RB	(OE=1, Rc=0)
subfco.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	8	Rc
0	6	11	16	21	22	31

```

(RT) ← ¬(RA) + (RB) + 1
if ¬(RA) + (RB) + 1  $\overset{u}{>} 2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the ones complement of register RA, register RB, and 1 is stored into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the subtract operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-29. Extended Mnemonics for subfc, subfc., subfco, subfco.

Mnemonic	Operands	Function	Other Registers Changed
subc	RT, RA, RB	Subtract (RB) from (RA). $(RT) \leftarrow \neg(RB) + (RA) + 1.$ Place carry-out in XER[CA]. <i>Extended mnemonic for subfc RT,RB,RA</i>	
subc.		<i>Extended mnemonic for subfc. RT,RB,RA</i>	CR[CR0]
subco		<i>Extended mnemonic for subfco RT,RB,RA</i>	XER[SO, OV]
subco.		<i>Extended mnemonic for subfco. RT,RB,RA</i>	CR[CR0] XER[SO, OV]

subfe

Subtract From Extended

subfe	RT,RA,RB	(OE=0, Rc=0)
subfe.	RT,RA,RB	(OE=0, Rc=1)
subfeo	RT,RA,RB	(OE=1, Rc=0)
subfeo.	RT,RA,RB	(OE=1, Rc=1)

31	RT	RA	RB	OE	136	Rc
0	6	11	16	21 22		31

```

(RT) ← ¬(RA) + (RB) + XER[CA]
if ¬(RA) + (RB) + XER[CA]  $\geq^u$  232 − 1 then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the ones complement of register RA, register RB, and XER[CA] is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the subtract operation.

Registers Altered

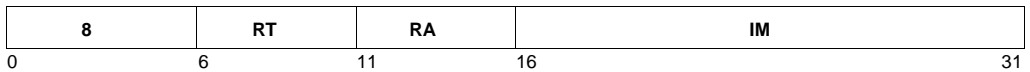
- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Architecture Note

11

This instruction is part of the PowerPC User Instruction Set Architecture.

subfic RT,RA,IM



```

(RT) ← ¬(RA) + EXTS(IM) + 1
if ¬(RA) + EXTS(IM) + 1 u > 232 - 1 then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the ones complement of RA, the IM field sign-extended to 32 bits, and 1 is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the subtract operation.

Registers Altered

- RT
- XER[CA]

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

subfme

Subtract from Minus One Extended

subfme	RT,RA	(OE=0, Rc=0)
subfme.	RT,RA	(OE=0, Rc=1)
subfmeo	RT,RA	(OE=1, Rc=0)
subfmeo.	RT,RA	(OE=1, Rc=1)

31	RT	RA		OE	232	Rc
0	6	11	16	21 22		31

$(RT) \leftarrow \neg(RA) - 1 + XER[CA]$
if $\neg(RA) + 0xFFFF\,FFFF + XER[CA] \stackrel{u}{>} 2^{32} - 1$ then
 $XER[CA] \leftarrow 1$
else
 $XER[CA] \leftarrow 0$

The sum of the ones complement of register RA, -1, and XER[CA] is placed into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the subtract operation.

Registers Altered

- RT
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1
- XER[CA]

Invalid Instruction Forms

- Reserved fields

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

subfze

Subtract from Zero Extended

subfze	RT,RA	(OE=0, Rc=0)
subfze.	RT,RA	(OE=0, Rc=1)
subfzeo	RT,RA	(OE=1, Rc=0)
subfzeo.	RT,RA	(OE=1, Rc=1)

31	RT	RA		OE	200	Rc
0	6	11	16	21	22	31

```

(RT) ← ¬(RA) + XER[CA]
if ¬(RA) + XER[CA]  $\geq$   $2^{32} - 1$  then
    XER[CA] ← 1
else
    XER[CA] ← 0

```

The sum of the ones complement of register RA and XER[CA] is stored into register RT.

XER[CA] is set to a value determined by the unsigned magnitude of the result of the subtract operation.

Registers Altered

- RT
- XER[CA]
- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- XER[SO, OV] if OE contains 1

Invalid Instruction Forms

- Reserved fields

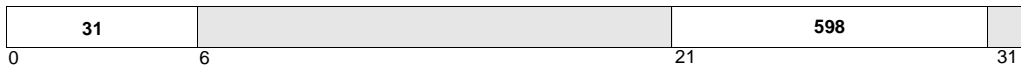
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

sync

Synchronize

sync



Synchronize System

The **sync** instruction guarantees that all instructions initiated by the processor preceding the **sync** instruction will complete before the **sync** instruction completes, and that no subsequent instructions will be initiated by the processor until after **sync** completes. When **sync** completes, all storage accesses initiated by the processor prior to **sync** will have been completed with respect to all mechanisms that access storage.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None.

Invalid Instruction Forms

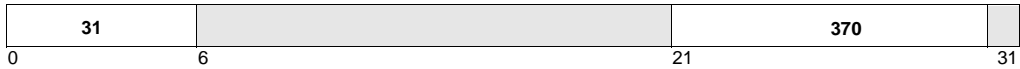
- Reserved fields

Programming Note

Architecturally, **eieio** orders storage access, not instruction completion. Therefore, non-storage operations after **eieio** could complete before storage operations that were before **eieio**. The **sync** instruction guarantees ordering of both instruction completion and storage access. For the PPC403GC, the **eieio** instruction is implemented to behave as a **sync** instruction. To write code which is portable between various PowerPC implementations, programmers should use the mnemonic which corresponds to the desired behavior.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

tlbia

All of the entries in the TLB are invalidated and become unavailable for translation by clearing the valid (V) bit in the TLBHI portion of each TLB entry. The rest of the fields in the TLB entries are unmodified.

Registers Altered

- None.

Invalid Instruction Forms

- None.

Programming Note

This instruction is privileged. Translation is not required to be active during the execution of this instruction. The effects of the invalidation are not guaranteed to be visible to the programming model until the completion of a context synchronizing operation.

Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

tlbre

TLB Read Entry

tlbre RT, RA, WS

31	RT	RA	WS	946	
0	6	11	16	21	31

```

if WS4 = 1
    (RT) ← TLBLO[(RA)26:31]
else
    (RT) ← TLBHI[(RA)26:31]
    (PID) ← TID from TLB[(RA)26:31]
    
```

The contents of the selected TLB entry are placed into register RT (and possibly into PID).

Bits 26:31 of the contents of RA are used as an index into the TLB.

The WS field specifies which portion (TLBHI or TLBLO) of the entry is loaded into RT. If TLBHI is being accessed, the PID SPR is set to the value of the TID field in the TLB entry.

If the WS field is not 0 or 1, the instruction form is invalid and the result is undefined.

If (RA)_{0:25} ≠ 0, the results are undefined.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- RT
- PID (if WS = 0)

Invalid Instruction Forms

- Reserved fields
- Invalid WS value

Programming Notes

This instruction is privileged. Translation is not required to be active during the execution of this instruction.

The contents of RT after the execution of this instruction are interpreted as follows:

If WS = 0 (TLBHI):

$RT[0:21] \leftarrow EPN[0:21]$
 $RT[22:24] \leftarrow SIZE[0:2]$
 $RT[25] \leftarrow V$
 $RT[26:31] \leftarrow 0$
 $PID[24:31] \leftarrow TID[0:7]$; (note that the TID is copied to the PID, not to RT)

If WS = 1 (TLBLO):

$RT[0:21] \leftarrow RPN[0:21]$
 $RT[22:23] \leftarrow EX, WR$
 $RT[24:27] \leftarrow ZSEL[0:3]$
 $RT[28:31] \leftarrow WIMG$

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

Table 11-30. Extended Mnemonics for tlbre

Mnemonic	Operands	Function	Other Registers Changed
tlbrehi	RT, RA	Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$ <i>Extended mnemonic for</i> tlbre RT,RA,0	
tlbrelo	RT, RA	Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$ <i>Extended mnemonic for</i> tlbre RT,RA,1	

tlbsx

TLB Search Indexed

tlbsx RT,RA,RB (Rc=0)
tlbsx. RT,RA,RB (Rc=1)

31	RT	RA	RB	914	Rc
0	6	11	16	21	31

```

EA ← (RA[0] + (RB))
if Rc = 1
    CR[CR0]LT ← 0
    CR[CR0]GT ← 0
    CR[CR0]SO ← XER[SO]
if Valid TLB entry matching EA and PID is in the TLB then
    (RT) ← Index of matching TLB Entry
    if Rc = 1
        CR[CR0]EQ ← 1
else
    (RT) Undefined
    if Rc = 1
        CR[CR0]EQ ← 0

```

An effective address is formed by adding an index to a base address. The index is the contents of register RB. The base address is 0 if the RA field is 0 and is the contents of register RA otherwise.

The TLB is searched for a valid entry which translates EA and PID. See Section 9.2.3.1 (Page Identification Fields) on page 9-8 for details. The record bit (Rc) specifies whether the results of the search will affect CR[CR0] as shown above. The intention is that CR[CR0]_{EQ} can be tested after a **tlbsx.** instruction if there is a possibility that the search may fail.

11

Registers Altered

- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1

Invalid Instruction Forms

- None.

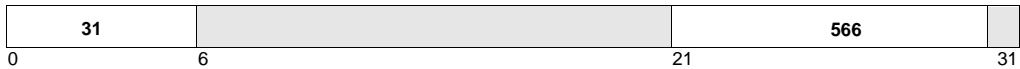
Programming Note

This instruction is privileged. Translation is not required to be active during the execution of this instruction.

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

tlbsync



The **tlbsync** instruction is provided in the PowerPC architecture to support synchronization of TLB operations among the processors of a multi-processor system. On PPC403GC, this instruction performs no operation, and is provided to facilitate code portability.

Registers Altered

- None.

Invalid Instruction Forms

- None.

Programming Notes

This instruction is privileged. Translation is not required to be active during the execution of this instruction.

Since PPC403GC does not support tightly-coupled multi-processor systems, **tlbsync** performs no operation.

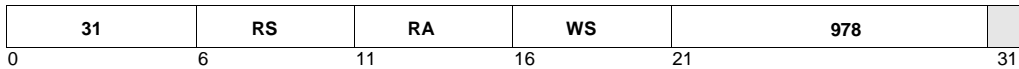
Architecture Note

This instruction is part of the PowerPC Operating Environment Architecture.

tlbwe

TLB Write Entry

tlbwe RS , RA, WS



```

if WS4 = 1
    TLBLO[(RA)26:31] ← (RS)
else
    TLBHI[(RA)26:31] ← (RS)
    TID of TLB[(RA)26:31] ← (PID)24:31
    
```

The contents of the selected TLB entry are replaced with the contents of register RS (and possibly PID).

Bits 26:31 of the contents of RA are used as an index into the TLB.

The WS field specifies which portion (TLBHI or TLBLO) of the entry is replaced from RS. For instructions that specify TLBHI, the TID field in the TLB entry is supplied from PID_{24:31}.

If the WS field is not 0 or 1, the instruction form is invalid and the result is undefined.

If (RA)_{0:25} ≠ 0, the results are undefined.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None.

Invalid Instruction Forms

- Reserved fields
- Invalid WS value

Programming Notes

This instruction is privileged. Translation is not required to be active during the execution of this instruction.

The effects of the update are not guaranteed to be visible to the programming model until the completion of a context synchronizing operation. For example, updating a zone selection field within the TLB while in supervisor code should be followed by an **isync** instruction (or other context synchronizing operation) to guarantee that the desired translation and protection domains are used.

The TLB fields are written from RS by this instruction as follows:

If WS = 0 (TLBHI):

EPN[0:21] \leftarrow RS[0:21]
 SIZE[0:2] \leftarrow RS[22:24]
 V \leftarrow RS[25]
 TID[0:7] \leftarrow PID[24:31]; (note that the TID is written from the PID, not RS)

If WS = 1 (TLBLO):

RPN[0:21] \leftarrow RS[0:21]
 EX,WR \leftarrow RS[22:23]
 ZSEL[0:3] \leftarrow RS[24:27]
 WIMG \leftarrow RS[28:31]

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

Table 11-31. Extended Mnemonics for tlbwe

Mnemonic	Operands	Function	Other Registers Changed
tlbwehi	RS, RA	Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$ <i>Extended mnemonic for</i> tlbwe RS,RA,0	
tlbwelo	RS, RA	Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$ <i>Extended mnemonic for</i> tlbwe RS,RA,1	

tw

Trap Word

tw TO,RA,RB

31	TO	RA	RB	4	
0	6	11	16	21	31

```

if ( ((RA) < (RB) ∧ TO0 = 1) ∨
      ((RA) > (RB) ∧ TO1 = 1) ∨
      ((RA) = (RB) ∧ TO2 = 1) ∨
      ((RA) ≤ (RB) ∧ TO3 = 1) ∨
      ((RA) ≥ (RB) ∧ TO4 = 1) ) then TRAP (see details below)

```

Register RA is compared with register RB. If any comparison condition selected by the TO field is true, a TRAP occurs. The behavior of a TRAP depends upon the Debug Mode of the processor, as described below:

- If TRAP is not enabled as a debug event (DBCR[TDE] = 0 or DBCR[EDM,IDM] = 0,0):

TRAP will cause a Program interrupt. See Section 6.9 (Program Exceptions) on page 6-32 and Section 6.2.5 (Exception Syndrome Register (ESR)) on page 6-12 for further information.

```

(SRR0) ← address of tw instruction
(SRR1) ← (MSR)
(ESR[PTR]) ← 1
(MSR[WE, EE, PR, PE, DR, IR]) ← 0
(MSR[LE]) ← (MSR[ILE])
PC ← EVPR0:15 || x'0700'

```

- If TRAP is enabled as an External debug event (DBCR[TDE] = 1 and DBCR[EDM] = 1):

TRAP will go to the Debug Stop state, to be handled by an external debugger with hardware control over the PPC403GC.

```
(DBSR[TIE]) ← 1
```

In addition, if TRAP is also enabled as an Internal debug event (DBCR[IDM] = 1) and Debug Exceptions are disabled (MSR[DE] = 0), then an imprecise event will be reported by setting (DBSR[IDE]) ← 1

```
PC ← address of tw instruction
```

- If TRAP is enabled as an Internal debug event and not an External debug event (DBCR[TDE] = 1 and DBCR[EDM,IDM] = 0,1) and Debug Exceptions are enabled (MSR[DE] = 1):

TRAP will cause a Debug interrupt. See Section 6.16 (Debug Exception Handling) on page 6-38 for further information.

$(SRR2) \leftarrow \text{address of tw instruction}$
 $(SRR3) \leftarrow (MSR)$
 $(DBSR[TIE]) \leftarrow 1$
 $(MSR[WE, EE, PR, PE, CE, DE, DR, IR]) \leftarrow 0$
 $(MSR[LE]) \leftarrow (MSR[ILE])$
 $PC \leftarrow EVPR_{0:15} \parallel x'2000'$

- If TRAP is enabled as an Internal debug event and not an External debug event ($DBCR[TDE] = 1$ and $DBCR[EDM, IDM] = 0, 1$) and Debug Exceptions are disabled ($MSR[DE] = 0$):

TRAP will report the debug event as an imprecise event and will cause a Program interrupt. See Section 6.9 (Program Exceptions) on page 6-32 and Section 6.2.5 (Exception Syndrome Register (ESR)) on page 6-12 for further information.

$(SRR0) \leftarrow \text{address of tw instruction}$
 $(SRR1) \leftarrow (MSR)$
 $(ESR[PTR]) \leftarrow 1$
 $(DBSR[TIE, IDE]) \leftarrow 1, 1$
 $(MSR[WE, EE, PR, PE, DR, IR]) \leftarrow 0$
 $(MSR[LE]) \leftarrow (MSR[ILE])$
 $PC \leftarrow EVPR_{0:15} \parallel x'0700'$

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- None

Invalid Instruction Forms

- Reserved fields

Programming Note

This instruction is inserted into the execution stream by a debugger to implement breakpoints, and is not typically used by application code.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-32. Extended Mnemonics for tw

Mnemonic	Operands	Function	Other Registers Changed
trap		Trap unconditionally. <i>Extended mnemonic for tw 31,0,0</i>	
tweq	RA, RB	Trap if (RA) equal to (RB). <i>Extended mnemonic for tw 4,RA,RB</i>	
twge		Trap if (RA) greater than or equal to (RB). <i>Extended mnemonic for tw 12,RA,RB</i>	
twgt		Trap if (RA) greater than (RB). <i>Extended mnemonic for tw 8,RA,RB</i>	
twle		Trap if (RA) less than or equal to (RB). <i>Extended mnemonic for tw 20,RA,RB</i>	
twlge		Trap if (RA) logically greater than or equal to (RB). <i>Extended mnemonic for tw 5,RA,RB</i>	
twlgt		Trap if (RA) logically greater than (RB). <i>Extended mnemonic for tw 1,RA,RB</i>	
twlle		Trap if (RA) logically less than or equal to (RB). <i>Extended mnemonic for tw 6,RA,RB</i>	
twlft		Trap if (RA) logically less than (RB). <i>Extended mnemonic for tw 2,RA,RB</i>	
twlng		Trap if (RA) logically not greater than (RB). <i>Extended mnemonic for tw 6,RA,RB</i>	
twlnl		Trap if (RA) logically not less than (RB). <i>Extended mnemonic for tw 5,RA,RB</i>	
twlt		Trap if (RA) less than (RB). <i>Extended mnemonic for tw 16,RA,RB</i>	
twne		Trap if (RA) not equal to (RB). <i>Extended mnemonic for tw 24,RA,RB</i>	
twng		Trap if (RA) not greater than (RB). <i>Extended mnemonic for tw 20,RA,RB</i>	
twnl		Trap if (RA) not less than (RB). <i>Extended mnemonic for tw 12,RA,RB</i>	

twi

TO,RA,IM

3	TO	RA	IM
0	6	11	16
			31

if (((RA) < EXTS(IM) \wedge TO₀ = 1) \vee
 ((RA) > EXTS(IM) \wedge TO₁ = 1) \vee
 ((RA) = EXTS(IM) \wedge TO₂ = 1) \vee
 ((RA) \leq EXTS(IM) \wedge TO₃ = 1) \vee
 ((RA) > EXTS(IM) \wedge TO₄ = 1)) then TRAP (see details below)

Register RA is compared with the IM field, which has been sign-extended to 32 bits. If any comparison condition selected by the TO field is true, a TRAP occurs. The behavior of a TRAP depends upon the Debug Mode of the processor, as described below:

- If TRAP is not enabled as a debug event (DBCR[TDE] = 0 or DBCR[EDM,IDM] = 0,0):

TRAP will cause a Program interrupt. See Section 6.9 (Program Exceptions) on page 6-32 and Section 6.2.5 (Exception Syndrome Register (ESR)) on page 6-12 for further information.

(SRR0) \leftarrow address of **twi** instruction
 (SRR1) \leftarrow (MSR)
 (ESR[PTR]) \leftarrow 1
 (MSR[WE, EE, PR, PE, DR, IR]) \leftarrow 0
 (MSR[LE]) \leftarrow (MSR[ILE])
 PC \leftarrow EVPR_{0:15} || x'0700'

- If TRAP is enabled as an External debug event (DBCR[TDE] = 1 and DBCR[EDM] = 1):

TRAP will go to the Debug Stop state, to be handled by an external debugger with hardware control over the PPC403GC.

(DBSR[TIE]) \leftarrow 1

In addition, if TRAP is also enabled as an Internal debug event (DBCR[IDM] = 1) and Debug Exceptions are disabled (MSR[DE] = 0), then an imprecise event will be reported by setting (DBSR[IDE]) \leftarrow 1

PC \leftarrow address of **twi** instruction

- If TRAP is enabled as an Internal debug event and not an External debug event (DBCR[TDE] = 1 and DBCR[EDM,IDM] = 0,1) and Debug Exceptions are enabled (MSR[DE] = 1):

TRAP will cause a Debug interrupt. See Section 6.16 (Debug Exception Handling) on page 6-38 for further information.

twi

Trap Word Immediate

(SRR2) \leftarrow address of **twi** instruction
(SRR3) \leftarrow (MSR)
(DBSR[TIE]) \leftarrow 1
(MSR[WE, EE, PR, PE, CE, DE, DR, IR]) \leftarrow 0
(MSR[LE]) \leftarrow (MSR[ILE])
PC \leftarrow EVPR_{0:15} || x'2000'

- If TRAP is enabled as an Internal debug event and not an External debug event (DBCR[TDE] = 1 and DBCR[EDM, IDM] = 0, 1) and Debug Exceptions are disabled (MSR[DE] = 0):

TRAP will report the debug event as an imprecise event and will cause a Program interrupt. See Section 6.9 (Program Exceptions) on page 6-32 and Section 6.2.5 (Exception Syndrome Register (ESR)) on page 6-12 for further information.

(SRR0) \leftarrow address of **twi** instruction
(SRR1) \leftarrow (MSR)
(ESR[PTR]) \leftarrow 1
(DBSR[TIE, IDE]) \leftarrow 1, 1
(MSR[WE, EE, PR, PE, DR, IR]) \leftarrow 0
(MSR[LE]) \leftarrow (MSR[ILE])
PC \leftarrow EVPR_{0:15} || x'0700'

Registers Altered

- None

11

Programming Note

This instruction is inserted into the execution stream by a debugger to implement breakpoints, and is not typically used by application code.

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

Table 11-33. Extended Mnemonics for twi

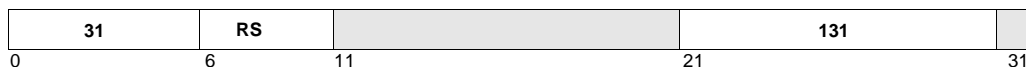
Mnemonic	Operands	Function	Other Registers Changed
tweqi	RA, IM	Trap if (RA) equal to EXTS(IM). <i>Extended mnemonic for twi 4,RA,IM</i>	
twgei		Trap if (RA) greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>	
twgti		Trap if (RA) greater than EXTS(IM). <i>Extended mnemonic for twi 8,RA,IM</i>	
twlei		Trap if (RA) less than or equal to EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>	
twlgei		Trap if (RA) logically greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>	
twlgti		Trap if (RA) logically greater than EXTS(IM). <i>Extended mnemonic for twi 1,RA,IM</i>	
twllei		Trap if (RA) logically less than or equal to EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>	
twllti		Trap if (RA) logically less than EXTS(IM). <i>Extended mnemonic for twi 2,RA,IM</i>	
twlngi		Trap if (RA) logically not greater than EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>	
twlnli		Trap if (RA) logically not less than EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>	
twlti		Trap if (RA) less than EXTS(IM). <i>Extended mnemonic for twi 16,RA,IM</i>	
twnei		Trap if (RA) not equal to EXTS(IM). <i>Extended mnemonic for twi 24,RA,IM</i>	
twngi		Trap if (RA) not greater than EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>	
twnli		Trap if (RA) not less than EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>	

This instruction is specific to the PowerPC Embedded Controller family

wrtee

Write External Enable

wrtee RS



$MSR[EE] \leftarrow (RS)_{16}$

The MSR[EE] is set to the value specified by bit 16 of register RS.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- MSR[EE]

Invalid Instruction Forms:

- Reserved fields

Programming Note

Execution of this instruction is privileged.

This instruction is used to provide atomic update of MSR[EE]. Typical usage is:

mfmsr	Rn	#save EE in Rn[16]
wrteei	0	#turn off EE
• • • • •	• • • • •	#code with EE disabled
wrtee	Rn	#restore EE without affecting other MSR changes that may have occurred during the disabled code

11

Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

wrteei E



MSR[EE] ← E

The MSR[EE] is set to the value specified by the E field.

If instruction bit 31 contains 1, the contents of CR[CR0] are undefined.

Registers Altered

- MSR[EE]

Invalid Instruction Forms:

- Reserved fields

Programming Note

Execution of this instruction is privileged.

This instruction is used to provide atomic update of MSR[EE]. Typical usage is:

mfmsr	Rn	#save EE in Rn[16]
wrteei	0	#turn off EE
• • • • •		#code with EE disabled
wrtee	Rn	#restore EE without affecting other MSR changes that may have occurred during the disabled code

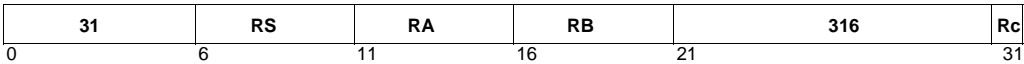
Architecture Note

This instruction is specific to the PowerPC Embedded Controller family; it is not described in *PowerPC Architecture*. Programs using this instruction may not be portable to other PowerPC implementations.

xor

XOR

xor RA,RS,RB (Rc=0)
xor. RA,RS,RB (Rc=1)



$(RA) \leftarrow (RS) \oplus (RB)$

The contents of register RS are XORed with the contents of register RB; the result is placed into register RA.

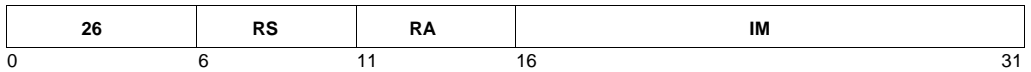
Registers Altered

- CR[CR0]_{LT, GT, EQ, SO} if Rc contains 1
- RA

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

xori RA,RS,IM



$$(RA) \leftarrow (RS) \oplus (^{16}0 \parallel IM)$$

The IM field is extended to 32 bits by concatenating 16 0-bits on the left. The contents of register RS are XORed with the extended IM field; the result is placed into register RA.

Registers Altered

- RA

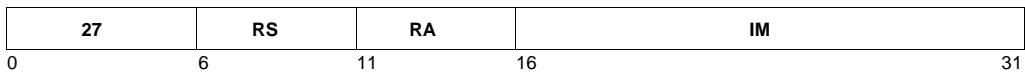
Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

xoris

XOR Immediate Shifted

xoris RA,RS,IM



$(RA) \leftarrow (RS) \oplus (IM \parallel ^{16}0)$

The IM field is extended to 32 bits by concatenating 16 0-bits on the right. The contents of register RS are XORed with the extended IM field; the result is placed into register RA.

Registers Altered

- RA

Architecture Note

This instruction is part of the PowerPC User Instruction Set Architecture.

With the exception of the serial port registers, all registers contained in the PPC403GC are architected as 32-bits. Table 12-1 through Table 12-4 define the addressing required to access the registers. The pages following these tables define the bit usage within each register.

12.1 Reserved Registers

Any register numbers not listed in the tables which follow are **reserved**, and should be neither read nor written. These reserved register numbers may be used for additional functions on future PowerPC Embedded Controllers.

12.2 Reserved Fields

For all registers with fields marked as **reserved**, the **reserved** fields should be written as **zero** and read as **undefined**. That is, when writing to a register with a **reserved** field, write a zero to that field. When reading from a register with a **reserved** field, ignore that field.

Good coding practice is to perform the initial write to a register with **reserved** fields as described in the preceding paragraph, and to perform all subsequent writes to the register using a read-modify-write strategy. That is, read the register, alter desired fields with logical instructions, and then write the register.

12.3 General Purpose Registers

The PPC403GC contains 32 General Purpose Registers (GPRs). The contents of these registers can be loaded from memory via load instructions and stored to memory via store instructions. GPRs are also addressed by all integer instructions.

Table 12-1. PPC403GC General Purpose Registers

Mnemonic	Register Name	GPR Number		Access
		Decimal	Hex	
R0-R31	General Purpose Register 0-31	0 - 31	0x0 - 0x1F	Read / Write

12.4 Machine State Register and Condition Register

These registers are accessed via special instructions, hence they do not require addressing.

12.5 Special Purpose Registers

Special Purpose Registers (SPRs) are on-chip registers that are architecturally part of the processor core. They are accessed with the **mtspr** (move to special purpose register) and **mfspr** (move from special purpose register) instructions which are defined in Chapter 11. In Table 12-2, the column “SPRN” lists register Numbers, which are used in the instruction mnemonics. The column “SPRF” lists the corresponding Fields, which are used in the instruction itself. These are related by ($\text{SPRN} \leftarrow \text{SPRF}_{5:9} \parallel \text{SPRF}_{0:4}$) as shown in the **mtspr** and **mfspr** instruction descriptions.

The only SPRs that are not privileged are the Time Base High User-mode (TBHU), Time Base Low User-mode (TBLU), Link Register (LR), Count Register (CTR), and the Fixed-point Exception Register (XER). All other SPRs are privileged, for both read and write. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion of privileged operation.

SPRs are used to control the use of the debug facilities, the timers, interrupts, storage attributes, and other architected processor resources.

All SPR numbers not listed are reserved, and should be neither read nor written.

Table 12-2. PPC403GC Special Purpose Registers

Mnemonic	Register Name	SPRN (Number)		SPRF (Field)	Access	Mode
		Decimal	Hex			
CDBCR	Cache Debug Control Register	983	0x3D7	0x2FE	Read / Write	Privileged
CTR	Count Register	9	0x009	0x120	Read / Write	User
DAC1	Data Address Compare 1	1014	0x3F6	0x2DF	Read / Write	Privileged
DAC2	Data Address Compare 2	1015	0x3F7	0x2FF	Read / Write	Privileged
DBCR	Debug Control Register	1010	0x3F2	0x25F	Read / Write	Privileged

Table 12-2. PPC403GC Special Purpose Registers (cont.)

Mnemonic	Register Name	SPRN (Number)		SPRF (Field)	Access	Mode
		Decimal	Hex			
DBSR	Debug Status Register	1008	0x3F0	0x21F	Read / Clear	Privileged
DCCR	Data Cache Cacheability Register	1018	0x3FA	0x35F	Read / Write	Privileged
DCWR	Data Cache Write-thru Register	954	0x3BA	0x35D	Read / Write	Privileged
DEAR	Data Error Address Register	981	0x3D5	0x2BE	Read Only	Privileged
ESR	Exception Syndrome Register	980	0x3D4	0x29E	Read / Write	Privileged
EVPR	Exception Vector Prefix Register	982	0x3D6	0x2DE	Read / Write	Privileged
IAC1	Instruction Address Compare 1	1012	0x3F4	0x29F	Read / Write	Privileged
IAC2	Instruction Address Compare 2	1013	0x3F5	0x2BF	Read / Write	Privileged
ICCR	Instruction Cache Cacheability Register	1019	0x3FB	0x37F	Read / Write	Privileged
ICDBDR	Instruction Cache Debug Data Register	979	0x3D3	0x27E	Read Only	Privileged
LR	Link Register	8	0x008	0x100	Read / Write	User
PBL1	Protection Bound Lower 1	1020	0x3FC	0x39F	Read / Write	Privileged
PBL2	Protection Bound Lower 2	1022	0x3FE	0x3DF	Read / Write	Privileged
PBU1	Protection Bound Upper 1	1021	0x3FD	0x3BF	Read / Write	Privileged
PBU2	Protection Bound Upper 2	1023	0x3FF	0x3FF	Read / Write	Privileged
PID	Process ID	945	0x3B1	0x23D	Read / Write	Privileged
PIT	Programmable Interval Timer	987	0x3DB	0x37E	Read / Write	Privileged
PVR	Processor Version Number	287	0x11F	0x3E8	Read Only	Privileged
SGR	Storage Guarded Register	953	0x3B9	0x33D	Read / Write	Privileged
SPRG0	SPR General 0	272	0x110	0x208	Read / Write	Privileged
SPRG1	SPR General 1	273	0x111	0x228	Read / Write	Privileged
SPRG2	SPR General 2	274	0x112	0x248	Read / Write	Privileged
SPRG3	SPR General 3	275	0x113	0x268	Read / Write	Privileged
SRR0	Save/Restore Register 0	26	0x01A	0x340	Read / Write	Privileged
SRR1	Save/Restore Register 1	27	0x01B	0x360	Read / Write	Privileged
SRR2	Save/Restore Register 2	990	0x3DE	0x3DE	Read / Write	Privileged
SRR3	Save/Restore Register 3	991	0x3DF	0x3FE	Read / Write	Privileged
TBHI	Time Base High	988	0x3DC	0x39E	Read / Write	Privileged
TBHU	Time Base High User-mode	972	0x3CC	0x19E	Read Only	User
TBLO	Time Base Low	989	0x3DD	0x3BE	Read / Write	Privileged

Table 12-2. PPC403GC Special Purpose Registers (cont.)

Mnemonic	Register Name	SPRN (Number)		SPRF (Field)	Access	Mode
		Decimal	Hex			
TBLU	Time Base Low User-mode	973	0x3CD	0x1BE	Read Only	User
TCR	Timer Control Register	986	0x3DA	0x35E	Read / Write	Privileged
TSR	Timer Status Register	984	0x3D8	0x31E	Read / Clear	Privileged
XER	Fixed Point Exception Register	1	0x001	0x020	Read / Write	User
ZPR	Zone Protection Register	944	0x3B0	0x21D	Read / Write	Privileged

12.6 Device Control Registers

Device Control Registers (DCRs) are on-chip registers that are architecturally outside of the processor core. They are accessed with the **mtdcr** (move to device control register) and **mfdcr** (move from device control register) instructions which are defined in Chapter 11. In Table 12-3, the column “DCRN” lists register Numbers, which are used in the instruction mnemonics. The column “DCRF” lists the corresponding Fields, which are used in the instruction itself. These are related by ($DCRN \leftarrow DCRF_{5:9} \parallel DCRF_{0:4}$) as shown in the **mtdcr** and **mfdcr** instruction descriptions.

The **mtdcr** / **mfdcr** instructions are privileged, for all DCR numbers. Therefore, all access to DCRs is privileged. See Section 2.9 (Privileged Mode Operation) on page 2-34 for further discussion of privileged operation.

DCRs are used to control, configure, and hold status for the various integrated peripherals, such as the DMA controller and the interrupt controller.

All DCR numbers not listed are reserved, and should be neither read nor written.

Table 12-3. PPC403GC Device Control Registers

Mnemonic	Register Name	DCRN (Number)		DCRF (Field)	Access
		Decimal	Hex		
BEAR	Bus Error Address Register	144	0x090	0x204	Read Only
BESR	Bus Error Syndrome Register	145	0x091	0x224	Read / Write
BR0	Bank Register 0	128	0x080	0x004	Read / Write
BR1	Bank Register 1	129	0x081	0x024	Read / Write
BR2	Bank Register 2	130	0x082	0x044	Read / Write
BR3	Bank Register 3	131	0x083	0x064	Read / Write
BR4	Bank Register 4	132	0x084	0x084	Read / Write

Table 12-3. PPC403GC Device Control Registers (cont.)

Mnemonic	Register Name	DCRN (Number)		DCRF (Field)	Access
		Decimal	Hex		
BR5	Bank Register 5	133	0x085	0x0A4	Read / Write
BR6	Bank Register 6	134	0x086	0x0C4	Read / Write
BR7	Bank Register 7	135	0x087	0x0E4	Read / Write
DMACC0	DMA Chained Count 0	196	0x0C4	0x086	Read / Write
DMACC1	DMA Chained Count 1	204	0x0CC	0x186	Read / Write
DMACC2	DMA Chained Count 2	212	0x0D4	0x286	Read / Write
DMACC3	DMA Chained Count 3	220	0x0DC	0x386	Read / Write
DMACR0	DMA Channel Control Register 0	192	0x0C0	0x006	Read / Write
DMACR1	DMA Channel Control Register 1	200	0x0C8	0x106	Read / Write
DMACR2	DMA Channel Control Register 2	208	0x0D0	0x206	Read / Write
DMACR3	DMA Channel Control Register 3	216	0x0D8	0x306	Read / Write
DMACT0	DMA Count Register 0	193	0x0C1	0x026	Read / Write
DMACT1	DMA Count Register 1	201	0x0C9	0x126	Read / Write
DMACT2	DMA Count Register 2	209	0x0D1	0x226	Read / Write
DMACT3	DMA Count Register 3	217	0x0D9	0x326	Read / Write
DMADA0	DMA Destination Address Reg. 0	194	0x0C2	0x046	Read / Write
DMADA1	DMA Destination Address Reg. 1	202	0x0CA	0x146	Read / Write
DMADA2	DMA Destination Address Reg. 2	210	0x0D2	0x246	Read / Write
DMADA3	DMA Destination Address Reg. 3	218	0x0DA	0x346	Read / Write
DMASA0	DMA Source Address Register 0	195	0x0C3	0x066	Read / Write
DMASA1	DMA Source Address Register 1	203	0x0CB	0x166	Read / Write
DMASA2	DMA Source Address Register 2	211	0x0D3	0x266	Read / Write
DMASA3	DMA Source Address Register 3	219	0x0DB	0x366	Read / Write
DMASR	DMA Status Register	224	0x0E0	0x007	Read / Clear
EXIER	External Interrupt Enable Register	66	0x042	0x042	Read / Write
EXISR	External Interrupt Status Register	64	0x040	0x002	Read / Clear
IOCR	Input/Output Configuration Register	160	0x0A0	0x005	Read / Write

12.7 Memory Mapped I/O Registers

The control/status/data registers for the serial port (attached to the OPB) are memory mapped. These registers are shown in the table below. Load and store instructions are used to access the serial port registers.

All addresses not shown in this table, and not in the DRAM space (0x0000 0000 - 0x0FFF FFFF) or the SRAM space (0xF000 0000 - 0xFFFF FFFF), are reserved, and should be neither read nor written.

Table 12-4. PPC403GC Memory Mapped I/O Registers

Mnemonic	Register Name	Address	Access
BRDH	Baud Rate Divisor High	0x4000 0004	Read / Write
BRDL	Baud Rate Divisor Low	0x4000 0005	Read / Write
SPCTL	Serial Port Control	0x4000 0006	Read / Write
SPHS	Serial Port Handshake Status	0x4000 0002	Read / Clear
SPLS	Serial Port Line Status	0x4000 0000	Read / Clear
SPRB	Serial Port Receive Buffer	0x4000 0009	Read Only
SPRC	Serial Port Receiver Command	0x4000 0007	Read / Write
SPTB	Serial Port Transmit Buffer	0x4000 0009	Write Only
SPTC	Serial Port Transmitter Command	0x4000 0008	Read / Write

12.8 Alphabetical Register Listing

The following pages list the registers (including memory-mapped registers) available in the PPC403GC. For each register, the following information is supplied:

- Register name and mnemonic.
- Register type (for SPR, DCR, MMIO).
- Register number (for SPR, DCR) or address (for MMIO).
- Diagram illustrating the register fields (all register fields have mnemonics, unless there is only one field).
- Table detailing the register fields, giving field mnemonic, field bit location, field name, and the function associated with various field values.

DCR 0x90 Read-Only
(see also Section 6.4.1.2 on page 6-17)

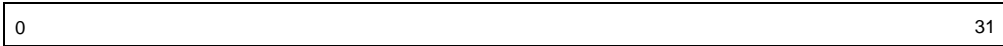


Figure 12-1. Bus Error Address Register (BEAR)

0:31	Address of Bus Error (asynchronous)
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BESR

DCR 0x91

(see also Section 6.4.1.1 on page 6-16)

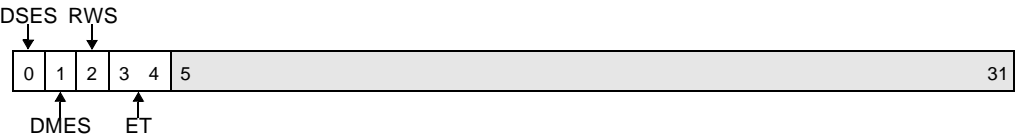


Figure 12-2. Bus Error Syndrome Register (BESR)

0	DSES	Data-Side Error Status 0 - No data-side error 1 - Data-side error
1	DMES	DMA Error Status 0 - No DMA operation error 1 - DMA operation error
2	RWS	Read/Write Status 0 - Error operation was a Write 1 - Error operation was a Read
3:4	ET	Error Type 00 - Protection violation (write to Read-Only bank, or read from Write-Only bank) 01 - Access to a non-configured bank 10 - Active level on bus error input pin 11 - Bus time-out
5:31		reserved

BR0-BR7 (SRAM Configuration)

DCR 0x80-0x87(see also Section 3.7.4 on page 3-24)

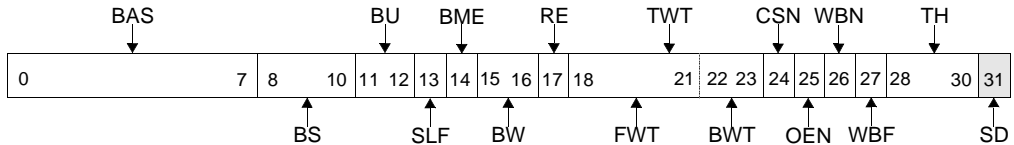


Figure 12-3. Bank Registers - SRAM Configuration (BR0-BR7)

0: 7	BAS	Base Address Select	Specifies the starting address of the SRAM bank.
8:10	BS	Bank Size 000 - 1 MB bank 001 - 2 MB bank 010 - 4 MB bank 011 - 8 MB bank 100 - 16 MB bank 101 - 32 MB bank 110 - 64 MB bank 111 - Reserved	
11:12	BU	Bank Usage 00 - Disabled, invalid, or unused bank 01 - Bank is valid for read only (RO) 10 - Bank is valid for write only (WO) 11 - Bank is valid for read/write (R/W)	
13	SLF	Sequential Line Fills 0 - Line fills are Target Word First 1 - Line fills are Sequential	
14	BME	Burst Mode Enable 0 - Bursting is disabled 1 - Bursting is enabled	For cache line fills and flushes, bus master burst operations, DMA flyby burst and DMA memory-to-memory line burst operations, and all packing and unpacking operations
15:16	BW	Bus Width 00 - 8-bit bus 01 - 16-bit bus 10 - 32-bit bus 11 - Reserved	
17	RE	Ready Enable 0 - Ready pin input is disabled 1 - Ready pin input is enabled	
18:23	TWT	Transfer Wait	Wait states on all non-burst transfers. Used if field BME=0.
18:21	FWT	First Wait	Wait states on first tranfer of a burst. Used if field BME=1.

BR0-BR7 (SRAM Configuration, cont.)

22:23	BWT	Burst Wait	Wait states on non-first transfers of a burst. Used if field BME=1.
24	CSN	Chip Select On Timing 0 - Chip select is valid when address is valid 1 - Chip select is valid one SysClk cycle after address is valid	
25	OEN	Output Enable On Timing 0 - Output Enable is valid when chip select is valid 1 - Output Enable is valid one SysClk cycle after chip select is valid	Controls when the data bus goes active, for writes as well as reads.
26	WBN	Write Byte Enable On Timing 0 - Write byte enables are valid when Chip Select is valid 1 - Write byte enables are valid one SysClk cycle after chip select is valid	
27	WBF	Write Byte Enable Off Timing 0 - Write byte enables become inactive when chip select becomes inactive 1 - Write byte enables become inactive one SysClk cycle before chip select becomes inactive	
28:30	TH	Transfer Hold	Contains the number of hold cycles inserted at the end of a transfer. Hold cycles insert idle bus cycles between transfers to enable slow peripherals to remove data from the data bus before the next transfer begins.
31		reserved, for BR0-BR3	(For BR0-BR3, on a write, this bit is ignored; on a read, a zero is returned.)
	SD	SRAM - DRAM Selection, for BR4-BR7 0 - DRAM usage. 1 - SRAM usage.	(For BR4-BR7 in SRAM configuration, this bit must be 1.)

BR4-BR7 (DRAM Configuration)

DCR 0x84-0x87(see also Section 3.8.2 on page 3-39)

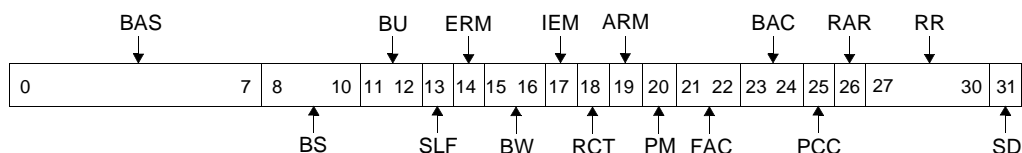


Figure 12-4. Bank Registers - DRAM Configuration (BR4-BR7)

0: 7	BAS	Base Address Select	Specifies the starting address of the DRAM bank.
8:10	BS	Bank Size 000 - 1 MB bank 001 - 2 MB bank 010 - 4 MB bank 011 - 8 MB bank 100 - 16 MB bank 101 - 32 MB bank 110 - 64 MB bank 111 - Reserved	
11:12	BU	Bank Usage 00 - Disabled, invalid, or unused bank 01 - Bank is valid for read only (RO) 10 - Bank is valid for write only (WO) 11 - Bank is valid for read/write (R/W)	
13	SLF	Sequential Line Fills 0 - Line fills are Target Word First 1 - Line fills are Sequential	
14	ERM	Early RAS Mode 0 - normal RAS activation (approximately 1/2 cycle following address valid) 1 - early RAS activation (approximately 1/4 cycle following address valid)	
15:16	BW	Bus Width 00 - 8-bit bus 01 - 16-bit bus 10 - 32-bit bus 11 - Reserved	
17	IEM	Internal / External Multiplex	If an external bus master is used, an external multiplexer must also be used.
18	RCT	RAS Active to CAS Active Timing 0 - CAS becomes active one SysClk cycle after RAS becomes active 1 - CAS becomes active two SysClk cycles after RAS becomes active	

BR4-BR7 (DRAM Configuration, cont.)

19	ARM	Alternate Refresh Mode 0 - Normal refresh 1 - Immediate or Self refresh (Use alternate values of field RR.)
20	PM	Page Mode 0 - Single accesses only, Page Mode not supported 1 - Page Mode burst access supported
21:22	FAC	First Access Timing 00 - First Wait = 0 SysClk cycles 01 - First Wait = 1 SysClk cycles 10 - First Wait = 2 SysClk cycles 11 - First Wait = 3 SysClk cycles First Access time is 2 + FAC if RCT = 0. First Access time is 3 + FAC if RCT = 1.
23:24	BAC	Burst Access Timing 00 - Burst Wait = 0 SysClk cycles 01 - Burst Wait = 1 SysClk cycles 10 - Burst Wait = 2 SysClk cycles 11 - Burst Wait = 3 SysClk cycles Burst Access time is 1 + BAC. Note: if FAC = 0, BAC is ignored and treated as 0.
25	PCC	Precharge Cycles 0 - One and one-half SysClk cycles 1 - Two and one-half SysClk cycles
26	RAR	RAS Active During Refresh 0 - One and one-half SysClk cycles 1 - Two and one-half SysClk cycles
27:30	RR	Refresh Interval See Table 3-4 on page 3-44 for bit values assigned to various refresh intervals. If field ARM=1, use Table 3-5 on page 3-44.
31	SD	SRAM - DRAM Selection 0 - DRAM usage. 1 - SRAM usage. Must be 0 for DRAM configuration.

MMIO 0x4000 0004
(see also Section 7.1.3 on page 7-3 and Section 7.2.1 on page 7-5)

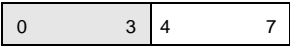


Figure 12-5. Baud Rate Divisor High Register (BRDH)

0:3		reserved
4:7		<div>Divisor High Bits</div> <div>The four most significant bits of the baud rate divisor; concatenated with the contents of the BRDL.</div>

BRDL

MMIO 0x4000 0005

(see also Section 7.1.3 on page 7-3 and Section 7.2.1 on page 7-5)



Figure 12-6. Baud Rate Divisor Low Register (BRDL)

0:7		Divisor Low Bits	The eight least significant bits of the baud rate divisor; concatenated with the contents of the BRDH.
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SPR 0x3D7

(see also Section 8.4 on page 8-12)

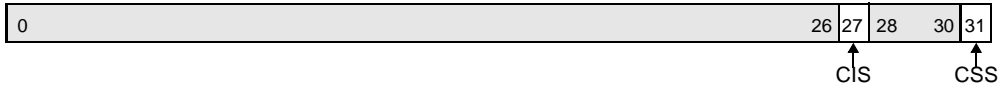


Figure 12-7. Cache Debug Control Register (CDBCR)

0:26		reserved
27	CIS	Cache Information Select 0 - Information is cache Data 1 - Information is cache Tag
28:30		reserved
31	CSS	Cache Side Select 0 - Cache side is A 1 - Cache side is B

CR

(see also Section 2.3.3 on page 2-13)

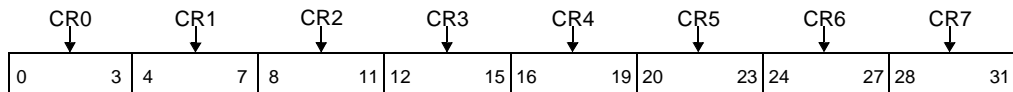


Figure 12-8. Condition Register (CR)

0:3	CR0	Condition Register Field 0
4:7	CR1	Condition Register Field 1
8:11	CR2	Condition Register Field 2
12:15	CR3	Condition Register Field 3
16:19	CR4	Condition Register Field 4
20:23	CR5	Condition Register Field 5
24:27	CR6	Condition Register Field 6
28:31	CR7	Condition Register Field 7

SPR 0x009
(see also Section 2.3.2.1 on page 2-7)

0	31
---	----

Figure 12-9. Count Register (CTR)

0:31	Count	(Count for branch conditional with decrement. Address for branch-to-counter instructions)
------	-------	--

DAC1-DAC2

SPR 0x3F6-0x3F7

(see also Section 10.6.3 on page 10-11)

0	31
---	----

Figure 12-10. Data Address Compare Registers (DAC1-DAC2)

0:31		Data Address Compare, Byte Address	Data Address Compare Size fields of DBCR determine byte, halfword, or word usage.
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SPR 0x3F2

(see also Section 10.6.1 on page 10-7)

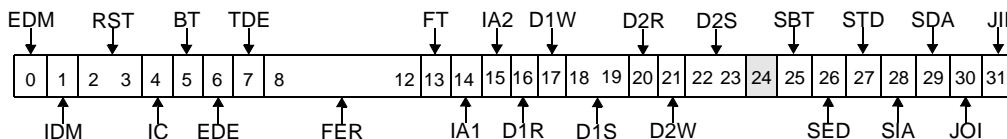


Figure 12-11. Debug Control Register (DBCR)

0	EDM	External Debug Mode 0 = Disable 1 = Enable
1	IDM	Internal Debug Mode 0 - Disable 1 - Enable
2 : 3	RST	Reset 00 - No Action 01 - Core Reset 10 - Chip Reset 11 - System Reset WARNING : Writing 01, 10, or 11 to these bits will cause a processor reset to occur.
4	IC	Instruction Completion Debug Event 0 - Disable 1 - Enable (Instruction Completion will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
5	BT	Branch Taken Debug Event 0 - Disable 1 - Enable (Branch Taken will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
6	EDE	Exception Debug Event 0 - Disable 1 - Enable (Critical Exceptions will not cause a debug event if MSR[DE] = 0 in Internal Debug Mode)
7	TDE	TRAP Debug Event 0 - Disable 1 - Enable
8:12	FER	First Events Remaining Action on Debug Events is enabled when FER = 0. If FER ≠ 0, a Debug Event causes FER to decrement.
13	FT	Freeze Timers On Debug Event 0 - Free-run Timers 1 - Freeze Timers
14	IA1	Instruction Address Compare 1 Enable 0 - Disable 1 - Enable

DBCR (cont.)

15	IA2	Instruction Address Compare 2 Enable 0 - Disable 1 - Enable	
16	D1R	Data Address Compare 1 Read Enable 0 - Disable 1 - Enable	
17	D1W	Data Address Compare 1 Write Enable 0 - Disable 1 - Enable	
18 : 19	D1S	Data Address Compare 1 Size 00 - Compare All Bits 01 - Ignore 1 least significant bit 10 - Ignore 2 least significant bits 11 - Ignore 4 least significant bits	(halfword) (word) (quadword, or cache line)
20	D2R	Data Address Compare 2 Read Enable 0 - Disable 1 - Enable	
21	D2W	Data Address Compare 2 Write Enable 0 - Disable 1 - Enable	
22 : 23	D2S	Data Address Compare 2 Size 00 - Compare All Bits 01 - Ignore 1 least significant bit 10 - Ignore 2 least significant bits 11 - Ignore 4 least significant bits	(halfword) (word) (quadword, or cache line)
24		reserved	
25	SBT	Second Branch Taken Debug Event 0 - Disable 1 - Enable	
26	SED	Second Exception Debug Event 0 - Disable 1 - Enable	
27	STD	Second TRAP Debug Event 0 - Disable 1 - Enable	
28	SIA	Second Instruction Address Compare Enable 0 - Disable 1 - Enable	(Uses address register IAC2.)
29	SDA	Second Data Address Compare Enable 0 - Disable 1 - Enable	(Uses DBCR fields D2R, D2W, and D2S, and address register DAC2.)
30	JOI	JTAG Serial Outbound Interrupt Enable 0 - Disable 1 - Enable	(not a debug event)
31	JII	JTAG Serial Inbound Interrupt Enable 0 - Disable 1 - Enable	(not a debug event)

SPR 0x3F0 Read / Clear
(see also Section 10.6.2 on page 10-9)

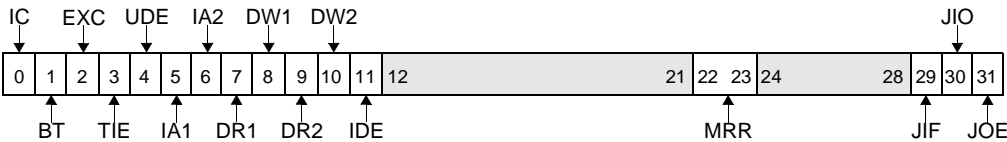


Figure 12-12. Debug Status Register (DBSR)

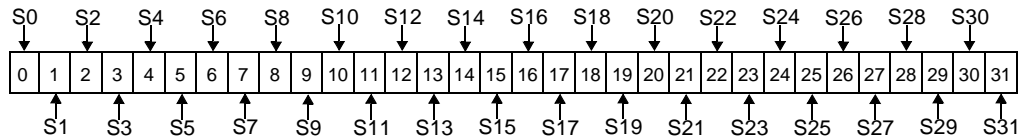
0	IC	Instruction Completion Debug Event 0 = Event Didn't Occur 1 = Event Occurred
1	BT	Branch Taken Debug Event 0 = Event Didn't Occur 1 = Event Occurred
2	EXC	Exception Debug Event 0 = Event Didn't Occur 1 = Event Occurred
3	TIE	TRAP Instruction Debug Event 0 = Event Didn't Occur 1 = Event Occurred
4	UDE	Unconditional Debug Event 0 = Event Didn't Occur 1 = Event Occurred
5	IA1	Instruction Address Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
6	IA2	Instruction Address Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
7	DR1	Data Address Read Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
8	DW1	Data Address Write Compare 1 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
9	DR2	Data Address Read Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred
10	DW2	Data Address Write Compare 2 Debug Event 0 = Event Didn't Occur 1 = Event Occurred

DBSR (cont.)

11	IDE	Imprecise Debug Event 0 = Event Didn't Occur 1 = Debug Event Occurred while MSR[DE] = 0	
12:21		reserved	
22 : 23	MRR	Most Recent Reset 00 = No Reset Occurred since these bits last cleared by software. 01 = Core Reset 10 = Chip Reset 11 = System Reset	These two bits are set to one of three values when a reset occurs. These two bits are undefined at power-up.
24:28		reserved	
29	JIF	JTAG Serial Inbound Buffer Full 0 = Empty 1 = Full	This bit is set to 1 when the JSIB is written. This bit is cleared to 0 when the JSIB is read.
30	JIO	JTAG Serial Inbound Buffer Overrun 0 = No Overrun 1 = Overrun Occurred	This bit is set to 1 when a second write to the JSIB via the JTAG port is done without an intervening read via software.
31	JOE	JTAG Serial Outbound Buffer Empty 0 = Full 1 = Empty	This bit is set to 1 when the JSOB is read via the JTAG port. This bit is cleared to 0 by writing to the JSOB via software.

SPR 0x3FA

(see also Section 9.5.1.2 on page 9-24)

**Figure 12-13. Data Cache Cacheability Register (DCCR)**

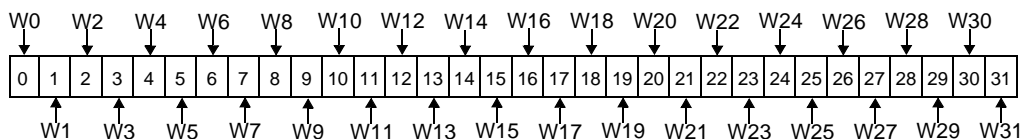
0	S0	0 = noncacheable; 1 = cacheable	0x0000 0000 --- 0x07FF FFFF
1	S1	0 = noncacheable; 1 = cacheable	0x0800 0000 --- 0x0FFF FFFF
2	S2	0 = noncacheable; 1 = cacheable	0x1000 0000 --- 0x17FF FFFF
3	S3	0 = noncacheable; 1 = cacheable	0x1800 0000 --- 0x1FFF FFFF
4	S4	0 = noncacheable; 1 = cacheable	0x2000 0000 --- 0x27FF FFFF
5	S5	0 = noncacheable; 1 = cacheable	0x2800 0000 --- 0x2FFF FFFF
6	S6	0 = noncacheable; 1 = cacheable	0x3000 0000 --- 0x37FF FFFF
7	S7	0 = noncacheable; 1 = cacheable	0x3800 0000 --- 0x3FFF FFFF
8	S8	0 = noncacheable; 1 = cacheable	0x4000 0000 --- 0x47FF FFFF
9	S9	0 = noncacheable; 1 = cacheable	0x4800 0000 --- 0x4FFF FFFF
10	S10	0 = noncacheable; 1 = cacheable	0x5000 0000 --- 0x57FF FFFF
11	S11	0 = noncacheable; 1 = cacheable	0x5800 0000 --- 0x5FFF FFFF
12	S12	0 = noncacheable; 1 = cacheable	0x6000 0000 --- 0x67FF FFFF
13	S13	0 = noncacheable; 1 = cacheable	0x6800 0000 --- 0x6FFF FFFF
14	S14	0 = noncacheable; 1 = cacheable	0x7000 0000 --- 0x77FF FFFF
15	S15	0 = noncacheable; 1 = cacheable	0x7800 0000 --- 0x7FFF FFFF
16	S16	0 = noncacheable; 1 = cacheable	0x8000 0000 --- 0x87FF FFFF
17	S17	0 = noncacheable; 1 = cacheable	0x8800 0000 --- 0x8FFF FFFF
18	S18	0 = noncacheable; 1 = cacheable	0x9000 0000 --- 0x97FF FFFF
19	S19	0 = noncacheable; 1 = cacheable	0x9800 0000 --- 0x9FFF FFFF
20	S20	0 = noncacheable; 1 = cacheable	0xA000 0000 --- 0xA7FF FFFF
21	S21	0 = noncacheable; 1 = cacheable	0xA800 0000 --- 0xAFFF FFFF
22	S22	0 = noncacheable; 1 = cacheable	0xB000 0000 --- 0xB7FF FFFF
23	S23	0 = noncacheable; 1 = cacheable	0xB800 0000 --- 0xBFFF FFFF

DCCR (cont.)

24	S24	0 = noncacheable; 1 = cacheable	0xC000 0000 --- 0xC7FF FFFF
25	S25	0 = noncacheable; 1 = cacheable	0xC800 0000 --- 0xCFFF FFFF
26	S26	0 = noncacheable; 1 = cacheable	0xD000 0000 --- 0xD7FF FFFF
27	S27	0 = noncacheable; 1 = cacheable	0xD800 0000 --- 0xDFFF FFFF
28	S28	0 = noncacheable; 1 = cacheable	0xE000 0000 --- 0xE7FF FFFF
29	S29	0 = noncacheable; 1 = cacheable	0xE800 0000 --- 0xEFFF FFFF
30	S30	0 = noncacheable; 1 = cacheable	0xF000 0000 --- 0xF7FF FFFF
31	S31	0 = noncacheable; 1 = cacheable	0xF800 0000 --- 0xFFFF FFFF

SPR 0x3BA

(see also Section 9.5.1.1 on page 9-22)

**Figure 12-14. Data Cache Write-thru Register (DCWR)**

0	W0	0 = copy-back; 1 = write-thru	0x0000 0000 --- 0x07FF FFFF
1	W1	0 = copy-back; 1 = write-thru	0x0800 0000 --- 0x0FFF FFFF
2	W2	0 = copy-back; 1 = write-thru	0x1000 0000 --- 0x17FF FFFF
3	W3	0 = copy-back; 1 = write-thru	0x1800 0000 --- 0x1FFF FFFF
4	W4	0 = copy-back; 1 = write-thru	0x2000 0000 --- 0x27FF FFFF
5	W5	0 = copy-back; 1 = write-thru	0x2800 0000 --- 0x2FFF FFFF
6	W6	0 = copy-back; 1 = write-thru	0x3000 0000 --- 0x37FF FFFF
7	W7	0 = copy-back; 1 = write-thru	0x3800 0000 --- 0x3FFF FFFF
8	W8	0 = copy-back; 1 = write-thru	0x4000 0000 --- 0x47FF FFFF
9	W9	0 = copy-back; 1 = write-thru	0x4800 0000 --- 0x4FFF FFFF
10	W10	0 = copy-back; 1 = write-thru	0x5000 0000 --- 0x57FF FFFF
11	W11	0 = copy-back; 1 = write-thru	0x5800 0000 --- 0x5FFF FFFF
12	W12	0 = copy-back; 1 = write-thru	0x6000 0000 --- 0x67FF FFFF
13	W13	0 = copy-back; 1 = write-thru	0x6800 0000 --- 0x6FFF FFFF
14	W14	0 = copy-back; 1 = write-thru	0x7000 0000 --- 0x77FF FFFF
15	W15	0 = copy-back; 1 = write-thru	0x7800 0000 --- 0x7FFF FFFF
16	W16	0 = copy-back; 1 = write-thru	0x8000 0000 --- 0x87FF FFFF
17	W17	0 = copy-back; 1 = write-thru	0x8800 0000 --- 0x8FFF FFFF
18	W18	0 = copy-back; 1 = write-thru	0x9000 0000 --- 0x97FF FFFF
19	W19	0 = copy-back; 1 = write-thru	0x9800 0000 --- 0x9FFF FFFF
20	W20	0 = copy-back; 1 = write-thru	0xA000 0000 --- 0xA7FF FFFF
21	W21	0 = copy-back; 1 = write-thru	0xA800 0000 --- 0xAFFF FFFF
22	W22	0 = copy-back; 1 = write-thru	0xB000 0000 --- 0xB7FF FFFF
23	W23	0 = copy-back; 1 = write-thru	0xB800 0000 --- 0xBFFF FFFF

DCWR (cont.)

24	W24	0 = copy-back; 1 = write-thru	0xC000 0000 --- 0xC7FF FFFF
25	W25	0 = copy-back; 1 = write-thru	0xC800 0000 --- 0xCFFF FFFF
26	W26	0 = copy-back; 1 = write-thru	0xD000 0000 --- 0xD7FF FFFF
27	W27	0 = copy-back; 1 = write-thru	0xD800 0000 --- 0xDFFF FFFF
28	W28	0 = copy-back; 1 = write-thru	0xE000 0000 --- 0xE7FF FFFF
29	W29	0 = copy-back; 1 = write-thru	0xE800 0000 --- 0xEFFF FFFF
30	W30	0 = copy-back; 1 = write-thru	0xF000 0000 --- 0xF7FF FFFF
31	W31	0 = copy-back; 1 = write-thru	0xF800 0000 --- 0xFFFF FFFF

SPR 0x3D5 Read-Only
(see also Section 6.2.6 on page 6-14)

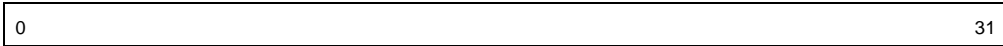


Figure 12-15. Data Exception Address Register (DEAR)

0:31	Address of Data Exception (synchronous)
------	---

DMACC0-DMACC3

DCR 0xC4, 0xCC, 0xD4, 0xDC
(see also Section 4.3.6 on page 4-40)

0	15	16	31
---	----	----	----

Figure 12-16. DMA Chained Count Registers (DMACC0-DMACC3)

0:15		reserved
16:31		Chained Count.

DMACR0-DMACR3

DCR 0xC0, 0xC8, 0xD0, 0xD8

(see also Section 4.3.1 on page 4-32)

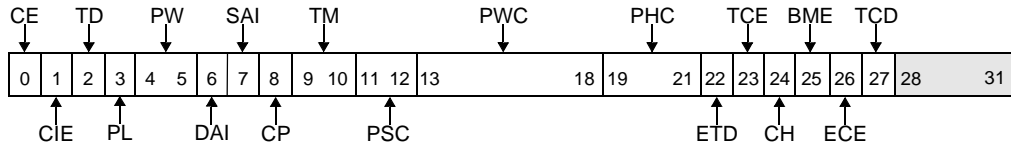


Figure 12-17. DMA Channel Control Registers (DMACR0-DMACR3)

0	CE	Channel Enable 0 - Channel is disabled 1 - Channel is enabled for DMA operation	(Hardware clears this bit when channel stopping conditions are satisfied.)
1	CIE	Channel Interrupt Enable 0 - Disable DMA interrupts from this channel to the processor 1 - All DMA interrupts from this channel (end-of-transfer, terminal count reached) are enabled.	
2	TD	Transfer Direction (Valid only for buffered mode and fly-by mode, don't care in memory-to-memory mode) 0 - Transfers are from memory to peripheral 1 - Transfers are from peripheral to memory	
3	PL	Peripheral Location 0 - Peripheral is external to the PPC403GC 1 - Peripheral is internal to PPC403GC	(internal peripherals are those on the OPB)
4:5	PW	Peripheral Width 00 - Byte (8-bits) 01 - Halfword (16-bits) 10 - Word (32-bits) 11 - M2M line (16 bytes)	Transfer Width is the same as Peripheral Width. M2M transfer initiated by software only.
6	DAI	Destination Address Increment 0 - Hold the destination address (do not increment) 1 - Increment the destination address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.	
7	SAI	Source Address Increment (valid only during memory-to memory moves, don't care in other modes) 0 - Hold the source address (do not increment) 1 - Increment the source address by: 1 - if the transfer width is one byte (8-bits), 2 - if the transfer width is a halfword (16-bits), or 4 - if the transfer width is a word (32-bits) after each transfer in the transaction.	
8	CP	Channel Priority 0 - Channel has low priority for the external or internal bus 1 - Channel has high priority for the external or internal bus	

DMACR0-DMACR3 (cont.)

9:10	TM	Transfer Mode 00 - Buffered mode DMA 01 - Fly-by mode DMA 10 - Software initiated memory-to-memory mode DMA 11 - Hardware initiated (device paced) memory-to-memory mode DMA
11:12	PSC	Peripheral Setup Cycles 00 - No cycles for setup time will be inserted during DMA transfers 01 - One SysClk cycle of setup time will be inserted between the time $\overline{\text{DMAA}}$ is accepted (on a peripheral read) or the data bus is driven (on a peripheral write) and $\overline{\text{DMAA}}$ is asserted for the peripheral part of the transfer in buffered and fly-by modes. 10 - Two SysClk cycles of setup time are inserted 11 - Three SysClk cycles of setup time are inserted
13:18	PWC	Peripheral Wait Cycles The value (0-63) of the PWC bits determines the number of SysClk cycles that $\overline{\text{DMAA}}$ stays active after the first full SysClk cycle $\overline{\text{DMAA}}$ is active. For instance, the PWC bits have a value of 5, then $\overline{\text{DMAA}}$ is active for six SysClk cycles.
19:21	PHC	Peripheral Hold Cycles The value (0-7) of these bits determines the number of SysClk cycles between the time that $\overline{\text{DMAA}}$ becomes inactive until the bus is available for the next bus access. During this period, the address bus, the data bus and control signals remain active.
22	ETD	End-of-Transfer / Terminal Count ($\overline{\text{EOT/TC}}$) Pin Direction 0 - The $\overline{\text{EOT/TC}}$ pin is programmed as an end-of-transfer ($\overline{\text{EOT}}$) input. 1 - The $\overline{\text{EOT/TC}}$ pin is programmed as a terminal count ($\overline{\text{TC}}$) output. When programmed as $\overline{\text{TC}}$ and the terminal count is reached, this signal will go active the cycle after $\overline{\text{DMAA}}$ goes inactive.
23	TCE	Terminal Count Enable 0 - Channel does not stop when terminal count reached. 1 - Channel stops when terminal count reached.
24	CH	Chaining Enable 0 - DMA Chaining is disabled 1 - DMA chaining is enabled for this channel (Hardware clears this bit when chaining occurs. Hardware sets this bit when DMACC is written.)
25	BME	Burst Mode Enable 0 - Channel does not burst to memory. 1 - Channel will burst to memory. (In all modes except fly-by and M2M line burst, must have BME = 0.)
26	ECE	EOT Chain Mode Enable 0 - Channel will stop when EOT is active. 1 - If Chaining is enabled, channel will chain when EOT is active. (ETD must be programmed for EOT)
27	TCD	TC Chain Mode Disable 0 - If Chaining is enabled, channel will chain when TC reaches zero. 1 - Channel will not chain when TC reaches zero.
28:31		reserved

DMACT0-DMACT3

DCR 0xC1, 0xC9, 0xD1, 0xD9
(see also Section 4.3.5 on page 4-39)

0	15	16	31
---	----	----	----

Figure 12-18. DMA Count Registers (DMACT0-DMACT3)

0:15		reserved
16:31		Number of Transfers remaining.

DMADA0-DMADA3

DCR 0xC2, 0xCA, 0xD2, 0xDA
(see also Section 4.3.3 on page 4-37)



Figure 12-19. DMA Destination Address Registers (DMADA0-DMADA3)

0:31		Memory address for transfers between memory and peripheral. Destination address for memory-to-memory transfers.
------	--	--

DCR 0xC3, 0xCB, 0xD3, 0xDB
(see also Section 4.3.4 on page 4-38)



Figure 12-20. DMA Source Address Registers (DMASA0-DMASA3)

0:31		Source address for memory-to-memory transfers. Replacement contents for Destination Address for chained transfers.
------	--	---

DMASR

DCR 0xE0 Read / Clear

(see also Section 4.3.2 on page 4-35)

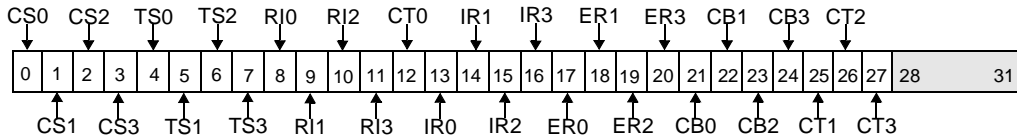


Figure 12-21. DMA Status Register (DMASR)

0:3	CS0: CS3	Channel 0-3 Terminal Count Status 0 - Terminal count has not been reached in the Transfer Count Register for channels 0-3, respectively. 1 - Terminal count has been reached in the Transfer Count Register for channels 0-, respectively.	TC will be set whenever the Transfer Count reaches 0 and the channel does not chain.
4:7	TS0: TS3	Channel 0-3 End-Of-Transfer Status (Valid only if $\overline{EOT}/\overline{TC}$ has been programmed for the \overline{EOT} function) 0 - End of transfer has not been requested for channels 0-3, respectively. 1 - End of transfer has been requested for channels 0-3, respectively.	
8:11	RI0: RI3	Channel 0-3 Error Status 0 - No error. 1 - Error.	BIU errors: - Bus Protection. - Non-configured Bank. - Bus Error Input. - Time-out Check. DMA errors: - Unaligned Address.
12	CT0	Chained Transfer on Channel 0. 0 - No chained transfer has occurred. 1 - Chaining has occurred.	
13:16	IR0: IR3	Internal DMA Request 0 - No internal DMA request pending 1 - A DMA request from an internal device is pending	
17:20	ER0: ER3	External DMA Request 0 - No external DMA request pending 1 - A DMA request from an external device is pending	
21:24	CB0: CB3	Channel Busy 0 - Channel not currently active 1 - Channel currently active	
25:27	CT1: CT3	Chained Transfer on Channel 1-3. 0 - No chained transfer has occurred. 1 - Chaining has occurred.	
28:31		reserved	

SPR 0x3D4

(see also Section 6.2.5 on page 6-12)

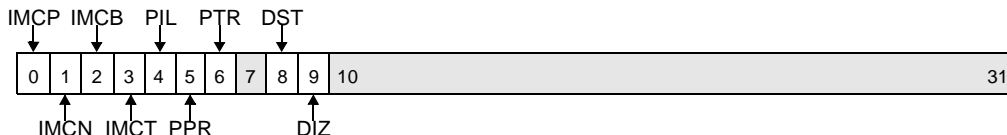


Figure 12-22. Exception Syndrome Register (ESR)

0	IMCP	Instruction Machine Check - Protection 0 - BIU Bank Protection Error did not occur. 1 - BIU Bank Protection Error occurred.
1	IMCN	Instruction Machine Check - Non-configured 0 - BIU Non-configured Error did not occur. 1 - BIU Non-configured Error occurred.
2	IMCB	Instruction Machine Check - Bus Error 0 - BIU Bus Error did not occur. 1 - BIU Bus Error occurred.
3	IMCT	Instruction Machine Check - Timeout 0 - BIU Timeout Error did not occur. 1 - BIU Timeout Error occurred.
4	PIL	Program Exception - Illegal 0 - Illegal Instruction Program Exception did not occur. 1 - Illegal Instruction Program Exception occurred.
5	PPR	Program Exception - Privileged 0 - Privileged Instruction Program Exception did not occur. 1 - Privileged Instruction Program Exception occurred.
6	PTR	Program Exception - Trap 0 - Trap Program Exception did not occur. 1 - Trap Program Exception occurred.
7		reserved
8	DST	Data Storage Exception / D-Miss — Store Operations 0 - Excepting instruction was not a store. (also 0 for Protection Bounds exception) 1 - Excepting instruction was a store (includes dcbz , dcbi , dccci).
9	DIZ	Data / Instruction Storage Exception — Zone Fault 0 - Excepting condition was not a zone fault. 1 - Excepting condition was a zone fault (any user-mode storage access instruction, except dcbt or dcbtst , executed in user mode with translation enabled and with (ZPR field) = 00).
10:31		reserved

EVPR

SPR 0x3D6
(see also Section 6.2.4 on page 6-11)

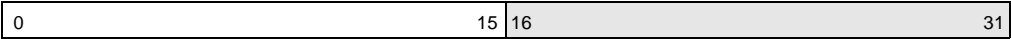
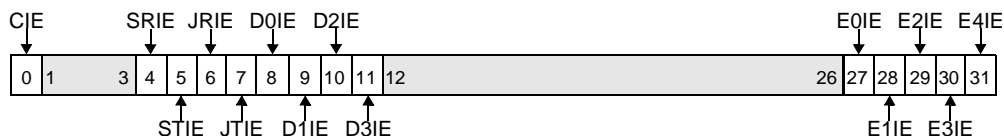


Figure 12-23. Exception Vector Prefix Register (EVPR)

0:15		Exception Vector Prefix
16:31		reserved

DCR 0x42

(see also Section 6.7.1.1 on page 6-24)

**Figure 12-24. External Interrupt Enable Register (EXIER)**

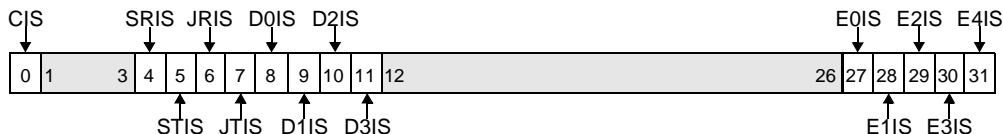
0	CIE	Critical Interrupt Enable 0 - Critical Interrupt Pin interrupt disabled 1 - Critical Interrupt Pin interrupt enabled
1:3		reserved
4	SRIE	Serial Port Receiver Interrupt Enable 0 - Serial port receiver interrupt disabled 1 - Serial port receiver interrupt enabled
5	STIE	Serial Port Transmitter Interrupt Enable 0 - Serial port transmitter interrupt disabled 1 - Serial port transmitter interrupt enabled
6	JRIE	JTAG Serial Port Receiver Interrupt Enable 0 - JTAG serial port receiver interrupt disabled 1 - JTAG serial port receiver interrupt enabled
7	JTIE	JTAG Serial Port Transmitter Interrupt Enable 0 - JTAG serial port transmitter interrupt disabled 1 - JTAG serial port transmitter interrupt enabled
8	D0IE	DMA Channel 0 Interrupt Enable 0 - DMA Channel 0 interrupt disabled 1 - DMA Channel 0 Interrupt enabled
9	D1IE	DMA Channel 1 Interrupt Enable 0 - DMA Channel 1 interrupt disabled 1 - DMA Channel 1 interrupt enabled
10	D2IE	DMA Channel 2 Interrupt Enable 0 - DMA Channel 2 interrupt disabled 1 - DMA Channel 2 interrupt enabled
11	D3IE	DMA Channel 3 Interrupt Enable 0 - DMA Channel 3 interrupt disabled 1 - DMA Channel 3 interrupt enabled
12:26		reserved
27	E0IE	External Interrupt 0 Enable 0 - Interrupt from External Interrupt 0 pin disabled 1 - Interrupt from External Interrupt 0 pin enabled

EXIER (cont.)

28	E1IE	External Interrupt 1 Enable 0 - Interrupt from External Interrupt 1 pin disabled 1 - Interrupt from External Interrupt 1 pin enabled
29	E2IE	External Interrupt 2 Enable 0 - Interrupt from External Interrupt 2 pin disabled 1 - Interrupt from External Interrupt 2 pin enabled
30	E3IE	External Interrupt 3 Enable 0 - Interrupt from External Interrupt 3 pin disabled 1 - Interrupt from External Interrupt 3 pin enabled
31	E4IE	External Interrupt 4 Enable 0 - Interrupt from External Interrupt 4 pin disabled 1 - Interrupt from External Interrupt 4 pin enabled

DCR 0x40 Read / Clear

(see also Section 6.7.1.2 on page 6-26)

**Figure 12-25. External Interrupt Status Register (EXISR)**

0	CIS	Critical Interrupt Status 0 - No interrupt pending from the critical interrupt pin 1 - Interrupt pending from the critical interrupt pin
1:3		reserved
4	SRIS	Serial Port Receiver Interrupt Status 0 - No interrupt pending from the serial port receiver 1 - Interrupt pending from the serial port receiver
5	STIS	Serial Port Transmitter Interrupt Status 0 - No interrupt pending from the serial port transmitter 1 - Interrupt pending from the serial port transmitter
6	JRIS	JTAG Serial Port Receiver Interrupt Status 0 - No interrupt pending from the JTAG serial port receiver 1 - Interrupt pending from the JTAG serial port receiver
7	JTIS	JTAG Serial Port Transmitter Interrupt Status 0 - No interrupt pending from the JTAG serial port transmitter 1 - Interrupt pending from the JTAG serial port transmitter
8	D0IS	DMA Channel 0 Interrupt Status 0 - No interrupt pending from DMA Channel 0 1 - Interrupt pending from DMA Channel 0
9	D1IS	DMA Channel 1 Interrupt Status 0 - No interrupt pending from DMA Channel 1 1 - Interrupt pending from DMA Channel 1
10	D2IS	DMA Channel 2 Interrupt Status 0 - No interrupt pending from DMA Channel 2 1 - Interrupt pending from DMA Channel 2
11	D3IS	DMA Channel 3 Interrupt Status 0 - No interrupt pending from DMA Channel 3 1 - Interrupt pending from DMA Channel 3
12:26		reserved
27	E0IS	External Interrupt 0 Status 0 - No interrupt pending from External Interrupt 0 pin 1 - Interrupt pending from External Interrupt 0 pin

EXISR (cont.)

28	E1IS	External Interrupt 1 Status 0 - No interrupt pending from External Interrupt 1 pin 1 - Interrupt pending from External Interrupt 1 pin
29	E2IS	External Interrupt 2 Status 0 - No interrupt pending from External Interrupt 2 pin 1 - Interrupt pending from External Interrupt 2 pin
30	E3IS	External Interrupt 3 Status 0 - No interrupt pending from External Interrupt 3 pin 1 - Interrupt pending from External Interrupt 3 pin
31	E4IS	External Interrupt 4 Status 0 - No interrupt pending from External Interrupt 4 pin 1 - Interrupt pending from External Interrupt 4 pin

(see also Section 2.3.1 on page 2-6)

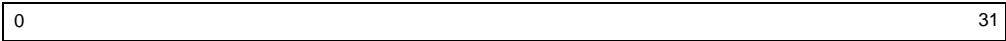


Figure 12-26. General Purpose Register (R0-R31)

0:31	General Purpose Register data
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IAC1-IAC2

SPR 0x3F4-0x3F5

(see also Section 10.6.4 on page 10-13)

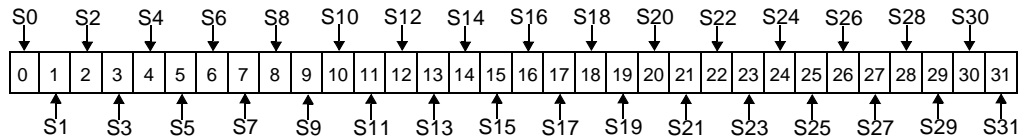
0	29	30	31
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Figure 12-27. Instruction Address Compare (IAC1-IAC2)

0:29		Instruction Address Compare, Word Address (omit 2 lo-order bits of complete address)
30:31		reserved

SPR 0x3FB

(see also Section 9.5.1.3 on page 9-26)

**Figure 12-28. Instruction Cache Cacheability Register (ICCR)**

0	S0	0 = noncacheable; 1 = cacheable	0x0000 0000 --- 0x07FF FFFF
1	S1	0 = noncacheable; 1 = cacheable	0x0800 0000 --- 0x0FFF FFFF
2	S2	0 = noncacheable; 1 = cacheable	0x1000 0000 --- 0x17FF FFFF
3	S3	0 = noncacheable; 1 = cacheable	0x1800 0000 --- 0x1FFF FFFF
4	S4	0 = noncacheable; 1 = cacheable	0x2000 0000 --- 0x27FF FFFF
5	S5	0 = noncacheable; 1 = cacheable	0x2800 0000 --- 0x2FFF FFFF
6	S6	0 = noncacheable; 1 = cacheable	0x3000 0000 --- 0x37FF FFFF
7	S7	0 = noncacheable; 1 = cacheable	0x3800 0000 --- 0x3FFF FFFF
8	S8	0 = noncacheable; 1 = cacheable	0x4000 0000 --- 0x47FF FFFF
9	S9	0 = noncacheable; 1 = cacheable	0x4800 0000 --- 0x4FFF FFFF
10	S10	0 = noncacheable; 1 = cacheable	0x5000 0000 --- 0x57FF FFFF
11	S11	0 = noncacheable; 1 = cacheable	0x5800 0000 --- 0x5FFF FFFF
12	S12	0 = noncacheable; 1 = cacheable	0x6000 0000 --- 0x67FF FFFF
13	S13	0 = noncacheable; 1 = cacheable	0x6800 0000 --- 0x6FFF FFFF
14	S14	0 = noncacheable; 1 = cacheable	0x7000 0000 --- 0x77FF FFFF
15	S15	0 = noncacheable; 1 = cacheable	0x7800 0000 --- 0x7FFF FFFF
16	S16	0 = noncacheable; 1 = cacheable	0x8000 0000 --- 0x87FF FFFF
17	S17	0 = noncacheable; 1 = cacheable	0x8800 0000 --- 0x8FFF FFFF
18	S18	0 = noncacheable; 1 = cacheable	0x9000 0000 --- 0x97FF FFFF
19	S19	0 = noncacheable; 1 = cacheable	0x9800 0000 --- 0x9FFF FFFF
20	S20	0 = noncacheable; 1 = cacheable	0xA000 0000 --- 0xA7FF FFFF
21	S21	0 = noncacheable; 1 = cacheable	0xA800 0000 --- 0xAFFF FFFF
22	S22	0 = noncacheable; 1 = cacheable	0xB000 0000 --- 0xB7FF FFFF
23	S23	0 = noncacheable; 1 = cacheable	0xB800 0000 --- 0xBFFF FFFF

ICCR (cont.)

24	S24	0 = noncacheable; 1 = cacheable	0xC000 0000 --- 0xC7FF FFFF
25	S25	0 = noncacheable; 1 = cacheable	0xC800 0000 --- 0xCFFF FFFF
26	S26	0 = noncacheable; 1 = cacheable	0xD000 0000 --- 0xD7FF FFFF
27	S27	0 = noncacheable; 1 = cacheable	0xD800 0000 --- 0xDFFF FFFF
28	S28	0 = noncacheable; 1 = cacheable	0xE000 0000 --- 0xE7FF FFFF
29	S29	0 = noncacheable; 1 = cacheable	0xE800 0000 --- 0xEFFF FFFF
30	S30	0 = noncacheable; 1 = cacheable	0xF000 0000 --- 0xF7FF FFFF
31	S31	0 = noncacheable; 1 = cacheable	0xF800 0000 --- 0xFFFF FFFF

SPR 0x3D3 Read-Only

(see also Section 8.4.1 on page 8-13)

0	31
---	----

Figure 12-29. Instruction Cache Debug Data Register (ICDBDR)

0:31		Instruction Cache Information	see icread , page 11-74
------	--	-------------------------------	--------------------------------

IOCR

DCR 0xA0

(see also Section 6.7.1.3 on page 6-28)



Figure 12-30. Input/Output Configuration Register (IOCR)

0	E0T	External Interrupt 0 Triggering 0 - External Interrupt 0 pin is level sensitive 1 - External Interrupt 0 pin is edge triggered
1	E0L	External Interrupt 0 Active Level 0 - External Interrupt 0 pin is negative level/edge triggered 1 - External Interrupt 0 pin is positive level/edge triggered
2	E1T	External Interrupt 1 Triggering 0 - The External Interrupt 1 pin is level sensitive 1 - The External Interrupt 1 pin is edge triggered
3	E1L	External Interrupt 1 Active Level 0 - External Interrupt 1 pin is negative level/edge triggered 1 - External Interrupt 1 pin is positive level/edge triggered
4	E2T	External Interrupt 2 Triggering 0 - The External Interrupt 2 pin is level sensitive 1 - The External Interrupt 2 pin is edge triggered
5	E2L	External Interrupt 2 Active Level 0 - External Interrupt 2 pin is negative level/edge triggered 1 - External Interrupt 2 pin is positive level/edge triggered
6	E3T	External Interrupt 3 Triggering 0 - The External Interrupt 3 pin is level sensitive 1 - The External Interrupt 3 pin is edge triggered
7	E3L	External Interrupt 3 Active Level 0 - External Interrupt 3 pin is negative level/edge triggered 1 - External Interrupt 3 pin is positive level/edge triggered
8	E4T	External Interrupt 4 Triggering 0 - The External Interrupt 4 pin is level sensitive 1 - The External Interrupt 4 pin is edge triggered
9	E4L	External Interrupt 4 Active Level 0 - External Interrupt 4 pin is negative level/edge triggered 1 - External Interrupt 4 pin is positive level/edge triggered
10:17		reserved

IOCR (cont.)

18	ATC	Address Tri-state Control 0 - Tri-state when idle 1 - Drive previous value when idle
19	SPD	Static Power Disable 0 - Normal operation 1 - Low power operation — Note: Early RAS Mode and TLB array disabled
20	BEM	Byte Enable Mode — SRAM accesses 0 - $\overline{\text{WBE}}$ pins are Write Byte Enables 1 - $\overline{\text{WBE}}$ pins are Read / Write Byte Enables (with altered timings of Write Byte Enables)
21	PTD	Device-Paced Timeout Disable — SRAM accesses with $\text{BRn}[\text{RE}] = 1$ 0 - Timeout occurs if Ready does not occur within 128 cycles 1 - No timeout occurs on external accesses
22:23		reserved
24	ARE	Asynchronous Ready Enable — SRAM accesses with $\text{BRn}[\text{RE}] = 1$ 0 - Data is latched 1 cycle after Ready is sampled high — setup time required 1 - Data is latched 3 cycles after Ready is sampled high — setup requirement removed
25		reserved
26	DRC	DRAM Read on CAS (For DRAM read operations only) 0 - Latch data bus on rising edge of SysClk 1 - Latch data bus on rising edge of $\overline{\text{CAS}}$ (on the deactivation of $\overline{\text{CAS}}$); provides more time for data to arrive
27:28	RDM	Real-Time Debug Mode 00 - Trace Status Outputs Disabled 01 - Program Status and Bus Status 10 - Program Status and Trace Output 11 - reserved
29	TCS	Timer Clock Source 0 - Clock source is the SysClk pin 1 - Clock source is the TimerClk pin
30	SCS	Serial Port Clock Source 0 - Clock source is the SysClk pin 1 - Clock source is the SerClk pin
31	SPC	Serial Port Configuration 0 - DSR/DTR 1 - CTS/RTS

LR

SPR 0x008

(see also Section 2.3.2.2 on page 2-8)



Figure 12-31. Link Register (LR)

0:31		Link Register Contents	If (LR) represents an instruction address, then LR _{30:31} should be zero.
------	--	------------------------	---

(see also Section 6.2.1 on page 6-8)

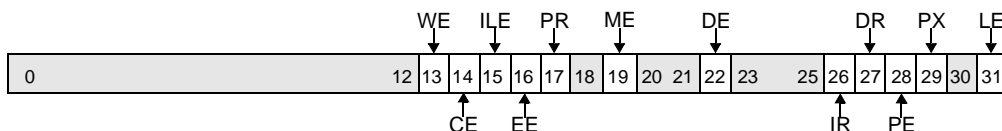


Figure 12-32. Machine State Register (MSR)

0:12		reserved
13	WE	Wait State Enable 0 - The processor is not in the wait state and continues processing. 1 - The processor enters the wait state and remains in the wait state until an exception is taken or the PPC403GC is reset or an external debug tool clears the WE bit.
14	CE	Critical Interrupt Enable 0 - Critical exceptions are disabled. 1 - Critical exceptions are enabled. CE controls these interrupts: critical interrupt pin, watchdog timer first time-out.
15	ILE	Interrupt Little Endian 0 - Interrupt handlers execute in Big-Endian mode. 1 - Interrupt handlers execute in Little-Endian mode. MSR(ILE) is copied to MSR(LE) when an interrupt is taken.
16	EE	External Interrupt Enable 0 - Asynchronous exceptions are disabled. 1 - Asynchronous exceptions are enabled. EE controls these interrupts: non-critical external, DMA, serial port, JTAG serial port, programmable interval timer, fixed interval timer.
17	PR	Problem State 0 - Supervisor State — all instructions allowed. 1 - Problem State — privileged instructions disallowed.
18		reserved
19	ME	Machine Check Enable 0 - Machine check exceptions are disabled 1 - Machine check exceptions are enabled
20:21		reserved
22	DE	Debug Exception Enable 0 - Debug exceptions are disabled 1 - Debug exceptions are enabled
23:25		reserved
26	IR	Instruction Relocate 0 - Instruction address translation is off 1 - Instruction address translation is on

MSR (cont.)

27	DR	Data Relocate 0 - Data address translation is off 1 - Data address translation is on
28	PE	Protection Enable 0 - Protection exceptions are disabled 1 - Protection exceptions are enabled — treated as 0 if MSR[DR] = 1
29	PX	Protection Exclusive Mode 0 - Protection mode is inclusive as defined in Section 9.4.2 on page 9-18 1 - Protection mode is exclusive as defined in Section 9.4.2 on page 9-18
30		reserved
31	LE	Little Endian 0 - Processor executes in Big-Endian mode. 1 - Processor executes in Little-Endian mode.

SPR 0x3FC, 0x3FE
(see also Section 9.4.2 on page 9-18)

0	19	20	31
---	----	----	----

Figure 12-33. Protection Bound Lower Register (PBL1-PBL2)

0-19		Lower Bound Address (address bits 0:19)
20-31		reserved

PBU1-PBU2

SPR 0x3FD, 0x3FF

(see also Section 9.4.2 on page 9-18)

PBU1-PBU2

0	19	20	31
---	----	----	----

Figure 12-34. Protection Bound Upper Register (PBU1-PBU2)

0-19		Upper Bound Address (address bits 0:19)
20-31		reserved

SPR 0x3B1
(see also Section 9.4.1.1 on page 9-15)



Figure 12-35. Process ID (PID)

0:23		reserved
24:31		Process ID

PIT

SPR 0x3DB

(see also Section 6.11 on page 6-34)



Figure 12-36. Programmable Interval Timer (PIT)

0:31		Programmed Interval Remaining	(the number of clocks remaining until the PIT event)
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SPR 0x11F Read-Only
(see also Section 2.3.2.3 on page 2-8)

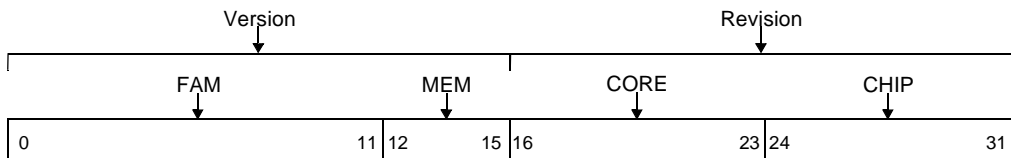


Figure 12-37. Processor Version Register (PVR)

0:11	FAM	Processor Family. Indicates a particular PowerPC family, such as 4xx or 6xx.	= 0x002 for the 4xx family.
12:15	MEM	Family Member. Indicates a specific family member, such as 403 or 601.	= 0 for PPC403GC
16:23	CORE	Core Revision. Identifies a specific implementation and revision of the processor core.	= 0x02 for PPC403GC
24:31	CHIP	Chip Revision. Identifies a specific configuration and revision of a chip that uses the processor core defined by the FAM/MEM/CORE fields.	= 0x00 for PPC403GC

SGR

SPR 0x3B9

(see also Section 9.5.1.4 on page 9-28)

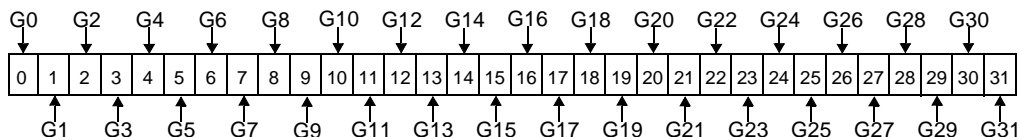


Figure 12-38. Storage Guarded Register (SGR)

0	G0	0 = normal; 1 = guarded	0x0000 0000 --- 0x07FF FFFF
1	G1	0 = normal; 1 = guarded	0x0800 0000 --- 0x0FFF FFFF
2	G2	0 = normal; 1 = guarded	0x1000 0000 --- 0x17FF FFFF
3	G3	0 = normal; 1 = guarded	0x1800 0000 --- 0x1FFF FFFF
4	G4	0 = normal; 1 = guarded	0x2000 0000 --- 0x27FF FFFF
5	G5	0 = normal; 1 = guarded	0x2800 0000 --- 0x2FFF FFFF
6	G6	0 = normal; 1 = guarded	0x3000 0000 --- 0x37FF FFFF
7	G7	0 = normal; 1 = guarded	0x3800 0000 --- 0x3FFF FFFF
8	G8	0 = normal; 1 = guarded	0x4000 0000 --- 0x47FF FFFF
9	G9	0 = normal; 1 = guarded	0x4800 0000 --- 0x4FFF FFFF
10	G10	0 = normal; 1 = guarded	0x5000 0000 --- 0x57FF FFFF
11	G11	0 = normal; 1 = guarded	0x5800 0000 --- 0x5FFF FFFF
12	G12	0 = normal; 1 = guarded	0x6000 0000 --- 0x67FF FFFF
13	G13	0 = normal; 1 = guarded	0x6800 0000 --- 0x6FFF FFFF
14	G14	0 = normal; 1 = guarded	0x7000 0000 --- 0x77FF FFFF
15	G15	0 = normal; 1 = guarded	0x7800 0000 --- 0x7FFF FFFF
16	G16	0 = normal; 1 = guarded	0x8000 0000 --- 0x87FF FFFF
17	G17	0 = normal; 1 = guarded	0x8800 0000 --- 0x8FFF FFFF
18	G18	0 = normal; 1 = guarded	0x9000 0000 --- 0x97FF FFFF
19	G19	0 = normal; 1 = guarded	0x9800 0000 --- 0x9FFF FFFF
20	G20	0 = normal; 1 = guarded	0xA000 0000 --- 0xA7FF FFFF
21	G21	0 = normal; 1 = guarded	0xA800 0000 --- 0xAFFF FFFF
22	G22	0 = normal; 1 = guarded	0xB000 0000 --- 0xB7FF FFFF
23	G23	0 = normal; 1 = guarded	0xB800 0000 --- 0xBFFF FFFF

SGR (cont.)

24	G24	0 = normal; 1 = guarded	0xC000 0000 --- 0xC7FF FFFF
25	G25	0 = normal; 1 = guarded	0xC800 0000 --- 0xCFFF FFFF
26	G26	0 = normal; 1 = guarded	0xD000 0000 --- 0xD7FF FFFF
27	G27	0 = normal; 1 = guarded	0xD800 0000 --- 0xDFFF FFFF
28	G28	0 = normal; 1 = guarded	0xE000 0000 --- 0xE7FF FFFF
29	G29	0 = normal; 1 = guarded	0xE800 0000 --- 0xEFFF FFFF
30	G30	0 = normal; 1 = guarded	0xF000 0000 --- 0xF7FF FFFF
31	G31	0 = normal; 1 = guarded	0xF800 0000 --- 0xFFFF FFFF

SPCTL

MMIO 0x4000 0006

(see also Section 7.3.2 on page 7-13)

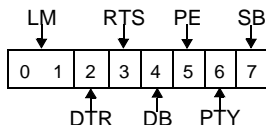
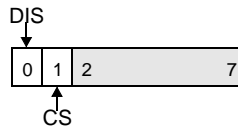


Figure 12-39. Serial Port Control Register (SPCTL)

0:1	LM	Loopback Modes 00 - Normal Operation 01 - Internal Loopback Mode 10 - Automatic Echo Mode 11 - Reserved	
2	DTR	Data Terminal Ready 0 - DTR signal is inactive 1 - DTR signal is active	
3	RTS	Request To Send 0 - RTS signal is inactive 1 - RTS is active	
4	DB	Data Bits 0 - 7 Data bits 1 - 8 Data bits	When DB = 0, a data frame contains the least significant seven bits (bits 1:7) in the SPTB or the SPRB.
5	PE	Parity Enable 0 - No parity 1 - Parity enabled	When PE = 0, parity detection and generation are disabled for the serial port receiver and transmitter.
6	PTY	Parity 0 - Even parity 1 - Odd parity	When PTY = 0, even parity is used in parity detection and generation. When PTY = 1, odd parity is used.
7	SB	Stop Bits 0 - One stop bit 1 - Two stop bits	When SB = 0, one stop bit is used to detect the end of a received frame, and one stop bit is transmitted at the end of each data frame. When SB = 1, two stop bits are used.

MMIO 0x4000 0002 Read / Clear

(see also Section 7.3.3 on page 7-14)

**Figure 12-40. Serial Port Handshake Register (SPHS)**

0	DIS	DSR Input Inactive Error: 0 - DSR input is active 1 - DSR input has gone inactive	To reset the DIS bit, the application software must store a 1 in this bit location at the address of the SPHS.
1	CS	CTS Input Inactive Error: 0 - CTS input is active 1 - CTS input has gone inactive	To reset the CS bit, the application software must store a 1 in this bit location at the address of the SPHS.
2:7		reserved	

SPLS

MMIO 0x4000 0000 Read / Clear

(see also Section 7.3.4 on page 7-15)

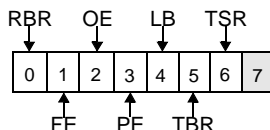


Figure 12-41. Serial Port Line Status Register (SPLS)

0	RBR	Receive Buffer Ready 0 - Receive buffer is not full 1 - Receive buffer is full	Reset by hardware when received data is read from the SPRB into a GPR using a load instruction or during chip reset; can be reset by software
1	FE	Framing Error 0 - No framing error detected 1 - Framing error detected	Must be reset by software
2	OE	Overrun Error 0 - No overrun error detected 1 - Overrun error detected	Must be reset by software
3	PE	Parity Error 0 - No parity error detected 1 - Parity error detected	Must be reset by software
4	LB	Line Break 0 - No line break detected 1 - Line break detected	Must be reset by software
5	TBR	Transmit Buffer Ready 0 - Transmit buffer is full (not ready) 1 - Transmit buffer is empty and ready	TBR is set to 1 whenever the SPTSR is loaded with a character from the SPTB. TBR is reset to 0 when a new character is stored in the SPTB.
6	TSR	Transmitter Shift Register Ready 0 - Transmitter Shift Register is full 1 - Transmitter Shift Register is empty	TSR is set to 1 whenever the SPTSR is empty. TSR is reset to 0 when a new character is transferred from the SPTB into the SPTSR and remains reset as characters are transmitted.
7		reserved	

MMIO 0x4000 0009 Read-Only
(see also Section 7.3.5 on page 7-16)



Figure 12-42. Serial Port Receive Buffer (SPRB)

0:7	Received Data
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SPRC

MMIO 0x4000 0007

(see also Section 7.3.6 on page 7-16)

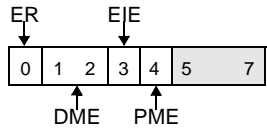


Figure 12-43. Serial Port Receiver Command Register (SPRC)

0	ER	Enable Receiver 0 - Disable receiver 1 - Enable receiver	For the serial port receiver to operate, ER must be set to 1. If ER is reset to 0, the serial port receiver is disabled, no data is shifted into the SPRSR, and no serial port receiver interrupts are active.
1:2	DME	DMA Mode, Interrupt Enable 00 - DMA is disabled; RBR interrupt is disabled 01 - DMA is disabled; RBR interrupt is enabled 10 - DMA is enabled; Receiver is source for DMA channel 2 11 - DMA is enabled; Receiver is source for DMA channel 3	
3	EIE	Error Interrupt Enable 0 - Receiver error interrupt disabled 1 - Receiver error interrupts enabled	
4	PME	Pause Mode Enable 0 - RTS is controlled by software 1 - RTS is controlled by hardware	
5:7		reserved	

SPR 0x110-0x113
(see also Section 2.3.2.4 on page 2-9)

0	31
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Figure 12-44. Special Purpose Register General (SPRG0-SPRG3)

0-31	General Data	(Privileged user-specified, no hardware usage.)
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SPTB

MMIO 0x4000 0009 Write-Only
(see also Section 7.3.7 on page 7-17)



Figure 12-45. Serial Port Transmit Buffer (SPTB)

0:7		Transmit Data	Data to be transmitted by the SPTSR
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MMIO 0x4000 0008

(see also Section 7.3.8 on page 7-18)

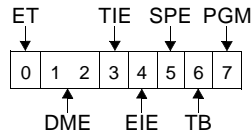


Figure 12-46. Serial Port Transmitter Command Register (SPTC)

0	ET	Enable Transmitter: 0 - Disable transmitter 1 - Enable transmitter (Chip Reset or System Reset clears to 0.)
1:2	DME	DMA Mode, Interrupt Enable 00 - DMA disabled; TBR interrupt disabled 01 -DMA disabled; TBR interrupt enabled 10 - DMA enabled; serial port transmitter is DMA channel 2 destination 11 - DMA enabled; serial port transmitter is DMA channel 3 destination
3	TIE	Transmitter Empty Interrupt Enable 0 - Transmitter shift register empty interrupt disabled 1 - Transmitter shift register empty interrupt enabled
4	EIE	Transmitter Error Interrupt Enable: 0 - Transmitter shift register error interrupt disabled 1 - Transmitter shift register error interrupt enabled
5	SPE	Stop/Pause on $\overline{\text{CTS}}$ Inactive 0 - Pause mode when $\overline{\text{CTS}}$ is inactive 1 - Stop mode when $\overline{\text{CTS}}$ is inactive
6	TB	Transmit Break 0 - Disable break character generation 1 - Enable break character generation
7	PGM	Pattern Generation Mode 0 - Disable pattern generation 1 - Enable pattern generation (Chip Reset or System Reset clears to 0.)

SRR0

SPR 0x01A
(see also Section 6.2.2 on page 6-10)

0	29	30	31
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Figure 12-47. Save / Restore Register 0 (SRR0)

0:29	SRR0 receives an instruction address when a non-critical interrupt is taken; the Program Counter is restored from SRR0 when rfi is executed.
30:31	reserved

SPR 0x01B

(see also Section 6.2.2 on page 6-10)

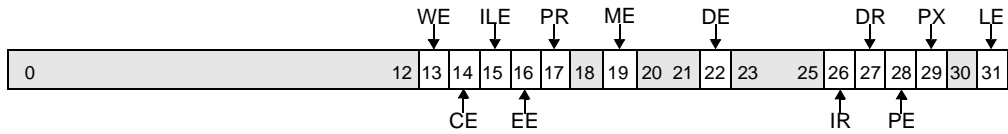


Figure 12-48. Save / Restore Register 1 (SRR1)

0:31	SRR1 receives a copy of the MSR when a non-critical interrupt is taken; MSR is restored from SRR1 when <i>rfi</i> is executed.
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SRR2

SPR 0x3DE

(see also Section 6.2.3 on page 6-11)

0	29	30	31
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Figure 12-49. Save / Restore Register 2 (SRR2)

0:29	SRR2 receives an instruction address when a critical interrupt is taken; the Program Counter is restored from SRR2 when rfci is executed.
30:31	reserved

SPR 0x3DF

(see also Section 6.2.3 on page 6-11)

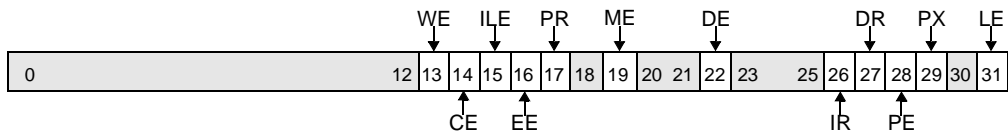


Figure 12-50. Save / Restore Register 3 (SRR3)

0:31	SRR3 receives a copy of the MSR when a critical interrupt is taken; MSR is restored from SRR3 when rfci is executed.
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TBHI

SPR 0x3DC

(see also Section 6.17.2 on page 6-41)



Figure 12-51. Time Base High Register (TBHI)

0:31		Time High	Current count, high-order.
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SPR 0x3CC Read-Only
(see also Section 6.17.2 on page 6-41)

0	31
---	----

Figure 12-52. Time Base High User-mode (TBHU)

0:31		Time High	Current count, high-order. (Note: TBHU is a read-only access vehicle to the time base register TBHI. It is not possible for the contents of TBHU and TBHI to differ.)
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TBLO

SPR 0x3DD

(see also Section 6.17.2 on page 6-41)



Figure 12-53. Time Base Low Register (TBLO)

0:31		Time Low	Current count, low-order.
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SPR 0x3CD Read-Only

(see also Section 6.17.2 on page 6-41)

0	31
---	----

Figure 12-54. Time Base Low User-mode (TBLU)

0:31		Time Low	Current count, low-order. (Note: TBLU is a read-only access vehicle to the time base register TBLO. It is not possible for the contents of TBLU and TBLO to differ.)
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TCR

SPR 0x3DA

(see also Section 6.17.7 on page 6-51)

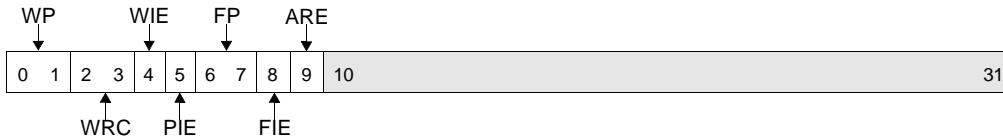


Figure 12-55. Timer Control Register (TCR)

0:1	WP	Watchdog Period 00 - 2^{17} clocks 01 - 2^{21} clocks 10 - 2^{25} clocks 11 - 2^{29} clocks	
2:3	WRC	Watchdog Reset Control 00 - No Watchdog reset will occur. 01 - Core reset will be forced by the Watchdog. 10 - Chip reset will be forced by the Watchdog. 11 - System reset will be forced by the Watchdog.	TCR[WRC] resets to 00. This field may be set by software, but cannot be cleared by software (except by a software-induced reset).
4	WIE	Watchdog Interrupt Enable 0 - Disable WDT interrupt. 1 - Enable WDT interrupt.	
5	PIE	PIT Interrupt Enable 0 - Disable PIT interrupt. 1 - Enable PIT interrupt.	
6:7	FP	FIT Period 00 - 2^9 clocks 01 - 2^{13} clocks 10 - 2^{17} clocks 11 - 2^{21} clocks	
8	FIE	FIT Interrupt Enable 0 - Disable FIT interrupt. 1 - Enable FIT interrupt.	
9	ARE	Auto Reload Enable 0 - Disable auto reload. 1 - Enable auto reload.	(disables on reset)
10:31		reserved	

SPR 0x3D8 Read / Clear

(see also Section 6.17.6 on page 6-50)

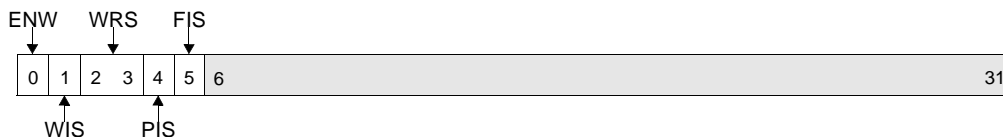


Figure 12-56. Timer Status Register (TSR)

0	ENW	Enable Next Watchdog (See Section 6.17.5 on page 6-47) 0 - Action on next Watchdog event is to set TSR[0]. 1 - Action on next Watchdog event is governed by TSR[1].
1	WIS	Watchdog Interrupt Status 0 - No Watchdog interrupt is pending. 1 - Watchdog interrupt is pending.
2:3	WRS	Watchdog Reset Status 00 - No Watchdog reset has occurred. 01 - Core reset has been forced by the Watchdog. 10 - Chip reset has been forced by the Watchdog. 11 - System reset has been forced by the Watchdog.
4	PIS	PIT Interrupt Status 0 - No PIT interrupt is pending. 1 - PIT interrupt is pending.
5	FIS	FIT Interrupt Status 0 - No FIT interrupt is pending. 1 - FIT interrupt is pending.
6:31		reserved

XER

SPR 0x001

(see also Section 2.3.2.5 on page 2-10)

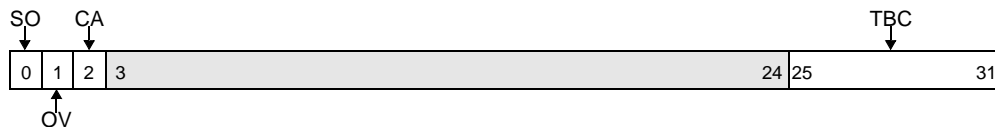
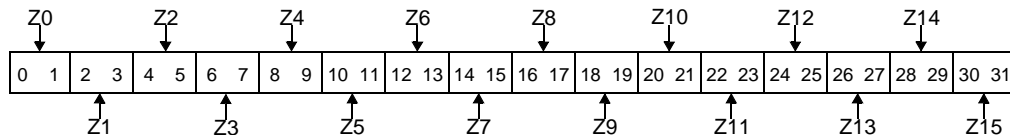


Figure 12-57. Fixed Point Exception Register (XER)

0	SO	Summary Overflow 0 - no overflow has occurred 1 - overflow has occurred	May be <u>set</u> by mtspr or by arithmetic instructions with the "OE" option (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr or by mcrxr .
1	OV	Overflow 0 - no overflow has occurred 1 - overflow has occurred	May be <u>set</u> by mtspr or by arithmetic instructions with the "OE" option (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr , by mcrxr , or by arithmetic instructions with the "OE" option.
2	CA	Carry 0 - carry has not occurred 1 - carry has occurred	May be <u>set</u> by mtspr or by arithmetic instructions that update CA (see Table 2-2 on page 2-11). May be <u>reset</u> by mtspr , by mcrxr , or by arithmetic instructions that update CA.
3:24		reserved	
25:31	TBC	Transfer Byte Count	Used by lswx and stswx . Written by mtspr specifying the XER.

SPR 0x3B0

(see also Section 9.4.1.4 on page 9-16)

**Figure 12-58. Zone Protection Register (ZPR)**

0:1	Z0	TLB Page Access Control for all pages in this Zone. EX (Execute Enable) and WR (Write Enable) are bits from the TLB entry which translates the effective address and PID.	
		In Problem State (MSR[PR] = 1) 00 - no access 01 - access governed by EX and WR 10 - access governed by EX and WR 11 - access as if EX and WR both set	In Supervisor State (MSR[PR] = 0) 00 - access governed by EX and WR 01 - access governed by EX and WR 10 - access as if EX and WR both set 11 - access as if EX and WR both set
2:3	Z1	see description of Z0	
4:5	Z2	see description of Z0	
6:7	Z3	see description of Z0	
8:9	Z4	see description of Z0	
10:11	Z5	see description of Z0	
12:13	Z6	see description of Z0	
14:15	Z7	see description of Z0	
16:17	Z8	see description of Z0	
18:19	Z9	see description of Z0	
20:21	Z10	see description of Z0	
22:23	Z11	see description of Z0	
24:25	Z12	see description of Z0	
26:27	Z13	see description of Z0	
28:29	Z14	see description of Z0	
30:31	Z15	see description of Z0	

Signal Descriptions

Table 13-1 lists the PPC403GC signals, ordered by signal name. Table 13-2 lists the PPC403GC signals, ordered by pin number.

Active-low signals are shown with overbars: $\overline{\text{CAS0}}$. Multiplexed signals are alphabetized under the first (unmultiplexed) signal names on the same pins.

Table 13-1. PPC403GC Signal Descriptions

Signal Name	Pin	I/O Type	Function
A6	92	I/O	Address Bus Bit 6. When the PPC403GC is bus master, this is an address output from the PPC403GC. When the PPC403GC is not bus master, this is an address input from the external bus master, to determine bank register usage. See Section 3.1.1 on page 3-3 for behavior when bus is idle.
A7	93	I/O	Address Bus Bit 7. See description of A6.
A8	94	I/O	Address Bus Bit 8. See description of A6.
A9	95	I/O	Address Bus Bit 9. See description of A6.
A10	96	I/O	Address Bus Bit 10. See description of A6.
A11	97	I/O	Address Bus Bit 11. See description of A6.
A12	98	O	Address Bus Bit 12. When the PPC403GC is bus master, this is an address output from the PPC403GC.
A13	99	O	Address Bus Bit 13. See description of A12.
A14	103	O	Address Bus Bit 14. See description of A12.
A15	104	O	Address Bus Bit 15. See description of A12.
A16	105	O	Address Bus Bit 16. See description of A12.
A17	106	O	Address Bus Bit 17. See description of A12.
A18	107	O	Address Bus Bit 18. See description of A12.
A19	108	O	Address Bus Bit 19. See description of A12.
A20	109	O	Address Bus Bit 20. See description of A12.
A21	110	O	Address Bus Bit 21. See description of A12.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
A22	112	I/O	Address Bus Bit 22. When the PPC403GC is bus master, this is an address output from the PPC403GC. When the PPC403GC is not bus master, this is an address input from the external bus master, to determine page crossings. See Section 3.1.1 on page 3-3 for behavior when bus is idle.
A23	113	I/O	Address Bus Bit 23. See description of A22.
A24	114	I/O	Address Bus Bit 24. See description of A22.
A25	115	I/O	Address Bus Bit 25. See description of A22.
A26	116	I/O	Address Bus Bit 26. See description of A22.
A27	117	I/O	Address Bus Bit 27. See description of A22.
A28	118	I/O	Address Bus Bit 28. See description of A22.
A29	119	I/O	Address Bus Bit 29. See description of A22.
AMuxCAS	139	O	DRAM External Address Multiplexer Select. AMuxCAS controls the select logic on an external multiplexer. If AMuxCAS is low, the multiplexer should select the row address for the DRAM and when AMuxCAS is 1, the multiplexer should select the column address.
BootW	11	I	Boot-up ROM Width Select. BootW is sampled while the $\overline{\text{Reset}}$ pin is active and again after $\overline{\text{Reset}}$ becomes inactive to determine the width of the boot-up ROM. If this pin is tied to logic 0 when sampled on reset, an 8-bit boot width is assumed. If BootW is tied to 1, a 32-bit boot width is assumed. For 16-bit boot widths, this pin should be tied to the $\overline{\text{Reset}}$ pin.
$\overline{\text{BusError}}$	12	I	Bus Error Input. A logic 0 input to the $\overline{\text{BusError}}$ pin by an external device signals to the PPC403GC that an error occurred on the bus transaction. $\overline{\text{BusError}}$ is only sampled during the data transfer cycle or the last wait cycle of the transfer.
BusReq/ $\overline{\text{DMADXFER}}$	135	O	Bus Request. While HoldAck is active, BusReq is active when the PPC403GC has a bus operation pending and needs to regain control of the bus. DMA Data Transfer. When HoldAck is not active, $\overline{\text{DMADXFER}}$ indicates a valid data transfer cycle. For DMA use, $\overline{\text{DMADXFER}}$ controls burst-mode fly-by DMA transfers between memory and peripherals. $\overline{\text{DMADXFER}}$ is not meaningful unless a DMA Acknowledge signal (DMAA0:DMAA3) is active. For transfer rates slower than one transfer per cycle, $\overline{\text{DMADXFER}}$ is active for one cycle when one transfer is complete and the next one starts. For transfer rates of one transfer per cycle, $\overline{\text{DMADXFER}}$ remains active throughout the transfer.
$\overline{\text{CAS0}}$	142	O	DRAM Column Address Select 0. $\overline{\text{CAS0}}$ is used with byte 0 of all DRAM banks.
$\overline{\text{CAS1}}$	143	O	DRAM Column Address Select 1. $\overline{\text{CAS1}}$ is used with byte 1 of all DRAM banks.
$\overline{\text{CAS2}}$	144	O	DRAM Column Address Select 2. $\overline{\text{CAS2}}$ is used with byte 2 of all DRAM banks.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
CAS3	145	O	DRAM Column Address Select 3. $\overline{\text{CAS3}}$ is used with byte 3 of all DRAM banks.
$\overline{\text{CINT}}$	36	I	Critical Interrupt. To initiate a critical interrupt, the user must maintain a logic 0 on the $\overline{\text{CINT}}$ pin for a minimum of one SysClk clock cycle followed by a logic 1 on the $\overline{\text{CINT}}$ pin for at least one SysClk cycle.
$\overline{\text{CS0}}$	155	O	SRAM Chip Select 0. Bank register 0 controls an SRAM bank, $\overline{\text{CS0}}$ is the chip select for that bank.
$\overline{\text{CS1}}$	154	O	SRAM Chip Select 1. Same function as $\overline{\text{CS0}}$ but controls bank 1.
$\overline{\text{CS2}}$	153	O	SRAM Chip Select 2. Same function as $\overline{\text{CS0}}$ but controls bank 2.
$\overline{\text{CS3}}$	152	O	SRAM Chip Select 3. Same function as $\overline{\text{CS0}}$ but controls bank 3.
$\overline{\text{CS4/RAS3}}$	151	O	Chip Select 4/ DRAM Row Address Select 3. When bank register 4 is configured to control an SRAM bank, $\overline{\text{CS4/RAS3}}$ functions as a chip select. When bank register 4 is configured to control a DRAM bank, $\overline{\text{CS4/RAS3}}$ is the row address select for that bank.
$\overline{\text{CS5/RAS2}}$	148	O	Chip Select 5/ DRAM Row Address Select 2. Same function as $\overline{\text{CS4/RAS3}}$ but controls bank 5.
$\overline{\text{CS6/RAS1}}$	147	O	Chip Select 6/ DRAM Row Address Select 1. Same function as $\overline{\text{CS4/RAS3}}$ but controls bank 6.
$\overline{\text{CS7/RAS0}}$	146	O	Chip Select 7/ DRAM Row Address Select 0. Same function as $\overline{\text{CS4/RAS3}}$ but controls bank 7.
D0	42	I/O	Data bus bit 0 (Most significant bit)
D1	43	I/O	Data bus bit 1
D2	44	I/O	Data bus bit 2
D3	45	I/O	Data bus bit 3
D4	46	I/O	Data bus bit 4
D5	47	I/O	Data bus bit 5
D6	48	I/O	Data bus bit 6
D7	51	I/O	Data bus bit 7
D8	52	I/O	Data bus bit 8
D9	53	I/O	Data bus bit 9
D10	54	I/O	Data bus bit 10
D11	55	I/O	Data bus bit 11
D12	56	I/O	Data bus bit 12
D13	57	I/O	Data bus bit 13
D14	58	I/O	Data bus bit 14
D15	62	I/O	Data bus bit 15

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
D16	63	I/O	Data bus bit 16
D17	64	I/O	Data bus bit 17
D18	65	I/O	Data bus bit 18
D19	66	I/O	Data bus bit 19
D20	67	I/O	Data bus bit 20
D21	68	I/O	Data bus bit 21
D22	71	I/O	Data bus bit 22
D23	72	I/O	Data bus bit 23
D24	73	I/O	Data bus bit 24
D25	74	I/O	Data bus bit 25
D26	75	I/O	Data bus bit 26
D27	76	I/O	Data bus bit 27
D28	77	I/O	Data bus bit 28
D29	78	I/O	Data bus bit 29
D30	79	I/O	Data bus bit 30
D31	82	I/O	Data bus bit 31
$\overline{\text{DMAA0}}$	156	O	DMA Channel 0 Acknowledge. $\overline{\text{DMAA0}}$ has an active level when a transaction is taking place between the PPC403GC and a peripheral.
$\overline{\text{DMAA1}}$	157	O	DMA Channel 1 Acknowledge. See description of $\overline{\text{DMAA0}}$
$\overline{\text{DMAA2}}$	158	O	DMA Channel 2 Acknowledge. See description of $\overline{\text{DMAA0}}$
$\overline{\text{DMAA3}} / \overline{\text{XACK}}$	159	O	DMA Channel 3 Acknowledge / External Master Transfer Acknowledge. When the PPC403GC is bus master, this signal is $\overline{\text{DMAA3}}$; see description of $\overline{\text{DMAA0}}$. When the PPC403GC is not the bus master, this signal is $\overline{\text{XACK}}$, an output from the PPC403GC which has an active level when data is valid during an external bus master transaction.
$\overline{\text{DMAR0}}$	2	I	DMA Channel 0 Request. External devices request a DMA transfer on channel 0 by putting a logic 0 on $\overline{\text{DMAR0}}$.
$\overline{\text{DMAR1}}$	3	I	DMA Channel 1 Request. See description of $\overline{\text{DMAR0}}$
$\overline{\text{DMAR2}}$	4	I	DMA Channel 2 Request. See description of $\overline{\text{DMAR0}}$
$\overline{\text{DMAR3}} / \overline{\text{XREQ}}$	5	I	DMA Channel 3 Request / External Master Transfer Request. When the PPC403GC is the bus master, this signal is $\overline{\text{DMAR3}}$; see description of $\overline{\text{DMAR0}}$. When the PPC403GC is not the bus master, this signal is the $\overline{\text{XREQ}}$ input. The external bus master places a logic 0 on $\overline{\text{XREQ}}$ to initiate a transfer to the DRAM controlled by the PPC403GC DRAM controller.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
DRAMOE	137	O	DRAM Output Enable. $\overline{\text{DRAMOE}}$ has an active level when either the PPC403GC or an external bus master is reading from a DRAM bank. This signal enables the selected DRAM bank to drive the data bus.
DRAMWE	138	O	DRAM Write Enable. $\overline{\text{DRAMWE}}$ has an active level when either the PPC403GC or an external bus master is writing to a DRAM bank.
DSR / CTS	28	I	Data Set Ready / Clear to Send. The function of this pin as either $\overline{\text{DSR}}$ or $\overline{\text{CTS}}$ is selectable via the Serial Port Configuration bit in the IOCR.
DTR / RTS	88	O	Data Terminal Ready / Request to Send. The function of this pin as either $\overline{\text{DTR}}$ or $\overline{\text{RTS}}$ is selectable via the Serial Port Configuration bit in the IOCR.
EOT0/TC0	128	I/O	End of Transfer 0 / Terminal Count 0. The function of the $\overline{\text{EOT0/TC0}}$ is controlled via the $\overline{\text{EOT/TC}}$ bit in the DMA Channel 0 Control Register. When $\overline{\text{EOT0/TC0}}$ is configured as an End of Transfer pin, external users may stop a DMA transfer by placing a logic 0 on this input pin. When configured as a Terminal Count pin, the PPC403GC signals the completion of a DMA transfer by placing a logic 0 on this pin.
EOT1/TC1	131	I/O	End of Transfer 1 / Terminal Count 1. See description of $\overline{\text{EOT0/TC0}}$
EOT2/TC2	132	I/O	End of Transfer 2 / Terminal Count 2. See description of $\overline{\text{EOT0/TC0}}$
EOT3/TC3/ XSize0	133	I/O	End of Transfer 3 / Terminal Count 3 / External Master Transfer Size 0. When the PPC403GC is bus master, this pin has the same function as $\overline{\text{EOT0/TC0}}$. When the PPC403GC is not bus master, $\overline{\text{EOT3/TC3/XSize0}}$ is used as one of two external transfer size input bits, XSize0:1.
Error	136	O	System Error. Error goes to a logic 1 whenever a machine check error is detected in the PPC403GC. The Error pin then remains a logic 1 until the machine check error is cleared in the Exception Syndrome Register and/or Bus Error Syndrome Register.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
GND	1		Ground. All ground pins must be used.
	10		Ground. All ground pins must be used.
	15		Ground. All ground pins must be used.
	29		Ground. All ground pins must be used.
	30		Ground. All ground pins must be used.
	41		Ground. All ground pins must be used.
	50		Ground. All ground pins must be used.
	59		Ground. All ground pins must be used.
	60		Ground. All ground pins must be used.
	70		Ground. All ground pins must be used.
	81		Ground. All ground pins must be used.
	90		Ground. All ground pins must be used.
	101		Ground. All ground pins must be used.
	102		Ground. All ground pins must be used.
	111		Ground. All ground pins must be used.
	121		Ground. All ground pins must be used.
	130		Ground. All ground pins must be used.
	141		Ground. All ground pins must be used.
	150		Ground. All ground pins must be used.
Halt	9	I	Halt from external debugger, active low.
HoldAck	134	O	Hold Acknowledge. HoldAck outputs a logic 1 when the PPC403GC relinquishes its external bus to an external bus master. HoldAck outputs a logic 0 when the PPC403GC regains control of the bus.
HoldReq	14	I	Hold Request. External bus masters can request the PPC403GC bus by placing a logic1 on this pin. The external bus master relinquishes the bus to the PPC403GC by deasserting HoldReq.
INT0	31	I	Interrupt 0. INT0 is an interrupt input to the PPC403GC and users may program the pin to be either edge-triggered or level triggered and may also program the polarity to be active high or active low. The IOCR contains the bits necessary to program the trigger type and polarity.
INT1	32	I	Interrupt 1. See description of INT0.
INT2	33	I	Interrupt 2. See description of INT0.
INT3	34	I	Interrupt 3. See description of INT0.
INT4	35	I	Interrupt 4. See description of INT0.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
IVR	39		Interface voltage reference. When connected to 3.3V supply, allows the device to interface to an exclusively 3V system. When connected to 5V supply, allows the device to interface to 5V or mixed 3V/5V system. If any input or output connects to 5V system, this pin must be connected to 5V supply.
\overline{OE} / XSize1	126	O/I	Output Enable / External Master Transfer Size 1. When the PPC403GC is bus master, \overline{OE} enables the selected SRAMs to drive the data bus. The timing parameters of \overline{OE} relative to the chip select, \overline{CS} , are programmable via bits in the PPC403GC bank registers. When the PPC403GC is not bus master, \overline{OE} / XSize1 is used as one of two external transfer size input bits, XSize0:1.
Ready	13	I	Ready. Ready is used to insert externally generated (device-paced) wait states into bus transactions. The Ready pin is enabled via the Ready Enable bit in PPC403GC bank registers.
RecvD	27	I	Serial Port Receive Data
Reset	91	I/O	Reset. A logic 0 input placed on this pin for eight SysClk cycles causes the PPC403GC to begin a system reset. When a system reset is internally invoked, the Reset pin becomes a logic 0 output for three SysClk cycles, and the system must maintain Reset active for a total of eight cycles minimum.
R/W	127	I/O	Read / Write. When the PPC403GC is bus master, R/W is an output which is high when data is read from memory and low when data is written to memory. R/W is driven with the same timings as the address bus. When the PPC403GC is not bus master, R/W is an input from the external bus master which indicates the direction of data transfer.
SerClk	26	I	Serial Port Clock. Through the Serial Port Clock Source bit in the Input/Output Configuration register (IOCR), users may choose the serial port clock source from either the input on the SerClk pin or processor SysClk. The maximum allowable input frequency into SerClk is half the SysClk frequency.
SysClk	22	I	SysClk is the processor system clock input. SysClk supports a 50/50 duty cycle clock input at the rated chip frequency.
TCK	6	I	JTAG Test Clock Input. TCK is the clock source for the PPC403GC test access port (TAP). The maximum clock rate into the TCK pin is one half of the processor SysClk clock rate.
TDI	8	I	Test Data In. The TDI is used to input serial data into the TAP. When the TAP enables the use of the TDI pin, the TDI pin is sampled on the rising edge of TClk and this data is input to the selected TAP shift register.
TDO	16	O	Test Data Output. TDO is used to transmit data from the PPC403GC TAP. Data from the selected TAP shift register is shifted out on TDO.
TestA	23	I	Reserved for manufacturing test. Tied low for normal operation.
TestB	24	I	Reserved for manufacturing test. Tied high for normal operation.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
TestC/HoldPri	37	I	TestC / HoldReq Priority. TestC. Reserved for manufacturing test during the reset interval. While $\overline{\text{Reset}}$ is active, this signal should be tied low for normal operation. HoldReq Priority. When $\overline{\text{Reset}}$ is not active, this signal is sampled to determine the priority of the external bus master signal HoldReq. If HoldPri = 0 then the HoldReq signal is considered high priority, otherwise HoldReq is considered low priority.
TestD	38	I	Reserved for manufacturing test. Tied low for normal operation.
TimerClk	25	I	Timer Facility Clock. Through the Timer Clock Source bit in the Input/Output Configuration register (IOCR), users may choose the clock source for the Timer facility from either the input on the TimerClk pin or processor SysClk. The maximum input frequency into TimerClk is half the SysClk frequency.
TMS	7	I	Test Mode Select. The TMS pin is sampled by the TAP on the rising edge of TCK. The TAP state machine uses the TMS pin to determine the mode in which the TAP operates.
TS0	17	O	Trace Status 0
TS1	18	O	Trace Status 1
TS2	19	O	Trace Status 2
TS3	86	O	Trace Status 3
TS4	85	O	Trace Status 4
TS5	84	O	Trace Status 5
TS6	83	O	Trace Status 6
V _{DD}	20		Power. All power pins must be connected to 3.3V supply.
	21		Power. All power pins must be connected to 3.3V supply.
	40		Power. All power pins must be connected to 3.3V supply.
	49		Power. All power pins must be connected to 3.3V supply.
	61		Power. All power pins must be connected to 3.3V supply.
	69		Power. All power pins must be connected to 3.3V supply.
	80		Power. All power pins must be connected to 3.3V supply.
	89		Power. All power pins must be connected to 3.3V supply.
	100		Power. All power pins must be connected to 3.3V supply.
	120		Power. All power pins must be connected to 3.3V supply.
	129		Power. All power pins must be connected to 3.3V supply.
	140		Power. All power pins must be connected to 3.3V supply.
	149		Power. All power pins must be connected to 3.3V supply.
	160		Power. All power pins must be connected to 3.3V supply.

Table 13-1. PPC403GC Signal Descriptions (cont.)

Signal Name	Pin	I/O Type	Function
$\overline{\text{WBE0}}$ / A4	122	O/I	<p>Write Byte Enable 0 / Address Bus Bit 4.</p> <p>When the PPC403GC is bus master, the write byte-enable outputs, $\overline{\text{WBE0:3}}$, select the active byte(s) in a memory write access to SRAM.</p> <p>For 8-bit memory regions, $\overline{\text{WBE2}}$ and $\overline{\text{WBE3}}$ are address bits 30 and 31 and $\overline{\text{WBE0}}$ is the byte-enable line.</p> <p>For 16-bit memory regions, $\overline{\text{WBE2:WBE3}}$ are address bits A30:A31 and $\overline{\text{WBE0}}$ and $\overline{\text{WBE1}}$ are the high-byte and low-byte enables, respectively.</p> <p>For 32-bit memory regions, $\overline{\text{WBE0:3}}$ are byte enables for bytes 0-3 on the data bus, respectively.</p> <p>The byte enables can also be programmed as read/write byte enables, if $\text{IOCR}[\text{BEM}] = 1$. See Figure 3-5 on page 3-12 and Figure 3-6 on page 3-13 for more detail.</p> <p>When the PPC403GC is not bus master, $\overline{\text{WBE0:1}}$ are used as the A4:5 inputs (for bank register selection) and $\overline{\text{WBE2:3}}$ are used as the A30:31 inputs (for byte selection and page crossing detection).</p>
$\overline{\text{WBE1}}$ / A5	123	O/I	Write Byte Enable 1 / Address Bus Bit 5. See description of $\overline{\text{WBE0}}$ / A4.
$\overline{\text{WBE2}}$ / A30	124	O/I	Write Byte Enable 2 / Address Bus Bit 30. See description of $\overline{\text{WBE0}}$ / A4.
$\overline{\text{WBE3}}$ / A31	125	O/I	Write Byte Enable 3 / Address Bus Bit 31. See description of $\overline{\text{WBE0}}$ / A4.
XmitD	87	O	Serial Port Transmit Data

Table 13-2. Signals Ordered by Pin Number

Pin	Signal Names	Pin	Signal Names	Pin	Signal Names	Pin	Signal Names	Pin	Signal Names
1	GND	33	INT2	65	D18	97	A11	129	V _{DD}
2	DMAR0	34	INT3	66	D19	98	A12	130	GND
3	DMAR1	35	INT4	67	D20	99	A13	131	EOT1/TC1
4	DMAR2	36	CINT	68	D21	100	V _{DD}	132	EOT2/TC2
5	DMAR3 / XREQ	37	TestC/HoldPri	69	V _{DD}	101	GND	133	EOT3/TC3/XSize0
6	TCK	38	TestD	70	GND	102	GND	134	HoldAck
7	TMS	39	IVR	71	D22	103	A14	135	BusReq/DMADXFER
8	TDI	40	V _{DD}	72	D23	104	A15	136	Error
9	Halt	41	GND	73	D24	105	A16	137	DRAMOE
10	GND	42	D0	74	D25	106	A17	138	DRAMWE
11	BootW	43	D1	75	D26	107	A18	139	AMuxCAS
12	BusError	44	D2	76	D27	108	A19	140	V _{DD}
13	Ready	45	D3	77	D28	109	A20	141	GND
14	HoldReq	46	D4	78	D29	110	A21	142	CAS0
15	GND	47	D5	79	D30	111	GND	143	CAS1
16	TDO	48	D6	80	V _{DD}	112	A22	144	CAS2
17	TS0	49	V _{DD}	81	GND	113	A23	145	CAS3
18	TS1	50	GND	82	D31	114	A24	146	CS7/RAS0
19	TS2	51	D7	83	TS6	115	A25	147	CS6/RAS1
20	V _{DD}	52	D8	84	TS5	116	A26	148	CS5/RAS2
21	V _{DD}	53	D9	85	TS4	117	A27	149	V _{DD}
22	SysClk	54	D10	86	TS3	118	A28	150	GND
23	TestA	55	D11	87	XmitD	119	A29	151	CS4/RAS3
24	TestB	56	D12	88	DTR / RTS	120	V _{DD}	152	CS3
25	TimerClk	57	D13	89	V _{DD}	121	GND	153	CS2
26	SerClk	58	D14	90	GND	122	WBE0 / A4	154	CS1
27	RecvD	59	GND	91	Reset	123	WBE1 / A5	155	CS0
28	DSR / CTS	60	GND	92	A6	124	WBE2 / A30	156	DMAA0
29	GND	61	V _{DD}	93	A7	125	WBE3 / A31	157	DMAA1
30	GND	62	D15	94	A8	126	OE / XSize1	158	DMAA2
31	INT0	63	D16	95	A9	127	R/W	159	DMAA3 / XACK
32	INT1	64	D17	96	A10	128	EOT0/TC0	160	V _{DD}



Instruction Summary

This appendix contains PPC403GC instructions summarized alphabetically and by opcode.

- On page A-1, Section A.1 lists all PPC403GC mnemonics, including extended mnemonics, alphabetically. A short functional description is included for each mnemonic.
- On page A-42, Section A.2 lists all PPC403GC instructions, sorted by primary and secondary opcodes. Extended mnemonics are not included in the opcode list.
- On page A-50, Section A.3 illustrates the “Forms” (allowed arrangement of fields within instructions) for PPC403GC instructions.

A.1 Instruction Set and Extended Mnemonics – Alphabetical

Table A-1 summarizes the PPC403GC instruction set, including required extended mnemonics. All mnemonics are listed alphabetically, without regard to whether the mnemonic is realized in hardware or software. When an instruction supports multiple hardware mnemonics (for example, **b**, **ba**, **bl**, **bla** are all forms of **b**), the instruction is alphabetized under the root form. The hardware instructions are described in detail in Chapter 11 (Instruction Set) which is also alphabetized under the root form. Chapter 11 also describes the instruction operands and notation.

Note the following for every Branch Conditional mnemonic:

Bit 4 of the BO field provides a hint about the most likely outcome of a conditional branch (see Section 2.7.5 for a full discussion of Branch Prediction). Assemblers should set $BO_4 = 0$ unless a specific reason exists otherwise. In the BO field values specified in the table below, $BO_4 = 0$ has always been assumed. The assembler must allow the programmer to specify Branch Prediction. To do this, the assembler will support a suffix to every conditional branch mnemonic, as follows:

- + Predict branch to be taken.
- Predict branch not to be taken.

As specific examples, **bc** also could be coded as **bc+** or **bc–**, and **bne** also could be coded **bne+** or **bne–**. These alternate codings set $BO_4 = 1$ only if the requested prediction differs from the Standard Prediction (see Section 2.7.5).

Table A-1. PPC403GC Instruction Syntax Summary

Mnemonic	Operands	Function	Other Registers Changed	Page
add	RT, RA, RB	Add (RA) to (RB). Place result in RT.		11-6
add.			CR[CR0]	
addo			XER[SO, OV]	
addo.			CR[CR0] XER[SO, OV]	
addc	RT, RA, RB	Add (RA) to (RB). Place result in RT. Place carry-out in XER[CA].		11-7
addc.			CR[CR0]	
addco			XER[SO, OV]	
addco.			CR[CR0] XER[SO, OV]	
adde	RT, RA, RB	Add XER[CA], (RA), (RB). Place result in RT. Place carry-out in XER[CA].		11-8
adde.			CR[CR0]	
addeo			XER[SO, OV]	
addeo.			CR[CR0] XER[SO, OV]	
addi	RT, RA, IM	Add EXTS(IM) to (RA 0). Place result in RT.		11-9
addic	RT, RA, IM	Add EXTS(IM) to (RA 0). Place result in RT. Place carry-out in XER[CA].		11-10
addic.	RT, RA, IM	Add EXTS(IM) to (RA 0). Place result in RT. Place carry-out in XER[CA].	CR[CR0]	11-11
addis	RT, RA, IM	Add (IM ¹⁶ 0) to (RA 0). Place result in RT.		11-12
addme	RT, RA	Add XER[CA], (RA), (-1). Place result in RT. Place carry-out in XER[CA].		11-13
addme.			CR[CR0]	
addmeo			XER[SO, OV]	
addmeo.			CR[CR0] XER[SO, OV]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
addze	RT, RA	Add XER[CA] to (RA). Place result in RT. Place carry-out in XER[CA].		11-14
addze.			CR[CR0]	
addzeo			XER[SO, OV]	
addzeo.			CR[CR0] XER[SO, OV]	
and	RA, RS, RB	AND (RS) with (RB). Place result in RA.		11-15
and.			CR[CR0]	
andc	RA, RS, RB	AND (RS) with \neg (RB). Place result in RA.		11-16
andc.			CR[CR0]	
andi.	RA, RS, IM	AND (RS) with $(^{16}0 \parallel \text{IM})$. Place result in RA.	CR[CR0]	11-17
andis.	RA, RS, IM	AND (RS) with $(\text{IM} \parallel ^{16}0)$. Place result in RA.	CR[CR0]	11-18
b	target	Branch unconditional relative. $\text{LI} \leftarrow (\text{target} - \text{CIA})_{6:29}$ $\text{NIA} \leftarrow \text{CIA} + \text{EXTS}(\text{LI} \parallel ^{20})$		11-19
ba		Branch unconditional absolute. $\text{LI} \leftarrow \text{target}_{6:29}$ $\text{NIA} \leftarrow \text{EXTS}(\text{LI} \parallel ^{20})$		
bl		Branch unconditional relative. $\text{LI} \leftarrow (\text{target} - \text{CIA})_{6:29}$ $\text{NIA} \leftarrow \text{CIA} + \text{EXTS}(\text{LI} \parallel ^{20})$	$(\text{LR}) \leftarrow \text{CIA} + 4.$	
bla		Branch unconditional absolute. $\text{LI} \leftarrow \text{target}_{6:29}$ $\text{NIA} \leftarrow \text{EXTS}(\text{LI} \parallel ^{20})$	$(\text{LR}) \leftarrow \text{CIA} + 4.$	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bc	BO, BI, target	Branch conditional relative. $BD \leftarrow (target - CIA)_{16:29}$ $NIA \leftarrow CIA + EXTS(BD \parallel ^20)$	CTR if $BO_2 = 0$.	11-20
bca		Branch conditional absolute. $BD \leftarrow target_{16:29}$ $NIA \leftarrow EXTS(BD \parallel ^20)$	CTR if $BO_2 = 0$.	
bcl		Branch conditional relative. $BD \leftarrow (target - CIA)_{16:29}$ $NIA \leftarrow CIA + EXTS(BD \parallel ^20)$	CTR if $BO_2 = 0$. (LR) $\leftarrow CIA + 4$.	
bcla		Branch conditional absolute. $BD \leftarrow target_{16:29}$ $NIA \leftarrow EXTS(BD \parallel ^20)$	CTR if $BO_2 = 0$. (LR) $\leftarrow CIA + 4$.	
bcctr	BO, BI	Branch conditional to address in CTR. Using (CTR) at exit from instruction, $NIA \leftarrow CTR_{0:29} \parallel ^20$.	CTR if $BO_2 = 0$.	11-27
bcctrl			CTR if $BO_2 = 0$. (LR) $\leftarrow CIA + 4$.	
bclr	BO, BI	Branch conditional to address in LR. Using (LR) at entry to instruction, $NIA \leftarrow LR_{0:29} \parallel ^20$.	CTR if $BO_2 = 0$.	11-31
bctrl			CTR if $BO_2 = 0$. (LR) $\leftarrow CIA + 4$.	
bctr		Branch unconditionally, to address in CTR. <i>Extended mnemonic for</i> bctr 20,0		11-27
bctrl		<i>Extended mnemonic for</i> bctrl 20,0	(LR) $\leftarrow CIA + 4$.	
bdnz	target	Decrement CTR. Branch if CTR $\neq 0$. <i>Extended mnemonic for</i> bc 16,0,target		11-20
bdnza		<i>Extended mnemonic for</i> bca 16,0,target		
bdnzl		<i>Extended mnemonic for</i> bcl 16,0,target	(LR) $\leftarrow CIA + 4$.	
bdnzla		<i>Extended mnemonic for</i> bcla 16,0,target	(LR) $\leftarrow CIA + 4$.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdnzlr		Decrement CTR. Branch if CTR \neq 0, to address in LR. <i>Extended mnemonic for</i> bclr 16,0		11-31
bdnzlrl		<i>Extended mnemonic for</i> bclrl 16,0	(LR) \leftarrow CIA + 4.	
bdnzf	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 0,cr_bit,target		11-20
bdnzfa		<i>Extended mnemonic for</i> bca 0,cr_bit,target		
bdnzfl		<i>Extended mnemonic for</i> bcl 0,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnzfla		<i>Extended mnemonic for</i> bcla 0,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnzflr	cr_bit	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for</i> bclr 0,cr_bit		11-31
bdnzflrl		<i>Extended mnemonic for</i> bclrl 0,cr_bit	(LR) \leftarrow CIA + 4.	
bdnzt	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 8,cr_bit,target		11-20
bdnzta		<i>Extended mnemonic for</i> bca 8,cr_bit,target		
bdnztl		<i>Extended mnemonic for</i> bcl 8,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnztla		<i>Extended mnemonic for</i> bcla 8,cr_bit,target	(LR) \leftarrow CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdnztlr	cr_bit	Decrement CTR. Branch if CTR $\neq 0$ AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 8,cr_bit		11-31
bdnztlrl		<i>Extended mnemonic for</i> bclrl 8,cr_bit	(LR) \leftarrow CIA + 4.	
bdz	target	Decrement CTR. Branch if CTR = 0. <i>Extended mnemonic for</i> bc 18,0,target		11-20
bdza		<i>Extended mnemonic for</i> bca 18,0,target		
bdzl		<i>Extended mnemonic for</i> bcl 18,0,target	(LR) \leftarrow CIA + 4.	
bdzla		<i>Extended mnemonic for</i> bcla 18,0,target	(LR) \leftarrow CIA + 4.	
bdzlr		Decrement CTR. Branch if CTR = 0, to address in LR. <i>Extended mnemonic for</i> bclr 18,0		11-31
bdzlrl		<i>Extended mnemonic for</i> bclrl 18,0	(LR) \leftarrow CIA + 4.	
bdzf	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 2,cr_bit,target		11-20
bdzfa		<i>Extended mnemonic for</i> bca 2,cr_bit,target		
bdzfl		<i>Extended mnemonic for</i> bcl 2,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdzfla		<i>Extended mnemonic for</i> bcla 2,cr_bit,target	(LR) \leftarrow CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdzflr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0 to address in LR. <i>Extended mnemonic for</i> bclr 2,cr_bit		11-31
bdzflrl		<i>Extended mnemonic for</i> bclrl 2,cr_bit	(LR) ← CIA + 4.	
bdzt	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 10,cr_bit,target		11-20
bdzta		<i>Extended mnemonic for</i> bca 10,cr_bit,target		
bdztl		<i>Extended mnemonic for</i> bcl 10,cr_bit,target	(LR) ← CIA + 4.	
bdztla		<i>Extended mnemonic for</i> bcla 10,cr_bit,target	(LR) ← CIA + 4.	
bdztlr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 10,cr_bit		11-31
bdztlrl		<i>Extended mnemonic for</i> bclrl 10,cr_bit	(LR) ← CIA + 4.	
beq	[cr_field,] target	Branch if equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+2,target		11-20
beqa		<i>Extended mnemonic for</i> bca 12,4*cr_field+2,target		
beql		<i>Extended mnemonic for</i> bcl 12,4*cr_field+2,target	(LR) ← CIA + 4.	
beqla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+2,target	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
beqctr	[cr_field]	Branch if equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+2		11-27
beqctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+2	(LR) ← CIA + 4.	
beqlr	[cr_field]	Branch if equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+2		11-31
beqlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+2	(LR) ← CIA + 4.	
bf	cr_bit, target	Branch if CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 4,cr_bit,target		11-20
bfa		<i>Extended mnemonic for</i> bca 4,cr_bit,target		
bfl		<i>Extended mnemonic for</i> bcl 4,cr_bit,target	(LR) ← CIA + 4.	
bfla		<i>Extended mnemonic for</i> bcla 4,cr_bit,target	(LR) ← CIA + 4.	
bfctr	cr_bit	Branch if CR _{cr_bit} = 0, to address in CTR. <i>Extended mnemonic for</i> bcctr 4,cr_bit		11-27
bfctrl		<i>Extended mnemonic for</i> bcctrl 4,cr_bit	(LR) ← CIA + 4.	
bflr	cr_bit	Branch if CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for</i> bclr 4,cr_bit		11-31
bflrl		<i>Extended mnemonic for</i> bclrl 4,cr_bit	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bge	[cr_field,] target	Branch if greater than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+0,target		11-20
bgea		<i>Extended mnemonic for</i> bca 4,4*cr_field+0,target		
bgel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bgeia		<i>Extended mnemonic for</i> bcla 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bgectr	[cr_field]	Branch if greater than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+0		11-27
bgectrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bgeihr	[cr_field]	Branch if greater than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclhr 4,4*cr_field+0		11-31
bgeihrl		<i>Extended mnemonic for</i> bclhrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bgt	[cr_field,] target	Branch if greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+1,target		11-20
bgtia		<i>Extended mnemonic for</i> bca 12,4*cr_field+1,target		
bgtl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+1,target	(LR) ← CIA + 4.	
bgtia		<i>Extended mnemonic for</i> bcla 12,4*cr_field+1,target	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bgtctr	[cr_field]	Branch if greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+1		11-27
bgtctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+1	(LR) ← CIA + 4.	
bgtlr	[cr_field]	Branch if greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+1		11-31
bgtlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+1	(LR) ← CIA + 4.	
ble	[cr_field,] target	Branch if less than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+1,target		11-20
blea		<i>Extended mnemonic for</i> bca 4,4*cr_field+1,target		
blel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+1,target	(LR) ← CIA + 4.	
blela		<i>Extended mnemonic for</i> bcla 4,4*cr_field+1,target	(LR) ← CIA + 4.	
blectr	[cr_field]	Branch if less than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+1		11-27
blectrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+1	(LR) ← CIA + 4.	
blelr	[cr_field]	Branch if less than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+1		11-31
blelrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+1	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
blr		Branch unconditionally, to address in LR. <i>Extended mnemonic for</i> bclr 20,0		11-31
blrl		<i>Extended mnemonic for</i> bclrl 20,0	(LR) ← CIA + 4.	
blt	[cr_field,] target	Branch if less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+0,target		11-20
blta		<i>Extended mnemonic for</i> bca 12,4*cr_field+0,target		
bltl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+0,target	(LR) ← CIA + 4.	
bltla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+0,target	(LR) ← CIA + 4.	
bltctr	[cr_field]	Branch if less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+0		11-27
bltctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+0	(LR) ← CIA + 4.	
bltlr	[cr_field]	Branch if less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+0		11-31
bltlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+0	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bne	[cr_field,] target	Branch if not equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+2,target		11-20
bnea		<i>Extended mnemonic for</i> bca 4,4*cr_field+2,target		
bnel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+2,target	(LR) ← CIA + 4.	
bnela		<i>Extended mnemonic for</i> bcla 4,4*cr_field+2,target	(LR) ← CIA + 4.	
bnctr	[cr_field]	Branch if not equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+2		11-27
bnctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+2	(LR) ← CIA + 4.	
bnelr	[cr_field]	Branch if not equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+2		11-31
bnelrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+2	(LR) ← CIA + 4.	
bng	[cr_field,] target	Branch if not greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+1,target		11-20
bnga		<i>Extended mnemonic for</i> bca 4,4*cr_field+1,target		
bngl		<i>Extended mnemonic for</i> bcl 4,4*cr_field+1,target	(LR) ← CIA + 4.	
bngla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+1,target	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bngctr	[cr_field]	Branch if not greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+1		11-27
bngctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+1	(LR) ← CIA + 4.	
bnglrr	[cr_field]	Branch if not greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclrr 4,4*cr_field+1		11-31
bnglrrl		<i>Extended mnemonic for</i> bclrrl 4,4*cr_field+1	(LR) ← CIA + 4.	
bnl	[cr_field,] target	Branch if not less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+0,target		11-20
bnla		<i>Extended mnemonic for</i> bca 4,4*cr_field+0,target		
bnll		<i>Extended mnemonic for</i> bcl 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bnlla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bnlctr	[cr_field]	Branch if not less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+0		11-27
bnlctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bnllrr	[cr_field]	Branch if not less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclrr 4,4*cr_field+0		11-31
bnllrrl		<i>Extended mnemonic for</i> bclrrl 4,4*cr_field+0	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bns	[cr_field,] target	Branch if not summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target		11-20
bnsa		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target		
bnsi		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnsia		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnsctr	[cr_field]	Branch if not summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+3		11-27
bnsctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnslr	[cr_field]	Branch if not summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+3		11-31
bnslrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnu	[cr_field,] target	Branch if not unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target		11-20
bnua		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target		
bnul		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnula		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bnuctr	[cr_field]	Branch if not unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+3		11-27
bnuctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnulr	[cr_field]	Branch if not unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+3		11-31
bnulrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bso	[cr_field,] target	Branch if summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target		11-20
bsoa		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target		
bsol		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bsola		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bsoctr	[cr_field]	Branch if summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+3		11-27
bsoctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+3	(LR) ← CIA + 4.	
bsolr	[cr_field]	Branch if summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+3		11-31
bsolrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+3	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bt	cr_bit, target	Branch if CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 12,cr_bit,target		11-20
bta		<i>Extended mnemonic for</i> bca 12,cr_bit,target		
btl		<i>Extended mnemonic for</i> bcl 12,cr_bit,target	(LR) ← CIA + 4.	
btla		<i>Extended mnemonic for</i> bcla 12,cr_bit,target	(LR) ← CIA + 4.	
btctr	cr_bit	Branch if CR _{cr_bit} = 1, to address in CTR. <i>Extended mnemonic for</i> bcctr 12,cr_bit		11-27
btctrl		<i>Extended mnemonic for</i> bcctrl 12,cr_bit	(LR) ← CIA + 4.	
btlr	cr_bit	Branch if CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 12,cr_bit		11-31
btlrl		<i>Extended mnemonic for</i> bclrl 12,cr_bit	(LR) ← CIA + 4.	
bun	[cr_field,] target	Branch if unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target		11-20
buna		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target		
bunl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bunla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bunctr	[cr_field]	Branch if unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+3		11-27
bunctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+3	(LR) ← CIA + 4.	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bunlr	[cr_field]	Branch if unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+3		11-31
bunlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+3	(LR) \leftarrow CIA + 4.	
clrlwi	RA, RS, n	Clear left immediate. (n < 32) (RA) _{0:n-1} \leftarrow ⁿ 0 <i>Extended mnemonic for</i> rlwinm RA,RS,0,n,31		11-130
clrlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,n,31	CR[CR0]	
clrlslwi	RA, RS, b, n	Clear left and shift left immediate. (n \leq b < 32) (RA) _{b-n:31-n} \leftarrow (RS) _{b:31} (RA) _{32-n:31} \leftarrow ⁿ 0 (RA) _{0:b-n-1} \leftarrow ^{b-n} 0 <i>Extended mnemonic for</i> rlwinm RA,RS,n,b-n,31-n		11-130
clrlslwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,b-n,31-n	CR[CR0]	
clrrwi	RA, RS, n	Clear right immediate. (n < 32) (RA) _{32-n:31} \leftarrow ⁿ 0 <i>Extended mnemonic for</i> rlwinm RA,RS,0,0,31-n		11-130
clrrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,0,31-n	CR[CR0]	
cmp	BF, 0, RA, RB	Compare (RA) to (RB), signed. Results in CR[CRn], where n = BF.		11-36
cmpi	BF, 0, RA, IM	Compare (RA) to EXTS(IM), signed. Results in CR[CRn], where n = BF.		11-37
cmpl	BF, 0, RA, RB	Compare (RA) to (RB), unsigned. Results in CR[CRn], where n = BF.		11-38
cmpli	BF, 0, RA, IM	Compare (RA) to (¹⁶ 0 IM), unsigned. Results in CR[CRn], where n = BF.		11-39

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
cmplw	[BF,] RA, RB	Compare Logical Word. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmpl BF,0,RA,RB		11-38
cmplwi	[BF,] RA, IM	Compare Logical Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmpli BF,0,RA,IM		11-39
cmpw	[BF,] RA, RB	Compare Word. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmp BF,0,RA,RB		11-36
cmpwi	[BF,] RA, IM	Compare Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmpi BF,0,RA,IM		11-37
cntlzw	RA, RS	Count leading zeros in RS. Place result in RA.		11-40
cntlzw.			CR[CR0]	
crand	BT, BA, BB	AND bit (CR _{BA}) with (CR _{BB}). Place result in CR _{BT} .		11-41
crandc	BT, BA, BB	AND bit (CR _{BA}) with \neg (CR _{BB}). Place result in CR _{BT} .		11-42
crclr	bx	Condition register clear. <i>Extended mnemonic for</i> crxor bx,bx,bx		11-48
creqv	BT, BA, BB	Equivalence of bit CR _{BA} with CR _{BB} . $CR_{BT} \leftarrow \neg(CR_{BA} \oplus CR_{BB})$		11-43
crmove	bx, by	Condition register move. <i>Extended mnemonic for</i> cror bx,by,by		11-46
crnand	BT, BA, BB	NAND bit (CR _{BA}) with (CR _{BB}). Place result in CR _{BT} .		11-44
crnor	BT, BA, BB	NOR bit (CR _{BA}) with (CR _{BB}). Place result in CR _{BT} .		11-45
crnot	bx, by	Condition register not. <i>Extended mnemonic for</i> crnor bx,by,by		11-45

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
cror	BT, BA, BB	OR bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-46
crorc	BT, BA, BB	OR bit (CR_{BA}) with $\neg(CR_{BB})$. Place result in CR_{BT} .		11-47
crset	bx	Condition register set. <i>Extended mnemonic for</i> creqv bx,bx,bx		11-43
crxor	BT, BA, BB	XOR bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-48
dcbf	RA, RB	Flush (store, then invalidate) the data cache block which contains the effective address ($RA 0$) + (RB).		11-49
dcbi	RA, RB	Invalidate the data cache block which contains the effective address ($RA 0$) + (RB).		11-50
dcbst	RA, RB	Store the data cache block which contains the effective address ($RA 0$) + (RB).		11-51
dcbt	RA, RB	Load the data cache block which contains the effective address ($RA 0$) + (RB).		11-52
dcbtst	RA, RB	Load the data cache block which contains the effective address ($RA 0$) + (RB).		11-54
dcbz	RA, RB	Zero the data cache block which contains the effective address ($RA 0$) + (RB).		11-56
dccci	RA, RB	Invalidate the data cache congruence class associated with the effective address ($RA 0$) + (RB).		11-58
dcread	RT, RA, RB	Read either tag or data information from the data cache congruence class associated with the effective address ($RA 0$) + (RB). Place the results in RT.		11-60
divw	RT, RA, RB	Divide (RA) by (RB), signed. Place result in RT.		11-62
divw.			CR[CR0]	
divwo			XER[SO, OV]	
divwo.			CR[CR0] XER[SO, OV]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
divwu	RT, RA, RB	Divide (RA) by (RB), unsigned. Place result in RT.		11-63
divwu.			CR[CR0]	
divwuo			XER[SO, OV]	
divwuo.			CR[CR0] XER[SO, OV]	
eieio		Storage synchronization. All loads and stores that precede the eieio instruction complete before any loads and stores that follow the instruction access main storage. Implemented as sync , which is more restrictive.		11-64
eqv	RA, RS, RB	Equivalence of (RS) with (RB). $(RA) \leftarrow \neg((RS) \oplus (RB))$		11-65
eqv.			CR[CR0]	
extlwi	RA, RS, n, b	Extract and left justify immediate. ($n > 0$) $(RA)_{0:n-1} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{n:31} \leftarrow 32-n_0$ <i>Extended mnemonic for</i> rlwinm RA,RS,b,0,n-1		11-130
extlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,b,0,n-1	CR[CR0]	
extrwi	RA, RS, n, b	Extract and right justify immediate. ($n > 0$) $(RA)_{32-n:31} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{0:31-n} \leftarrow 32-n_0$ <i>Extended mnemonic for</i> rlwinm RA,RS,b+n,32-n,31		11-130
extrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,b+n,32-n,31	CR[CR0]	
extsb	RA, RS	Extend the sign of byte $(RS)_{24:31}$. Place the result in RA.		11-66
extsb.			CR[CR0]	
extsh	RA, RS	Extend the sign of halfword $(RS)_{16:31}$. Place the result in RA.		11-67
extsh.			CR[CR0]	
icbi	RA, RB	Invalidate the instruction cache block which contains the effective address $(RA 0) + (RB)$.		11-68
icbt	RA, RB	Load the instruction cache block which contains the effective address $(RA 0) + (RB)$.		11-70

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
iccci	RA, RB	Invalidate instruction cache congruence class associated with the effective address (RA 0) + (RB).		11-72
icread	RA, RB	Read either tag or data information from the instruction cache congruence class associated with the effective address (RA 0) + (RB). Place the results in ICDBDR.		11-74
inslwi	RA, RS, n, b	Insert from left immediate. (n > 0) $(RA)_{b:b+n-1} \leftarrow (RS)_{0:n-1}$ <i>Extended mnemonic for</i> rlwimi RA,RS,32-b,b,b+n-1		11-129
inslwi.		<i>Extended mnemonic for</i> rlwimi. RA,RS,32-b,b,b+n-1	CR[CR0]	
insrwi	RA, RS, n, b	Insert from right immediate. (n > 0) $(RA)_{b:b+n-1} \leftarrow (RS)_{32-n:31}$ <i>Extended mnemonic for</i> rlwimi RA,RS,32-b-n,b,b+n-1		11-129
insrwi.		<i>Extended mnemonic for</i> rlwimi. RA,RS,32-b-n,b,b+n-1	CR[CR0]	
isync		Synchronize execution context by flushing the prefetch queue.		11-76
la	RT, D(RA)	Load address. (RA ≠ 0) D is an offset from a base address that is assumed to be (RA). $(RT) \leftarrow (RA) + \text{EXTS}(D)$ <i>Extended mnemonic for</i> addi RT,RA,D		11-9
lbz	RT, D(RA)	Load byte from EA = (RA 0) + EXTS(D) and pad left with zeroes, $(RT) \leftarrow {}^{24}0 \parallel \text{MS}(EA,1)$.		11-77
lbzu	RT, D(RA)	Load byte from EA = (RA 0) + EXTS(D) and pad left with zeroes, $(RT) \leftarrow {}^{24}0 \parallel \text{MS}(EA,1)$. Update the base address, $(RA) \leftarrow EA$.		11-78

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
lbzux	RT, RA, RB	Load byte from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{24}0 \parallel$ MS(EA,1). Update the base address, (RA) \leftarrow EA.		11-79
lbzx	RT, RA, RB	Load byte from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{24}0 \parallel$ MS(EA,1).		11-80
lha	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)).		11-81
lhau	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)). Update the base address, (RA) \leftarrow EA.		11-82
lhaux	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)). Update the base address, (RA) \leftarrow EA.		11-83
lhax	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)).		11-84
lbrx	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) then reverse byte order and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel$ MS(EA+1,1) \parallel MS(EA,1).		11-85
lhz	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel$ MS(EA,2).		11-86
lhz	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel$ MS(EA,2). Update the base address, (RA) \leftarrow EA.		11-87

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
lhux	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel$ MS(EA,2). Update the base address, (RA) \leftarrow EA.		11-88
lhzx	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel$ MS(EA,2).		11-89
li	RT, IM	Load immediate. (RT) \leftarrow EXTS(IM) <i>Extended mnemonic for addi RT,0,value</i>		11-9
lis	RT, IM	Load immediate shifted. (RT) \leftarrow (IM \parallel $^{16}0$) <i>Extended mnemonic for addis RT,0,value</i>		11-12
lmw	RT, D(RA)	Load multiple words starting from EA = (RA 0) + EXTS(D). Place into consecutive registers, RT through GPR(31). RA is not altered unless RA = GPR(31).		11-90
lswi	RT, RA, NB	Load consecutive bytes from EA=(RA 0). Number of bytes n=32 if NB=0, else n=NB. Stack bytes into words in CEIL(n/4) consecutive registers starting with RT, to R _{FINAL} \leftarrow ((RT + CEIL(n/4) – 1) % 32). GPR(0) is consecutive to GPR(31). RA is not altered unless RA = R _{FINAL} .		11-91
lswx	RT, RA, RB	Load consecutive bytes from EA=(RA 0)+(RB). Number of bytes n=XER[TBC]. Stack bytes into words in CEIL(n/4) consecutive registers starting with RT, to R _{FINAL} \leftarrow ((RT + CEIL(n/4) – 1) % 32). GPR(0) is consecutive to GPR(31). RA is not altered unless RA = R _{FINAL} . RB is not altered unless RB = R _{FINAL} . If n=0, content of RT is undefined.		11-93
lwarx	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4). Set the Reservation bit.		11-95

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
lwbrx	RT, RA, RB	Load word from EA = (RA 0) + (RB) then reverse byte order, (RT) \leftarrow MS(EA+3,1) MS(EA+2,1) MS(EA+1,1) MS(EA,1).		11-96
lwz	RT, D(RA)	Load word from EA = (RA 0) + EXTS(D) and place in RT, (RT) \leftarrow MS(EA,4).		11-97
lwzu	RT, D(RA)	Load word from EA = (RA 0) + EXTS(D) and place in RT, (RT) \leftarrow MS(EA,4). Update the base address, (RA) \leftarrow EA.		11-98
lwzux	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4). Update the base address, (RA) \leftarrow EA.		11-99
lwzx	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4).		11-100
mcrf	BF, BFA	Move CR field, (CR[CRn]) \leftarrow (CR[CRm]) where m \leftarrow BFA and n \leftarrow BF.		11-101
mcrxr	BF	Move XER[0:3] into field CRn, where n \leftarrow BF. CR[CRn] \leftarrow (XER[SO, OV, CA]). (XER[SO, OV, CA]) \leftarrow ³ 0.		11-102
mfcrr	RT	Move from CR to RT, (RT) \leftarrow (CR).		11-103

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mfbea mfbes mfbr0 mfbr1 mfbr2 mfbr3 mfbr4 mfbr5 mfbr6 mfbr7 mfdmacc0 mfdmacc1 mfdmacc2 mfdmacc3 mfdmacr0 mfdmacr1 mfdmacr2 mfdmacr3 mfdmact0 mfdmact1 mfdmact2 mfdmact3 mfdmada0 mfdmada1 mfdmada2 mfdmada3 mfdmasa0 mfdmasa1 mfdmasa2 mfdmasa3 mfdmasr mfexisr mfexier mfio cr	RT	Move from device control register DCRN. <i>Extended mnemonic for</i> mfdcr RT,DCRN See Table 12-3 on page 12-4 for listing of valid DCRN values.		11-104
mfdcr	RT, DCRN	Move from DCR to RT, (RT) \leftarrow (DCR(DCRN)).		11-104
mfmsr	RT	Move from MSR to RT, (RT) \leftarrow (MSR).		11-106

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mfcdbcr mfctr mfdac1 mfdac2 mfdbsr mfdccr mfdcwr mfdear mfesr mfevpr mfiac1 mfiac2 mficcr mficdbdr mflr mfpbl1 mfpbl2 mfpbu1 mfpbu2 mfpid mfpit mfpvr mfsgsr mfspgr0 mfspgr1 mfspgr2 mfspgr3 mfssr0 mfssr1 mfssr2 mfssr3 mftbhi mftbhu mftblo mftblu mftcr mftsr mfxer mfzpr	RT	Move from special purpose register SPRN. <i>Extended mnemonic for</i> mfsprr RT,SPRN See Table 12-2 on page 12-2 for listing of valid SPRN values.		11-107
mfsprr	RT, SPRN	Move from SPR to RT, (RT) ← (SPR(SPRN)).		11-107

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mr	RT, RS	Move register. $(RT) \leftarrow (RS)$ <i>Extended mnemonic for</i> or RT,RS,RS		11-123
mr.		<i>Extended mnemonic for</i> or. RT,RS,RS	CR[CR0]	
mtr	RS	Move to Condition Register. <i>Extended mnemonic for</i> mtrcf 0xFF,RS		11-109
mtrcf	FXM, RS	Move some or all of the contents of RS into CR as specified by FXM field, mask $\leftarrow {}^4(FXM_0) \parallel {}^4(FXM_1) \parallel \dots \parallel {}^4(FXM_6) \parallel {}^4(FXM_7)$. $(CR) \leftarrow ((RS) \wedge \text{mask}) \vee (CR) \wedge \neg \text{mask}$.		11-109

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mtbear mtbesr mtbr0 mtbr1 mtbr2 mtbr3 mtbr4 mtbr5 mtbr6 mtbr7 mtdmacc0 mtdmacc1 mtdmacc2 mtdmacc3 mtdmacr0 mtdmacr1 mtdmacr2 mtdmacr3 mtdmact0 mtdmact1 mtdmact2 mtdmact3 mtdmada0 mtdmada1 mtdmada2 mtdmada3 mtdmasa0 mtdmasa1 mtdmasa2 mtdmasa3 mtdmasr mtexisr mtexier mtiocr	RS	Move to device control register DCRN. <i>Extended mnemonic for mtdcr DCRN,RS</i> See Table 12-3 on page 12-4 for listing of valid DCRN values.		11-111
mtdcr	DCRN, RS	Move to DCR from RS, (DCR(DCRN)) ← (RS).		11-111
mtmsr	RS	Move to MSR from RS, (MSR) ← (RS).		11-113

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mtcdbr mtctr mtdac1 mtdac2 mtdbsr mtdccr mtdcwr mtesr mtevpr mtiac1 mtiac2 mticcr mticdbdr mtlr mtpbl1 mtpbl2 mtpbu1 mtpbu2 mtpid mtpit mtsgr mtsprg0 mtsprg1 mtsprg2 mtsprg3 mtsrr0 mtsrr1 mtsrr2 mtsrr3 mttbhi mttblo mttcr mttsr mtxer mtzpr	RS	Move to special purpose register SPRN. <i>Extended mnemonic for</i> mtspr SPRN,RS See Table 12-2 on page 12-2 for listing of valid SPRN values.		11-114
mtspr	SPRN, RS	Move to SPR from RS, (SPR(SPRN)) \leftarrow (RS).		11-114
mulhw	RT, RA, RB	Multiply (RA) and (RB), signed. Place hi-order result in RT. $\text{prod}_{0:63} \leftarrow (\text{RA}) \times (\text{RB})$ (signed). (RT) $\leftarrow \text{prod}_{0:31}$.		11-116
mulhw.			CR[CR0]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mulhwu	RT, RA, RB	Multiply (RA) and (RB), unsigned. Place hi-order result in RT. $\text{prod}_{0:63} \leftarrow (\text{RA}) \times (\text{RB})$ (unsigned). $(\text{RT}) \leftarrow \text{prod}_{0:31}$.		11-117
mulhwu.			CR[CR0]	
mulli	RT, RA, IM	Multiply (RA) and IM, signed. Place lo-order result in RT. $\text{prod}_{0:47} \leftarrow (\text{RA}) \times \text{IM}$ (signed) $(\text{RT}) \leftarrow \text{prod}_{16:47}$		11-118
mullw	RT, RA, RB	Multiply (RA) and (RB), signed. Place lo-order result in RT. $\text{prod}_{0:63} \leftarrow (\text{RA}) \times (\text{RB})$ (signed). $(\text{RT}) \leftarrow \text{prod}_{32:63}$.		11-119
mullw.			CR[CR0]	
mullwo			XER[SO, OV]	
mullwo.			CR[CR0] XER[SO, OV]	
nand	RA, RS, RB	NAND (RS) with (RB). Place result in RA.		11-120
nand.			CR[CR0]	
neg	RT, RA	Negative (two's complement) of RA. $(\text{RT}) \leftarrow \neg(\text{RA}) + 1$		11-121
neg.			CR[CR0]	
nego			XER[SO, OV]	
nego.			CR[CR0] XER[SO, OV]	
nop		Preferred no-op, triggers optimizations based on no-ops. <i>Extended mnemonic for</i> ori 0,0,0		11-125
nor	RA, RS, RB	NOR (RS) with (RB). Place result in RA.		11-122
nor.			CR[CR0]	
not	RA, RS	Complement register. $(\text{RA}) \leftarrow \neg(\text{RS})$ <i>Extended mnemonic for</i> nor RA,RS,RS		11-122
not.		<i>Extended mnemonic for</i> nor. RA,RS,RS	CR[CR0]	
or	RA, RS, RB	OR (RS) with (RB). Place result in RA.		11-123
or.			CR[CR0]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
orc	RA, RS, RB	OR (RS) with \neg (RB). Place result in RA.		11-124
orc.			CR[CR0]	
ori	RA, RS, IM	OR (RS) with ($^{16}0 \parallel$ IM). Place result in RA.		11-125
oris	RA, RS, IM	OR (RS) with (IM \parallel $^{16}0$). Place result in RA.		11-126
rfci		Return from critical interrupt (PC) \leftarrow (SRR2). (MSR) \leftarrow (SRR3).		11-127
rfi		Return from interrupt. (PC) \leftarrow (SRR0). (MSR) \leftarrow (SRR1).		11-128
rlwimi	RA, RS, SH, MB, ME	Rotate left word immediate, then insert according to mask. $r \leftarrow \text{ROTL}((RS), SH)$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m) \vee ((RA) \wedge \neg m)$		11-129
rlwimi.			CR[CR0]	
rlwinm	RA, RS, SH, MB, ME	Rotate left word immediate, then AND with mask. $r \leftarrow \text{ROTL}((RS), SH)$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m)$		11-130
rlwinm.			CR[CR0]	
rlwnm	RA, RS, RB, MB, ME	Rotate left word, then AND with mask. $r \leftarrow \text{ROTL}((RS), (RB)_{27:31})$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m)$		11-133
rlwnm.			CR[CR0]	
rotlw	RA, RS, RB	Rotate left. $(RA) \leftarrow \text{ROTL}((RS), (RB)_{27:31})$ <i>Extended mnemonic for rlwnm RA,RS,RB,0,31</i>		11-133
rotlw.		<i>Extended mnemonic for rlwnm. RA,RS,RB,0,31</i>	CR[CR0]	
rotlwi	RA, RS, n	Rotate left immediate. $(RA) \leftarrow \text{ROTL}((RS), n)$ <i>Extended mnemonic for rlwinm RA,RS,n,0,31</i>		11-130
rotlwi.		<i>Extended mnemonic for rlwinm. RA,RS,n,0,31</i>	CR[CR0]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
rotwi	RA, RS, n	Rotate right immediate. $(RA) \leftarrow \text{ROTL}((RS), 32-n)$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,0,31		11-130
rotwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,0,31	CR[CR0]	
sc		System call exception is generated. $(SRR1) \leftarrow (MSR)$ $(SRR0) \leftarrow (PC)$ $PC \leftarrow \text{EVPR}_{0:15} \parallel \text{x'0C00'}$ $(MSR[WE, PR, EE, PE, DR, IR]) \leftarrow 0$ $(MSR[LE]) \leftarrow (MSR[ILE])$		11-134
slw	RA, RS, RB	Shift left (RS) by $(RB)_{27:31}$. $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), n)$. if $(RB)_{26} = 0$ then $m \leftarrow \text{MASK}(0, 31 - n)$ else $m \leftarrow {}^{32}0$. $(RA) \leftarrow r \wedge m$.		11-135
slw.			CR[CR0]	
slwi	RA, RS, n	Shift left immediate. ($n < 32$) $(RA)_{0:31-n} \leftarrow (RS)_{n:31}$ $(RA)_{32-n:31} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,0,31-n		11-130
slwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,0,31-n	CR[CR0]	
sraw	RA, RS, RB	Shift right algebraic (RS) by $(RB)_{27:31}$. $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. if $(RB)_{26} = 0$ then $m \leftarrow \text{MASK}(n, 31)$ else $m \leftarrow {}^{32}0$. $s \leftarrow (RS)_0$. $(RA) \leftarrow (r \wedge m) \vee ({}^{32}s \wedge \neg m)$. $\text{XER}[CA] \leftarrow s \wedge ((r \wedge \neg m) \neq 0)$.		11-136
sraw.			CR[CR0]	
srawi	RA, RS, SH	Shift right algebraic (RS) by SH. $n \leftarrow SH$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. $m \leftarrow \text{MASK}(n, 31)$. $s \leftarrow (RS)_0$. $(RA) \leftarrow (r \wedge m) \vee ({}^{32}s \wedge \neg m)$. $\text{XER}[CA] \leftarrow s \wedge ((r \wedge \neg m) \neq 0)$.		11-137
srawi.			CR[CR0]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
srw	RA, RS, RB	Shift right (RS) by (RB) _{27:31} . $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. if (RB) ₂₆ = 0 then $m \leftarrow \text{MASK}(n, 31)$ else $m \leftarrow {}^{32}0$. $(RA) \leftarrow r \wedge m$.		11-138
srw.			CR[CR0]	
srwi	RA, RS, n	Shift right immediate. ($n < 32$) $(RA)_{n:31} \leftarrow (RS)_{0:31-n}$ $(RA)_{0:n-1} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,n,31		11-130
srwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,n,31	CR[CR0]	
stb	RS, D(RA)	Store byte (RS) _{24:31} in memory at EA = (RA 0) + EXTS(D).		11-139
stbu	RS, D(RA)	Store byte (RS) _{24:31} in memory at EA = (RA 0) + EXTS(D). Update the base address, (RA) \leftarrow EA.		11-140
stbux	RS, RA, RB	Store byte (RS) _{24:31} in memory at EA = (RA 0) + (RB). Update the base address, (RA) \leftarrow EA.		11-141
stbx	RS, RA, RB	Store byte (RS) _{24:31} in memory at EA = (RA 0) + (RB).		11-142
sth	RS, D(RA)	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + EXTS(D).		11-143
sthbrx	RS, RA, RB	Store halfword (RS) _{16:31} byte-reversed in memory at EA = (RA 0) + (RB). $\text{MS}(EA, 2) \leftarrow (RS)_{24:31} \parallel (RS)_{16:23}$		11-144
sthu	RS, D(RA)	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + EXTS(D). Update the base address, (RA) \leftarrow EA.		11-145
sthux	RS, RA, RB	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + (RB). Update the base address, (RA) \leftarrow EA.		11-146

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
sthx	RS, RA, RB	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + (RB).		11-147
stmw	RS, D(RA)	Store consecutive words from RS through GPR(31) in memory starting at EA = (RA 0) + EXTS(D).		11-148
stswi	RS, RA, NB	Store consecutive bytes in memory starting at EA=(RA 0). Number of bytes n=32 if NB=0, else n=NB. Bytes are unstacked from CEIL(n/4) consecutive registers starting with RS. GPR(0) is consecutive to GPR(31).		11-149
stswx	RS, RA, RB	Store consecutive bytes in memory starting at EA=(RA 0)+(RB). Number of bytes n=XER[TBC]. Bytes are unstacked from CEIL(n/4) consecutive registers starting with RS. GPR(0) is consecutive to GPR(31).		11-150
stw	RS, D(RA)	Store word (RS) in memory at EA = (RA 0) + EXTS(D).		11-152
stwbrx	RS, RA, RB	Store word (RS) byte-reversed in memory at EA = (RA 0) + (RB). $MS(EA, 4) \leftarrow (RS)_{24:31} \parallel (RS)_{16:23} \parallel (RS)_{8:15} \parallel (RS)_{0:7}$		11-153
stwcx.	RS, RA, RB	Store word (RS) in memory at EA = (RA 0) + (RB) only if reservation bit is set. if RESERVE = 1 then $MS(EA, 4) \leftarrow (RS)$ $RESERVE \leftarrow 0$ $(CR[CR0]) \leftarrow {}^20 \parallel 1 \parallel XER_{so}$ else $(CR[CR0]) \leftarrow {}^20 \parallel 0 \parallel XER_{so}.$		11-154
stwu	RS, D(RA)	Store word (RS) in memory at EA = (RA 0) + EXTS(D). Update the base address, (RA) \leftarrow EA.		11-156
stwux	RS, RA, RB	Store word (RS) in memory at EA = (RA 0) + (RB). Update the base address, (RA) \leftarrow EA.		11-157

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
stwx	RS, RA, RB	Store word (RS) in memory at $EA = (RA 0) + (RB)$.		11-158
sub	RT, RA, RB	Subtract (RB) from (RA). $(RT) \leftarrow \neg(RB) + (RA) + 1$. <i>Extended mnemonic for subf RT,RB,RA</i>		11-159
sub.		<i>Extended mnemonic for subf. RT,RB,RA</i>	CR[CR0]	
subo		<i>Extended mnemonic for subfo RT,RB,RA</i>	XER[SO, OV]	
subo.		<i>Extended mnemonic for subfo. RT,RB,RA</i>	CR[CR0] XER[SO, OV]	
subc	RT, RA, RB	Subtract (RB) from (RA). $(RT) \leftarrow \neg(RB) + (RA) + 1$. Place carry-out in XER[CA]. <i>Extended mnemonic for subfc RT,RB,RA</i>		11-160
subc.		<i>Extended mnemonic for subfc. RT,RB,RA</i>	CR[CR0]	
subco		<i>Extended mnemonic for subfco RT,RB,RA</i>	XER[SO, OV]	
subco.		<i>Extended mnemonic for subfco. RT,RB,RA</i>	CR[CR0] XER[SO, OV]	
subf	RT, RA, RB	Subtract (RA) from (RB). $(RT) \leftarrow \neg(RA) + (RB) + 1$.		11-159
subf.			CR[CR0]	
subfo			XER[SO, OV]	
subfo.			CR[CR0] XER[SO, OV]	
subfc	RT, RA, RB	Subtract (RA) from (RB). $(RT) \leftarrow \neg(RA) + (RB) + 1$. Place carry-out in XER[CA].		11-160
subfc.			CR[CR0]	
subfco			XER[SO, OV]	
subfco.			CR[CR0] XER[SO, OV]	

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
subfe	RT, RA, RB	Subtract (RA) from (RB) with carry-in. (RT) $\leftarrow \neg(RA) + (RB) + XER[CA]$. Place carry-out in XER[CA].		11-162
subfe.			CR[CR0]	
subfeo			XER[SO, OV]	
subfeo.			CR[CR0] XER[SO, OV]	
subfic	RT, RA, IM	Subtract (RA) from EXTS(IM). (RT) $\leftarrow \neg(RA) + EXTS(IM) + 1$. Place carry-out in XER[CA].		11-163
subfme	RT, RA, RB	Subtract (RA) from (−1) with carry-in. (RT) $\leftarrow \neg(RA) + (−1) + XER[CA]$. Place carry-out in XER[CA].		11-164
subfme.			CR[CR0]	
subfmeo			XER[SO, OV]	
subfmeo.			CR[CR0] XER[SO, OV]	
subfze	RT, RA, RB	Subtract (RA) from zero with carry-in. (RT) $\leftarrow \neg(RA) + XER[CA]$. Place carry-out in XER[CA].		11-165
subfze.			CR[CR0]	
subfzeo			XER[SO, OV]	
subfzeo.			CR[CR0] XER[SO, OV]	
subi	RT, RA, IM	Subtract EXTS(IM) from (RA 0). Place result in RT. <i>Extended mnemonic for</i> addi RT,RA,−IM		11-9
subic	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for</i> addic RT,RA,−IM		11-10
subic.	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for</i> addic. RT,RA,−IM	CR[CR0]	11-11
subis	RT, RA, IM	Subtract (IM ¹⁶ 0) from (RA 0). Place result in RT. <i>Extended mnemonic for</i> addis RT,RA,−IM		11-12

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
sync		Synchronization. All instructions that precede sync complete before any instructions that follow sync begin. When sync completes, all storage accesses initiated prior to sync will have completed.		11-166
tlbia		All of the entries in the TLB are invalidated and become unavailable for translation by clearing the valid (V) bit in the TLBHI portion of each TLB entry. The rest of the fields in the TLB entries are unmodified.		11-167
tlbre	RT, RA, WS	If WS = 0: Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$ If WS = 1: Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$		11-168
tlbrehi	RT, RA	Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$ <i>Extended mnemonic for</i> tlbre RT, RA, 0		11-168
tlbrelo	RT, RA	Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$ <i>Extended mnemonic for</i> tlbre RT, RA, 1		11-168

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbsx	RT, RA, RB	Search the TLB array for a valid entry which translates the effective address $EA = (RA 0) + (RB)$. If found, $(RT) \leftarrow \text{Index of TLB entry.}$ If not found, $(RT) \text{ Undefined.}$		11-170
tlbsx.		If found, $(RT) \leftarrow \text{Index of TLB entry.}$ $CR[CR0]_{EQ} \leftarrow 1.$ If not found, $(RT) \text{ Undefined.}$ $CR[CR0]_{EQ} \leftarrow 1.$	CR[CR0] _{LT,GT,SO}	
tlbsync		tlbsync does not complete until all previous TLB-update instructions executed by this processor have been received and completed by all other processors. For PPC403GC, tlbsync is a no-op.		11-171
tlbwe	RS, RA, WS	If WS = 0: Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$ If WS = 1: Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$		11-172
tlbwehi	RS, RA	Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$ <i>Extended mnemonic for</i> tlbwe RS,RA,0		11-172
tlbwelo	RS, RA	Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$ <i>Extended mnemonic for</i> tlbwe RS,RA,1		11-172

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
trap		Trap unconditionally. <i>Extended mnemonic for tw 31,0,0</i>		11-174
tweq	RA, RB	Trap if (RA) equal to (RB). <i>Extended mnemonic for tw 4,RA,RB</i>		
twge		Trap if (RA) greater than or equal to (RB). <i>Extended mnemonic for tw 12,RA,RB</i>		
twgt		Trap if (RA) greater than (RB). <i>Extended mnemonic for tw 8,RA,RB</i>		
twle		Trap if (RA) less than or equal to (RB). <i>Extended mnemonic for tw 20,RA,RB</i>		
twlge		Trap if (RA) logically greater than or equal to (RB). <i>Extended mnemonic for tw 5,RA,RB</i>		
twlgt		Trap if (RA) logically greater than (RB). <i>Extended mnemonic for tw 1,RA,RB</i>		
twlle		Trap if (RA) logically less than or equal to (RB). <i>Extended mnemonic for tw 6,RA,RB</i>		
twllt		Trap if (RA) logically less than (RB). <i>Extended mnemonic for tw 2,RA,RB</i>		
twlng		Trap if (RA) logically not greater than (RB). <i>Extended mnemonic for tw 6,RA,RB</i>		
twlnl		Trap if (RA) logically not less than (RB). <i>Extended mnemonic for tw 5,RA,RB</i>		
twlt		Trap if (RA) less than (RB). <i>Extended mnemonic for tw 16,RA,RB</i>		
twne		Trap if (RA) not equal to (RB). <i>Extended mnemonic for tw 24,RA,RB</i>		
twng		Trap if (RA) not greater than (RB). <i>Extended mnemonic for tw 20,RA,RB</i>		
twnl		Trap if (RA) not less than (RB). <i>Extended mnemonic for tw 12,RA,RB</i>		
tw	TO, RA, RB	Trap exception is generated if, comparing (RA) with (RB), any condition specified by TO is true.		11-174

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tweqi	RA, IM	Trap if (RA) equal to EXTS(IM). <i>Extended mnemonic for twi 4,RA,IM</i>		11-177
twgei		Trap if (RA) greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>		
twgti		Trap if (RA) greater than EXTS(IM). <i>Extended mnemonic for twi 8,RA,IM</i>		
twlei		Trap if (RA) less than or equal to EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>		
twlgei		Trap if (RA) logically greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>		
twlgti		Trap if (RA) logically greater than EXTS(IM). <i>Extended mnemonic for twi 1,RA,IM</i>		
twllei		Trap if (RA) logically less than or equal to EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>		
twllti		Trap if (RA) logically less than EXTS(IM). <i>Extended mnemonic for twi 2,RA,IM</i>		
twlngi		Trap if (RA) logically not greater than EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>		
twlnli		Trap if (RA) logically not less than EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>		
twlti		Trap if (RA) less than EXTS(IM). <i>Extended mnemonic for twi 16,RA,IM</i>		
twnei		Trap if (RA) not equal to EXTS(IM). <i>Extended mnemonic for twi 24,RA,IM</i>		
twngi		Trap if (RA) not greater than EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>		
twnli		Trap if (RA) not less than EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>		
twi	TO, RA, IM	Trap exception is generated if, comparing (RA) with EXTS(IM), any condition specified by TO is true.		11-177

Table A-1. PPC403GC Instruction Syntax Summary (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
wrtee	RS	Write value of RS ₁₆ to the External Enable bit (MSR[EE]).		11-180
wrteei	E	Write value of E to the External Enable bit (MSR[EE]).		11-181
xor	RA, RS, RB	XOR (RS) with (RB). Place result in RA.		11-182
xor.			CR[CR0]	
xori	RA, RS, IM	XOR (RS) with (¹⁶ 0 IM). Place result in RA.		11-183
xoris	RA, RS, IM	XOR (RS) with (IM ¹⁶ 0). Place result in RA.		11-184

A.2 Instructions Sorted by Opcode

All instructions are four bytes long and word aligned. All instructions have a primary opcode field (shown as field OPCODE in Figure A-1 through Figure A-9 beginning on page A-52) in bits 0:5. Some instructions also have a secondary opcode field (shown as field XO in Figure A-1 through Figure A-9). PPC403GC instructions sorted by primary and secondary opcode may be found in Table A-2 below.

The “Form” indicated in the table refers to the arrangement of valid field combinations within the four-byte instruction. See Section A.3 (Instruction Formats) on page A-50 for illustration of the field layouts associated with each form.

Form X has a 10-bit secondary opcode field, while form XO uses only the low-order 9-bits of that field. Form XO uses the high-order secondary opcode bit (the tenth bit) as a variable; therefore, every form XO instruction really consumes two secondary opcodes from the 10-bit secondary-opcode space. The implicitly consumed secondary opcode is listed in parentheses for form XO instructions in the table below.

Table A-2. PPC403GC Instructions by Opcode

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
3		D	twi	TO, RA, IM	11-177
7		D	mulli	RT, RA, IM	11-118
8		D	subfic	RT, RA, IM	11-163
10		D	cmpli	BF, 0, RA, IM	11-39
11		D	cmpi	BF, 0, RA, IM	11-37
12		D	addic	RT, RA, IM	11-10
13		D	addic.	RT, RA, IM	11-11
14		D	addi	RT, RA, IM	11-9
15		D	addis	RT, RA, IM	11-12
16		B	bc	BO, BI, target	11-20
			bca		
			bcl		
			bcla		
17		SC	sc		11-134

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
18		I	b	target	11-19
			ba		
			bl		
			bla		
19	0	XL	mcrf	BF, BFA	11-101
19	16	XL	bclr	BO, BI	11-31
			bclrl		
19	33	XL	crnor	BT, BA, BB	11-45
19	50	XL	rfi		11-128
19	51	XL	rfdi		11-127
19	129	XL	crandc	BT, BA, BB	11-42
19	150	XL	isync		11-76
19	193	XL	crxor	BT, BA, BB	11-48
19	225	XL	crnand	BT, BA, BB	11-44
19	257	XL	crand	BT, BA, BB	11-41
19	289	XL	creqv	BT, BA, BB	11-43
19	417	XL	crorc	BT, BA, BB	11-47
19	449	XL	cror	BT, BA, BB	11-46
19	528	XL	bcctr	BO, BI	11-27
			bcctrl		
20		M	rlwimi	RA, RS, SH, MB, ME	11-129
			rlwimi.		
21		M	rlwinm	RA, RS, SH, MB, ME	11-130
			rlwinm.		
23		M	rlwnm	RA, RS, RB, MB, ME	11-133
			rlwnm.		
24		D	ori	RA, RS, IM	11-125
25		D	oris	RA, RS, IM	11-126
26		D	xori	RA, RS, IM	11-183

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
27		D	xoris	RA, RS, IM	11-184
28		D	andi.	RA, RS, IM	11-17
29		D	andis.	RA, RS, IM	11-18
31	0	X	cmp	BF, 0, RA, RB	11-36
31	4	X	tw	TO, RA, RB	11-174
31	8 (520)	XO	subfc	RT, RA, RB	11-160
			subfc.		
			subfco		
			subfco.		
31	10 (522)	XO	addc	RT, RA, RB	11-7
			addc.		
			addco		
			addco.		
31	11 (523)	XO	mulhwu	RT, RA, RB	11-117
			mulhwu.		
31	19	X	mfcrr	RT	11-103
31	20	X	lwarx	RT, RA, RB	11-95
31	23	X	lwzx	RT, RA, RB	11-100
31	24	X	slw	RA, RS, RB	11-135
			slw.		
31	26	X	cntlzw	RA, RS	11-40
			cntlzw.		
31	28	X	and	RA, RS, RB	11-15
			and.		
31	32	X	cmpl	BF, 0, RA, RB	11-38
31	40 (552)	XO	subf	RT, RA, RB	11-159
			subf.		
			subfo		
			subfo.		

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
31	54	X	dcbst	RA, RB	11-51
31	55	X	lwzux	RT, RA, RB	11-99
31	60	X	andc	RA, RS, RB	11-16
			andc.		
31	75 (587)	XO	mulhw	RT, RA, RB	11-116
			mulhw.		
31	83	X	mfmsr	RT	11-106
31	86	X	dcbf	RA, RB	11-49
31	87	X	lbzx	RT, RA, RB	11-80
31	104 (616)	XO	neg	RT, RA	11-121
			neg.		
			nego		
			nego.		
31	119	X	lbzux	RT, RA, RB	11-79
31	124	X	nor	RA, RS, RB	11-122
			nor.		
31	131	X	wrtree	RS	11-180
31	136 (648)	XO	subfe	RT, RA, RB	11-162
			subfe.		
			subfeo		
			subfeo.		
31	138 (650)	XO	adde	RT, RA, RB	11-8
			adde.		
			addeo		
			addeo.		
31	144	AFX	mtcrf	FXM, RS	11-109
31	146	X	mtmsr	RS	11-113
31	150	X	stwcx.	RS, RA, RB	11-154
31	151	X	stwx	RS, RA, RB	11-158

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
31	163	X	wrtnei	E	11-181
31	183	X	stwux	RS, RA, RB	11-157
31	200 (712)	XO	subfze	RT, RA, RB	11-165
			subfze.		
			subfzeo		
			subfzeo.		
31	202 (714)	XO	addze	RT, RA	11-14
			addze.		
			addzeo		
			addzeo.		
31	215	X	stbx	RS, RA, RB	11-142
31	232 (744)	XO	subfme	RT, RA, RB	11-164
			subfme.		
			subfmeo		
			subfmeo.		
31	234 (746)	XO	addme	RT, RA	11-13
			addme.		
			addmeo		
			addmeo.		
31	235 (747)	XO	mullw	RT, RA, RB	11-119
			mullw.		
			mullwo		
			mullwo.		
31	246	X	dcbtst	RA, RB	11-54
31	247	X	stbux	RS, RA, RB	11-141
31	262	X	icbt	RA, RB	11-70

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
31	266 (778)	XO	add	RT, RA, RB	11-6
			add.		
			addo		
			addo.		
31	278	X	dcbt	RA, RB	11-52
31	279	X	lhzx	RT, RA, RB	11-89
31	284	X	eqv	RA, RS, RB	11-65
			eqv.		
31	311	X	lhzux	RT, RA, RB	11-88
31	316	X	xor	RA, RS, RB	11-182
			xor.		
31	323	XFX	mfdcr	RT, DCRN	11-104
31	339	XFX	mfspr	RT, SPRN	11-107
31	343	X	lhax	RT, RA, RB	11-84
31	370	X	tlbia		11-167
31	375	X	lhaux	RT, RA, RB	11-83
31	407	X	sthx	RS, RA, RB	11-147
31	412	X	orc	RA, RS, RB	11-124
			orc.		
31	439	X	sthux	RS, RA, RB	11-146
31	444	X	or	RA, RS, RB	11-123
			or.		
31	451	XFX	mtdcr	DCRN, RS	11-111
31	454	X	dccci	RA, RB	11-58
31	459 (971)	XO	divwu	RT, RA, RB	11-63
			divwu.		
			divwuo		
			divwuo.		
31	467	XFX	mtspr	SPRN, RS	11-114

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
31	470	X	dcbi	RA, RB	11-50
31	476	X	nand	RA, RS, RB	11-120
			nand.		
31	486	X	dcread	RT, RA, RB	11-60
31	491 (1003)	XO	divw	RT, RA, RB	11-62
			divw.		
			divwo		
			divwo.		
31	512	X	mcrxr	BF	11-102
31	533	X	lswx	RT, RA, RB	11-93
31	534	X	lwbrx	RT, RA, RB	11-96
31	536	X	srw	RA, RS, RB	11-138
			srw.		
31	566	X	tlbsync		11-171
31	597	X	lswi	RT, RA, NB	11-91
31	598	X	sync		11-166
31	661	X	stswx	RS, RA, RB	11-150
31	662	X	stwbrx	RS, RA, RB	11-153
31	725	X	stswi	RS, RA, NB	11-149
31	790	X	lhbrx	RT, RA, RB	11-85
31	792	X	sraw	RA, RS, RB	11-136
			sraw.		
31	824	X	srawi	RA, RS, SH	11-137
			srawi.		
31	854	X	eieio		11-64
31	914	X	tlbsx	RT, RA, RB	11-170
			tlbsx.		
31	918	X	sthbrx	RS, RA, RB	11-144

Table A-2. PPC403GC Instructions by Opcode (cont.)

Primary Opcode	Secondary Opcode	Form	Mnemonic	Operands	Page
31	922	X	extsh	RA, RS	11-67
			extsh.		
31	946	X	tlbre	RT, RA,WS	11-168
31	954	X	extsb	RA, RS	11-66
			extsb.		
31	966	X	iccci	RA, RB	11-72
31	978	X	tlbwe	RS, RA,WS	11-172
31	982	X	icbi	RA, RB	11-68
31	998	X	icread	RA, RB	11-74
31	1014	X	dcbz	RA, RB	11-56
32		D	lwz	RT, D(RA)	11-97
33		D	lwzu	RT, D(RA)	11-98
34		D	lbz	RT, D(RA)	11-77
35		D	lbzu	RT, D(RA)	11-78
36		D	stw	RS, D(RA)	11-152
37		D	stwu	RS, D(RA)	11-156
38		D	stb	RS, D(RA)	11-139
39		D	stbu	RS, D(RA)	11-140
40		D	lhz	RT, D(RA)	11-86
41		D	lhzu	RT, D(RA)	11-87
42		D	lha	RT, D(RA)	11-81
43		D	lhau	RT, D(RA)	11-82
44		D	sth	RS, D(RA)	11-143
45		D	sthu	RS, D(RA)	11-145
46		D	lmw	RT, D(RA)	11-90
47		D	stmw	RS, D(RA)	11-148

A.3 Instruction Formats

Instructions are four bytes long. Instruction addresses are always word-aligned.

Instruction bits 0 through 5 always contain the primary opcode. Many instructions have an extended opcode in another field. The remaining instruction bits contain additional fields. All instruction fields belong to one of the following categories:

- **Defined**

These instructions contain values, such as opcodes, that cannot be altered. The instruction format diagrams specify the values of defined fields.

- **Variable**

These fields contain operands, such as general purpose register selectors and immediate values, that may vary from execution to execution. The instruction format diagrams specify the operands in variable fields.

- **Reserved**

Bits in a reserved field should be set to 0. In the instruction format diagrams, reserved fields are shaded.

If any bit in a defined field does not contain the expected value, the instruction is illegal and an illegal instruction exception occurs. If any bit in a reserved field does not contain 0, the instruction form is invalid and its result is architecturally undefined. The PPC403GC executes all invalid instruction forms without causing an illegal instruction exception.

A.3.1 Instruction Fields

PPC403GC instructions contain various combinations of the following fields, as indicated in the instruction format diagrams. The numbers, enclosed in parentheses, that follow the field names indicate the bit positions; bit fields are indicated by starting and stopping bit positions separated by colons.

AA (30)	Absolute address bit.
0	The immediate field represents an address relative to the current instruction address (CIA). The effective address (EA) of the branch is either the sum of the LI field sign-extended to 32 bits and the branch instruction address, or the sum of the BD field sign-extended to 32 bits and the branch instruction address.
1	The immediate field represents an absolute address. The EA of the branch is either the LI field or the BD field, sign-extended to 32 bits.
BA (11:15)	Specifies a bit in the condition register (CR) used as a source of a CR-Logical instruction.
BB (16:20)	Specifies a bit in the CR used as a source of a CR-Logical instruction.

BD (16:29)	An immediate field specifying a 14-bit signed twos complement branch displacement. This field is concatenated on the right with 0b00 and sign-extended to 32 bits.
BF (6:8)	Specifies a field in the CR used as a target in a compare or mcrf instruction.
BFA (11:13)	Specifies a field in the CR used as a source in a mcrf instruction.
BI (11:15)	Specifies a bit in the CR used as a source for the condition of a conditional branch instruction.
BO (6:10)	Specifies options for conditional branch instructions. See Section 2.7.4.
BT (6:10)	Specifies a bit in the CR used as a target as the result of a CR-Logical instruction.
D (16:31)	Specifies a 16-bit signed two's-complement integer displacement for load/store instructions.
DCRN (11:20)	Specifies a device control register (DCR).
FXM (12:19)	Field mask used to identify CR fields to be updated by the mtcrf instruction.
IM (16:31)	An immediate field used to specify a 16-bit value (either signed integer or unsigned).
LI (6:29)	An immediate field specifying a 24-bit signed twos complement branch displacement; this field is concatenated on the right with b'00' and sign-extended to 32 bits.
LK (31)	Link bit. 0 Do not update the link register (LR). 1 Update the LR with the address of the next instruction.
MB (21:25)	Mask begin. Used in rotate-and-mask instructions to specify the beginning bit of a mask.
ME (26:30)	Mask end. Used in rotate-and-mask instructions to specify the ending bit of a mask.
NB (16:20)	Specifies the number of bytes to move in an immediate string load or store.
OPCD (0:5)	Primary opcode. Primary opcodes, in decimal, appear in the instruction format diagrams presented with individual instructions. The OPCD field name does not appear in instruction descriptions.
OE (21)	Enables setting the OV and SO fields in the fixed-point exception register (XER) for extended arithmetic.

RA (11:15)	A GPR used as a source or target.
RB (16:20)	A GPR used as a source.
Rc (31)	Record bit. 0 Do not set the CR. 1 Set the CR to reflect the result of an operation. See Section 2.3.3 on page 2-13 for a further discussion of how the CR bits are set.
RS (6:10)	A GPR used as a source.
RT (6:10)	A GPR used as a target.
SH (16:20)	Specifies a shift amount.
SPRF (11:20)	Specifies a special purpose register (SPR).
TO (6:10)	Specifies the conditions on which to trap, as described under tw and twi instructions.
XO (21:30)	Extended opcode for instructions without an OE field. Extended opcodes, in decimal, appear in the instruction format diagrams presented with individual instructions. The XO field name does not appear in instruction descriptions.
XO (22:30)	Extended opcode for instructions with an OE field. Extended opcodes, in decimal, appear in the instruction format diagrams presented with individual instructions. The XO field name does not appear in instruction descriptions.

A.3.2 Instruction Format Diagrams

The “Forms” shown in Figure A-1 through Figure A-9 are valid combinations of instruction fields for the PPC403GC. Table A-2 on page A-42 indicates which “Form” is utilized by each PPC403GC opcode. Fields indicated by slashes (/ , // , or ///) are reserved. These figures have been adapted from the PowerPC User Instruction Set Architecture.

I-Form

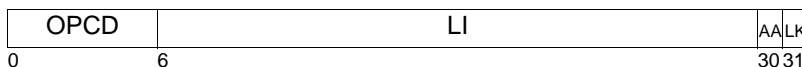


Figure A-1. I Instruction Format

B-Form

OPCD	BO	BI	BD	AA	LK
0	6	11	16	30	31

Figure A-2. B Instruction Format

SC-Form

OPCD	///	///	///	1	/
0	6	11	16	30	31

Figure A-3. SC Instruction Format

D-Form

OPCD	RT	RA	D
OPCD	RT	RA	SI
OPCD	RS	RA	D
OPCD	RS	RA	UI
OPCD	BF	/ L	RA
OPCD	BF	/ L	RA
OPCD	TO	RA	SI
0	6	11	16
			31

Figure A-4. D Instruction Format

X-Form

OPCD	RT	RA	RB	XO	Rc		
OPCD	RT	RA	RB	XO	/		
OPCD	RT	RA	NB	XO	/		
OPCD	RT	RA	WS	XO	/		
OPCD	RT	///	RB	XO	/		
OPCD	RT	///	///	XO	/		
OPCD	RS	RA	RB	XO	Rc		
OPCD	RS	RA	RB	XO	1		
OPCD	RS	RA	RB	XO	/		
OPCD	RS	RA	NB	XO	/		
OPCD	RS	RA	WS	XO	/		
OPCD	RS	RA	SH	XO	Rc		
OPCD	RS	RA	///	XO	Rc		
OPCD	RS	///	RB	XO	/		
OPCD	RS	///	///	XO	/		
OPCD	BF	/ L	RA	RB	XO	/	
OPCD	BF	//	BFA	//	///	XO	/
OPCD	BF	//	///	U	/	XO	Rc
OPCD	BF	//	///	///	XO	/	
OPCD	TO	RA	RB	XO	/		
OPCD	BT	///	///	XO	Rc		
OPCD	///	RA	RB	XO	/		
OPCD	///	///	RB	XO	/		
OPCD	///	///	///	XO	/		
OPCD	///	///	E	//	XO	/	
0	6	11	16	21	31		

Figure A-5. X Instruction Format

XL-Form

OPCD	BT	BA	BB	XO	/
OPCD	BO	BI	///	XO	LK
OPCD	BF	//	BFA	///	XO
OPCD	///	///	///	XO	/
0	6	11	16	21	31

Figure A-6. XL Instruction Format

XFX-Form

OPCD	RT	SPRF	XO	/
OPCD	RT	DCRF	XO	/
OPCD	RT	/	FXM	/
OPCD	RS	SPRF	XO	/
OPCD	RS	DCRF	XO	/
0	6	11	21	31

Figure A-7. XFX Instruction Format

XO-Form

OPCD	RT	RA	RB	O E	XO	Rc
OPCD	RT	RA	RB	/	XO	Rc
OPCD	RT	RA	///	O E	XO	Rc
0	6	11	16	21 22		31

Figure A-8. XO Instruction Format

M-Form

OPCD	RS	RA	RB	MB	ME	Rc
OPCD	RS	RA	SH	MB	ME	Rc
0	6	11	16	21	26	31

Figure A-9. M Instruction Format

B

Instructions By Category

B.1 Instruction Set Summary – Categories

Chapter 11 (Instruction Set) contains detailed descriptions of the instructions, their operands, and notation.

Table B-1 summarizes the instruction categories in the PPC403GC instruction set. The instructions within each category are listed in subsequent tables.

Table B-1. PPC403GC Instruction Set Summary

Instruction Category	Base Instructions
Storage Reference	load, store
Arithmetic / Logical	add, subtract, negate, multiply, divide, and, or, xor, nand, nor, xnor, sign extension, count leading zeros, andc, orc
Comparison	compare algebraic, compare logical, compare immediate
Branch	branch, branch conditional, branch to LR, branch to CTR
CR Logical	crand, crnor, crxnor, crxor, crandc, crorc, crnand, cror, move cr field
Rotate/Shift	rotate and mask, rotate and insert, shift left, shift right
Cache Control	invalidate, touch, zero, flush, store, read
Interrupt Control	write to external interrupt enable bit, move to/from machine state register, return from interrupt, return from critical interrupt
TLB Management	invalidate, read entry, write entry, search, synchronize
Processor Management	system call, synchronize, trap, move to/from Device Control Registers, move to/from Special Purpose Registers, move to/from Condition Register, move to/from Machine State Register

B.2 Instructions Specific to PowerPC Embedded Controllers

To meet the functional requirements of processors for embedded systems and real-time applications, the PowerPC Embedded Controller family defines instructions that are not part of the PowerPC Architecture.

Table B-2 summarizes the PPC403GC instructions specific to the PowerPC Embedded Controller family.

Table B-2. Instructions Specific to PowerPC Embedded Controllers

Mnemonic	Operands	Function	Other Registers Changed	Page
dccci	RA, RB	Invalidate the data cache congruence class associated with the effective address (RA 0) + (RB).		11-58
dcread	RT, RA, RB	Read either tag or data information from the data cache congruence class associated with the effective address (RA 0) + (RB). Place the results in RT.		11-60
icbt	RA, RB	Load the instruction cache block which contains the effective address (RA 0) + (RB).		11-70
iccci	RA, RB	Invalidate instruction cache congruence class associated with the effective address (RA 0) + (RB).		11-72
icread	RA, RB	Read either tag or data information from the instruction cache congruence class associated with the effective address (RA 0) + (RB). Place the results in ICDBDR.		11-74
mfdcr	RT, DCRN	Move from DCR to RT, (RT) \leftarrow (DCR(DCRN)).		11-104
mtdcr	DCRN, RS	Move to DCR from RS, (DCR(DCRN)) \leftarrow (RS).		11-111
rfci		Return from critical interrupt (PC) \leftarrow (SRR2). (MSR) \leftarrow (SRR3).		11-127

Table B-2. Instructions Specific to PowerPC Embedded Controllers (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbre	RT, RA, WS	<p>If WS = 0: Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$</p> <p>If WS = 1: Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$</p>		11-168
tlbsx	RT, RA, RB	<p>Search the TLB array for a valid entry which translates the effective address $EA = (RA 0) + (RB)$. If found, $(RT) \leftarrow \text{Index of TLB entry.}$ If not found, (RT) Undefined.</p>		11-170
tlbsx.		<p>If found, $(RT) \leftarrow \text{Index of TLB entry.}$ $CR[CR0]_{EQ} \leftarrow 1$. If not found, (RT) Undefined. $CR[CR0]_{EQ} \leftarrow 1$.</p>	CR[CR0] _{LT,GT,SO}	
tlbwe	RS, RA, WS	<p>If WS = 0: Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$</p> <p>If WS = 1: Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$</p>		11-172
wrttee	RS	Write value of RS ₁₆ to the External Enable bit (MSR[EE]).		11-180
wrtteei	E	Write value of E to the External Enable bit (MSR[EE]).		11-181

B.3 Privileged Instructions

The following instructions are under control of the MSR[PR] bit, and are not allowed to be executed when MSR[PR] = b'1':

Table B-3. Privileged Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
dcbi	RA, RB	Invalidate the data cache block which contains the effective address (RA 0) + (RB).		11-50
dccci	RA, RB	Invalidate the data cache congruence class associated with the effective address (RA 0) + (RB).		11-58
dcread	RT, RA, RB	Read either tag or data information from the data cache congruence class associated with the effective address (RA 0) + (RB). Place the results in RT.		11-60
icbt	RA, RB	Load the instruction cache block which contains the effective address (RA 0) + (RB).		11-70
iccci	RA, RB	Invalidate instruction cache congruence class associated with the effective address (RA 0) + (RB).		11-72
icread	RA, RB	Read either tag or data information from the instruction cache congruence class associated with the effective address (RA 0) + (RB). Place the results in ICDBDR.		11-74
mfdcr	RT, DCRN	Move from DCR to RT, (RT) ← (DCR(DCRN)).		11-104
mfmsr	RT	Move from MSR to RT, (RT) ← (MSR).		11-106
mfspir	RT, SPRN	Move from SPR to RT, (RT) ← (SPR(SPRN)). Privileged for all SPRs except TBHU, TBLU, LR, CTR, and XER.		11-107
mtdcr	DCRN, RS	Move to DCR from RS, (DCR(DCRN)) ← (RS).		11-111
mtmsr	RS	Move to MSR from RS, (MSR) ← (RS).		11-113

Table B-3. Privileged Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mtspr	SPRN, RS	Move to SPR from RS, (SPR(SPRN)) \leftarrow (RS). Privileged for all SPRs except LR, CTR, and XER.		11-114
rftci		Return from critical interrupt (PC) \leftarrow (SRR2). (MSR) \leftarrow (SRR3).		11-127
rfti		Return from interrupt. (PC) \leftarrow (SRR0). (MSR) \leftarrow (SRR1).		11-128
tlbia		All of the entries in the TLB are invalidated and become unavailable for translation by clearing the valid (V) bit in the TLBHI portion of each TLB entry. The rest of the fields in the TLB entries are unmodified.		11-167
tlbre	RT, RA, WS	If WS = 0: Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. (RT) \leftarrow TLBHI[(RA)] (PID) \leftarrow TLB[(RA)] _{TID} If WS = 1: Load TLBLO portion of the selected TLB entry into RT. (RT) \leftarrow TLBLO[(RA)]		11-168
tlbsx	RT, RA, RB	Search the TLB array for a valid entry which translates the effective address EA = (RA[0] + (RB)). If found, (RT) \leftarrow Index of TLB entry. If not found, (RT) Undefined.		11-170
tlbsx.		If found, (RT) \leftarrow Index of TLB entry. CR[CR0] _{EQ} \leftarrow 1. If not found, (RT) Undefined. CR[CR0] _{EQ} \leftarrow 1.	CR[CR0] _{LT,GT,SO}	

Table B-3. Privileged Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbsync		tlbsync does not complete until all previous TLB-update instructions executed by this processor have been received and completed by all other processors. For PPC403GC, tlbsync is a no-op.		11-171
tlbwe	RS, RA, WS	If WS = 0: Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$ If WS = 1: Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$		11-172
wrtee	RS	Write value of RS_{16} to the External Enable bit (MSR[EE]).		11-180
wrteei	E	Write value of E to the External Enable bit (MSR[EE]).		11-181

B.4 Assembler Extended Mnemonics

In the appendix “Assembler Extended Mnemonics” of the PowerPC Architecture, it is required that a PowerPC assembler support at least a minimal set of extended mnemonics. These mnemonics encode to the opcodes of other instructions; the only benefit of extended mnemonics is improved usability. Code using extended mnemonics can be easier to write and to understand. Table B-4 lists the extended mnemonics required for the PPC403GC.

Note the following for every Branch Conditional mnemonic:

Bit 4 of the BO field provides a hint about the most likely outcome of a conditional branch (see Section 2.7.5 for a full discussion of Branch Prediction). Assemblers should set $BO_4 = 0$ unless a specific reason exists otherwise. In the BO field values specified in the table below, $BO_4 = 0$ has always been assumed. The assembler must allow the programmer to specify Branch Prediction. To do this, the assembler will support a suffix to every conditional branch mnemonic, as follows:

- + Predict branch to be taken.
- Predict branch not to be taken.

As specific examples, **bc** also could be coded as **bc+** or **bc–**, and **bne** also could be coded **bne+** or **bne–**. These alternate codings set $BO_4 = 1$ only if the requested prediction differs from the Standard Prediction (see Section 2.7.5).

Table B-4. Extended Mnemonics for PPC403GC

Mnemonic	Operands	Function	Other Registers Changed	Page
bctr		Branch unconditionally, to address in CTR. <i>Extended mnemonic for bcctr 20,0</i>		11-27
bctrl		<i>Extended mnemonic for bcctrl 20,0</i>	(LR) ← CIA + 4.	
bdnz	target	Decrement CTR. Branch if CTR ≠ 0. <i>Extended mnemonic for bc 16,0,target</i>		11-20
bdnza		<i>Extended mnemonic for bca 16,0,target</i>		
bdnzl		<i>Extended mnemonic for bcl 16,0,target</i>	(LR) ← CIA + 4.	
bdnzla		<i>Extended mnemonic for bcla 16,0,target</i>	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdnzlr		Decrement CTR. Branch if CTR \neq 0, to address in LR. <i>Extended mnemonic for</i> bclr 16,0		11-31
bdnzlrl		<i>Extended mnemonic for</i> bclrl 16,0	(LR) \leftarrow CIA + 4.	
bdnzf	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 0,cr_bit,target		11-20
bdnzfa		<i>Extended mnemonic for</i> bca 0,cr_bit,target		
bdnzfl		<i>Extended mnemonic for</i> bcl 0,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnzfla		<i>Extended mnemonic for</i> bcla 0,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnzflr	cr_bit	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for</i> bclr 0,cr_bit		11-31
bdnzflrl		<i>Extended mnemonic for</i> bclrl 0,cr_bit	(LR) \leftarrow CIA + 4.	
bdnzt	cr_bit, target	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 8,cr_bit,target		11-20
bdnzta		<i>Extended mnemonic for</i> bca 8,cr_bit,target		
bdnztl		<i>Extended mnemonic for</i> bcl 8,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdnztl a		<i>Extended mnemonic for</i> bcla 8,cr_bit,target	(LR) \leftarrow CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdnztlr	cr_bit	Decrement CTR. Branch if CTR \neq 0 AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 8,cr_bit		11-31
bdnztlrl		<i>Extended mnemonic for</i> bclrl 8,cr_bit	(LR) \leftarrow CIA + 4.	
bdz	target	Decrement CTR. Branch if CTR = 0. <i>Extended mnemonic for</i> bc 18,0,target		11-20
bdza		<i>Extended mnemonic for</i> bca 18,0,target		
bdzl		<i>Extended mnemonic for</i> bcl 18,0,target	(LR) \leftarrow CIA + 4.	
bdzla		<i>Extended mnemonic for</i> bcla 18,0,target	(LR) \leftarrow CIA + 4.	
bdzlr		Decrement CTR. Branch if CTR = 0, to address in LR. <i>Extended mnemonic for</i> bclr 18,0		11-31
bdzlrl		<i>Extended mnemonic for</i> bclrl 18,0	(LR) \leftarrow CIA + 4.	
bdzf	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 2,cr_bit,target		11-20
bdzfa		<i>Extended mnemonic for</i> bca 2,cr_bit,target		
bdzfl		<i>Extended mnemonic for</i> bcl 2,cr_bit,target	(LR) \leftarrow CIA + 4.	
bdzflla		<i>Extended mnemonic for</i> bcla 2,cr_bit,target	(LR) \leftarrow CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bdzflr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 0 to address in LR. <i>Extended mnemonic for</i> bclr 2,cr_bit		11-31
bdzflrl		<i>Extended mnemonic for</i> bclrl 2,cr_bit	(LR) ← CIA + 4.	
bdzt	cr_bit, target	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 10,cr_bit,target		11-20
bdzta		<i>Extended mnemonic for</i> bca 10,cr_bit,target		
bdztl		<i>Extended mnemonic for</i> bcl 10,cr_bit,target	(LR) ← CIA + 4.	
bdztla		<i>Extended mnemonic for</i> bcla 10,cr_bit,target	(LR) ← CIA + 4.	
bdztlr	cr_bit	Decrement CTR. Branch if CTR = 0 AND CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 10,cr_bit		11-31
bdztlrl		<i>Extended mnemonic for</i> bclrl 10,cr_bit	(LR) ← CIA + 4.	
beq	[cr_field,] target	Branch if equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+2,target		11-20
beqa		<i>Extended mnemonic for</i> bca 12,4*cr_field+2,target		
beql		<i>Extended mnemonic for</i> bcl 12,4*cr_field+2,target	(LR) ← CIA + 4.	
beqla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+2,target	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
beqctr	[cr_field]	Branch if equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+2		11-27
beqctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+2	(LR) ← CIA + 4.	
beqlr	[cr_field]	Branch if equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+2		11-31
beqlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+2	(LR) ← CIA + 4.	
bf	cr_bit, target	Branch if CR _{cr_bit} = 0. <i>Extended mnemonic for</i> bc 4,cr_bit,target		11-20
bfa		<i>Extended mnemonic for</i> bca 4,cr_bit,target		
bfl		<i>Extended mnemonic for</i> bcl 4,cr_bit,target	(LR) ← CIA + 4.	
bfla		<i>Extended mnemonic for</i> bcla 4,cr_bit,target	(LR) ← CIA + 4.	
bfctr	cr_bit	Branch if CR _{cr_bit} = 0, to address in CTR. <i>Extended mnemonic for</i> bcctr 4,cr_bit		11-27
bfctrl		<i>Extended mnemonic for</i> bcctrl 4,cr_bit	(LR) ← CIA + 4.	
bflr	cr_bit	Branch if CR _{cr_bit} = 0, to address in LR. <i>Extended mnemonic for</i> bclr 4,cr_bit		11-31
bflrl		<i>Extended mnemonic for</i> bclrl 4,cr_bit	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bge	[cr_field,] target	Branch if greater than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+0,target		11-20
bgea		<i>Extended mnemonic for</i> bca 4,4*cr_field+0,target		
bgei		<i>Extended mnemonic for</i> bcl 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bgeia		<i>Extended mnemonic for</i> bcla 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bgectr	[cr_field]	Branch if greater than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+0		11-27
bgectrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bgei	[cr_field]	Branch if greater than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+0		11-31
bgei		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bgt	[cr_field,] target	Branch if greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+1,target		11-20
bgt		<i>Extended mnemonic for</i> bca 12,4*cr_field+1,target		
bgti		<i>Extended mnemonic for</i> bcl 12,4*cr_field+1,target	(LR) ← CIA + 4.	
bgtia		<i>Extended mnemonic for</i> bcla 12,4*cr_field+1,target	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bgtctr	[cr_field]	Branch if greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+1		11-27
bgtctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+1	(LR) ← CIA + 4.	
bgtlr	[cr_field]	Branch if greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+1		11-31
bgtlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+1	(LR) ← CIA + 4.	
ble	[cr_field,] target	Branch if less than or equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+1,target		11-20
blea		<i>Extended mnemonic for</i> bca 4,4*cr_field+1,target		
blel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+1,target	(LR) ← CIA + 4.	
blela		<i>Extended mnemonic for</i> bcla 4,4*cr_field+1,target	(LR) ← CIA + 4.	
blectr	[cr_field]	Branch if less than or equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+1		11-27
blectrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+1	(LR) ← CIA + 4.	
blelr	[cr_field]	Branch if less than or equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+1		11-31
blelrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+1	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
blr		Branch unconditionally, to address in LR. <i>Extended mnemonic for</i> bclr 20,0		11-31
blrl		<i>Extended mnemonic for</i> bclrl 20,0	(LR) ← CIA + 4.	
blt	[cr_field,] target	Branch if less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+0,target		11-20
blta		<i>Extended mnemonic for</i> bca 12,4*cr_field+0,target		
bltl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+0,target	(LR) ← CIA + 4.	
bltla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+0,target	(LR) ← CIA + 4.	
bltctr	[cr_field]	Branch if less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+0		11-27
bltctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+0	(LR) ← CIA + 4.	
bltlr	[cr_field]	Branch if less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+0		11-31
bltlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+0	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bne	[cr_field,] target	Branch if not equal. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+2,target		11-20
bnea		<i>Extended mnemonic for</i> bca 4,4*cr_field+2,target		
bnel		<i>Extended mnemonic for</i> bcl 4,4*cr_field+2,target	(LR) ← CIA + 4.	
bnela		<i>Extended mnemonic for</i> bcla 4,4*cr_field+2,target	(LR) ← CIA + 4.	
bnctr	[cr_field]	Branch if not equal, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+2		11-27
bnctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+2	(LR) ← CIA + 4.	
bnelr	[cr_field]	Branch if not equal, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+2		11-31
bnelrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+2	(LR) ← CIA + 4.	
bng	[cr_field,] target	Branch if not greater than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+1,target		11-20
bnga		<i>Extended mnemonic for</i> bca 4,4*cr_field+1,target		
bngl		<i>Extended mnemonic for</i> bcl 4,4*cr_field+1,target	(LR) ← CIA + 4.	
bngla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+1,target	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bngctr	[cr_field]	Branch if not greater than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+1		11-27
bngctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+1	(LR) ← CIA + 4.	
bnglrr	[cr_field]	Branch if not greater than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclrr 4,4*cr_field+1		11-31
bnglrrl		<i>Extended mnemonic for</i> bclrrl 4,4*cr_field+1	(LR) ← CIA + 4.	
bnl	[cr_field,] target	Branch if not less than. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+0,target		11-20
bnla		<i>Extended mnemonic for</i> bca 4,4*cr_field+0,target		
bnll		<i>Extended mnemonic for</i> bcl 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bnlla		<i>Extended mnemonic for</i> bcla 4,4*cr_field+0,target	(LR) ← CIA + 4.	
bnlctr	[cr_field]	Branch if not less than, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+0		11-27
bnlctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+0	(LR) ← CIA + 4.	
bnllrr	[cr_field]	Branch if not less than, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclrr 4,4*cr_field+0		11-31
bnllrrl		<i>Extended mnemonic for</i> bclrrl 4,4*cr_field+0	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bns	[cr_field,] target	Branch if not summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target		11-20
bnsa		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target		
bnsi		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnsia		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnsctr	[cr_field]	Branch if not summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+3		11-27
bnsctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnslr	[cr_field]	Branch if not summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+3		11-31
bnslrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnu	[cr_field,] target	Branch if not unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 4,4*cr_field+3,target		11-20
bnuu		<i>Extended mnemonic for</i> bca 4,4*cr_field+3,target		
bnul		<i>Extended mnemonic for</i> bcl 4,4*cr_field+3,target	(LR) ← CIA + 4.	
bnula		<i>Extended mnemonic for</i> bcla 4,4*cr_field+3,target	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bnuctr	[cr_field]	Branch if not unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 4,4*cr_field+3		11-27
bnuctrl		<i>Extended mnemonic for</i> bcctrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bnulr	[cr_field]	Branch if not unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 4,4*cr_field+3		11-31
bnulrl		<i>Extended mnemonic for</i> bclrl 4,4*cr_field+3	(LR) ← CIA + 4.	
bso	[cr_field,] target	Branch if summary overflow. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target		11-20
bsoa		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target		
bsol		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bsola		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bsoctr	[cr_field]	Branch if summary overflow, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+3		11-27
bsoctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+3	(LR) ← CIA + 4.	
bsolr	[cr_field]	Branch if summary overflow, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+3		11-31
bsolrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+3	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bt	cr_bit, target	Branch if CR _{cr_bit} = 1. <i>Extended mnemonic for</i> bc 12,cr_bit,target		11-20
bta		<i>Extended mnemonic for</i> bca 12,cr_bit,target		
btl		<i>Extended mnemonic for</i> bcl 12,cr_bit,target	(LR) ← CIA + 4.	
btla		<i>Extended mnemonic for</i> bcla 12,cr_bit,target	(LR) ← CIA + 4.	
btctr	cr_bit	Branch if CR _{cr_bit} = 1, to address in CTR. <i>Extended mnemonic for</i> bcctr 12,cr_bit		11-27
btctrl		<i>Extended mnemonic for</i> bcctrl 12,cr_bit	(LR) ← CIA + 4.	
btlr	cr_bit	Branch if CR _{cr_bit} = 1, to address in LR. <i>Extended mnemonic for</i> bclr 12,cr_bit		11-31
btlrl		<i>Extended mnemonic for</i> bclrl 12,cr_bit	(LR) ← CIA + 4.	
bun	[cr_field,] target	Branch if unordered. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bc 12,4*cr_field+3,target		11-20
buna		<i>Extended mnemonic for</i> bca 12,4*cr_field+3,target		
bunl		<i>Extended mnemonic for</i> bcl 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bunla		<i>Extended mnemonic for</i> bcla 12,4*cr_field+3,target	(LR) ← CIA + 4.	
bunctr	[cr_field]	Branch if unordered, to address in CTR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bcctr 12,4*cr_field+3		11-27
bunctrl		<i>Extended mnemonic for</i> bcctrl 12,4*cr_field+3	(LR) ← CIA + 4.	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bunlr	[cr_field]	Branch if unordered, to address in LR. Use CR0 if cr_field is omitted. <i>Extended mnemonic for</i> bclr 12,4*cr_field+3		11-31
bunlrl		<i>Extended mnemonic for</i> bclrl 12,4*cr_field+3	(LR) \leftarrow CIA + 4.	
clrlwi	RA, RS, n	Clear left immediate. ($n < 32$) $(RA)_{0:n-1} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,0,n,31		11-130
clrlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,n,31	CR[CR0]	
clrlslwi	RA, RS, b, n	Clear left and shift left immediate. ($n \leq b < 32$) $(RA)_{b-n:31-n} \leftarrow (RS)_{b:31}$ $(RA)_{32-n:31} \leftarrow {}^n0$ $(RA)_{0:b-n-1} \leftarrow {}^{b-n}0$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,b-n,31-n		11-130
clrlslwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,b-n,31-n	CR[CR0]	
clrrwi	RA, RS, n	Clear right immediate. ($n < 32$) $(RA)_{32-n:31} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,0,0,31-n		11-130
clrrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,0,0,31-n	CR[CR0]	
cmplw	[BF,] RA, RB	Compare Logical Word. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmpl BF,0,RA,RB		11-38
cmplwi	[BF,] RA, IM	Compare Logical Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmpli BF,0,RA,IM		11-39
cmpw	[BF,] RA, RB	Compare Word. Use CR0 if BF is omitted. <i>Extended mnemonic for</i> cmp BF,0,RA,RB		11-36

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
cmpwi	[BF,] RA, IM	Compare Word Immediate. Use CR0 if BF is omitted. <i>Extended mnemonic for cmpi BF,0,RA,IM</i>		11-37
crclr	bx	Condition register clear. <i>Extended mnemonic for crxor bx,bx,bx</i>		11-48
crmove	bx, by	Condition register move. <i>Extended mnemonic for cror bx,by,by</i>		11-46
crnot	bx, by	Condition register not. <i>Extended mnemonic for crnor bx,by,by</i>		11-45
crset	bx	Condition register set. <i>Extended mnemonic for creqv bx,bx,bx</i>		11-43
extlwi	RA, RS, n, b	Extract and left justify immediate. ($n > 0$) $(RA)_{0:n-1} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{n:31} \leftarrow 32-n0$ <i>Extended mnemonic for rlwinm RA,RS,b,0,n-1</i>		11-130
extlwi.		<i>Extended mnemonic for rlwinm. RA,RS,b,0,n-1</i>	CR[CR0]	
extrwi	RA, RS, n, b	Extract and right justify immediate. ($n > 0$) $(RA)_{32-n:31} \leftarrow (RS)_{b:b+n-1}$ $(RA)_{0:31-n} \leftarrow 32-n0$ <i>Extended mnemonic for rlwinm RA,RS,b+n,32-n,31</i>		11-130
extrwi.		<i>Extended mnemonic for rlwinm. RA,RS,b+n,32-n,31</i>	CR[CR0]	
inslwi	RA, RS, n, b	Insert from left immediate. ($n > 0$) $(RA)_{b:b+n-1} \leftarrow (RS)_{0:n-1}$ <i>Extended mnemonic for rlwimi RA,RS,32-b,b,b+n-1</i>		11-129
inslwi.		<i>Extended mnemonic for rlwimi. RA,RS,32-b,b,b+n-1</i>	CR[CR0]	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
insrwi	RA, RS, n, b	Insert from right immediate. ($n > 0$) $(RA)_{b:b+n-1} \leftarrow (RS)_{32-n:31}$ <i>Extended mnemonic for</i> rlwimi RA,RS,32-b-n,b,b+n-1		11-129
insrwi.		<i>Extended mnemonic for</i> rlwimi. RA,RS,32-b-n,b,b+n-1	CR[CR0]	
la	RT, D(RA)	Load address. ($RA \neq 0$) D is an offset from a base address that is assumed to be (RA). $(RT) \leftarrow (RA) + \text{EXTS}(D)$ <i>Extended mnemonic for</i> addi RT,RA,D		11-9
li	RT, IM	Load immediate. $(RT) \leftarrow \text{EXTS}(IM)$ <i>Extended mnemonic for</i> addi RT,0,value		11-9
lis	RT, IM	Load immediate shifted. $(RT) \leftarrow (IM \parallel 160)$ <i>Extended mnemonic for</i> addis RT,0,value		11-12

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mbear mbesr mibr0 mibr1 mibr2 mibr3 mibr4 mibr5 mibr6 mibr7 mfdmacc0 mfdmacc1 mfdmacc2 mfdmacc3 mfdmacr0 mfdmacr1 mfdmacr2 mfdmacr3 mfdmact0 mfdmact1 mfdmact2 mfdmact3 mfdmada0 mfdmada1 mfdmada2 mfdmada3 mfdmasa0 mfdmasa1 mfdmasa2 mfdmasa3 mfdmasr mfexisr mfexier mfiochr	RT	Move from device control register DCRN. <i>Extended mnemonic for</i> mfdcr RT,DCRN See Table 12-3 on page 4 for listing of valid DCRN values.		11-104

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mfcdbcr mfctr mfdac1 mfdac2 mfdbsr mfdccr mfdcwr mfdear mfesr mfevpr mfiac1 mfiac2 mficcr mficdbdr mflr mfpbl1 mfpbl2 mfpbu1 mfpbu2 mfpid mfpit mfpvr mfsgr mfsprg0 mfsprg1 mfsprg2 mfsprg3 mfsrr0 mfsrr1 mfsrr2 mfsrr3 mftbhi mftbhu mftblo mftblu mftcr mftsr mfxer mfzpr	RT	Move from special purpose register SPRN. <i>Extended mnemonic for</i> mf spr RT,SPRN See Table 12-2 on page 2 for listing of valid SPRN values.		11-107
mr	RT, RS	Move register. (RT) ← (RS) <i>Extended mnemonic for</i> or RT,RS,RS		11-123
mr.		<i>Extended mnemonic for</i> or. RT,RS,RS	CR[CR0]	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mtcr	RS	Move to Condition Register. <i>Extended mnemonic for mtcrr 0xFF,RS</i>		11-109
mtbear mtbesr mtbr0 mtbr1 mtbr2 mtbr3 mtbr4 mtbr5 mtbr6 mtbr7 mtdmacc0 mtdmacc1 mtdmacc2 mtdmacc3 mtdmacr0 mtdmacr1 mtdmacr2 mtdmacr3 mtdmact0 mtdmact1 mtdmact2 mtdmact3 mtdmada0 mtdmada1 mtdmada2 mtdmada3 mtdmasa0 mtdmasa1 mtdmasa2 mtdmasa3 mtdmasr mtexisr mtexier mtiocr	RS	Move to device control register DCRN. <i>Extended mnemonic for mtdcr DCRN,RS</i> See Table 12-3 on page 4 for listing of valid DCRN values.		11-111

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
mtcdbc mtctr mtdac1 mtdac2 mtdbsr mtdccr mtdcwr mtesr mtevr mtiac1 mtiac2 mticcr mticdbdr mtlr mtpbl1 mtpbl2 mtpbu1 mtpbu2 mtpid mtpit mtmgr mtsrg0 mtsrg1 mtsrg2 mtsrg3 mtsrr0 mtsrr1 mtsrr2 mtsrr3 mtbhi mtblo mttcr mttsr mtxer mtzpr	RS	Move to special purpose register SPRN. <i>Extended mnemonic for</i> mtspr SPRN,RS See Table 12-2 on page 2 for listing of valid SPRN values.		11-114
nop		Preferred no-op, triggers optimizations based on no-ops. <i>Extended mnemonic for</i> ori 0,0,0		11-125

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
not	RA, RS	Complement register. $(RA) \leftarrow \neg(RS)$ <i>Extended mnemonic for</i> nor RA,RS,RS		11-122
not.		<i>Extended mnemonic for</i> nor. RA,RS,RS	CR[CR0]	
rotlw	RA, RS, RB	Rotate left. $(RA) \leftarrow \text{ROTL}((RS), (RB)_{27:31})$ <i>Extended mnemonic for</i> rlwnm RA,RS,RB,0,31		11-133
rotlw.		<i>Extended mnemonic for</i> rlwnm. RA,RS,RB,0,31	CR[CR0]	
rotlwi	RA, RS, n	Rotate left immediate. $(RA) \leftarrow \text{ROTL}((RS), n)$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,0,31		11-130
rotlwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,0,31	CR[CR0]	
rotrwi	RA, RS, n	Rotate right immediate. $(RA) \leftarrow \text{ROTL}((RS), 32-n)$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,0,31		11-130
rotrwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,0,31	CR[CR0]	
slwi	RA, RS, n	Shift left immediate. ($n < 32$) $(RA)_{0:31-n} \leftarrow (RS)_{n:31}$ $(RA)_{32-n:31} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,n,0,31-n		11-130
slwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,n,0,31-n	CR[CR0]	
srwi	RA, RS, n	Shift right immediate. ($n < 32$) $(RA)_{n:31} \leftarrow (RS)_{0:31-n}$ $(RA)_{0:n-1} \leftarrow {}^n0$ <i>Extended mnemonic for</i> rlwinm RA,RS,32-n,n,31		11-130
srwi.		<i>Extended mnemonic for</i> rlwinm. RA,RS,32-n,n,31	CR[CR0]	

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
sub	RT, RA, RB	Subtract (RB) from (RA). (RT) $\leftarrow \neg(\text{RB}) + (\text{RA}) + 1$. <i>Extended mnemonic for</i> subf RT,RB,RA		11-159
sub.		<i>Extended mnemonic for</i> subf. RT,RB,RA	CR[CR0]	
subo		<i>Extended mnemonic for</i> subfo RT,RB,RA	XER[SO, OV]	
subo.		<i>Extended mnemonic for</i> subfo. RT,RB,RA	CR[CR0] XER[SO, OV]	
subc	RT, RA, RB	Subtract (RB) from (RA). (RT) $\leftarrow \neg(\text{RB}) + (\text{RA}) + 1$. Place carry-out in XER[CA]. <i>Extended mnemonic for</i> subfc RT,RB,RA		11-160
subc.		<i>Extended mnemonic for</i> subfc. RT,RB,RA	CR[CR0]	
subco		<i>Extended mnemonic for</i> subfco RT,RB,RA	XER[SO, OV]	
subco.		<i>Extended mnemonic for</i> subfco. RT,RB,RA	CR[CR0] XER[SO, OV]	
subi	RT, RA, IM	Subtract EXTS(IM) from (RA 0). Place result in RT. <i>Extended mnemonic for</i> addi RT,RA,-IM		11-9
subic	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for</i> addic RT,RA,-IM		11-10
subic.	RT, RA, IM	Subtract EXTS(IM) from (RA). Place result in RT. Place carry-out in XER[CA]. <i>Extended mnemonic for</i> addic. RT,RA,-IM	CR[CR0]	11-11
subis	RT, RA, IM	Subtract (IM \parallel ¹⁶ 0) from (RA 0). Place result in RT. <i>Extended mnemonic for</i> addis RT,RA,-IM		11-12

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbrehi	RT, RA	Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$ <i>Extended mnemonic for</i> tlbre RT,RA,0		11-168
tlbrelo	RT, RA	Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$ <i>Extended mnemonic for</i> tlbre RT,RA,1		11-168
tlbwehi	RS, RA	Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$ <i>Extended mnemonic for</i> tlbwe RS,RA,0		11-172
tlbwelo	RS, RA	Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$ <i>Extended mnemonic for</i> tlbwe RS,RA,1		11-172

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
trap		Trap unconditionally. <i>Extended mnemonic for tw 31,0,0</i>		11-174
tweq	RA, RB	Trap if (RA) equal to (RB). <i>Extended mnemonic for tw 4,RA,RB</i>		
twge		Trap if (RA) greater than or equal to (RB). <i>Extended mnemonic for tw 12,RA,RB</i>		
twgt		Trap if (RA) greater than (RB). <i>Extended mnemonic for tw 8,RA,RB</i>		
twle		Trap if (RA) less than or equal to (RB). <i>Extended mnemonic for tw 20,RA,RB</i>		
twlge		Trap if (RA) logically greater than or equal to (RB). <i>Extended mnemonic for tw 5,RA,RB</i>		
twlgt		Trap if (RA) logically greater than (RB). <i>Extended mnemonic for tw 1,RA,RB</i>		
twlle		Trap if (RA) logically less than or equal to (RB). <i>Extended mnemonic for tw 6,RA,RB</i>		
twllt		Trap if (RA) logically less than (RB). <i>Extended mnemonic for tw 2,RA,RB</i>		
twlng		Trap if (RA) logically not greater than (RB). <i>Extended mnemonic for tw 6,RA,RB</i>		
twlnl		Trap if (RA) logically not less than (RB). <i>Extended mnemonic for tw 5,RA,RB</i>		
twlt		Trap if (RA) less than (RB). <i>Extended mnemonic for tw 16,RA,RB</i>		
twne		Trap if (RA) not equal to (RB). <i>Extended mnemonic for tw 24,RA,RB</i>		
twng		Trap if (RA) not greater than (RB). <i>Extended mnemonic for tw 20,RA,RB</i>		
twnl		Trap if (RA) not less than (RB). <i>Extended mnemonic for tw 12,RA,RB</i>		

Table B-4. Extended Mnemonics for PPC403GC (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tweqi	RA, IM	Trap if (RA) equal to EXTS(IM). <i>Extended mnemonic for twi 4,RA,IM</i>		11-177
twgei		Trap if (RA) greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>		
twgti		Trap if (RA) greater than EXTS(IM). <i>Extended mnemonic for twi 8,RA,IM</i>		
twlei		Trap if (RA) less than or equal to EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>		
twlgei		Trap if (RA) logically greater than or equal to EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>		
twlgti		Trap if (RA) logically greater than EXTS(IM). <i>Extended mnemonic for twi 1,RA,IM</i>		
twllei		Trap if (RA) logically less than or equal to EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>		
twllti		Trap if (RA) logically less than EXTS(IM). <i>Extended mnemonic for twi 2,RA,IM</i>		
twlngi		Trap if (RA) logically not greater than EXTS(IM). <i>Extended mnemonic for twi 6,RA,IM</i>		
twlnli		Trap if (RA) logically not less than EXTS(IM). <i>Extended mnemonic for twi 5,RA,IM</i>		
twlti		Trap if (RA) less than EXTS(IM). <i>Extended mnemonic for twi 16,RA,IM</i>		
twnei		Trap if (RA) not equal to EXTS(IM). <i>Extended mnemonic for twi 24,RA,IM</i>		
twngi		Trap if (RA) not greater than EXTS(IM). <i>Extended mnemonic for twi 20,RA,IM</i>		
twnli		Trap if (RA) not less than EXTS(IM). <i>Extended mnemonic for twi 12,RA,IM</i>		

B.5 Storage Reference Instructions

The PPC403GC uses load and store instructions to transfer data between memory and the general purpose registers. Load and store instructions operate on byte, halfword and word data. The Storage Reference instructions also support loading or storing multiple registers, character strings, and byte-reversed data. Table B-5 shows the Storage Reference instructions available for use in the PPC403GC.

Table B-5. Storage Reference Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
lbz	RT, D(RA)	Load byte from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{24}0$ MS(EA,1).		11-77
lbzu	RT, D(RA)	Load byte from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{24}0$ MS(EA,1). Update the base address, (RA) \leftarrow EA.		11-78
lbzux	RT, RA, RB	Load byte from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{24}0$ MS(EA,1). Update the base address, (RA) \leftarrow EA.		11-79
lbzx	RT, RA, RB	Load byte from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{24}0$ MS(EA,1).		11-80
lha	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)).		11-81
lhau	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)). Update the base address, (RA) \leftarrow EA.		11-82
lhaux	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)). Update the base address, (RA) \leftarrow EA.		11-83
lhax	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and sign extend, (RT) \leftarrow EXTS(MS(EA,2)).		11-84

Table B-5. Storage Reference Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
lhbrx	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) then reverse byte order and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel MS(EA+1,1) \parallel MS(EA,1)$.		11-85
lhz	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel MS(EA,2)$.		11-86
lhzu	RT, D(RA)	Load halfword from EA = (RA 0) + EXTS(D) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel MS(EA,2)$. Update the base address, (RA) \leftarrow EA.		11-87
lhzux	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel MS(EA,2)$. Update the base address, (RA) \leftarrow EA.		11-88
lhzx	RT, RA, RB	Load halfword from EA = (RA 0) + (RB) and pad left with zeroes, (RT) \leftarrow $^{16}0 \parallel MS(EA,2)$.		11-89
lmw	RT, D(RA)	Load multiple words starting from EA = (RA 0) + EXTS(D). Place into consecutive registers, RT through GPR(31). RA is not altered unless RA = GPR(31).		11-90
lswi	RT, RA, NB	Load consecutive bytes from EA=(RA 0). Number of bytes n=32 if NB=0, else n=NB. Stack bytes into words in CEIL(n/4) consecutive registers starting with RT, to $R_{FINAL} \leftarrow ((RT + CEIL(n/4) - 1) \% 32)$. GPR(0) is consecutive to GPR(31). RA is not altered unless RA = R_{FINAL} .		11-91
lswx	RT, RA, RB	Load consecutive bytes from EA=(RA 0)+(RB). Number of bytes n=XER[TBC]. Stack bytes into words in CEIL(n/4) consecutive registers starting with RT, to $R_{FINAL} \leftarrow ((RT + CEIL(n/4) - 1) \% 32)$. GPR(0) is consecutive to GPR(31). RA is not altered unless RA = R_{FINAL} . RB is not altered unless RB = R_{FINAL} . If n=0, content of RT is undefined.		11-93

Table B-5. Storage Reference Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
lwarx	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4). Set the Reservation bit.		11-95
lwbx	RT, RA, RB	Load word from EA = (RA 0) + (RB) then reverse byte order, (RT) \leftarrow MS(EA+3,1) MS(EA+2,1) MS(EA+1,1) MS(EA,1).		11-96
lwz	RT, D(RA)	Load word from EA = (RA 0) + EXTS(D) and place in RT, (RT) \leftarrow MS(EA,4).		11-97
lwzu	RT, D(RA)	Load word from EA = (RA 0) + EXTS(D) and place in RT, (RT) \leftarrow MS(EA,4). Update the base address, (RA) \leftarrow EA.		11-98
lwzux	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4). Update the base address, (RA) \leftarrow EA.		11-99
lwzx	RT, RA, RB	Load word from EA = (RA 0) + (RB) and place in RT, (RT) \leftarrow MS(EA,4).		11-100
stb	RS, D(RA)	Store byte (RS) _{24:31} in memory at EA = (RA 0) + EXTS(D).		11-139
stbu	RS, D(RA)	Store byte (RS) _{24:31} in memory at EA = (RA 0) + EXTS(D). Update the base address, (RA) \leftarrow EA.		11-140
stbux	RS, RA, RB	Store byte (RS) _{24:31} in memory at EA = (RA 0) + (RB). Update the base address, (RA) \leftarrow EA.		11-141
stbx	RS, RA, RB	Store byte (RS) _{24:31} in memory at EA = (RA 0) + (RB).		11-142
sth	RS, D(RA)	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + EXTS(D).		11-143

Table B-5. Storage Reference Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
sthbrx	RS, RA, RB	Store halfword (RS) _{16:31} byte-reversed in memory at EA = (RA 0) + (RB). MS(EA, 2) \leftarrow (RS) _{24:31} (RS) _{16:23}		11-144
sthu	RS, D(RA)	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + EXTS(D). Update the base address, (RA) \leftarrow EA.		11-145
sthux	RS, RA, RB	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + (RB). Update the base address, (RA) \leftarrow EA.		11-146
sthx	RS, RA, RB	Store halfword (RS) _{16:31} in memory at EA = (RA 0) + (RB).		11-147
stmw	RS, D(RA)	Store consecutive words from RS through GPR(31) in memory starting at EA = (RA 0) + EXTS(D).		11-148
stswi	RS, RA, NB	Store consecutive bytes in memory starting at EA=(RA 0). Number of bytes n=32 if NB=0, else n=NB. Bytes are unstacked from CEIL(n/4) consecutive registers starting with RS. GPR(0) is consecutive to GPR(31).		11-149
stswx	RS, RA, RB	Store consecutive bytes in memory starting at EA=(RA 0)+(RB). Number of bytes n=XER[TBC]. Bytes are unstacked from CEIL(n/4) consecutive registers starting with RS. GPR(0) is consecutive to GPR(31).		11-150
stw	RS, D(RA)	Store word (RS) in memory at EA = (RA 0) + EXTS(D).		11-152
stwbrx	RS, RA, RB	Store word (RS) byte-reversed in memory at EA = (RA 0) + (RB). MS(EA, 4) \leftarrow (RS) _{24:31} (RS) _{16:23} (RS) _{8:15} (RS) _{0:7}		11-153

Table B-5. Storage Reference Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
stwcx.	RS, RA, RB	Store word (RS) in memory at $EA = (RA 0) + (RB)$ only if reservation bit is set. if RESERVE = 1 then $MS(EA, 4) \leftarrow (RS)$ RESERVE \leftarrow 0 $(CR[CR0]) \leftarrow {}^20 \parallel 1 \parallel XER_{so}$ else $(CR[CR0]) \leftarrow {}^20 \parallel 0 \parallel XER_{so}.$		11-154
stwu	RS, D(RA)	Store word (RS) in memory at $EA = (RA 0) + EXTS(D).$ Update the base address, $(RA) \leftarrow EA.$		11-156
stwux	RS, RA, RB	Store word (RS) in memory at $EA = (RA 0) + (RB).$ Update the base address, $(RA) \leftarrow EA.$		11-157
stwx	RS, RA, RB	Store word (RS) in memory at $EA = (RA 0) + (RB).$		11-158

B.6 Arithmetic and Logical Instructions

Table B-6 shows the set of arithmetic and logical instructions supported by the PPC403GC. Arithmetic operations are performed on integer or ordinal operands stored in registers. Instructions using two operands are defined in a three operand format where the operation is performed on the operands stored in two registers and the result is placed in a third register. Instructions using one operand are defined in a two operand format where the operation is performed on the operand in one register and the result is placed in another register. Several instructions also have immediate formats in which one operand is coded as part of the instruction itself. Most arithmetic and logical instructions can optionally set the condition code register based on the outcome of the instruction.

Table B-6. Arithmetic and Logical Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
add	RT, RA, RB	Add (RA) to (RB). Place result in RT.		11-6
add.			CR[CR0]	
addo			XER[SO, OV]	
addo.			CR[CR0] XER[SO, OV]	
addc	RT, RA, RB	Add (RA) to (RB). Place result in RT. Place carry-out in XER[CA].		11-7
addc.			CR[CR0]	
addco			XER[SO, OV]	
addco.			CR[CR0] XER[SO, OV]	
adde	RT, RA, RB	Add XER[CA], (RA), (RB). Place result in RT. Place carry-out in XER[CA].		11-8
adde.			CR[CR0]	
addeo			XER[SO, OV]	
addeo.			CR[CR0] XER[SO, OV]	
addi	RT, RA, IM	Add EXTS(IM) to (RA)0. Place result in RT.		11-9
addic	RT, RA, IM	Add EXTS(IM) to (RA)0. Place result in RT. Place carry-out in XER[CA].		11-10
addic.	RT, RA, IM	Add EXTS(IM) to (RA)0. Place result in RT. Place carry-out in XER[CA].	CR[CR0]	11-11

Table B-6. Arithmetic and Logical Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
addis	RT, RA, IM	Add (IM \parallel ¹⁶ 0) to (RA 0). Place result in RT.		11-12
addme	RT, RA	Add XER[CA], (RA), (-1). Place result in RT. Place carry-out in XER[CA].		11-13
addme.			CR[CR0]	
addmeo			XER[SO, OV]	
addmeo.			CR[CR0] XER[SO, OV]	
addze	RT, RA	Add XER[CA] to (RA). Place result in RT. Place carry-out in XER[CA].		11-14
addze.			CR[CR0]	
addzeo			XER[SO, OV]	
addzeo.			CR[CR0] XER[SO, OV]	
and	RA, RS, RB	AND (RS) with (RB). Place result in RA.		11-15
and.			CR[CR0]	
andc	RA, RS, RB	AND (RS) with \neg (RB). Place result in RA.		11-16
andc.			CR[CR0]	
andi.	RA, RS, IM	AND (RS) with (¹⁶ 0 \parallel IM). Place result in RA.	CR[CR0]	11-17
andis.	RA, RS, IM	AND (RS) with (IM \parallel ¹⁶ 0). Place result in RA.	CR[CR0]	11-18
cntlzw	RA, RS	Count leading zeros in RS. Place result in RA.		11-40
cntlzw.			CR[CR0]	
divw	RT, RA, RB	Divide (RA) by (RB), signed. Place result in RT.		11-62
divw.			CR[CR0]	
divwo			XER[SO, OV]	
divwo.			CR[CR0] XER[SO, OV]	

Table B-6. Arithmetic and Logical Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
divwu	RT, RA, RB	Divide (RA) by (RB), unsigned. Place result in RT.		11-63
divwu.			CR[CR0]	
divwuo			XER[SO, OV]	
divwuo.			CR[CR0] XER[SO, OV]	
eqv	RA, RS, RB	Equivalence of (RS) with (RB). $(RA) \leftarrow \neg((RS) \oplus (RB))$		11-65
eqv.			CR[CR0]	
extsb	RA, RS	Extend the sign of byte (RS) _{24:31} . Place the result in RA.		11-66
extsb.			CR[CR0]	
extsh	RA, RS	Extend the sign of halfword (RS) _{16:31} . Place the result in RA.		11-67
extsh.			CR[CR0]	
mulhw	RT, RA, RB	Multiply (RA) and (RB), signed. Place hi-order result in RT. $prod_{0:63} \leftarrow (RA) \times (RB)$ (signed). $(RT) \leftarrow prod_{0:31}$.		11-116
mulhw.			CR[CR0]	
mulhwu	RT, RA, RB	Multiply (RA) and (RB), unsigned. Place hi-order result in RT. $prod_{0:63} \leftarrow (RA) \times (RB)$ (unsigned). $(RT) \leftarrow prod_{0:31}$.		11-117
mulhwu.			CR[CR0]	
mulli	RT, RA, IM	Multiply (RA) and IM, signed. Place lo-order result in RT. $prod_{0:47} \leftarrow (RA) \times IM$ (signed) $(RT) \leftarrow prod_{16:47}$		11-118
mulhw	RT, RA, RB	Multiply (RA) and (RB), signed. Place lo-order result in RT. $prod_{0:63} \leftarrow (RA) \times (RB)$ (signed). $(RT) \leftarrow prod_{32:63}$.		11-119
mulhw.			CR[CR0]	
mulwuo			XER[SO, OV]	
mulwuo.			CR[CR0] XER[SO, OV]	
nand	RA, RS, RB	NAND (RS) with (RB). Place result in RA.		11-120
nand.			CR[CR0]	

Table B-6. Arithmetic and Logical Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
neg	RT, RA	Negative (two's complement) of RA. $(RT) \leftarrow \neg(RA) + 1$		11-121
neg.			CR[CR0]	
nego			XER[SO, OV]	
nego.			CR[CR0] XER[SO, OV]	
nor	RA, RS, RB	NOR (RS) with (RB). Place result in RA.		11-122
nor.			CR[CR0]	
or	RA, RS, RB	OR (RS) with (RB). Place result in RA.		11-123
or.			CR[CR0]	
orc	RA, RS, RB	OR (RS) with $\neg(RB)$. Place result in RA.		11-124
orc.			CR[CR0]	
ori	RA, RS, IM	OR (RS) with ($^{16}0 \parallel IM$). Place result in RA.		11-125
oris	RA, RS, IM	OR (RS) with ($IM \parallel ^{16}0$). Place result in RA.		11-126
subf	RT, RA, RB	Subtract (RA) from (RB). $(RT) \leftarrow \neg(RA) + (RB) + 1.$		11-159
subf.			CR[CR0]	
subfo			XER[SO, OV]	
subfo.			CR[CR0] XER[SO, OV]	
subfc	RT, RA, RB	Subtract (RA) from (RB). $(RT) \leftarrow \neg(RA) + (RB) + 1.$ Place carry-out in XER[CA].		11-160
subfc.			CR[CR0]	
subfco			XER[SO, OV]	
subfco.			CR[CR0] XER[SO, OV]	
subfe	RT, RA, RB	Subtract (RA) from (RB) with carry-in. $(RT) \leftarrow \neg(RA) + (RB) + XER[CA].$ Place carry-out in XER[CA].		11-162
subfe.			CR[CR0]	
subfeo			XER[SO, OV]	
subfeo.			CR[CR0] XER[SO, OV]	

Table B-6. Arithmetic and Logical Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
subfic	RT, RA, IM	Subtract (RA) from EXTS(IM). $(RT) \leftarrow \neg(RA) + \text{EXTS}(IM) + 1$. Place carry-out in XER[CA].		11-163
subfme	RT, RA, RB	Subtract (RA) from (−1) with carry-in. $(RT) \leftarrow \neg(RA) + (-1) + \text{XER}[CA]$. Place carry-out in XER[CA].		11-164
subfme.			CR[CR0]	
subfmeo			XER[SO, OV]	
subfmeo.			CR[CR0] XER[SO, OV]	
subfze	RT, RA, RB	Subtract (RA) from zero with carry-in. $(RT) \leftarrow \neg(RA) + \text{XER}[CA]$. Place carry-out in XER[CA].		11-165
subfze.			CR[CR0]	
subfzeo			XER[SO, OV]	
subfzeo.			CR[CR0] XER[SO, OV]	
xor	RA, RS, RB	XOR (RS) with (RB). Place result in RA.		11-182
xor.			CR[CR0]	
xori	RA, RS, IM	XOR (RS) with (¹⁶ 0 IM). Place result in RA.		11-183
xoris	RA, RS, IM	XOR (RS) with (IM ¹⁶ 0). Place result in RA.		11-184

B.7 Condition Register Logical Instructions

Condition Register (CR) logical instructions allow the user to combine the results of several comparisons without incurring the overhead of conditional branching. These instructions can significantly improve code performance if multiple conditions are tested prior to making a branch decision. Table B-7 summarizes the CR logical instructions.

Table B-7. Condition Register Logical Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
crand	BT, BA, BB	AND bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-41
crandc	BT, BA, BB	AND bit (CR_{BA}) with $\neg(CR_{BB})$. Place result in CR_{BT} .		11-42
creqv	BT, BA, BB	Equivalence of bit CR_{BA} with CR_{BB} . $CR_{BT} \leftarrow \neg(CR_{BA} \oplus CR_{BB})$		11-43
crnand	BT, BA, BB	NAND bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-44
crnor	BT, BA, BB	NOR bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-45
cror	BT, BA, BB	OR bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-46
crorc	BT, BA, BB	OR bit (CR_{BA}) with $\neg(CR_{BB})$. Place result in CR_{BT} .		11-47
crxor	BT, BA, BB	XOR bit (CR_{BA}) with (CR_{BB}). Place result in CR_{BT} .		11-48
mcrf	BF, BFA	Move CR field, ($CR[CRn] \leftarrow CR[CRm]$) where $m \leftarrow BFA$ and $n \leftarrow BF$.		11-101

B.8 Branch Instructions

The architecture provides conditional and unconditional branches to any storage location. The conditional branch instructions test condition codes set previously and branch accordingly. Conditional branch instructions may decrement and test the Count Register (CTR) as part of determination of the branch condition and may save the return address in the Link Register (LR). The target address for a branch may be a displacement from the current instruction address (CIA), or may be contained in the LR or CTR, or may be an absolute address.

Table B-8. Branch Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
b	target	Branch unconditional relative. $LI \leftarrow (target - CIA)_{6:29}$ $NIA \leftarrow CIA + EXTS(LI \parallel 20)$		11-19
ba		Branch unconditional absolute. $LI \leftarrow target_{6:29}$ $NIA \leftarrow EXTS(LI \parallel 20)$		
bl		Branch unconditional relative. $LI \leftarrow (target - CIA)_{6:29}$ $NIA \leftarrow CIA + EXTS(LI \parallel 20)$	$(LR) \leftarrow CIA + 4.$	
bla		Branch unconditional absolute. $LI \leftarrow target_{6:29}$ $NIA \leftarrow EXTS(LI \parallel 20)$	$(LR) \leftarrow CIA + 4.$	
bc	BO, BI, target	Branch conditional relative. $BD \leftarrow (target - CIA)_{16:29}$ $NIA \leftarrow CIA + EXTS(BD \parallel 20)$	CTR if $BO_2 = 0.$	11-20
bca		Branch conditional absolute. $BD \leftarrow target_{16:29}$ $NIA \leftarrow EXTS(BD \parallel 20)$	CTR if $BO_2 = 0.$	
bcl		Branch conditional relative. $BD \leftarrow (target - CIA)_{16:29}$ $NIA \leftarrow CIA + EXTS(BD \parallel 20)$	CTR if $BO_2 = 0.$ $(LR) \leftarrow CIA + 4.$	
bcla		Branch conditional absolute. $BD \leftarrow target_{16:29}$ $NIA \leftarrow EXTS(BD \parallel 20)$	CTR if $BO_2 = 0.$ $(LR) \leftarrow CIA + 4.$	
bcctr	BO, BI	Branch conditional to address in CTR. Using (CTR) at exit from instruction, $NIA \leftarrow CTR_{0:29} \parallel 20.$	CTR if $BO_2 = 0.$	11-27
bcctrl			CTR if $BO_2 = 0.$ $(LR) \leftarrow CIA + 4.$	

Table B-8. Branch Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
bclr	BO, BI	Branch conditional to address in LR. Using (LR) at entry to instruction, $NIA \leftarrow LR_{0:29} \parallel {}^20$.	CTR if $BO_2 = 0$.	11-31
bclrl			CTR if $BO_2 = 0$. (LR) $\leftarrow CIA + 4$.	

B.9 Comparison Instructions

Comparison instructions perform arithmetic and logical comparisons between two operands and set one of the eight condition code register fields based on the outcome of the comparison. Table B-9 shows the comparison instructions supported by the PPC403GC.

Table B-9. Comparison Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
cmp	BF, 0, RA, RB	Compare (RA) to (RB), signed. Results in CR[CRn], where n = BF.		11-36
cmpi	BF, 0, RA, IM	Compare (RA) to EXTS(IM), signed. Results in CR[CRn], where n = BF.		11-37
cmpl	BF, 0, RA, RB	Compare (RA) to (RB), unsigned. Results in CR[CRn], where n = BF.		11-38
cmpli	BF, 0, RA, IM	Compare (RA) to (${}^{16}0 \parallel IM$), unsigned. Results in CR[CRn], where n = BF.		11-39

B.10 Rotate and Shift Instructions

Rotate and shift instructions rotate and shift operands which are stored in the general purpose registers. Rotate instructions can also mask rotated operands. Table B-10 shows the PPC403GC rotate and shift instructions.

Table B-10. Rotate and Shift Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
rlwimi	RA, RS, SH, MB, ME	Rotate left word immediate, then insert according to mask. $r \leftarrow \text{ROTL}((RS), SH)$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m) \vee ((RA) \wedge \neg m)$		11-129
rlwimi.			CR[CR0]	
rlwinm	RA, RS, SH, MB, ME	Rotate left word immediate, then AND with mask. $r \leftarrow \text{ROTL}((RS), SH)$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m)$		11-130
rlwinm.			CR[CR0]	
rlwnm	RA, RS, RB, MB, ME	Rotate left word, then AND with mask. $r \leftarrow \text{ROTL}((RS), (RB)_{27:31})$ $m \leftarrow \text{MASK}(MB, ME)$ $(RA) \leftarrow (r \wedge m)$		11-133
rlwnm.			CR[CR0]	
slw	RA, RS, RB	Shift left (RS) by $(RB)_{27:31}$. $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), n)$. if $(RB)_{26} = 0$ then $m \leftarrow \text{MASK}(0, 31 - n)$ else $m \leftarrow {}^{32}0$. $(RA) \leftarrow r \wedge m$.		11-135
slw.			CR[CR0]	
sraw	RA, RS, RB	Shift right algebraic (RS) by $(RB)_{27:31}$. $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. if $(RB)_{26} = 0$ then $m \leftarrow \text{MASK}(n, 31)$ else $m \leftarrow {}^{32}0$. $s \leftarrow (RS)_0$. $(RA) \leftarrow (r \wedge m) \vee ({}^{32}s \wedge \neg m)$. $\text{XER}[CA] \leftarrow s \wedge ((r \wedge \neg m) \neq 0)$.		11-136
sraw.			CR[CR0]	
srawi	RA, RS, SH	Shift right algebraic (RS) by SH. $n \leftarrow SH$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. $m \leftarrow \text{MASK}(n, 31)$. $s \leftarrow (RS)_0$. $(RA) \leftarrow (r \wedge m) \vee ({}^{32}s \wedge \neg m)$. $\text{XER}[CA] \leftarrow s \wedge ((r \wedge \neg m) \neq 0)$.		11-137
srawi.			CR[CR0]	

Table B-10. Rotate and Shift Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
srw	RA, RS, RB	Shift right (RS) by $(RB)_{27:31}$. $n \leftarrow (RB)_{27:31}$. $r \leftarrow \text{ROTL}((RS), 32 - n)$. if $(RB)_{26} = 0$ then $m \leftarrow \text{MASK}(n, 31)$ else $m \leftarrow {}^{32}0$. $(RA) \leftarrow r \wedge m$.		11-138
srw.			CR[CR0]	

B.11 Cache Control Instructions

Cache control instructions allow the user to indirectly control the contents of the data and instruction caches. The user may fill, flush, invalidate and zero blocks (16-byte lines) in the data cache. The user may also invalidate congruence classes in both caches and invalidate individual lines in the instruction cache.

Table B-11. Cache Control Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
dcbf	RA, RB	Flush (store, then invalidate) the data cache block which contains the effective address (RA 0) + (RB).		11-49
dcbi	RA, RB	Invalidate the data cache block which contains the effective address (RA 0) + (RB).		11-50
dcbst	RA, RB	Store the data cache block which contains the effective address (RA 0) + (RB).		11-51
dcbt	RA, RB	Load the data cache block which contains the effective address (RA 0) + (RB).		11-52
dcbtst	RA, RB	Load the data cache block which contains the effective address (RA 0) + (RB).		11-54
dcbz	RA, RB	Zero the data cache block which contains the effective address (RA 0) + (RB).		11-56
dccci	RA, RB	Invalidate the data cache congruence class associated with the effective address (RA 0) + (RB).		11-58
dcread	RT, RA, RB	Read either tag or data information from the data cache congruence class associated with the effective address (RA 0) + (RB). Place the results in RT.		11-60
icbi	RA, RB	Invalidate the instruction cache block which contains the effective address (RA 0) + (RB).		11-68
icbt	RA, RB	Load the instruction cache block which contains the effective address (RA 0) + (RB).		11-70
iccci	RA, RB	Invalidate instruction cache congruence class associated with the effective address (RA 0) + (RB).		11-72

Table B-11. Cache Control Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
icread	RA, RB	Read either tag or data information from the instruction cache congruence class associated with the effective address (RA 0) + (RB). Place the results in ICDBDR.		11-74

B.12 Interrupt Control Instructions

The interrupt control instructions allow the user to move data between general purpose registers and the machine state register, return from interrupts and enable or disable maskable external interrupts. Table B-12 shows the Interrupt control instruction set.

Table B-12. Interrupt Control Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
mfmsr	RT	Move from MSR to RT, (RT) \leftarrow (MSR).		11-106
mtmsr	RS	Move to MSR from RS, (MSR) \leftarrow (RS).		11-113
rfci		Return from critical interrupt (PC) \leftarrow (SRR2). (MSR) \leftarrow (SRR3).		11-127
rfi		Return from interrupt. (PC) \leftarrow (SRR0). (MSR) \leftarrow (SRR1).		11-128
wrtee	RS	Write value of RS ₁₆ to the External Enable bit (MSR[EE]).		11-180
wrteei	E	Write value of E to the External Enable bit (MSR[EE]).		11-181

B.13 TLB Management Instructions

The TLB management instructions read and write entries of the TLB array in the MMU, search the TLB array for an entry which will translate a given address, invalidate all TLB entries, and synchronize TLB updates with other processors.

Table B-13. TLB Management Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbia		All of the entries in the TLB are invalidated and become unavailable for translation by clearing the valid (V) bit in the TLBHI portion of each TLB entry. The rest of the fields in the TLB entries are unmodified.		11-167
tlbre	RT, RA, WS	<p>If WS = 0: Load TLBHI portion of the selected TLB entry into RT. Load the PID register with the contents of the TID field of the selected TLB entry. $(RT) \leftarrow TLBHI[(RA)]$ $(PID) \leftarrow TLB[(RA)]_{TID}$</p> <p>If WS = 1: Load TLBLO portion of the selected TLB entry into RT. $(RT) \leftarrow TLBLO[(RA)]$</p>		11-168
tlbsx	RT, RA, RB	Search the TLB array for a valid entry which translates the effective address $EA = (RA 0) + (RB)$. If found, $(RT) \leftarrow \text{Index of TLB entry.}$ If not found, $(RT) \text{ Undefined.}$		11-170
tlbsx.		If found, $(RT) \leftarrow \text{Index of TLB entry.}$ $CR[CR0]_{EQ} \leftarrow 1.$ If not found, $(RT) \text{ Undefined.}$ $CR[CR0]_{EQ} \leftarrow 1.$	$CR[CR0]_{LT,GT,SO}$	
tlbsync		tlbsync does not complete until all previous TLB-update instructions executed by this processor have been received and completed by all other processors. For PPC403GC, tlbsync is a no-op.		11-171

Table B-13. TLB Management Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
tlbwe	RS, RA, WS	<p>If WS = 0: Write TLBHI portion of the selected TLB entry from RS. Write the TID field of the selected TLB entry from the PID register. $TLBHI[(RA)] \leftarrow (RS)$ $TLB[(RA)]_{TID} \leftarrow (PID)_{24:31}$</p> <p>If WS = 1: Write TLBLO portion of the selected TLB entry from RS. $TLBLO[(RA)] \leftarrow (RS)$</p>		11-172

B.14 Processor Management Instructions

The processor management instructions move data between GPRs and SPRs and DCRs in the PPC403GC; these instructions also provide traps, system calls and synchronization controls.

Table B-14. Processor Management Instructions

Mnemonic	Operands	Function	Other Registers Changed	Page
eieio		Storage synchronization. All loads and stores that precede the eieio instruction complete before any loads and stores that follow the instruction access main storage. Implemented as sync , which is more restrictive.		11-64
isync		Synchronize execution context by flushing the prefetch queue.		11-76
mcrxr	BF	Move XER[0:3] into field CR _n , where $n \leftarrow \text{BF}$. $\text{CR}[\text{CR}_n] \leftarrow (\text{XER}[\text{SO}, \text{OV}, \text{CA}])$. $(\text{XER}[\text{SO}, \text{OV}, \text{CA}]) \leftarrow {}^3_0$.		11-102
mfcrr	RT	Move from CR to RT, $(\text{RT}) \leftarrow (\text{CR})$.		11-103
mfdcr	RT, DCRN	Move from DCR to RT, $(\text{RT}) \leftarrow (\text{DCR}(\text{DCRN}))$.		11-104
mfspr	RT, SPRN	Move from SPR to RT, $(\text{RT}) \leftarrow (\text{SPR}(\text{SPRN}))$.		11-107
mtcrf	FXM, RS	Move some or all of the contents of RS into CR as specified by FXM field, $\text{mask} \leftarrow {}^4(\text{FXM}_0) \parallel {}^4(\text{FXM}_1) \parallel \dots \parallel {}^4(\text{FXM}_6) \parallel {}^4(\text{FXM}_7)$. $(\text{CR}) \leftarrow ((\text{RS}) \wedge \text{mask}) \vee (\text{CR}) \wedge \neg \text{mask}$.		11-109
mtdcr	DCRN, RS	Move to DCR from RS, $(\text{DCR}(\text{DCRN})) \leftarrow (\text{RS})$.		11-111
mtspr	SPRN, RS	Move to SPR from RS, $(\text{SPR}(\text{SPRN})) \leftarrow (\text{RS})$.		11-114
sc		System call exception is generated. $(\text{SRR1}) \leftarrow (\text{MSR})$ $(\text{SRR0}) \leftarrow (\text{PC})$ $\text{PC} \leftarrow \text{EVPR}_{0:15} \parallel \text{x'0C00'}$ $(\text{MSR}[\text{WE}, \text{PR}, \text{EE}, \text{PE}, \text{DR}, \text{IR}]) \leftarrow 0$ $(\text{MSR}[\text{LE}]) \leftarrow (\text{MSR}[\text{ILE}])$		11-134

Table B-14. Processor Management Instructions (cont.)

Mnemonic	Operands	Function	Other Registers Changed	Page
sync		Synchronization. All instructions that precede sync complete before any instructions that follow sync begin. When sync completes, all storage accesses initiated prior to sync will have completed.		11-166
tw	TO, RA, RB	Trap exception is generated if, comparing (RA) with (RB), any condition specified by TO is true.		11-174
twi	TO, RA, IM	Trap exception is generated if, comparing (RA) with EXTS(IM), any condition specified by TO is true.		11-177



Instruction Timing and Optimization

This appendix contains information in three categories:

- 1) Much of the opportunity for code optimization for the PPC403GC derives from the superscalar operation of the processor. Many of the coding guidelines for optimization derive from the restrictions which the processor places on superscalar operation. A very brief introduction to this topic is given in Section C.1 (Background Information) below. A detailed reference on folding is given in Section C.4 (Detailed Folding Rules) on page C-10.
- 2) Optimization for faster-running code is supported by the rules given in Section C.2 (Coding Guidelines) on page C-3.
- 3) Guidelines for estimating the number of clock cycles required for the execution of a program is given in Section C.3 (Instruction Timings) on page C-7.

C.1 Background Information

C.1.1 Superscalar Operation

The PPC403GC is a scalar processor (its instructions operate on individual data items, not on arrays). It is, under some circumstances, able to execute more than one instruction at a time (hence the term superscalar). If appropriate dependency rules are satisfied, the PPC403GC can execute Branches and Condition-Register Logical instructions simultaneous with other instructions. Section C.4 on page C-10 defines the necessary dependency rules. These rules must be understood if it is desired to precisely predict code performance.

See Section 2.6 on page 2-25 for a brief introduction to the Instruction Queue of the PPC403GC. That discussion will define terminology used in this chapter.

C.1.2 Folding Defined

Superscalar operation requires the presence of at least two instructions in the queue. If superscalar operation takes place, it occurs via the passage of the second instruction from the IQ1 stage to the limited-function execution unit (EXE*). This passage is conventionally referred to as Folding. PPC403GC requires in-order execution, therefore it is required that

Dispatch of the predecessor instruction in DCD has occurred for Folding from IQ1 to be permitted.

Note that the PPC403GC can only fold one instruction at a time. Suppose that “A”, “B”, and “C” are sequential instructions. If instruction “A” is executing and instruction “B” is executing in parallel (folded onto “A”), then it is not possible to fold instruction “C” onto instruction “B”.

C.1.3 Branch Folding

The PPC403GC will “fold” branch instructions in several situations (see Section C.3.2 on page C-7 and Section C.4 on page C-10). When a branch instruction is folded, it will effectively take zero cycles to execute. For the PPC403GC to allow the branch to fold, dependencies of the branch (CR and CTR contents that are tested by conditional branches; CTR and LR contents that are used as branch target addresses) must have already been satisfied. If the instructions that created those dependencies occurred immediately before the branch, those dependencies would not yet be satisfied, and wait states would be added to allow the dependency satisfaction. The wait states can be avoided (hidden by useful code) by including either one or two instructions between the instruction that created the dependency and the branch, as listed in Section C.2.6 and Section C.2.7.

C.2 Coding Guidelines

C.2.1 Condition Register Bits for Boolean Variables

A compiler can often get better performance for Boolean variables (with False and True values represented by 0 and 1 respectively) by using Condition Register bits to hold these variables instead of using General Purpose Registers. Most common operations on Boolean variables can be accomplished using Condition Register Logical instructions. An example of such use may be found in Section C.2.2 below.

C.2.2 CR Logical Instructions for Compound Branches

Better or equal performance will always result when one or more Condition Register Logical instructions are used to replace a like number of Conditional Branch instructions in cases where compound conditions are being tested.

As an example, consider code of this form:

```
if ( Var28 || Var29 || Var30 || Var31 ) { /* branch to "target" */ }
```

where Var28 - Var31 are Boolean variables, maintained as bits 28 - 31 of the Condition Register, with a value of 1 representing True and 0 representing False.

This might be coded entirely with branches as:

```
bt      28,target
bt      29,target
bt      30,target
bt      31,target
```

An equivalent coding using CR-Logical instructions would be:

```
cror    2,28,29
cror    2,2,30
cror    2,2,31
bt      2,target
```

C.2.3 Floating Point Emulation

There are two ways of handling floating point on the PPC403GC. The preferred way of handling floating point emulation is via a call interface to subroutines located in a floating point emulation run-time library.

The alternative approach is to write code that uses the PowerPC floating point opcodes. The PPC403GC, being an integer-only processor, will not recognize these floating point opcodes, and will respond to their presence by taking an illegal instruction interrupt. The interrupt handler can be written to determine which opcode was used, and to provide equivalent function by executing appropriate (integer-based) library routines. This method is not preferred, since it adds the execution time of the interrupt context switching to the

execution time of the same library routines which would have been called directly in the first method. However, the interrupt-based technique does allow the PPC403GC to execute code that assumes the existence of the standard PowerPC floating point instructions.

C.2.4 Data Cache Usage

- Recognize the size and structure of the data cache, so that data may be organized to minimize cache misses.

For the data cache, any two addresses which are the same in address bits 23:27, but which differ in address bits 0:22, are called congruent. Address bits 28:31 define the 16 bytes within a line, which is the minimum size object which is brought into the cache. Two congruent lines may be present in the cache simultaneously; accessing a third congruent line will cause the removal from the cache of one of the two lines previously there.

Continually moving data into and out of the cache is time consuming, since it occurs at the speed of external memory. Much faster execution occurs if data can be accessed exclusively from the cache. This is accomplished by organizing data such that it uniformly uses address bits 23:27, minimizing the use of data with congruent addresses.

C.2.5 Instruction Cache Usage

- Recognize the size and structure of the instruction cache, so that code may be organized to minimize cache misses.

For the instruction cache, any two addresses which are the same in address bits 22:27, but which differ in address bits 0:21, are called congruent. Address bits 28:31 define the 16 bytes within a line, which is the minimum size object which is brought into the cache. Two congruent lines may be present in the cache simultaneously; accessing a third congruent line will cause the removal from the cache of one of the two lines previously there.

Continually moving new code into the cache is time consuming, since it occurs at the speed of external memory. Much faster execution occurs if blocks of code can be accessed exclusively from the cache. This is accomplished by organizing code such that frequently accessed blocks of code uniformly use address bits 22:27, minimizing the use of code with congruent addresses.

C.2.6 Dependency Upon CR

- For CR-setting instructions of categories Arithmetic, Logical, Compare, and the **mctr** instruction:

Put two instructions between a CR-setting instruction and a Branch instruction that uses a CR bit in the CR field being set by the CR-setting instruction.

- For CR-setting instructions of category CR-Logical, except for the **mcr** instruction:

Put one instruction between a CR-setting instruction and a Branch instruction that uses the CR bit being set by the CR-setting instruction.

- For CR-setting instructions **mcrf** and **mcrxr**:

Put one instruction between a CR-setting instruction and a Branch instruction that uses a CR bit in the CR field being set by the CR-setting instruction.

- Put one instruction between a normal Condition Register-updating instruction and a Condition Register Logical instruction.

C.2.7 Dependency Upon LR and CTR

- If a Branch instruction uses the contents of the Link Register or the Count Register as a target address:
 - If the branch is actually taken, one instruction between CTR / LR update and the Branch is sufficient to eliminate the wait state.
 - Pre-fetch will halt whenever there is a LR / CTR update ahead of a branch to the LR / CTR and the branch is predicted taken. If the branch is actually not taken, the absence of pre-fetch will harm performance. Put three instructions between a LR / CTR updating instruction and a Branch that uses the Link Register or Count Register as a branch target address. This allows pre-fetch to continue.
- Put one instruction between a Count Register updating instruction and a Branch that uses the Count Register as a branch condition (note that any Branch which tests CTR also alters CTR by decrementing it).

C.2.8 Load Latency

- Put one instruction between a Load instruction and an instruction that uses the data from the Load instruction.

Registers loaded via any of the byte, halfword, or fullword load instructions on the PPC403GC are not available for use until one clock cycle after the load instruction completes. If the instruction immediately following the load uses the register which is the target of the load, then a wait state will be added. If the instruction following the load does not use the register which is the load target, the PPC403GC will execute the instruction without a wait state.

C.2.9 Branch Prediction

- Use the Y bit in branch instructions to force the prediction (whether the conditional branch will be taken or not) properly if there is known to be a more likely prediction than the standard prediction. See Section 2.7.5 on page 2-28 for a thorough discussion of Branch Prediction.

C.2.10 Alignment

- Keep all accesses aligned on the operand size boundary (i.e. load/store word should be word aligned, etc.) to avoid alignment exceptions.
- Use the string instructions to handle byte strings or any unaligned accesses.
- Align branch targets that are not likely to be hit by “fall-through” code (for example, the beginning of subroutines like strcpy) on cache line boundaries to minimize the number of instruction cache line fills.

C.3 Instruction Timings

This section provides information about the instruction timings of the PPC403GC.

These timings only take into account “first order” affects of cache misses on the I-side and D-side. They give the number of **extra** cycles associated with getting the target word (data or instruction) into the processor. The timings do NOT give a complete indication of the performance penalty associated with cache misses, as they do not take into account bus contention between I-side and D-side, nor the time associated with finishing line fills or flushes. Unless specifically stated otherwise, these numbers all assume a single cycle memory access.

C.3.1 General Rules

- Instructions are executed in order.
- All instructions (assuming cache hits) take 1 cycle to execute, except:
 - Folded branches take 0 clock cycles
 - Folded Condition Register Logical instructions (CR-Logicals) take 0 clock cycles
 - Multiply takes 4 clock cycles
 - Divide takes 33 clock cycles
 - Load-Store String/Multiple takes 1 cycle/word

C.3.2 Branch and CR Logical Opcodes

This section discusses the timings associated with the folding of Branch and CR-Logical instructions. For a thorough discussion of the dependency rules which govern folding, see Section C.4 on page C-10.

All Branches and CR-Logicals take 0 cycles except under the following conditions.

- CR-Logicals that immediately follow any type of CR-setting operation will take 1 cycle.
- A CR dependent Branch (where the CR was altered by a “long” CR updating instruction: arithmetic, logical, compare, and **mtrcf**) takes :
 - 2 cycles if the instruction that sets the CR immediately precedes the Branch instruction.
 - 1 cycle if the instruction that sets the CR is separated from the Branch instruction by one instruction that does not effect the CR bit used by the Branch instruction.

- A CR dependent Branch (where the CR was altered by a “short” CR updating instruction: CR-Logical, **mcrxr**, **mcrf**) takes :
 - 1 cycle if the instruction that sets the CR immediately precedes the Branch instruction.
 - 0 cycle if the instruction that sets the CR is separated from the Branch instruction by one instruction that does not effect the CR bit used by the Branch instruction.
- A Branch instruction that is dependent upon and immediately follows the setting of the Link Register (LR) or the Count Register (CTR) takes 1 cycle.

The Branch instructions that depend on the LR or CTR are Branch to LR, Branch to CTR, and any Branch instruction that is dependent on the condition of the Count Register (that is, any Branch with Decrement).

C.3.3 Branch Prediction

This section discusses the timings associated with branch prediction. See Section 2.7.5 on page 2-28 for a thorough discussion of the prediction of branch direction and of programmer control of prediction direction.

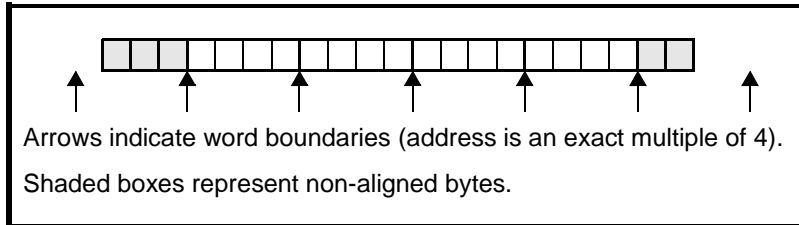
- A correctly predicted branch (predicted to be taken and it is taken; or predicted to be not taken and it is not taken) does not add any extra cycles.
- A branch that is predicted not taken, but which actually is taken, adds 1 extra clock cycle.
- A branch that is predicted taken, but which is actually not taken, does not add any cycles, except for this case:

An I-cache miss that occurs while fetching the correct instruction adds 4 extra clock cycles (3 + memory speed).

- Pre-fetch will halt whenever there is a LR / CTR update ahead of a branch to the LR / CTR and the branch is predicted taken. As a result of pre-fetch halt, a mtlr / blr pair (or a mtctr / bctr pair) has a 2 cycle penalty if there are no instructions between.

C.3.4 String Opcodes

- Computation of execution time for string instructions requires understanding of data alignment, and of the behavior of the string instructions with respect to alignment. Illustrated below is an example string of 21 bytes. The beginning 3 bytes do not begin on a word address boundary, and the final 2 bytes do not end on a word address boundary. The PPC403GC handles any unaligned bytes at the beginning of the string as special cases, then moves as many bytes as possible in the form of aligned words, and finally handles any trailing bytes as special cases.



- To determine the execution time of the string instruction, first determine the number of word-aligned transfers required. Assuming single cycle memory access, they require 1 cycle each.
- Next, determine the number of non-aligned bytes at the beginning of the transfer.
 - 1 or 2 non-aligned starting bytes, add 1 cycle.
 - 3 non-aligned starting bytes, add 2 cycles.
- Finally, determine the number of non-aligned trailing bytes.
 - 1 or 2 non-aligned trailing bytes, add 1 cycle.
 - 3 non-aligned trailing bytes, add 2 cycles.

C.3.5 Data Cache Loads and Stores

- Cacheable stores that miss in the D-cache take 0 extra cycles.
- Cacheable loads that miss in the D-cache take 3 extra cycles (2 + memory speed).
- Non-cacheable stores take 0 extra cycles.
- Non-cacheable loads take 2 extra cycles (1 + memory speed).

C.3.6 Instruction Cache Misses

- In general, when the pre-fetch queue is full and instructions are being fetched from cacheable memory there is no penalty. (The penalty is -1 + memory speed, hence 0 for single cycle memory.)
- If the queue only has one instruction in it at the time of the I-cache miss, then a 3-cycle penalty is incurred (2 + memory speed).
- When executing instructions from non-cacheable memory, a 3 cycle penalty (2 + memory speed) is incurred.

C.4 Detailed Folding Rules

C.4.1 Instruction Classifications for Folding

The discussion which follows will define dependency rules based on these instruction categories: CTR Updating Instructions, LR Updating Instructions, and CR Updating Instructions. These are defined in Table C-1 and Table C-2.

Table C-1. CTR and LR Updating Instructions

CTR Updating		LR Updating
bc	with BO(2) = 0	bl
bca	with BO(2) = 0	bla
bcl	with BO(2) = 0	bcl
bcla	with BO(2) = 0	bcla
bclr	with BO(2) = 0	bclrl
bclrl	with BO(2) = 0	bcctrl

Table C-2. CR Updating Instructions

CR Logical	Arithmetic		Logical	Rotate and Shift	Compare
crand cror crxor crnand crnor creqv crandc crorc mcrf	add. addo. addic. addc. addco. adde. addeo. addme. addmeo. addze. addzeo. divw. divwo. divwu. divwuo.	mullw. mullwo. mulhw. mulhwu. neg. nego. subf. subfo. subfc. subfco. subfe. subfeo. subfme. subfmeo. subfze. subfzeo.	and. andi. andis. cntlzw. extsb. extsh. or. xor. nand. nor. eqv. andc. orc.	rlwinm. rlwnm. rlwimi. slw. srw. srawi. sraw.	cmp cmpi cmpl cmpli
Data Movement	Memory Management	Processor Management			
stwcx.	tlbsx.	mcrxr mtcrf			

NOTE : **mcrxr** and the CR Logical instructions are able to produce their results while in EXE such that the instruction in DCD can use the results (bypass) thereby avoiding inserting a bubble (idle cycle).

C.4.2 Instructions That Can Be Folded

- Only instructions in IQ1 can be folded.
- No instructions can be folded onto a **mtmsr**, **isync**, **sc**, **rfi**, **rftci**, **wrttee**, or **wrtteei** instruction.
- Only the next sequential instruction can be folded, i.e. the folded instruction always has an address of the the dispatched instruction + 4.
- The instructions that can be folded are

Table C-3. Foldable Instructions

Branch	CR Logical	CR Move
b	crand	mcrf
ba	cror	
bl	crxor	
bla	crnand	
bc	crnor	
bca	creqv	
bcl	crandc	
bcla	crorc	
bclr		
bclrl		
bcctr		
bcctrl		

C.4.3 Fold Blocking Rules For CR Logical and mcrf Instructions

- A CR logical instruction or the **mcrf** instruction cannot be folded if any CR Updating Instruction is in DCD.

C.4.4 Fold Blocking Rules For Branch Instructions

- A branch can be folded only if both :
 - 1) the branch direction is known
 - 2) the branch target address is known.

- Branch Direction is known if :
 - 1) It is an unconditional branch.
 - 2) If the branch is dependent on the CTR for the condition and the instruction in DCD is not a CTR Updating Instruction.
 - 3) If the branch is dependent on the CR, then any instruction updating the CR field being used cannot be in :
 - DCD for :
 - CR Logical Instructions
 - **mcrf** and **mcrxr**
 - DCD or EXE for :
 - Arithmetic Instructions
 - Logical Instructions
 - Extend Sign Instructions
 - Count Instructions
 - Rotate and Shift Instructions
 - Set/Clear Bit Instructions
 - Compare Instructions
 - **mtcrf** (considered to update ALL CR fields)
 - Special Instructions
 - 4) NOTE : If a branch is dependent on both CTR and CR then both conditions (2) and (3) must be met.
- Branch Target Address is known if :
 - 1) The branch is known to be NOT TAKEN, in which case the target address is known to be the next sequential address.
 - 2) The branch does not use the LR or CTR as the target address.
 - 3) The branch uses the LR as the target address and the the instruction in DCD is not a LR Updating Instruction.
 - 4) The branch uses the CTR as the target address and the the instruction in DCD is not a CTR Updating Instruction.

- Blocking Examples

- 1) IQ1 Blocking

- The instruction in IQ1 is not the CORRECT next instruction after a branch. This could be either (not the correct next instruction if a DCD branch is NOT TAKEN) or (not the target of a DCD branch that is taken).

- 2) EXE Blocking

- The instruction in IQ1 is a branch that is using CR field 0 (BO(0)=0 and BI=000xx) AND the instruction in EXE is updating CR field 0 via RC=1.
 - The instruction in IQ1 is a branch that is using CR (BO(0)=0) AND the instruction in EXE is a compare instruction updating the same CR field being used by the branch instruction in decode (BF=BI<0:2>).
 - The instruction in IQ1 is a branch using CR (BO(0)=0) AND the instruction in EXE is a **mtcrf** instruction.

- 3) DCD Blocking

- If the instruction in DCD is being held from moving to EXE then an instruction in IQ1 will not be folded into EXE until the DCD instruction moves to EXE.
 - If the instruction in IQ1 is a branch using the LR as the target AND the instruction in DCD is updating the LR AND the IQ1 branch direction is TAKEN or UNKNOWN.
 - If the instruction in IQ1 is a branch using the CTR as a target address (**bctr**) AND the instruction in DCD is updating the CTR AND the IQ1 branch direction is TAKEN or UNKNOWN.
 - If the instruction in IQ1 is a branch using the CTR as a condition AND the instruction in DCD is updating the CTR.
 - If the instruction in IQ1 is a branch using CR AND the instruction in DCD is a CR-updating instruction that is updating the same CR field that is being used by the IQ1 branch.

C.4.5 Fold Blocking During Debug

- The blocking of folding can be controlled by a debug tool such as RISCWatch, via the JTAG port.
- Folding is blocked for all instructions if the IC debug event is enabled and the Debug Mode is set to either Internal or External Mode.

- The instruction at the IAC1 compare address is blocked from folding if the IAC1 debug event is enabled and the Debug Mode is set to either Internal or External Mode. The instruction following the instruction at the compare address is not blocked from folding. The same is true for IAC2.
- Folding is blocked for all branch taken instructions if the BRT debug is enabled and the Debug Mode is set to either Internal or External Mode.
- Folding is blocked while instruction stuffing is being done via the JTAG port.

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